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Effects of Action Video Game Play on Arithmetic Performance in Adults

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Abstract
This experimental study investigated the state (short-term) effects of action video game (AVG) training on arithmetic performance and their persistence over time. In addition, it examined group differences between experienced and novice AVGers. Twenty-nine college students without a prior AVG experience were randomly assigned to one of the two training groups: AVG and non-AVG. After 40 minutes of video game training, the arithmetic problem-solving speed and accuracy of non-AVG group increased, while the AVG group's arithmetic performance decreased, thus suggesting a possibility of state effects of a non-AVG training on arithmetic performance. The state effects did not persist over time; on a delayed posttest, both groups' arithmetic performance was similar to their pretraining scores. In addition, there were nonsignificant differences in arithmetic performance between experienced and novice AVGers. Implications for investigating the game mechanics and transfer mechanism between the game and transfer task are discussed.

Keywords
action video games, training, arithmetic problem-solving, cognition

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Over the past 20 years, a large body of literature has documented the beneficial effects of playing action video games (AVGs) on various perceptual, attentional, and cognitive abilities producing real-world training and learning benefits that transfer from the actual act of the video gaming to novel tasks and stimuli (Bediou et al., 2018). AVG is a particular game genre characterized by the high speed of game events, a constant need to make predictions regarding future game events, and emphasis on peripheral vision that pose high cognitive,

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perceptual, and motor loads (Bediou et al., 2018). Fast-action first-person shooter games, such as *Halo* and *Call of Duty*, are prototypical examples of AVGs. AVGs were documented to improve a variety of cognitive and perceptual skills including working memory capabilities (Green & Bavelier, 2007), spatial cognition (Feng et al., 2007), reaction times (Clark et al., 1987), geometry skills (Novak & Tassell, 2015), reading skills (Franceschini et al., 2013), laparoscopic skills (Schlickum et al., 2009), science domain knowledge (Sanchez, 2012), and general test performance (Frederiksen & White, 1989). Even the U.S. Navy has considered AVG as a training approach (Hsu, 2010).

Despite these promising findings, the research in the field presents mixed evidence regarding the relationship between playing AVGs and enhanced cognitive abilities. For example, Boot et al. (2008) found no evidence in support of the AVG training effectiveness on different cognitive abilities, such as, enumeration, n-back tasks, and operation span. Oei and Patterson (2015) examined four different AVGs with varying speed, visual, and attention demands as a training strategy to ascertain their common demands hypothesis, according to which transfer from the act of video gaming to novel tasks depends on similarities between the video game and the task. Oei and Patterson's (2015) results supported their hypothesis showing that games with higher demands had a better transfer to novel tasks than games with lower demands. Nevertheless, a recent meta-analysis by Bediou et al. (2018) found that AVG training has a long-lasting impact on experienced AVG players' perceptual, attentional, and cognitive skills when compared with individuals who play non-AVG games or who do not play video games at all (e.g., visual sensitivity, Appelbaum et al., 2013; attentional control, Bavelier & Green, 2019; Föcker et al., 2018, 2019; Green & Bavelier, 2012; visual short-term memory, Pavan et al., 2019). The meta-analysis findings extended to intervention studies that show casual effects as well: Long-term AVG training can positively enhance various areas of human cognition when compared with training with non-AVG commercial games (Bediou et al., 2018). These intervention studies suggest that playing AVGs presents advantages over playing non-AVGs regarding their impact on cognition. Yet, another meta-analysis showed only a weak relationship between playing video games and enhanced cognitive abilities and no evidence of causal relationships between video games and enhanced cognition (Sala et al., 2018). These results were consistent for both action and non-AVGs.

Although the AVG research has received considerable attention, most of the research in the field used long-term video game training (5+ hours) to investigate durable effects of video gaming using delayed posttests (at least 24 hours after the last video game training session; see Green et al., 2019 and Bediou et al., 2018 for methodological standards in video game training for cognitive enhancement). Very little research has been done on how AVG training affects human cognition immediately after the game play, that is, short-term (state) effects (Kozhevnikov et al., 2018). The literature on video games suggests the existence of the enhanced cognitive states after video gaming. Several researchers proposed that video games, and AVG in particular, can induce a state of flow or *peak experiences*, which enhance various attentional, perceptual, and cognitive abilities for limited durations (Cowley et al., 2008; Csikszentmihalyi, 1975; Klasen et al., 2011; Maslow, 1999). However, most of the reports come from phenomenological research (qualitative analysis of narrative data; e.g., Csikszentmihalyi, 1975; Kozhevnikov et al., 2018; Maslow, 1999). To address this gap, this experimental study examined the state effects of video game training on arithmetic performance in college students.

Although experimental research on the state effects of video games is scarce, several studies have shown that video game training, including both AVG and non-AVG, can temporarily boost human performance on various novel tasks and stimuli immediately after playing a video game. For instance, non-AVG training was used as a warm-up training strategy for improving psychomotor skills in the field of surgery (Plerhoples et al., 2011; Rosser et al., 2007). Surgical residents who played a non-AVG balance game on a mobile device for 10 minutes performed significantly fewer errors on a laparoscopic surgery simulator than the control group that did not receive any training.

In addition to psychomotor skills, video game training was examined for improving spatial attention. Kozhevnikov et al. (2018) reported significant improvements in temporal and spatial aspects of attention in participants immediately after a 30-minute long AVG training but not in those who observed AVG play. These cognitive enhancements disappeared after a 30 minute break from video gaming.

Sanchez (2012) explored the immediate effects of AVG training on students' visuospatial capabilities and science learning to examine the causal relationships between successful science learning and good visuospatial skills (Black, 2005). Participants were assigned to either a visuospatial (AVG, *Halo: Combat Evolved*) or a nonspatial (non-AVG, *Word Whomp'*) training of 25 minutes. The spatial-training group outperformed the non-spatial-training group on the visuospatial and academic tasks (reading a text and writing an essay). The author argued that the visuospatial training produced real cognitive enhancements that went beyond simple activation of dormant cognitive processes as a result of a video gaming warm-up, because participants improved both their spatial skills and science learning. However, because no delayed posttest assessments were performed, it is unknown whether these effects persisted over time.

Nelson and Strachan (2009) examined participants' performance using a task that emphasized both speed and accuracy immediately after playing an hour of an AVG (*Unreal Tournament*) or a puzzle video game (*Portal*). The results showed that after playing the AVG, participants were much faster but less accurate than before, while after playing the puzzle game, participants were more accurate but slower than before.In addition, the AVG group outperformed the puzzle game group on the posttest. The authors attributed the shifts in the speed-accuracy trade-offs to specific game demands that could require using an optimal strategy to win the game. For example, a fast AVG like *Unreal Tournament* might require constant attention to constantly scan the screen and rapidly execute motor actions, while a puzzle game like *Portal* did not require rapid responses or heighten attention levels but involved more accurate estimation of actions.

However, the beneficial effects of playing *Portal* were not supported by Adams et al.'s (2015) study showing that playing *Portal* for 75 minutes failed to improve spatial cognition skills and physics intuitions in college students. The authors randomly assigned participants to three video game training groups: *Portal*, *Tetris* (spatial control group), and *TextTwist* (non-spatial control group). Nonsignificant group differences in spatial cognition skills (mental rotation and perspective taking) or physics intuitions were found.

The AVG research spans a wide variety of tasks and stimuli, but the literature cites improvements in spatial cognition (e.g., mental rotation, spatial working memory tasks) and problem-solving (e.g., Tower of Hanoi, Tower of London) among the fairly consistent benefits of playing AVGs (Bediou et al., 2018; Powers & Brooks, 2013, 2014). These cognitive capabilities play a critical role in mathematical abilities (Hawes et al., 2015; Kyttälä & Lehto, 2008; LeFevre et al., 2005; Raghubar et al., 2010; Swanson & Beebe-Frankenberger, 2004; Trbovich & LeFevre, 2003). Positive relationships among spatial skills and mathematical abilities as well as working memory and mathematics have been found across different mathematics tasks, including mental arithmetic (Kyttälä & Lehto, 2008; Trbovich & LeFevre, 2003), word problems (Swanson & Beebe-Frankenberger, 2004), general problem-solving (Bühner et al., 2008), and geometry (Delgado & Prieto, 2004).For instance, arithmetic problem-solving requires considerable spatial working memory resources to select and update new input, retrieve necessary information from the long-term memory, interpret and process the new and retrieved information, and manipulate the mental number line (Ashcraft & Kirk, 2001; Maloney et al., 2012).

A considerable body of research examined the effects of video games on mathematics achievement (see Tokac et al., 2019, for a meta-analysis). However, only a few studies examining the effects of noneducational video game training on mathematics performance were found. Novak and Tassell (2015) used long-term video game training with an AVG (*Unreal Tournament*) and non-AVG (*Angry Birds*) to establish a connection between enhanced attentional skills and mathematics performance focusing on three distinct mathematics tasks: geometry, word, and non-word problem-solving. Both groups significantly improved their working memory and spatial and geometry skills after 10 hours of video game training. Libertus et al. (2017) examined the impact of an extended AVG training on a range of mathematical abilities, including standardized mathematics assessment and basic arithmetic that involved two- and three-operand addition and subtraction problems. AVG (*Unreal Tournament*) and non-AVG (*The Sims 2*) intervention groups were tested before, after 25 hours, and after 40 hours of video game training. The results showed that AVG training improved some of the standardized mathematics skills requiring complex mathematical computations but not those requiring the application of complex mathematics to solve everyday problems or basic arithmetic after 25 hours of video game training. Nonsignificant findings were reported for attentional skills, foundational number processing, or basic arithmetic. These findings contrast with Green and Bavelier's (2006) and Halberda et al.'s (2013) studies that reported beneficial effects of AVG training on approximate number-processing skills and number comparison, respectively. No research examining the state effects of AVG training on mathematics performance was found.

The goal of the present study was twofold. First, group differences were examined between experienced and novice AVGers in arithmetic performance such as speed and accuracy. Second, the state effects of AVG training on arithmetic performance and their persistence over time were explored with a working hypothesis predicting improved arithmetic performance immediately after AVG training when compared with non-AVG training. The length of video game training (40 minutes) was determined based on experimental research that investigated the existence of flow experiences and their effects of cognition (Kozhevnikov et al., 2009, 2018; May et al., 2011). Participants' arithmetic performance was assessed using the *NeuroSky SpeedMath* mini-game before and after a video game training. The *SpeedMath* mini-game emphasizes both speed and accuracy, both of which are the most common outcomes examined in the video game training literature (Bediou et al., 2018; Nelson & Strachan, 2009). Moreover, using *SpeedMath* intended to promote participants' motivation to do their best on the arithmetic performance assessments (Chen et al., 2019; Hooshyar et al., 2016).

Method

Participants

Forty-six undergraduate students (age $M = 20.57$, $SD = 1.63$) from a large public university in the United States participated in the study. Among them were 32 females and 14 males. The study was advertised in undergraduate classes in the College of Education; students received a $25 gift card for their participation. All study applicants completed an AVG background questionnaire (Terlecki & Newcombe, 2005) where they reported their demographics and prior video gaming experience, for example, their favorite video games and genres, which games they usually played, and how long and often they played the games. Individuals were considered experienced AVGers if they played action or fast-paced games on a weekly basis for the past 6–12 months (Bediou et al., 2018). Those who did not meet this criterion were labeled as novice AVGers. Seventeen participants were experienced AVGers (5 females, 12 males) and 29 were novice AVGers (27 females, 2 males). All novice AVG participants reported some experience playing video games. However, none of them played AVGs, and their current video gaming experience was once in 6–12 months. None of the participants was familiar with the *SpeedMath* mini-game.

Tasks and Materials

The research design included two intervention groups: an AVG and a non-AVG group. The AVG group played a first-person shooter game, *Unreal Tournament 2004*. This game is considered a prototypical AVG, and its beneficial effects on attentional capabilities are documented in the literature (e.g., Green & Bavelier, 2007; Nelson & Strachan, 2009). The non-AVG group played a low-stress casual game, *Angry Birds*. This game was selected based on the absence of AVG qualities, thus serving as an active control group, which is considered a “gold standard training in training experiments” by cognitive training researchers (Green & Bavelier, 2012, p. 200). *Angry Birds*, unlike the *Unreal Tournament* AVG, did not involve fast-paced events or process, attention to transient events, or need to make motor responses under time constraints. In *Angry Birds*, players had to destroy different structures by throwing birds into them through a careful estimation of the trajectories of the thrown birds.

Apparatus

Participants viewed stimuli on Dell P2217H monitors with 21.5″ viewable screens in a computer lab. The monitors were set to their maximum supported resolution and refresh rate of $1{,}920 \times 1{,}080$ at 60 Hz.

Procedures

The study took place in a computer lab with a maximum of four students in a training session. First, participants rated their daily stress level (*Assess your daily stress level on a scale of 1–9: 1 = very relaxed and 9 = very stressed*) and watched a video recording of a boring, old-style talking-head lecture on a computer for 3–4 minutes. The video was intentionally selected to be not engaging to induce a neutral emotional state in participants. After watching the video, all participants completed a pretest, that is, they played three sessions of the *SpeedMath* mini-game. Following the pretest, participants classified as novice AVGers ($n = 29$) were randomly assigned to an AVG ($n = 13$; 1 male) or a non-AVG ($n = 16$; 1 male) intervention and asked to play the assigned video game for 40 minutes. Both AVG and non-AVG participants shared a similar academic background (undergraduate education majors) and were matched with regard to their age, gender, and previous non-AVG experience.

Because none of the participants was familiar with *Unreal Tournament*, the AVG group completed a 10-minute game tutorial before the training. The initial game difficulty level was set to three bots. Players’ game performance was closely monitored, and the game difficulty was adjusted based on a participant’s kill/death ratio. The *Angry Birds* active control group was guided to score as many points as possible at each game level.

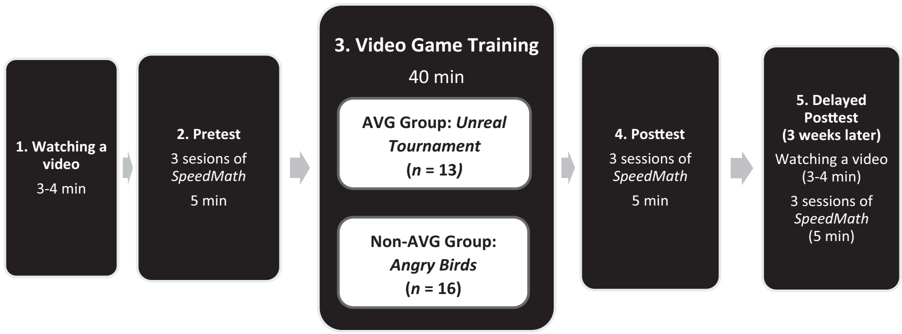

Figure 1. An overview of the AVG training study's procedures: Steps 1–4 took place on the same day; Step 5 took place 3 weeks later.
AVG = action video game.

Once they fulfilled all game level requirements, a more advanced level was unlocked for them to play.

Immediately after the intervention, participants completed a posttest that involved playing three sessions of *SpeedMath* again. The whole experiment, including explanations of the study procedures, informed consent forms, and completion of all study procedures and tasks, lasted approximately 90 minutes. Consistent with the study intent to examine the state effects of video game training, the pretest, video game training, and posttest were administered on the same day (Green et al., 2019).

Three weeks later, AVG and non-AVG participants returned to the computer lab to take a delayed posttest. Similar to the pretest procedures, they rated their daily stress level and watched the same video recording on a computer for 3–4 minutes followed by three sessions of the *SpeedMath* mini-game. Figure 1 presents an overview of the study procedures. All experiment procedures were individually supervised, and participants' computer interactions were screen captured to collect their video game performance and time line of the completed tasks.

Dependent Variables

Participants' arithmetic problem-solving and accuracy were assessed using the *SpeedMath* video game. Participants played three sessions of *SpeedMath*, 60 seconds each. The game goal was to solve correctly as many arithmetic problems as possible. The arithmetic problems involved adding and subtracting numbers between 1 and 30 (e.g., 28–17). At the end of each game session, players received a game summary (Figure 2) with the following information:

1. *Game score* reflected both speed and accuracy of arithmetic problem-solving; *SpeedMath* does not explain how this score is calculated.
2. *Number of correctly solved problems* was used as an arithmetic problem-solving accuracy indicator.
3. *Number of incorrectly solved problems* was used as an error rate of arithmetic performance.

Arithmetic problem-solving speed was calculated by adding the number of correctly and incorrectly solved problems. The game also assessed participants' attention levels using *NeuroSky MindSet* electroencephalography device. However, due to a low reliability of the EEG data, attention scores were not considered in this study. Participants' indicators

Figure 2. A screenshot of a *SpeedMath* session summary.

of their arithmetic performance were calculated by averaging the scores of the three *SpeedMath* mini-game sessions.

Data Analysis

We used a one-way analysis of variance (ANOVA) to examine group differences between experienced and novice AVGers, analysis of covariance (ANCOVA) to compute intervention effects of AVG and non-AVG training, and repeated-measures mixed ANOVA for testing interaction effects over time. The data were inspected before running the analyses, and relevant assumptions were tested prior to each test. Specifically, for ANOVA, the normality assumption was tested using skewness and kurtosis values as well as an inspection of the histograms; the homogeneity of variance was checked using Levene's test. In ANCOVA analyses, normality and homogeneity of variance were checked as described earlier. In addition, a linear relationship between covariate and dependent variable as well as homogeneity of regression slopes were investigated. For repeated-measures mixed ANOVA, normality, homogeneity of variance, sphericity, and homogeneity of covariance were examined. No violation of the assumptions was found.

Because the AVG and non-AVG groups included unequal samples with regard to gender (only one male in each training group) and males are usually better at playing video games than females, we examined intervention and time effects with and without males. The two analyses revealed similar results. In the next section, we reported results using the data with males. All statistical analyses were performed using SPSS 25.

Results

Group Differences Between Experienced and Novice AVGers

Table 1 presents pretest means and standard deviations for all study variables across all participants. Because the variation in the Experienced AVGers group was larger compared with the novice AVGers group, we examined the data for outliers and identified two potential

Table 1. Means and Standard Deviations for Pretest Measures by AVG Experience Level.

	Experienced AVGers ($n = 17$) *M* (*SD*)	Novice AVGers ($n = 29$) *M* (*SD*)
Game score	777.80 (729.69)	490.41 (377.18)
Number of correctly solved problems (accuracy)	20.29 (9.06)	16.69 (5.76)
Number of incorrectly solved problems (error rates)	2.75 (2.07)	2.92 (1.95)
Number of attempted problems (speed)	23.04 (8.71)	19.61 (5.86)

Note. AVGers = action video gamers.

outliers among experienced AVGers. We computed an ANOVA to examine group differences with and without the outliers. However, neither of the analyses identified significant differences between experienced and novice AVGers. All ANOVA assumptions were met in both cases. We reported results using the data with the outliers only. There were nonsignificant differences between experienced and novice AVGers' arithmetic performance, indicating that, on average, experienced and novice AVGers demonstrated similar arithmetic performance—Game score: $F(1, 44) = 3.12$, $p = .085$, $\eta^2 = .07$; Number of correctly solved problem: $F(1, 44) = 2.73$, $p = .105$, $\eta^2 = .06$; Number of attempted problems: $F(1, 44) = 2.55$, $p = .117$, $\eta^2 = .06$; Number of incorrectly solved problem: $F(1, 44) = .08$, $p = .776$, $\eta^2 = .00$.

Intervention Effects

Table 2 presents means and standard deviations for pretest, posttest, and delayed posttest measures for novice AVGers. Using an ANOVA, nonsignificant ($p > .05$) differences between the AVG and non-AVG groups were revealed for all variables measured at the outset of the study.

The intervention state effects of video game training on players' arithmetic performance (posttest measures) were analyzed using an ANCOVA with the pretest stress level as a covariate. After controlling for participants' pretest stress level, there was a nonsignificant intervention state effect of the video game training on participants' posttest arithmetic performance—Game score: $F(1, 26) = .62$, $p = .440$, $\eta_p^2 = .02$; Number of correctly solved problem: $F(1, 26) = .49$, $p = .489$, $\eta_p^2 = .02$; Number of attempted problems: $F(1, 26) = .04$, $p = .837$, $\eta_p^2 = .00$; Number of incorrectly solved problem: $F(1, 26) = 1.47$, $p = .236$, $\eta^2 = .05$—indicating that participants' posttest arithmetic performance from the AVG and non-AVG groups was in general the same.

The intervention trait effects on players' arithmetic performance (delayed posttest measures) were analyzed using an ANCOVA with the delayed posttest stress level as a covariate. After controlling for participants' delayed posttest stress level, there was a nonsignificant intervention trait effect of the video game training on participants' delayed posttest arithmetic performance—Game score: $F(1, 21) = .101$, $p = .754$, $\eta_p^2 = .01$; Number of correctly solved problem: $F(1, 21) = .07$, $p = .772$, $\eta_p^2 = .00$; Number of attempted problems: $F(1, 21) = .02$, $p = .892$, $\eta_p^2 = .00$; Number of incorrectly solved problem: $F(1, 21) = .14$, $p = .715$, $\eta^2 = .01$—indicating that participants' arithmetic performance on the delayed posttest from the AVG and non-AVG groups was in general the same.

Time Effects

To compute the pretest and posttest time effects and their interactions while controlling for participants' stress levels, a repeated-measures mixed ANOVA with test

Table 2. Means and Standard Deviations for Pretest, Posttest, and Delayed Posttest Measures by Intervention Group.

	Non-AVG group			AVG group		
	Pretest *M* (*SD*)	Posttest *M* (*SD*)	Delayed *M* (*SD*)	Pretest *M* (*SD*)	Posttest *M* (*SD*)	Delayed *M* (*SD*)
n	16	16	13	13	13	13
Game score	461.96 (322.19)	545.77 (296.80)	567.77 (310.83)	525.45 (446.98)	466.10 (318.75)	581.82 (468.72)
Number of correctly solved problems (accuracy)	16.21 (5.45)	17.90 (5.95)	17.92 (6.58)	17.28 (6.28)	16.54 (5.65)	17.97 (5.82)
Number of incorrectly solved problems (error rates)	2.35 (1.16)	2.94 (2.14)	5.03 (9.21)	3.62 (2.51)	4.00 (2.43)	4.03 (2.35)
Number of attempted problems (speed)	18.56 (5.54)	20.83 (5.95)	22.95 (6.71)	20.90 (6.20)	20.54 (6.01)	22.00 (5.38)
Stress level[a]	5.13 (1.41)	N/A	4.92 (1.44)	5.00 (1.47)	N/A	5.08 (1.17)

Note. AVG = action video game.
[a]Possible scores: 1 = very relaxed and 9 = very stressed.

time (pretest/posttest) as a within-subjects variable, intervention (AVG/non-AVG) as a between-subjects variable, and pretest stress level as a covariate was performed.

Game score: There was a significant Time × Stress interaction effect, *Wilks'* $\lambda = .84$, $F(1, 26) = 5.02$, $p = .034$, $\eta_p^2 = .162$, and Time × Intervention interaction effect, *Wilks'* $\lambda = .84$, $F(1, 26) = 5.13$, $p = .032$, $\eta_p^2 = .165$ (Figure 3A). A follow-up analysis indicated that the non-AVG group's game scores increased from pretest ($M = 468.22$, $SE = 88.54$) to posttest ($M = 549.31$, $SE = 74.68$), while the AVG group's game scores decreased from pretest ($M = 517.73$, $SE = 98.24$) to posttest ($M = 461.75$, $SE = 82.86$).

Number of correctly solved problems (accuracy): There was a significant Time × Intervention interaction effect, *Wilks'* $\lambda = .81$, $F(1, 26) = 6.13$, $p = .020$, $\eta_p^2 = .191$ (Figure 3B). A follow-up analysis indicated that the non-AVG group's accuracy improved from pretest ($M = 16.29$,

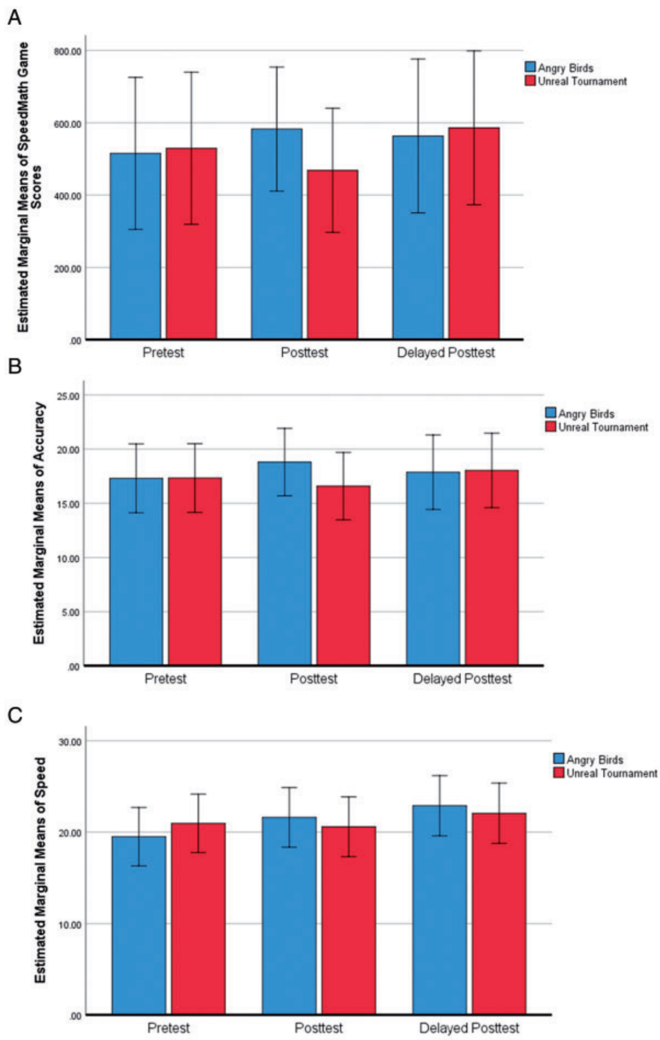

Figure 3. A: *SpeedMath* game scores (error bars: 95% confidence interval); B: Arithmetic problem-solving accuracy (measured by the number of correctly solved problems; error bars: 95% confidence interval); C: Arithmetic problem-solving speed (measured by the number of attempted problems; error bars: 95% confidence interval).

$SE = 1.39$) to posttest ($M = 17.96$, $SE = 1.43$), while the AVG group's accuracy decreased from pretest ($M = 17.18$, $SE = 1.54$) to posttest ($M = 16.46$, $SE = 1.58$).

Number of attempted problems (speed): There was a significant Time × Intervention interaction, *Wilks'* $\lambda = .80$, $F(1, 26) = 6.57$, $p = .016$, $\eta_p^2 = .204$ (Figure 3C), indicating that the AVG and non-AVG participants' speed changed differently from pre- to posttest. A follow-up analysis indicated that the non-AVG group's speed increased from pretest ($M = 18.66$, $SE = 1.36$) to posttest ($M = 20.9$, $SE = 1.45$), while the AVG group's speed decreased from pretest ($M = 20.78$, $SE = 1.51$) to posttest ($M = 20.45$, $SE = 1.61$).

Number of incorrectly solved problems (error rate) was not significantly affected by time. An intervention by time interaction was not statistically significant, *Wilks'* $\lambda = .10$, $F(1, 26) = .08$, $p = .781$, $\eta_p^2 = .003$, indicating that AVG and non-AVG groups' error rates changed similarly over time.

Stress level: A repeated-measures mixed ANOVA with test time (pretest/delayed posttest) as a within-subjects variable and intervention (AVG/non-AVG) as a between-subjects variable was performed to examine differences in participants' stress levels between pretest and delayed posttest. Participants' stress levels were not significantly affected by time. A non-significant intervention by time interaction was obtained, *Wilks'* $\lambda = .99$, $F(1, 22) = .23$, $p = .638$, $\eta_p^2 = .01$, indicating that AVG and non-AVG groups' stress levels changed similarly over time.

To compute the pretest, posttest, and delayed posttest time effects and their interactions, a repeated-measures mixed ANOVA with test time (pretest/posttest/delayed posttest) as a within-subjects variable, intervention (AVG/non-AVG) as a between-subjects variable, and pretest stress level as a covariate was performed. None of the variables were significantly affected by time. Using Pillai's trace, a nonsignificant intervention by time interaction was obtained, indicating that AVG and non-AVG groups' arithmetic performance changed similarly from pretest to delayed posttest. Table 3 shows all related statistics.

Discussion

The major goal of this study was to investigate the state effects of a single AVG training session (40 minutes) on arithmetic performance when compared with non-AVG training.

Table 3. Time, Time × Intervention, and Time × Stress Interaction Effects With Test Time (Pretest/Posttest/Delayed Posttest) as a Within-Subjects Variable, Intervention (AVG/Non-AVG) as a Between-Subjects Variable, and Pretest Stress Level as a Covariate.

	Time effect			Time × Intervention interaction effect			Time × Stress interaction effect		
Variable	λ	$F(2, 22)$	p	λ	$F(2, 22)$	p	λ	$F(2, 22)$	p
Game score	.82	2.38	.116	.82	2.38	.116	.84	2.16	.139
Number of correctly solved problems (accuracy)	.99	.14	.872	.80	2.68	.091	.98	2.00	.823
Number of incorrectly solved problems (error rates)	.99	.11	.900	.96	.49	.620	1.00	.00	.998
Number of attempted problems (speed)	.98	.24	.789	.78	3.14	.063	.98	.21	.813

In addition, differences between experienced and novice AVGers were investigated. To our knowledge, this is the first study that empirically investigated the possibility of boosting arithmetic performance on demand using video game training. The study was motivated by the literature suggesting that both AVG play and arithmetic performance may rely on the same perceptual and cognitive abilities (Arsalidou & Taylor, 2011; Libertus et al., 2017).

State Effects of Video Game Training

The present study did not reveal significant differences in arithmetic performance between the two groups immediately after the video game training. However, significant Time $\times$ Intervention interaction effects were found with medium to large effect sizes, indicating that the AVG and non-AVG participants' *SpeedMath* game scores, arithmetic problem-solving speed, and accuracy changed differently from pre- to posttest. Contrary to the study hypothesis predicting enhanced arithmetic performance after AVG training, non-AVG group's performance increased, while the AVG group's performance decreased after the video game training. Moreover, both groups showed significant changes in their *SpeedMath* game scores after the video game training that were impacted by participants' stress levels. However, the changes were in the opposite directions, that is, increased game scores in the control group and decreased game scores in the AVG group. The effect of the stress level on participants' game performance is not surprising, as psychometrical research clearly shows the detrimental effects of stress and anxiety on cognitive performance (Raghubar et al., 2010). Feelings of stress and anxiety produce a task-irrelevant cognitive activity that negatively affects human performance, particularly in mathematics (Ashcraft & Krause, 2007; LeFevre et al., 2005).

It is important to note that the significant Time $\times$ Intervention interaction effects do not reflect a shift in participants' game strategy, for example, a speed-accuracy trade-off, because there was an improvement in the both speed and accuracy in non-AVG participants and a decrease in these two variables in AVG participants. One of the possible explanations for the decreased speed and accuracy of arithmetic problem-solving in AVG participants could be that this group had become tired after the video game training, as *Unreal Tournament* poses much higher perceptual, cognitive, and motor demands than *Angry Birds*, and consequently did not invest effort into the *SpeedMath* game play. However, Kozhevnikov et al.'s (2018) and Nelson and Strachan's (2009) findings may not support this explanation, as their AVG participants significantly improved various aspects of attention immediately after playing an AVG. However, neither of these studies did focus on arithmetic performance.

One of the unexpected findings of the present study was an improved arithmetic performance after playing the non-AVG *Angry Birds* game. These findings converge with other studies that documented enhanced cognitive and psychomotor performance after playing non-AVG games. For example, Plerhoples et al. (2011) and Rosser et al. (2007) found significant improvements in surgical residents' laparoscopic and suturing skills immediately after playing a non-AVG game. Studies that employed long-term AVG training also reported improvements after playing non-AVG games (Libertus et al., 2017; Novak & Tassell, 2015; Oei & Patterson, 2014, 2015; West et al., 2013; Wu & Spence, 2013). Many researchers agree that the mechanism of transfer from a video game play to novel tasks is not well understood. One of the possible explanations of the mechanism of transfer was proposed by Oei and Patterson (2015), suggesting that the success of transfer depends on common perceptual, cognitive, and psychomotor demands between the video game and the transfer task. Another possible explanation involves the flow state experienced after a video game play. Kozhevnikov et al. (2018) argue that flow requires a balance between boredom and anxiety, as it cannot be induced by too relaxed or too stressful activities. Perhaps, the *Angry Birds* game was able to induce higher flow when compared with the *Unreal Tournament*, playing which was often reported as a stressful experience for novice players. The higher level of flow induced by the *Angry Birds* may explain the improved arithmetic performance in the non-AVG group. However, further research is needed to better understand how various factors including flow and participants' emotional states can explain the mechanism of transfer in video games.

The arithmetic performance task employed in the present study required foundational mathematics skills that involved addition or subtraction of numbers between 1 and 30. These skills are developed in early childhood and serve as a foundation for learning more advanced mathematics (Fazio et al., 2014; Lyons et al., 2014). Arithmetic skills were successfully trained in young children using educational video games (Beserra et al., 2014; Moreno & Duran, 2004). However, training foundational number-processing skills in adults did not yield considerable improvements (DeWind & Brannon, 2012; Park & Brannon, 2014). Thus, it is plausible to suggest that improving these skills in adults can be very difficult. Moreover, one could argue that a 40-minute long training session might not be sufficient to elicit changes in arithmetic skills in adults.

Long-Term Effects of Video Game Training

An examination of participants' arithmetic performance 3 weeks after the video game training did not reveal any significant group or time differences. These findings are in line with the literature that argues that cognitive enhancements observed immediately after playing a video game are due to a heightened arousal and not due to durable, long-lasting effects on cognition (Bediou et al., 2018).

Group Differences Between Experienced and Novice AVGers

Nonsignificant group differences between experienced and novice AVGers were observed. These findings converge with the literature that shows that habitual AVGer do not necessarily have better perceptual, attentional, or cognitive skills than novice AVGers or individuals who do not play video games (see Sala et al., 2018, for a meta-analysis).

In conclusion, the study findings suggest a possibility of enhanced arithmetic performance after a mere 40 minutes of non-AVG training. It extends previous findings by investigating the state effects of AVG training on arithmetic problem-solving in adults. However, because the study did not employ a passive control group without a video game training, the results should not be generalized to conclude that the non-AVG training was the primary cause for these findings. Nevertheless, based on prior research on the state effects of AVG (Plerhoples et al., 2011; Rosser et al., 2007), it is plausible that the non-AVG training had a positive effect on arithmetic performance. In addition, the study employed unequal samples in terms of gender, which is common in AVG research, as AVGs primarily appeal to males. Therefore, it was impossible to examine gender differences between experienced and novice AVGers and between AVG and non-AVG groups.

More generally, the findings underscore the importance of investigating the transfer mechanism of video games as well as the game mechanics and play elements to better understand how different game elements or a combination of them impact human cognition (Dale at el., 2020; Nelson & Strachan, 2009; Oei & Patterson, 2015). For example, the *Angry Birds* game is considered a casual game that poses considerably less cognitive demands than an AVG such as *Unreal Tournament*, which makes a game like *Angry Birds* more accessible to wider audience, because unlike AVGs, it does not require special skills or time to master the game play. It is also noteworthy to mention that participants' stress levels and possibly other emotions can mediate the effects of video game training. As such, future research should consider participants' emotional states when investigating the impact of AVG on human performance.

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Ethical Guidelines

The research was approved by an Institutional Review Board.

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References

Adams, D. M., Pilegard, C., & Mayer, R. E. (2015). Evaluating the cognitive consequences of playing portal for a short duration. *Journal of Educational Computing Research*, *54*, 173–195. https://doi.org/10.1177/0735633115620431

Appelbaum, L. G., Cain, M. S., Darling, E. F., & Mitroff, S. R. (2013). Action video game playing is associated with improved visual sensitivity, but not alterations in visual sensory memory. *Attention, Perception, & Psychophysics*, *75*, 1161–1167. https://doi.org/10.3758/s13414-013-0472-7

Arsalidou, M., & Taylor, M. J. (2011). Is 2 + 2=4? Meta-analyses of brain areas needed for numbers and calculations. *Neuroimage*, *54*, 2382–2393.

Ashcraft, M. H., & Kirk, E. P. (2001). The relationships among working memory, math anxiety, and performance. *Journal of Experimental Psychology: General*, *130*, 224–237.

Ashcraft, M. H., & Krause, J. A. (2007). Working memory, math performance, and math anxiety. *Psychonomic Bulletin & Review*, *14*, 243–248.

Bavelier, D., & Green, C. S. (2019). Enhancing attentional control: Lessons from action video games. *Neuron*, *104*, 147–163.

Bediou, B., Adams, D. M., Mayer, R. E., Tipton, E., Green, C. S., & Bavelier, D. (2018). Meta-analysis of action video game impact on perceptual, attentional, and cognitive skills. *Psychological Bulletin*, *144*, 77–110.

Beserra, V., Nussbaum, M., Zeni, R., Rodriguez, W., & Wurman, G. (2014). Practising arithmetic using educational video games with an interpersonal computer. *Educational Technology & Society*, *17*, 343–358.

Black, A. A. (2005). Spatial ability and earth science conceptual understanding. *Journal of Geoscience Education*, *53*, 402–414.

Boot, W. R., Kramer, A. F., Simons, D. J., Fabiani, M., & Gratton, G. (2008). The effects of video game playing on attention, memory, and executive control. *Acta Psychologica*, *129*, 387–398. http://dx.doi.org/10.1016/j.actpsy.2008.09.005

Bühner, M., Kröner, S., & Ziegler, M. (2008). Working memory, visual -spatial-intelligence and their relationship to problem-solving. *Intelligence*, *36*, 672–680.

Chen, Z.-H., Lu, H.-D., & Chou, C.-Y. (2019). Using game-based negotiation mechanism to enhance students' goal setting and regulation. *Computers & Education*, *129*, 71–81. https://doi.org/10.1016/j.compedu.2018.10.011

Clark, J. E., Lanphear, A. K., & Riddick, C. C. (1987). The effects of videogame playing on the response selection processing of elderly adults. *Journal of Gerontology*, *42*, 82–85.

Cowley, B., Charles, D., Black, M., & Hickey, R. (2008). Toward an understanding of flow in video games. *Computers in Entertainment*, *6*, 1–27.

Csikszentmihalyi, M. (1975). Play and intrinsic rewards. *Journal of Humanistic Psychology*, *15*, 41–63.

Dale, G., Joessel, A., Bavelier, D., & Green, C. S. (2020). A new look at the cognitive neuroscience of video game play. *Annals of the New York Academy of Sciences*, *1464*, 192–103. https://doi.org/10.1111/nyas.14295

Delgado, A. R., & Prieto, G. (2004). Cognitive mediators and sex-related differences in mathematics. *Intelligence*, *32*, 25–32.

DeWind, N. K., & Brannon, E. M. (2012). Malleability of the approximate number system: Effects of feedback and training. *Frontiers in Human Neuroscience*, *6*, 68.

Fazio, L. K., Bailey, D. H., Thompson, C. A., & Siegler, R. S. (2014). Relations of different types of numerical magnitude representations to each other and to mathematics achievement. *Journal of Experimental Child Psychology*, *123*, 53–72.

Feng, J., Spence, I., & Pratt, J. (2007). Playing an action video game reduces gender differences in spatial cognition. *Psychological Science*, *18*, 850–855.

Föcker, J., Cole, D., Beer, A. L., & Bavelier, D. (2018). Neural bases of enhanced attentional control: Lessons from action video game players. *Brain and Behavior*, *8*, e01019. https://doi.org/10.1002/brb3.1019

Föcker, J., Mortazavi, M., Khoe, W., Hillyard, S. A., & Bavelier, D. (2019). Neural correlates of enhanced visual attentional control in action video game players: An event-related potential study. *Journal of Cognitive Neuroscience*, *31*, 377–389.

Franceschini, S., Gori, S., Ruffino, M., Viola, S., Molteni, M., & Facoetti, A. (2013). Action video games make dyslexic children read better. *Current Biology*, *23*, 462–466. https://doi.org/10.1016/j.cub.2013.01.044

Frederiksen, J. R., & White, B. Y. (1989). An approach to training based upon principled task decomposition. *Acta Psychologica*, *71*, 89–146.

Green, C. S., & Bavelier, D. (2006). Enumeration versus multiple object tracking: The case of action video game players. *Cognition*, *101*, 217–245.

Green, C. S., & Bavelier, D. (2007). Action-video-game experience alters the spatial resolution of vision. *Psychological Science*, *18*, 88–94. http://dx.doi.org/10.1111/j.1467-9280.2007.01853.x

Green, C. S., & Bavelier, D. (2012). Learning, attentional control, and action video games. *Current Biology*, *22*, R197–R206. https://doi.org/10.1016/j.cub.2012.02.012

Green, C. S., Bavelier, D., Kramer, A. F., Vinogradov, S., Ansorge, U., Ball, K. K., Bingel, U., Chein, J. M., Colzato, L. S., Edwards, J. D., Facoetti, A., Gazzaley, A., Gathercole, S. E., Ghisletta, P., Gori, S., Granic, I., Hillman, C. H., Hommel, B., Jaeggi, S. M., ... Witt, C. M. (2019). Improving methodological standards in behavioral interventions for cognitive enhancement. *Journal of Cognitive Enhancement*, *3*, 2–29. https://doi.org/10.1007/s41465-018-0115-y

Halberda, J., Bavelier, D., Landau, B., Hellgren, K., Forsman, L., Jacques, T., & Libertus, M. (2013). Training of number sense transfers broadly. Talk presented at The Vision Sciences Society Meeting. Naples, Florida.

Hawes, Z., Moss, J., Caswell, B., & Poliszczuk, D. (2015). Effects of mental rotation training on children's spatial and mathematics performance: A randomized controlled study. *Trends in Neuroscience and Education*, *4*, 60–68.

Hooshyar, D., Ahmad, R. B., Yousefi, M., Fathi, M., Horng, S.-J., & Lim, H. (2016). Applying an online game-based formative assessment in a flowchart-based intelligent tutoring system for improving problem-solving skills. *Computers & Education*, *94*, 18–36. https://doi.org/10.1016/j.compedu.2015.10.013

Hsu, J. (2010). *Navy says video games can boost "fluid intelligence" of warfighters*. http://www.popsci.com/technology/article/2010-01/navy-says-video-games-can-boost-fluid-intelligencewarfighters

Klasen, M., Weber, R., Kircher, T. T. J., Mathiak, K. A., & Mathiak, K. (2011). Neural contributions to flow experience during video game playing. *Social Cognitive and Affective Neuroscience*, *7*, 485–495.

Kozhevnikov, M., Li, Y., Wong, S., Obana, T., & Amihai, I. (2018). Do enhanced states exist? Boosting cognitive capacities through an action video-game. *Cognition*, *173*, 93–105. https://doi.org/10.1016/j.cognition.2018.01.006

Kozhevnikov, M., Louchakova, O., Josipovic, Z., & Motes, M. A. (2009). The enhancement of visuospatial processing efficiency through Buddhist Deity meditation. *Psychological Science*, *2005*, 645–653.

Kyttälä, M., & Lehto, J. (2008). Some factors underlying mathematical performance: The role of visuospatial working memory and non-verbal intelligence. *European Journal of Psychology of Education*, *23*, 77–94.

LeFevre, J.-A., DeStefano, D., Coleman, B., & Shanahan, T. (2005). Mathematical cognition and working memory. In J. I. D. Campbell (Ed.), Handbook of mathematical cognition (pp. 361–378). Psychology Press.

Libertus, M. E., Liu, A., Pikul, O., Jacques, T., Cardoso-Leite, P., Halberda, J., & Bavelier, D. (2017). The impact of action video game training on mathematical abilities in adults. *AERA Open*, *3*, 233285841774085. https://doi.org/10.1177/2332858417740857

Lyons, I. M., Price, G. R., Vaessen, A., Blomert, L., & Ansari, D. (2014). Numerical predictors of arithmetic success in Grades 1–6. *Developmental Science*, *17*, 714–726.

Maloney, E. A., Waechter, S., Risko, E. F., & Fugelsang, J. A. (2012). Reducing the sex difference in math anxiety: The role of spatial processing ability. *Learning and Individual Differences*, *22*, 380–384.

Maslow, A. H. (1999). *Toward a psychology of being* (3rd ed.). J. Wiley & Sons.

May, C. J., Burgard, M., Mena, M., Abbasi, I., Bernhardt, N., Clemens, S., ... Williamson, R. (2011). Short-term training in loving-kindness meditation produces a state, *but not a trait, alteration of attention*. *Mindfulness*, *2*, 143–153. https://doi.org/10.1007/s12671-011-0053-6

Moreno, R., & Duran, R. (2004). Do multiple representations need explanations? The role of verbal guidance and individual differences in multimedia mathematics learning. *Journal of Educational Psychology*, *96*, 492–503.

Nelson, R. A., & Strachan, I. (2009). Action and puzzle video games prime different speed/accuracy tradeoffs. *Perception*, *38*, 1678–1687. https://doi.org/10.1068/p6324

Novak, E., & Tassell, J. (2015). Using video game play to improve education-majors' mathematical performance: An experimental study. *Computers in Human Behavior*, *53*, 124–130. https://doi.org/10.1016/j.chb.2015.07.001

Oei, A. C., & Patterson, M. D. (2014). Are videogame training gains specific or general? *Frontiers in Systems Neuroscience*, *8*, 54. https://doi.org/10.3389/fnsys.2014.00054

Oei, A. C., & Patterson, M. D. (2015). Enhancing perceptual and attentional skills requires common demands between the action video games and transfer tasks. *Frontiers in Psychology*, *6*, 113. http://dx.doi.org/10.3389/fpsyg.2015.00113

Park, J., & Brannon, E. M. (2014). Improving arithmetic performance with number sense training: An investigation of underlying mechanism. *Cognition*, *133*, 188–200.

Pavan, A., Hobaek, M., Blurton, S. P., Contillo, A., Ghin, F., & Greenlee, M. W. (2019). Visual short-term memory for coherent motion in video game players: Evidence from a memory-masking paradigm. *Scientific Reports*, *9*, 6027. https://doi.org/10.1038/s41598-019-42593-0

Plerhoples, T. A., Zak, Y., Hernandez-Boussard, T., & Lau, J. (2011). Another use of the mobile device: Warm-up for laparoscopic surgery. *Journal of Surgical Research*, *170*, 185–188. https://doi.org/10.1016/j.jss.2011.03.015

Powers, K. L., & Brooks, P. J. (2014). Evaluating the specificity of effects of video game training. In F. Blumberg (Ed.), Learning by playing: Frontiers of video gaming in education (pp. 302–330). Oxford University Press. http://dx.doi.org/10.1093/acprof:osobl/9780199896646.003.0021

Powers, K. L., Brooks, P. J., Aldrich, N. J., Palladino, M. A., & Alfieri, L. (2013). Effects of video-game play on information processing: A meta analytic investigation. *Psychonomic Bulletin & Review*, *20*, 1055–1079. http://dx.doi.org/10.3758/s13423-013-0418-z

Raghubar, K. P., Barnes, M. A., & Hecht, S. A. (2010). Working memory and mathematics: A review of developmental, individual difference, and cognitive approaches. *Learning and Individual Differences*, *20*, 110–122.

Rosser, J. C., Jr., Lynch, P. J., Cuddihy, L., Gentile, D. A., Klonsky, J., & Merrell, R. (2007). The impact of video games on training surgeons in the 21st century. *JAMA Surgery*, *142*, 181–186. https://doi.org/10.1001/archsurg.142.2.181

Sala, G., Tatlidil, K. S., & Gobet, F. (2018). Video game training does not enhance cognitive ability: A comprehensive meta-analytic investigation. *Psychological Bulletin*, *144*, 111–139.

Sanchez, C. A. (2012). Enhancing visuospatial performance through video game training to increase learning in visuospatial science domains. *Psychonomic Bulletin & Review*, *19*, 58–65. https://doi.org/10.3758/s13423-011-0177-7

Schlickum, M. K., Hedman, L., Enochsson, L., Kjellin, A., & Fellander-Tsai, L. (2009). Systematic video game training in surgical novices improves performance in virtual reality endoscopic surgical simulators: A prospective randomized study. *World Journal of Surgery*, *33*, 2360–2367.

Swanson, H. L., & Beebe-Frankenberger, M. (2004). The relationship between working memory and mathematical problem solving in children at risk and not at risk for serious math difficulties. *Journal of Educational Psychology*, *96*, 471–491.

Terlecki, M., & Newcombe, N. (2005). How important is the digital divide? The relation of computer- and videogame usage to gender differences in mental rotation ability. *Sex Roles*, *53*, 433–441.

Tokac, U., Novak, E., & Thompson, C. (2019). Effects of game-based learning on preK-12 students' mathematics achievement: A meta-analysis. *Journal of Computer Assisted Learning*, *35*, 407–420. https://doi.org/10.1111/jcal.12347

Trbovich, P. L., & LeFevre, J.-A. (2003). Phonological and visual working memory in mental addition. *Memory & Cognition*, *31*, 738–745.

West, G. L., Al-Aidroos, N., & Pratt, J. (2013). Action video game experience affects oculomotor performance. *Acta Psychologica*, *142*, 38–42. https://doi.org/10.1016/j.actpsy.2011.08.005

Wu, S., & Spence, I. (2013). Playing shooter and driving videogames improves top-down guidance in visual search. *Attention, Perception, & Psychophysics*, *75*, 673–686. https://doi.org/10.3758/s13414-013-0440-2