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Is Playing Video Games Related to Cognitive Abilities?

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Abstract

The relations between video-game experience and cognitive abilities were examined in the current study. In two experiments, subjects performed a number of working memory, fluid intelligence, and attention-control measures and filled out a questionnaire about their video-game experience. In Experiment 1, an extreme-groups analysis indicated that experienced video-game players outperformed nonplayers on several cognitive-ability measures. However, in Experiments 1 and 2, when analyses examined the full range of subjects at both the task level and the latent-construct level, nearly all of the relations between video-game experience and cognitive abilities were near zero. These results cast doubt on recent claims that playing video games leads to enhanced cognitive abilities. Statistical and methodological issues with prior studies of video-game experience are discussed along with recommendations for future studies.

Keywords

cognitive ability, individual differences

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In recent years, there has been an explosion of research examining whether prior experience playing video games—in particular, action or first-person shooter games—is related to various cognitive skills and abilities. This research has demonstrated that video-game players outperform non-video-game players on tests of attention control, visual-spatial abilities, working memory, and executive control (Blacker & Curby, 2013; Cain, Landau, & Shimamura, 2012; Castel, Pratt, & Drummond, 2005; Chisholm & Kingstone, 2012; Colzato, van den Wildenberg, Zmigrod, & Hommel, 2013; Green & Bavelier, 2003, 2006, 2007; McDermott, Bavelier, & Green, 2014; Powers, Brooks, Aldrich, Palladino, & Alfieri, 2013). Furthermore, a typical finding across studies is that video-game players are faster on a number of measures compared with non-video-game players. These findings have led many researchers to conclude that playing video games can enhance a variety of cognitive abilities (Bavelier, Green, Pouget, & Schrater, 2012; Granic, Lobel, & Engels, 2014; Green & Bavelier, 2012; Spence & Feng, 2010). This conclusion has been bolstered by experimental training studies in which subjects who played a game for a certain amount of time subsequently demonstrated increased performance on a number of measures compared with control subjects who did not play the game (Glass, Maddox, & Love, 2013; Green & Bavelier, 2006, 2007; Powers et al., 2013).

Despite the impressive number of studies that have found positive results, other studies have failed to find differences between video-game players and non-video-game players on a number of measures. For example, although some studies have suggested that there are differences on measures of selective attention (Green & Bavelier, 2003, 2006, 2007), others have failed to replicate these effects (Irons, Remington, & McLean, 2011; Murphy

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& Spencer, 2009; Wilms, Petersen, & Vangkilde, 2013). Likewise, some studies have suggested that there are differences on working memory measures (Blacker & Curby, 2013; Colzato et al., 2013; McDermott et al., 2014), whereas others have not (Boot, Kramer, Simons, Fabiani, & Gratton, 2008; Hambrick, Oswald, Darowski, Rench, & Brou, 2010). Thus, despite the promise of examining video-game playing as a means to enhance cognitive abilities, it is still unclear how robust these effects are and whether possible confounds, such as subject recruitment and demand characteristics, may be influencing the results (Boot, Blakely, & Simons, 2011; Green, Strobach, & Schubert, in press).

In addition, studies that have compared video-game players and non-video-game players have a number of methodological and statistical problems. For example, many of these studies have relied on very small sample sizes (in some cases, as few as 7 to 8 subjects per group). Given recent meta-analytic results suggesting that many of these effects are small (Powers et al., 2013), it is possible that discrepancies in the literature are due to the use of small sample sizes, which not only drastically reduce the power to find small effects, but also increase the likelihood of Type 1 errors (Button et al., 2013; Ingre, 2013).

Furthermore, most of these studies have used extreme-groups designs, in which frequent video-game players are compared with non-video-game players. In a typical study, subjects with significant video-game experience (typically 5+ hr a week) are compared with non-video-game players (less than 1 hr of video-game play a week) on a variety of tasks, with more intermediate, casual gamers omitted. Extreme-groups designs can be problematic for a number of reasons (Preacher, Rucker, MacCallum, & Nicewander, 2005). For example, when only the top and bottom portions of the distribution are examined, a great deal of information is lost, as the entire middle of the distribution has been excluded. Additionally, although extreme-groups designs are known to increase the ability to detect an effect, these designs can also lead to an increased likelihood of making a Type I error as a result of overestimated effect sizes (Conway et al., 2005; Preacher et al., 2005). Finally, in extreme-groups designs, subjects within a particular group are treated as equal when they are not. In the case of video-game experience, it is likely that most of the subjects in the non-game-player group are similar in the number of hours of game play (they all report less than 1 hr per week), but it is unlikely that subjects in the experienced group are so similar; rather, variability in the experienced group will likely be considerable and positively skewed, with some subjects gaming only 6 hr per week and others playing 20 or more (see Latham, Patston, & Tippett, 2013, for a similar critique).

Although extreme-groups studies have their place, particularly in early stages of empirical investigation (indeed, we have published a number of extreme-groups studies), it is always desirable to subsequently test the effects found in extreme-groups studies with a full range of subjects and, ideally, to examine the results at the latent-construct level. Given that video-game experience (hours per week of game play) is a continuous variable, the relation between game playing and cognitive abilities should be examined across all subjects rather than just compared between the extremes. Furthermore, given issues with unreliability of measures and idiosyncratic task effects, it is desirable to examine the relation between video-game experience and cognitive abilities with multiple measures of cognitive ability and with latent-variable techniques. Finally, multiple constructs should be examined simultaneously to ensure that any relations found are not due to an unmeasured third variable. For example, the relation between video-game experience and working memory could be due to shared variance with attention control.

With these issues in mind, we examined the relation between video-game experience and cognitive abilities (attention control, working memory, and fluid intelligence) in two experiments using fairly large samples of subjects and measures. If video-game experience is related to cognitive abilities, then these relations should be found not only when extreme groups are compared, but also when the full range of subjects is examined and the relations are examined at the latent level.

Experiment 1

To examine whether playing video games is related to cognitive abilities, we reanalyzed data from Unsworth and McMillan (2014). In that study, a large number of subjects completed multiple cognitive-ability measures and filled out a questionnaire on their video-game experience.

Method

Subjects. The data analyzed in Experiment 1 include a subset of data reported in Unsworth and McMillan (2014). The video-game data have not been published previously. A total of 252 subjects were recruited from the subject pool at the University of Oregon; the recruitment materials did not mention video-game experience or playing, as recommended by Boot et al. (2011). Recruited participants received course credit for their participation. Data from 11 subjects who failed to complete two or more of the cognitive-ability tasks were dropped. The video-game-experience questionnaire was administered to 218 of the subjects, 20 of whom failed to complete the questionnaire and were excluded from data analysis. The remaining 198 subjects were between the ages of 18 and 35 ($M = 19.49$, $SD = 1.75$). Subjects were tested in groups of 1 to 6 in laboratory sessions lasting approximately 2 hr. The testing took place over two full academic quarters; the stopping rule was to end data collection at the end of the second quarter. During the attention-control tasks, subjects were periodically presented with thought probes asking them to classify their immediately preceding thoughts. The results for these probes were reported in Unsworth and McMillan and are not discussed here.

Procedure. After providing informed consent, all subjects completed the following tasks (in the order listed): operation span, symmetry span, reading span, Raven's Advanced Progressive Matrices, number series, letter sets, sustained attention to response (SART), antisaccade, arrow flankers, Stroop, and psychomotor vigilance. All tasks were computerized. Following the tasks, subjects filled out a battery of questionnaires, including the video-game-experience questionnaire.

Working memory tasks. Working memory was tested with three span tasks. A recalled item was scored as correct if the item had the correct identity (or location, in the case of the symmetry-span task) and was recalled in the correct list position. The score for each task was the total number of correct items across all trials. Higher scores represented better performance.

Operation span. On each trial in this task, subjects solved a series of math problems while trying to remember a set of unrelated letters (taken from the set F, H, J, K, L, N, P, Q, R, S, T, Y). After subjects solved a math problem, they were presented with a letter for 1 s. Immediately afterward, the next problem was presented and solved, and then another letter was presented. After this alternating sequence occurred three to seven times, subjects were asked to recall the presented letters in order (i.e., list lengths ranged from 3 to 7). Three trials of each list length were presented, for a total possible of 75 letters correctly recalled. The order in which the different list lengths were presented varied randomly. At recall, subjects reported the list as they remembered it by clicking on the appropriate letters (see Unsworth, Heitz, Schrock, & Engle, 2005, and Redick et al., 2012, for more details). Subjects received three practice trials (list length = 2).

Symmetry span. On each trial in this task, subjects performed a symmetry-judgment task while trying to remember a sequence of locations in which red squares were presented within a matrix. Subjects viewed an 8 × 8 matrix with some squares filled in black, reported whether the design was symmetrical about its vertical axis (which it was half of the time), and then were presented with a 4 × 4 matrix with one of the cells filled in red for 650 ms. They then performed the judgment task again and were presented with another matrix with a red square. After this alternating sequence occurred two to five times, subjects were asked to report the sequence of red-square locations in the preceding displays (i.e., list lengths ranged from 2 to 5), in the order in which they had appeared, by clicking on the cells of an empty matrix (see Unsworth, Redick, Heitz, Broadway, & Engle, 2009, for more details). There were three trials of each list length, for a total possible of 42 locations correctly recalled.

Reading span. On each trial of this task, subjects were required to read sentences while trying to remember a set of unrelated letters (the same sets from the operation-span task were used). Subjects read a sentence (e.g., "The prosecutor's case was lost because it was not based on fact"), reported whether it made sense (which it did half the time), and then were presented with a letter for 1 s. Immediately afterward, the next sentence was presented and judged, and then another letter was presented. After this alternating sequence occurred three to seven times, subjects were asked to recall the presented letters in order (i.e., list lengths ranged from 3 to 7), by clicking on the appropriate letters. Nonsense sentences were made by simply changing one word in an otherwise normal sentence (e.g., changing "case" to "dish" in the preceding example; see Unsworth et al., 2009, for more details on this task). There were three trials of each list length, for a total possible of 75 letters correctly recalled.

Fluid intelligence tasks

Raven's Advanced Progressive Matrices. This test is a measure of abstract, inductive reasoning (Raven, Raven, & Court, 1998). Thirty-six items are presented in ascending order of difficulty. Each item consists of a display of 3 × 3 matrices of geometric patterns, arranged according to an unknown set of rules, with the bottom right pattern missing. The task is to select, among eight alternatives, the one that correctly completes the overall series of patterns. After completing two practice problems, subjects had 10 min to complete the 18 odd-numbered items from the test. A subject's score was the total number of correct solutions. Higher scores represented better performance.

Number series. In this task, subjects saw a series of numbers, arranged according to an unstated rule, and were required to induce what the next number in the series should be (Thurstone, 1962). Subjects selected their answer from five possible numbers that were presented. After working on five practice items, subjects had 4.5 min to complete 15 test items. A subject's score was the total number of items solved correctly. Higher scores represented better performance.

Letter sets. In this task, subjects saw five sets of four letters and were required to induce a rule that described the composition and ordering of four of the five sets (Ekstrom, French, Harman, & Dermen, 1976). Subjects were then required to indicate the set that violated the rule. After working on two example problems, subjects had 5 min to complete 20 test items. A subject's score was the total number of items solved correctly. Higher scores represented better performance.

Attention-control tasks

SART. Subjects completed a version of the SART with semantic stimuli, adapted from McVay and Kane (2009). The SART is a go/no-go task in which subjects must respond quickly with a key press to all presented stimuli except infrequent (11%) target stimuli. In this version of the SART, each word stimulus was presented in 18-point Courier New font for 300 ms and followed by a 900-ms mask. The nontarget stimuli were members of one category (animals), and the infrequent targets were members of a different category (foods). The SART had 470 trials, on 50 of which targets were presented. The dependent variables were accuracy on no-go trials (i.e., successful withholding of responses) and standard deviation of response time (RT) on go trials. Higher accuracy and lower standard deviation represented better performance.

Antisaccade. Subjects began each trial in this task by staring at a fixation point that was on-screen for a variable interval (200–2,200 ms). A white equal sign ("="), the cue, was then flashed either to the left or to the right of fixation (11.33° of visual angle) for 100 ms. This was followed by a 50-ms blank screen and a second appearance of the flashed cue for 100 ms on-screen. After another 50-ms blank screen, the target stimulus ("B," "P," or "R") appeared on-screen (11.33° to the left or right of fixation) for 100 ms, followed by masking stimuli ("H" for 50 ms and then "8" until a response was given). All stimuli were presented in 12-point Courier New font. The subjects' task was to report the target letter by pressing "1" (for "B"), "2" (for "P"), or "3" (for "R") on the number key pad as quickly and accurately as possible. In the prosaccade condition, the flashing cue and the target appeared in the same location. In the antisaccade condition, they appeared in opposite locations. Subjects received, in order, 10 practice trials to learn the response mapping, 10 trials of the prosaccade condition, and 50 trials of the antisaccade condition. The dependent variable was accuracy on the antisaccade trials. Higher scores represented better performance.

Arrow flankers. Each trial in this task began with a fixation point that was presented for 400 ms. An arrow was then displayed directly above the fixation point for 1,700 ms. The subjects' task was to indicate the direction in which the arrow was pointing (by pressing the "F" key for left-pointing arrows and the "J" key for right-pointing arrows) as quickly and accurately as possible. On 30 neutral trials, the arrow was flanked by two horizontal lines on each side. On 30 congruent trials, the flankers were arrows pointing in the same direction as the target arrow. Finally, on 30 incongruent trials, the flankers were arrows pointing in the direction opposite the direction in which the target arrow was pointing. The three trial types were randomly intermixed. The dependent variable was the RT difference between incongruent and congruent trials. Lower scores represented better performance.

Stroop. On each trial of this task, subjects were presented with a color word ("red," "green," or "blue") presented in one of three font colors (red, green, or blue). The task was to indicate the font color via a key press ("1" = red, "2" = green, "3" = blue), as quickly and accurately as possible. After completing 15 trials of response-mapping practice and 6 trials of practice with the real task, subjects received 135 test trials. Of these trials, 67% were congruent; that is, the word's meaning and font color matched (e.g., "red" printed in red). The other 33% of the trials were incongruent (e.g., "red" printed in green). The dependent variable was the RT difference between incongruent and congruent trials. Lower scores represented better performance.

Psychomotor vigilance. The psychomotor vigilance task (Dinges & Powell, 1985) was used as the primary measure of sustained attention. A row of zeroes appeared on-screen, and after a variable amount of time, the zeros began to count up to indicate the passage of time, in 1-ms intervals from 0 ms. The subjects' task was to press the space bar as quickly as possible once the counting began. After the space bar was pressed, the current count remained on-screen for 1 s to provide feedback on RT for that trial. Interstimulus intervals were randomly distributed and ranged from 1 to 10 s. The entire task lasted for 10 min (roughly 75 trials). The dependent variable was the average RT for the slowest 20% of trials (Dinges & Powell, 1985). Lower scores represented better performance.

Video-game-experience questionnaire. The video-game-experience questionnaire asked subjects to indicate their expertise (scale from 1 to 7; results not discussed here) and the number of hours per week that they had played various types of video games over the last year (*never, 0+ to 1, 1+ to 3, 3+ to 5, 5+ to 10*, or *10+*;

Table 1. Differences Between Video-Game Players and Non-Video-Game Players on the Cognitive-Ability Measures in Experiment 1

Measure	Players (n = 18)	Nonplayers (n = 29)	t(46)	p	Cohen's d	r_{pb}
Operation span	58.22 (9.40)	52.48 (12.99)	1.63	.11	0.51	.24
Symmetry span	33.39 (5.44)	27.03 (6.64)	3.41	.00	1.05	.45
Reading span	48.39 (13.32)	50.66 (13.74)	–0.56	.58	–0.17	–.08
Raven's matrices	9.33 (3.58)	6.69 (2.74)	2.86	.00	0.83	.39
Letter sets	9.94 (2.39)	8.57 (2.21)	1.99	.05	0.59	.28
Number series	10.00 (2.89)	7.24 (1.84)	4.00	.00	1.14	.51
Antisaccade	.51 (.15)	.44 (.08)	2.12	.04	0.67	.30
Flankers (ms)	124.27 (81.95)	115.27 (129.86)	0.26	.79	0.08	.04
SART *SD*	152.98 (36.80)	180.64 (56.42)	–1.85	.07	–0.58	–.27
SART accuracy	.54 (.17)	.53 (.16)	0.21	.83	0.08	.03
Stroop (ms)	177.79 (100.38)	179.23 (122.28)	–0.04	.97	0.01	–.01
PVT (ms)	566.87 (133.83)	692.16 (268.21)	–1.84	.07	0.60	–.26
WM	.12 (.70)	–.22 (.82)	1.46	.15	0.44	.21
*g*F	.40 (.93)	–.50 (.54)	4.22	.00	1.18	.53
AC	.11 (.81)	–.34 (.73)	1.98	.05	0.58	.28

Note: Video-game players and nonplayers were identified on the basis of their experience playing first-person shooter games. SART = sustained-attention-to-response task; PVT = psychomotor vigilance task; WM = working memory factor composite; *g*F = fluid intelligence factor composite; AC = attention-control factor composite; r_{pb} = point-biserial correlation.

B. Hubert-Wallander, C. S. Green, & D. Bavelier, personal communication, October 12, 2011). The different types of games were first-person shooter games (e.g., *Halo, Call of Duty*), action games (e.g., *God of War, Mario Kart*), real-time strategy games (e.g., *Warcraft, Starcraft*), turn-based and puzzle games (e.g., *Sims, Solitaire*), role-playing games (e.g., *World of Warcraft, Final Fantasy*), and music games (e.g., *Guitar Hero, Rock Band*).

Results

Extreme-groups analyses. For our first set of analyses, we examined whether video-game players outperformed non-video-game players on the different tasks. In particular, we were interested in whether subjects who reported playing first-person shooter games frequently outperformed non-video-game players; most previous research has specifically examined differences between individuals who self-report playing first-person shooter games several hours per week and individuals who report playing no games. For this comparison, video-game players were identified as subjects who reported playing first-person shooter games for more than 5 hr per week over the last year. Non-video-game players were identified as those who reported both not playing first-person shooter games at all and playing the other types of games less than 1 hr a week. These criteria match those used in many prior similar studies (e.g., Green & Bavelier, 2007; McDermott et al., 2014). In this experiment, the criteria identified 18 video-game players and 29 non-video-game players. Table 1 summarizes their performance on each measure and shows that the groups differed significantly on a number of them: Video-game players outperformed nongamers on one measure of working memory (symmetry span), all the fluid intelligence measures, and some of the attention-control measures. Furthermore, across most measures, there was a trend for video-game players to outperform non-video-game players.

We also computed factor composites for the three different abilities (working memory, fluid intelligence, and attention control) to get a sense for whether broader measures of abilities would show group differences. As Table 1 shows, the two groups differed on both fluid intelligence and attention control, but the difference was not significant for working memory. Overall, these results are broadly consistent with prior extreme-groups studies suggesting that video-game players have superior cognitive abilities compared with nonplayers.

Correlations. Next, we examined the zero-order correlations between video-game playing experience (hours per week) for each game type and the cognitive-ability measures, using the full range of subjects (N = 198). In other words, rather than examining extreme groups, we utilized the full data set to determine the relations between video-game playing and cognitive abilities. Table 2 shows the descriptive statistics for all of the measures for all subjects. Table 3 presents the zero-order correlations between the cognitive-ability measures and self-reported experience playing each type of video game. For first-person shooter games, only 3 of the correlations were statistically significant, and all

Table 2. Descriptive Statistics and Reliability Estimates for All Measures in Experiment 1

Measure	*M*	*SD*	Range	Reliability
Cognitive-ability measures				
Operation span	56.67	11.41	10–75	.77
Symmetry span	30.30	6.75	3–42	.71
Reading span	51.62	13.65	0–75	.82
Raven's matrices	8.02	2.99	1–15	.70
Letter sets	9.82	2.76	3–16	.64
Number series	8.61	2.45	1–14	.70
Antisaccade	.48	.12	.21–.88	.76
Flankers (ms)	112.06	80.32	–44.89–697.50	.60
SART *SD*	152.44	50.75	35.61–352.83	.92
SART accuracy	.53	.17	.16–.98	.83
Stroop (ms)	155.18	99.35	–29.77–536.57	.58
PVT (ms)	631.56	280.91	322.42–2,887.13	.90
Video-game experience[a]				
Shooter games	.88	1.32	0–5	—
Action games	.92	1.18	0–5	—
Real-time strategy games	.29	.85	0–5	—
Turn-based games	.79	.98	0–5	—
Role-playing games	.35	.99	0–5	—
Music games	.56	.87	0–5	—

Note: SART = sustained-attention-to-response task; PVT = psychomotor vigilance task; Reliability estimates are from the full data set from Unsworth and McMillan (2014).
[a]Subjects' responses as to how many hours a week they played each category of video games were coded on a scale from 0 (*never*) to 5 (*10+ hr*).

were relatively weak. Thus, whereas the extreme-groups analysis suggested a number of significant relations between cognitive abilities and experience playing first-person shooter games, the correlational analysis, relying on the full range of subjects, suggested fewer and weaker relations. Similarly, weak to null relations were found for action video games (1 significant correlation), real-time strategy games (1 significant correlation), turn-based games (3 significant correlations), role-playing games (no significant correlations), and music games (1 significant correlation in the nonpredicted direction). In total, only 8 out of a possible 72 correlations between video-game

Table 3. Zero-Order Correlations Between the Cognitive-Ability Measures and Video-Game Experience for Each Type of Game in Experiment 1

	Game type					
Measure	Shooter	Action	Real-time strategy	Turn-based	Role-playing	Music
Operation span	.05	.08	–.02	.03	.04	–.10
Symmetry span	.14*	.11	.07	.05	.01	–.10
Reading span	–.06	–.08	–.01	.18*	–.02	.00
Raven's matrices	.14*	.11	.22*	.07	.08	–.04
Letter sets	.05	.04	–.02	.16*	–.03	.02
Number series	.18*	.20*	.06	–.04	.07	–.14*
Antisaccade	.05	.04	.11	.06	–.04	.11
Flankers	.05	–.06	.10	–.12	.10	.07
SART *SD*	–.06	–.05	–.05	–.15*	–.03	–.02
SART accuracy	–.03	.02	.08	–.10	.03	.02
Stroop	.04	.06	.06	.02	–.04	.01
PVT	–.04	–.07	.01	–.07	.03	.05

Note: SART = sustained-attention-to-response task; PVT = psychomotor vigilance task.
*$p < .05$.

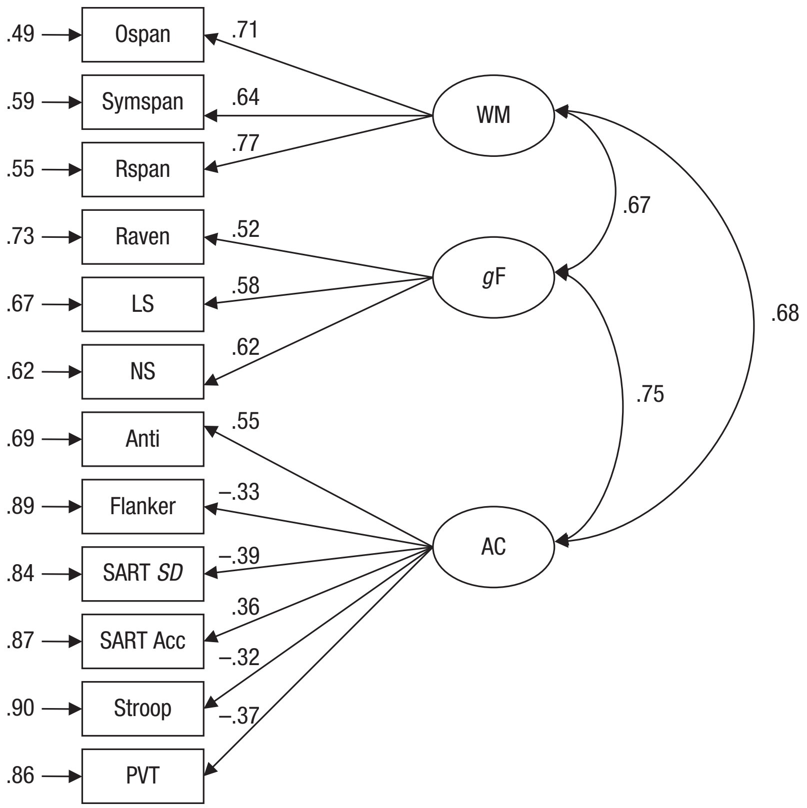

Fig. 1. Confirmatory factor analysis model of working memory (WM), fluid intelligence (*g*F), and attention control (AC) in Experiment 1. Paths connecting the latent variables (circles) to each other represent the correlations between the constructs, the numbers from the latent variables to the manifest variables (squares) represent the loadings of the tasks onto the corresponding latent variables, and the numbers next to the manifest variables represent error variance associated with each task. Ospan = operation span; Symspan = symmetry span; Rspan = reading span; Raven = Raven's Advanced Progressive Matrices; LS = letter sets; NS = number series; Anti = antisaccade; Flanker = arrow flankers; SART *SD* = standard deviation on the sustained-attention-to-response task; SART Acc = accuracy on the sustained-attention-to-response task; PVT = psychomotor vigilance task. All loadings and paths were significant, $p < .05$.

experience and cognitive abilities were statistically significant ($p < .05$) in the expected direction, and none of the significant correlations were greater than .22 (53 correlations, or 74%, had absolute values < .10). We also calculated the correlations separately for each gender to see if gender had any influence and found that the correlations were virtually the same for males and females.

Latent-variable analyses. Although all of the cognitive-ability measures had adequate reliabilities (Table 2), perhaps the weak to nonexistent relationship between video-game experience and cognitive abilities was due to idiosyncratic task effects. Examining these relations at the latent-variable level, rather than the task level, should provide a better estimate of the relations between video-game experience and cognitive abilities. For this analysis, we first specified a model for the cognitive-ability measures using confirmatory factor analysis. Specifically, we specified a model with a working memory latent variable (composed of the three working memory measures), a fluid intelligence latent variable (composed of the three fluid intelligence measures), and an attention-control latent variable (composed of the six attention-control measures). All measures were specified to load only on the factor of interest, and all three latent variables were free to correlate. The fit of the model was excellent, $\chi^2(51) = 46.99$, $p > .63$, $\chi^2/df = 0.92$, root-mean-square error of approximation (RMSEA) = .00, standardized root-mean-square residual (SRMR) = .04, nonnormed fit index (NNFI) = 1.0, comparative fit index (CFI) = 1.0. As illustrated in Figure 1, each measure loaded significantly on its factor of interest, and the factors were strongly intercorrelated, which is consistent with prior research (Unsworth, Fukuda, Awh, & Vogel, 2014; Unsworth & Spillers, 2010).

Table 4. Latent Correlations Between the Cognitive-Ability Measures and Video-Game Experience for Each Type of Game in Experiment 1

	Game type					
Measure	Shooter	Action	Real-time strategy	Turn-based	Role-playing	Music
Working memory	.06	.05	.02	.13	.01	–.10
Fluid intelligence	.23*	.23*	.14	.09	.08	–.12
Attention control	.04	.08	.07	.12	–.04	.05

*$p < .05$.

Next, we added in the video-game-experience measure for each type of video game. The video-game loadings were set equal to 1, and each type of video game was allowed to correlate with each cognitive-ability factor and with the other video-game measures. The fit of this model was also good, $\chi^2(105) = 126.35$, $p > .08$, $\chi^2/df = 1.20$, RMSEA = .03, SRMR = .05, NNFI = .94, CFI = .96. As Table 4 shows, the only significant latent correlations were between experience playing first-person shooter games and fluid intelligence and between experience playing action games and fluid intelligence (both *r*s = .23). All of the other relations were not significantly different from zero, despite the large sample size. Thus, as did the zero-order correlation analyses, the latent-variable analyses suggested that the relations between video-game experience and cognitive abilities were weak to nonexistent; only 2 out of a possible 18 correlations were statistically significant ($p < .05$), which is not much more than one would expect by chance.

RT correlations. Our final set of analyses examined whether video-game experience was related to speed of responding in attention-control tasks. Prior extreme-groups studies (see Dye, Green, & Bavelier, 2009, for a review) have consistently suggested that video-game players are faster than non-video-game players on a variety of attention measures. To examine this relation, we computed mean RT for correct responses only across all trials in each attention-control task. RTs less than 200 ms or 3 standard deviations above an individual's mean were excluded from all RT analyses. We then correlated RT in each attention-control task with video-game experience for each type of game. Table 5 shows the resulting zero-order correlations. Once again, most of the correlations were near zero; only 6 out of a possible 30 correlations were significant, and these were weak. Furthermore, it should be noted that 3 of these significant correlations (2 for the antisaccade task and 1 for the Stroop task) were in the wrong direction, suggesting that more experience playing video games was related with slower (not faster) RTs. Thus, only 3 correlations actually suggested that more video-game experience led to faster RTs.

To examine these issues further, we used confirmatory factor analysis to specify a latent-variable model in which a single RT latent variable was formed by having RTs from the five attention-control tasks load on it; this factor was allowed to correlate with experience playing each of the different types of video games. The fit of this model was acceptable, $\chi^2(29) = 50.41$, $p < .01$, $\chi^2/df = 1.74$, RMSEA = .06, SRMR = .06, NNFI = .85, CFI = .90 and all of the RT measures (except for the antisaccade task) loaded significantly on the RT factor (antisaccade: .04; flankers: .58; SART: .23; Stroop: .78; psychomotor vigilance: .34). The only latent-variable correlation between video-game experience and RT that was significant was the correlation for turn-based games, $r = -.21$. The other

Table 5. Zero-Order Correlations Between Mean Reaction Time on the Attention-Control Measures and Video-Game Experience for Each Type of Game in Experiment 1

	Game type					
Measure	Shooter	Action	Real-time strategy	Turn-based	Role-playing	Music
Antisaccade	–.01	–.10	.16*	.06	.19*	.05
Flankers	–.04	–.15*	–.12	–.16*	–.08	.04
SART	–.05	.11	–.04	–.16*	–.02	–.04
Stroop	.01	.16*	–.04	–.11	–.03	.03
PVT	–.03	–.08	–.02	–.09	–.01	.01

Note: SART = sustained-attention-to-response task; PVT = psychomotor vigilance task.
*$p < .05$.

five correlations were nonsignificant—first-person shooter games: $r = -.03$; action games: $r = .08$; real-time strategy games: $r = -.10$; role-playing games: $r = -.08$; and music games: $r = .05$. Thus, as in the prior analyses, these results suggest weak to null correlations between video-game experience and cognitive abilities (in this case, speed of processing indexed by RT on the attention-control measures).

Discussion

The extreme-groups analyses in Experiment 1 suggested a number of significant effects indicating that video-game players outperform non-video-game players on a variety of cognitive measures. However, data for 151 subjects had to be excluded from these analyses. In contrast, when we calculated the zero-order and latent correlations using the full range of subjects, nearly all of these effects were no longer significant and were very weak in magnitude. The only consistent relations between video-game experience and cognitive abilities were the relations between fluid intelligence and experience with first-person shooter and action games. However, these effects should be interpreted cautiously, given that prior extreme-groups and correlational studies have failed to find a relation between action-video-game experience and measures of fluid intelligence (Boot et al., 2008; Colzato et al., 2013; Hambrick et al., 2010) and the meta-analytic effect size is rather small (Powers et al., 2013). Thus, Experiment 1 suggests that the associations between video-game playing and cognitive abilities are weak to nonexistent.

There are two significant limitations to this experiment that could hinder this interpretation. First, the video-game questionnaire that we used (and that is used by many researchers in the field) is categorical, and thus it is possible that we found only weak relations because there was not enough variability between responses categories to detect real relations. Second, although we relied on a fairly large sample size, it is possible that there was range restriction in the data; all of the subjects came from a single university sample, and most of the students did not report playing video games with high frequency.

Experiment 2

To rectify the limitations from Experiment 1, we reanalyzed data from Redick et al. (2014). The purpose of Experiment 2 was to replicate and extend the results of Experiment 1 using a larger and more representative sample, a continuous (rather than categorical) measure of video-game experience, and (again) a large number of measures for each construct.

Method

Subjects. The data analyzed for this experiment are a subset of the data reported in Redick et al. (2014). A total of 586 subjects (226 male, 354 female, gender information missing for 6 subjects) were tested at four universities: Georgia Institute of Technology (Georgia Tech), University of Georgia, Michigan State University, and University of North Carolina at Greensboro. All subjects were healthy young adults between the ages of 18 and 30. Not all were college students; 117 of the subjects tested at the Georgia Tech site were community volunteers who were not attending that school (although some attended other local universities). The recruitment materials made no mention of video-game experience. The analyses reported here were based on only the 466 subjects who both completed all cognitive-ability tests in all three test sessions (110 subjects did not have complete data) and filled out the video-game questionnaire with plausible answers (10 subjects did not provide plausible answers, as described later). Subjects at the Georgia Tech site were compensated $30 for each session; subjects at all other sites received course credit in exchange for their participation.

Procedure. All subjects completed the tasks in three sessions, each lasting approximately 2 hr. At the beginning of the first session, subjects provided demographic information and completed a questionnaire about their video-game experience (Hambrick et al., 2010). The demographic questions asked subjects their age, gender, handedness, native language, and race. No information was obtained on socioeconomic status, although future research should address whether this variable influences the relations between cognitive abilities and video-game experience. All subjects completed the tasks in the same order. The tasks in Session 1 were operation span, control tower, change detection, paper folding, arrow flankers, continuous counters, spatial Stroop, and reading span. The tasks in Session 2 were matrix monitoring, visual brief report, letter sets, cued visual search, keeping track, symmetry span, SART, Raven's, and Air Traffic Control (ATC) lab. Finally, in Session 3, subjects completed the antisaccade, number-series, rotation-span, SynWin, spatial delayed match-to-sample (DMTS), dual *n*-back, cued-flankers, and math-access tasks. Data from the control-tower, ATC-lab, SynWin, spatial DMTS, dual *n*-back, and math-access tasks were not analyzed in the current study. All tasks were computerized.

Working memory tasks. The operation-span, symmetry-span, and reading-span tasks were the same as in Experiment 1.

Rotation span. In this task, subjects viewed rotated letters and judged whether they were mirror-reversed while they tried to remember a series of short or long arrows each of which pointed in one of eight specific directions. After two to five alternations of letters and arrows, subjects were required to report the directions of the arrows in serial order, choosing each in turn from the full complement of possibilities. The score was the total number of arrows recalled in the correct order (maximum = 42).

Keeping track. Each trial of this task began with the presentation of exemplars from two to six different categories (tools, animals, etc.). Then, a list of 16 words was presented, with each word shown on-screen for 1,500 ms (250-ms blank screen between words). After the final word in the list was presented, six exemplars were shown for each category, and subjects were asked to use the mouse to click on the most recently presented exemplar in each case. The total number of correctly recalled final exemplars across the 15 lists was used as the dependent variable. Higher scores indicated better performance.

Matrix monitoring. In each trial of this task, subjects were presented with either one or two 4 × 4 matrices in which a single cell was highlighted for 2,500 ms. Next, a series of one to four arrows was presented, indicating movement of the highlighted target cell or cells. A probe matrix was displayed, and subjects had to report whether the target cell would be in the indicated location in the probe matrix if the target cell had moved as indicated by the arrows. A single target matrix was presented on half of the 16 trials, and two target matrices were presented simultaneously on the other half. The proportion of correct responses to the probes was used as the dependent variable. Higher scores indicated better performance.

Continuous counters. In this task, subjects were instructed to keep separate running counts of the numbers of squares, circles, and triangles presented across 15 trials. Shapes were presented individually. Counting the shapes of each type was difficult because the type of shape changed randomly from trial to trial and the number of stimuli on each trial was unpredictable. The proportion of correct final counts was used as the dependent variable. Higher scores indicated better performance.

Change detection. On each trial of this task, subjects were briefly presented with a display of four to eight colored squares. The display disappeared for 900 ms and then reappeared with all the squares in the same locations. One of the squares was circled, and subjects reported whether that square was the same color it had been when originally presented. There were 60 trials in all. A bias-corrected measure of capacity (*k*; Cowan et al., 2005) was used as the dependent variable. Higher scores indicated better performance.

Visual brief report. On each trial of this task, subjects were presented with three to eight letters in random locations within a 4 × 4 grid. The letters were presented for 100 ms, and subjects then were instructed to report as many letters as possible, by clicking on the appropriate letters. The total number of letters correctly reported across 24 arrays was used as the dependent variable (maximum = 132). Higher scores indicated better performance.

Fluid intelligence tasks. The Raven's Advanced Progressive Matrices, letter-sets task, and number-series task were the same as in Experiment 1.

For each problem of the *paper-folding* task, subjects were presented with an illustration of a square piece of paper on the left. Markings indicated how the paper had been folded before a hole was punched through it. The task was to decide which one of five response options represented what the piece of paper would look like if it was completely unfolded after the hole was punched. The number of problems (out of 10) solved within the 4-min time limit was used as the dependent variable. Higher scores indicated better performance.

Attention-control tasks

Antisaccade. This task was the same as in Experiment 1 except that the proportion of errors across a total of 30 trials was used as the dependent variable. Lower scores indicated better performance.

Arrow flankers. This task was the same as in Experiment 1 except that there were 50 trials of each type.

SART. This task was the same as in Experiment 1 except that go stimuli occurred on 88.9% of all trials (540 trials total) and sensitivity (d') and RT variability (standard deviation) for correct responses were the dependent variables.

Spatial Stroop. In this task, subjects were presented with arrows and were asked to indicate whether each arrow pointed to the left or right, while ignoring its location (left, center, or right portion of the computer screen). These decisions were made difficult because on the majority of the 144 trials, the location and direction information were congruent (e.g., a left-pointing arrow on the left side of the screen), whereas on a small number of trials, the location and direction information were incongruent (e.g., a left-pointing arrow on the right side of the screen). The dependent variable was the RT difference between incongruent and congruent trials. Lower scores indicated better performance.

Cued visual search (Poole & Kane, 2009). On each trial of this task, subjects decided whether an *F* located within a 5 × 5 array of 25 letters (*E*s, backward *E*s, *F*s, backward *F*s, 90°-tilted *T*s, and 270°-tilted *T*s) was mirror-reversed (facing left) or normal (facing right). Before each multiletter visual array, subjects were given a 500-ms arrow cue indicating in which 2 or 4 of the 25 possible array locations the *F* might appear (always along the internal 3 × 3 "ring" of the array). Because other *F*s were randomly presented in noncued locations as irrelevant distractors, subjects had to maintain the cue information in order to respond correctly. The mean RT for correct responses across the 160 trials was used as the dependent variable. Lower scores indicated better performance.

Cued flankers. On each trial in this task, subjects decided whether a target *F* located within a horizontal array of seven letters (including a distractor *F*) was mirror-reversed (facing left) or normal (facing right). Before each array, subjects were given a location cue (a digit presented for 500 ms) that indicated which of the following seven letters was the target. The target was restricted to one of the middle five positions in the row (i.e., Locations 2–6). There were 120 trials in total. On compatible trials, all of the letters faced the same direction as the target. However, on the 20 incompatible-lure trials, the target and some of the irrelevant flanker letters faced in opposite directions, and subjects had to remember the cue information to respond correctly. The mean RT for correct responses on the incompatible-lure trials was used as the dependent variable. Lower scores indicated better performance.

Video-game-experience questionnaire. The video-game-experience questionnaire asked subjects to estimate the number of hours per week that they played different types of video games (Hambrick et al., 2010). Before providing these estimates, subjects were explicitly told that "with 24 hours per day, and 7 days per week, the maximum number of hours is 168." The different types of games were first- and third-person shooter games (e.g., *Halo, Medal of Honor, Call of Duty, Gears of War, Resident Evil*); sports, action, and "other" games (e.g., *Madden, Wii Sports, Super Mario Brothers, Sonic, Tetris*); real-time strategy games (e.g., *Age of Empires, Starcraft, Halo Wars*); and role-playing games (e.g., *World of Warcraft, Grand Theft Auto, Fable, Final Fantasy*). Of the 10 subjects excluded on the basis of their responses to this questionnaire, 9 provided total values that equaled or exceeded 168 hr per week; 1 additional subject reported playing first- and third-person shooter games for 121 hr each week.

Results

Correlations. First, we examined the zero-order correlations between video-game-playing experience (hours per week) and the cognitive-ability measures, using the full range of subjects. Table 6 shows the descriptive statistics for all measures. On average, subjects played video games for a total of 6.5 hr per week (SD = 14.67) and played each individual type of game roughly 1 to 2 hr a week (Fig. S1 in the Supplemental Material shows the distribution of the number of hours of playing time for each type of video game). Table 7 presents the zero-order correlations between the cognitive-ability measures and responses on the video-game questionnaire for the four types of video games. Only 4 of the correlations were statistically significant (1 was in the nonpredicted direction), and all were relatively weak. Thus, only 3 out of a possible 80 correlations between video-game experience and cognitive abilities were significant in the expected direction, and none were greater than .13. Note that for the RT measures, only 1 correlation was significant (that between cued visual search and experience with role-playing games). Thus, the data provide little evidence for a relation between processing speed and video-game experience. As in Experiment 1, we also examined the correlations separately for males and females and found that there were no differences as a function of gender.

Latent-variable analyses. As in Experiment 1, we next used latent-variable techniques to better examine the relation between video-game experience and cognitive abilities. We first specified a model for the cognitive-ability measures using confirmatory factor analysis. As before, the model had a working memory latent variable (composed of the nine working memory measures), a fluid intelligence latent variable (composed of the four fluid intelligence measures), and an attention-control latent variable (composed of the seven attention control measures). All measures were specified to load only on the factor of interest, and all three latent variables were free to correlate. The fit of the model was good, $\chi^2(167) = 658.71$, $p < .01$, $\chi^2/df = 3.94$, RMSEA = .08, SRMR = .06, NNFI = .93, CFI = .94. As shown in Figure 2, each measure loaded significantly on its factor of interest, and the factors were strongly intercorrelated.

Next, we added in the video-game-experience measures. The video-game loadings were set equal to 1, and each type of video game was allowed to correlate with each cognitive-ability factor and with the other video-game measures. The fit of this model was also adequate, $\chi^2(235) = 738.09$, $p < .01$, $\chi^2/df = 3.14$, RMSEA = .07, SRMR = .06, NNFI = .93, CFI = .94. As Table 8 shows,

Table 6. Descriptive Statistics and Reliability Estimates for All Measures in Experiment 2

Measure	*M*	*SD*	Range	Reliability
Cognitive-ability measures				
Operation span	54.75	14.45	2–75	.84
Reading span	52.30	14.11	0–75	.83
Symmetry span	25.94	8.88	0–42	.81
Rotation span	27.82	8.69	0–42	.80
Change detection (*k*)	3.44	1.27	−1.33–5.80	.78
Continuous counters	.83	.18	.16–1.00	.91
Keeping track	35.14	8.82	6–53	.85
Brief report	94.46	11.00	64–119	.73
Matrix monitoring	.81	.14	.31–1.00	.57
Antisaccade	.47	.16	.07–.80	.86
Arrow flankers (ms)	100.15	67.94	−276.94–518.64	.61
Cued flankers (ms)	717.34	245.52	210.00–1,824.93	.87
Cued visual search (ms)	1,258.58	277.50	519.69–2,468.99	.89
SART *d*′	1.69	1.05	−3.61–3.90	.96
SART *SD*	162.90	49.07	50.35–354.34	.86
Spatial Stroop (ms)	137.12	74.20	−7.09–487.33	.48
Letter sets	10.33	3.13	1–18	.72
Raven's matrices	9.14	3.57	0–17	.79
Number series	8.83	2.96	1–15	.75
Paper folding	5.94	2.65	0–10	.78
Video-game experience (hr/week)				
Shooter games	1.70	5.58	0–48	—
Strategy games	0.76	3.57	0–45	—
Role-playing games	1.93	6.80	0–78	—
Sports, action games	2.14	5.30	0–40	—

Note: SART = sustained-attention-to-response task. Reliability estimates are from the full data set in Redick et al. (2014).

none of the 12 latent correlations between video-game experience and cognitive abilities was statistically significant. Thus, as did the zero-order correlation analyses, the latent-variable analyses suggested that the relations between video-game experience and cognitive abilities were weak to nonexistent.

Discussion

Using a large and more representative sample of subjects, along with a continuous measure of video-game experience, Experiment 2 largely replicated Experiment 1 in finding weak to null correlations between video-game experience and measures of cognitive abilities. Experiment 2 also extended the results from Experiment 1 to a number of additional measures of working memory and attention control. Finally, unlike in Experiment 1, the relation between video-game experience and fluid intelligence was not significant in Experiment 2. These results, coupled with prior research that failed to find a relation between video-game experience and fluid intelligence (Boot et al., 2008; Colzato et al., 2013; Hambrick et al., 2010), cast doubt on the stability of this relation.

General Discussion

In the current study, we examined whether experience playing video games is related to cognitive abilities using large samples of subjects and a variety of tasks. In Experiment 1, we examined the data using an extreme-groups design, as has been done previously in the literature, and found a number of significant effects suggesting that video-game players outperformed non-video-game players on a variety of cognitive measures. However, when we analyzed the data in Experiments 1 and 2 using the full range of subjects, many of these effects were no longer significant and were very weak in magnitude. Likewise, when we examined the relationships using latent variables, which more accurately represent the intended constructs, most of the latent correlations in Experiments 1 and 2 were near zero; those that were significant were very weak compared with the relationships among the cognitive-abilities factors themselves.

Table 7. Zero-Order Correlations Between the Cognitive-Ability Measures and Video-Game Experience for Each Type of Game in Experiment 2

	Game type			
Measure	Shooter	Strategy	Role-playing	Sports, action
Operation span	.01	.00	−.02	.03
Reading span	−.03	.05	−.04	−.04
Symmetry span	.02	.03	.05	−.03
Rotation span	.04	.08	.06	.05
Change detection	.02	.05	−.01	−.02
Continuous counters	−.08	−.07	−.04	−.07
Keeping track	−.13*	−.06	−.07	−.05
Brief report	.06	.03	.04	.13*
Matrix monitoring	−.04	.00	.00	−.02
Antisaccade	−.05	−.09*	−.07	−.03
Arrow flankers	−.06	−.06	−.04	−.06
Cued flankers	−.03	−.02	−.08	−.08
Cued visual search	−.03	−.05	−.10*	−.05
SART *d′*	−.05	−.05	−.06	−.01
SART *SD*	.03	.05	.01	−.03
Spatial Stroop	−.08	−.03	−.05	.03
Letter sets	−.01	.03	.00	−.02
Raven's matrices	−.05	−.02	.00	−.06
Number series	.00	−.03	.02	.00
Paper folding	−.01	−.01	.03	−.03

Note: SART = sustained-attention-to-response task.
*$p < .05$.

That is, the presence of strong intercorrelations among working memory, fluid intelligence, and attention control indicates that there was sufficient variability present among the subjects to allow for strong relationships with the video-game variables to be observed, if they existed.

These results are in direct contrast with those of many prior studies that have suggested a strong relationship between video-game experience and cognitive abilities. One potential reason for these discrepant findings is that many prior studies relied on relatively small sample sizes and extreme-groups designs, which resulted in overestimated effect sizes and increased likelihood of Type 1 errors. Indeed, by analyzing the data in Experiment 1 both ways, we demonstrated that effect sizes obtained from extreme-groups analyses were much larger than those obtained from analyses including the full range of subjects. Specifically, as shown in Table 1, the point-biserial correlations for several of the significant relations between experience playing first-person shooter games and the cognitive-ability measures had values greater than .30 in the extreme-group comparisons. However, the correlations for the exact same relations were smaller than .25 when calculations were based on the full range of subjects. Thus, the effect sizes obtained using the full range of subjects were drastically smaller than those found when we relied on extreme-groups analyses, which suggests that prior extreme-groups studies overestimated the effect sizes and may have found spurious relations as a result. We also suggest that effect sizes were likely overestimated in the prior meta-analysis, given that it was largely based on extreme-groups studies (Powers et al., 2013; see Redick & Webster, 2014, for a similar critique).

Overall, the current results suggest weak to nonexistent relations between video-game experience—across a variety of different games—and fundamental cognitive abilities (working memory, fluid intelligence, attention control, and speed of processing). In order to fruitfully examine whether playing video games is related to cognitive abilities, future research should examine the full range of subjects (i.e., not rely exclusively on extreme-groups analyses), should rely on sufficiently large sample sizes to estimate stable correlational effects, and should examine these relations across a number of similar measures thought to represent the constructs of interest (ideally using latent-variable techniques). More research is needed to examine whether there are any stable relations between video-game experience and cognitive abilities and, if there are, what their overall magnitude is.

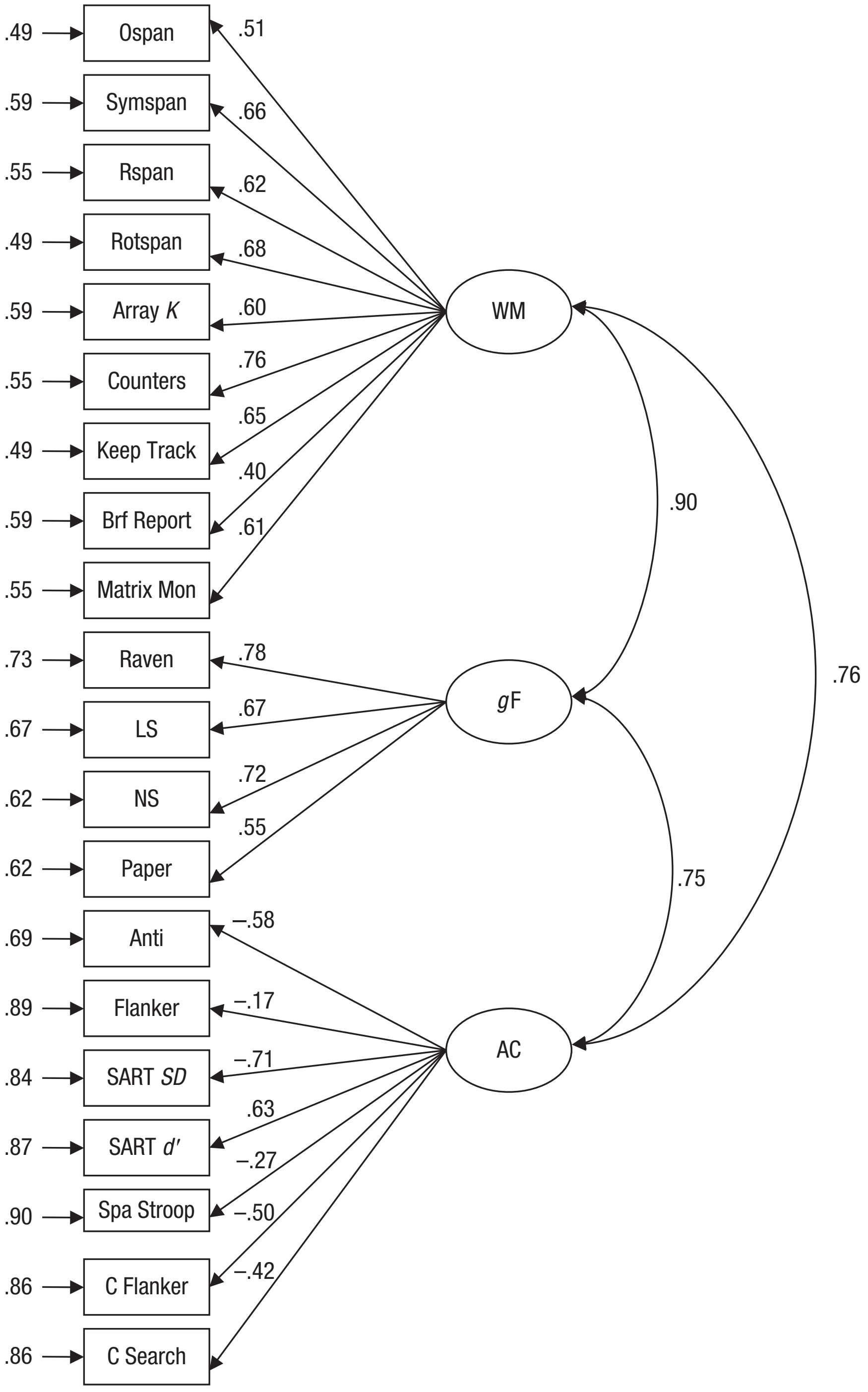

Fig. 2. Confirmatory factor analysis model of working memory (WM), fluid intelligence (*g*F), and attention control (AC) in Experiment 2. Paths connecting the latent variables (circles) to each other represent the correlations between the constructs, the numbers from the latent variables to the manifest variables (squares) represent the loadings of the tasks onto the corresponding latent variables, and the numbers next to the manifest variables represent error variance associated with each task. Ospan = operation span; Symspan = symmetry span; Rspan = reading span; Rotspan = rotation span; Array *K* = change detection; Counters = continuous counters; Keep Track = keeping track; Brf Report = visual brief report; Matrix Mon = matrix monitoring; Raven = Raven's Advanced Progressive Matrices; LS = letter sets; NS = number series; Paper = paper folding; Anti = antisaccade; Flanker = arrow flankers; SART *SD* = standard deviation on the sustained-attention-to-response task; SART *d′* = *d′* on the sustained-attention-to-response task; Spa Stroop = spatial Stroop; C Flanker = cued flankers; C Search = cued visual search. All loadings and paths were significant, $p < .05$.

Table 8. Latent Correlations Between the Cognitive-Ability Measures and Video-Game Experience for Each Type of Game in Experiment 2

	Game type			
Measure	Shooter	Strategy	Role-playing	Sports, action
Working memory	–.04	.01	–.01	–.03
Fluid intelligence	–.03	–.02	.01	–.04
Attention control	.01	.01	.04	.05

$^{*}p < .05$.

Author Contributions

N. Unsworth developed the study concept. B. D. McMillan and N. Unsworth designed Experiment 1 and conducted the testing and data collection. R. W. Engle, D. Z. Hambrick, M. J. Kane, T. S. Redick, and N. Unsworth designed Experiment 2 and conducted the testing and data collection. N. Unsworth performed the data analysis. N. Unsworth drafted the manuscript, and T. S. Redick, B. D. McMillan, D. Z. Hambrick, M. J. Kane, and R. W. Engle provided critical revisions. All authors approved the final version of the manuscript for submission.

Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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Supplemental Material

Additional supporting information can be found at http://pss.sagepub.com/content/by/supplemental-data

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