Learning Cognitive Skills by Playing Video Games at Home: Testing the Specific Transfer of General Skills Theory

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Abstract
Can people learn cognitive skills by playing video games at home? In the present study, college students took a pretest consisting of four cognitive tasks and 2 weeks later took a posttest consisting of the same four tasks (i.e., n-back and letter-number tasks tapping executive function skills and mental rotation and multiple object tracking tasks tapping perceptual processing skills). During the 2-week period, students engaged in no game activity, or played designed video games (targeting executive function skills) or an action video game (targeting perceptual processing skills) at home for 6 30-min sessions. The two game groups did not show greater gains than the control group on any of the tasks overall, but the designed game group outperformed the control group on the difficult trials of the n-back task and the action game group outperformed the control group on the difficult trials of the mental rotation tasks. Results provide partial evidence for the specific transfer of general skills theory, and show that the training effects of game playing are focused on skills that are exercised in the game.

Keywords Cognitive skills · Video games · Computer games · n-back · Working memory

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Objective and Rationale
This paper aims to determine the effects of game playing on improving cognitive skills performed outside the game environment, particularly cognitive skills that are targeted in the game. Specifically, we focus on whether playing games designed for training executive function skills cause improvements in executive function skills, and whether playing action video games that tap perceptual processing skills cause improvements in perceptual processing skills.

Mayer et al. (2019) have described three stages in the evolving story of research of game-based training of cognitive skills. In the first stage, researchers examined the effects of playing off-the-shelf games that focused on entertainment. Results showed that off-the-shelf games intended for entertainment generally did not significantly affect cognitive skills performed outside the game environment, except that playing action video games tended to improve perceptual processing skills (Bediou et al., 2018, in press; Green & Bavelier, 2003, 2006; Mayer, 2014, 2019). In the second stage, researchers examined the effects of playing brain training games that mainly involved gamified versions of cognitive skill tasks. Results showed that using brain training games generally did not have significant effects on cognitive skills performed outside the game environment (Bainbridge & Mayer, 2018; Hardy et al., 2015).

In spite of these disappointing results, in the third stage, researchers focused on the effects of playing games that are designed to train specific cognitive skills based on cognitive theories of skill learning. The emerging literature in this phase has yielded preliminary evidence that playing custom-designed games targeting focused cognitive skills are effective in improving the targeted skills performed outside the game environment (Anguera et al., 2013; Parong et al., 2017, Parong et al., 2020; Wells et al., 2021). This evolving research base encourages new research on the effects of playing games that target focused skills.
**Literature Review**

In this review, we focus on research on the effects of playing action video games on perceptual processing skills and the effects of playing custom-designed executive function games on executive function skills.

**Action Video Games**

Action video games involve interactive digital environments that require fast pacing, precise visual–motor coordination, working memory, planning, and a heavy load of attention (Bavelier et al., 2013). A review by Mayer (2014) reported that playing action games improved performance on perceptual processing tasks, with a median effect size of $d = 1.18$ based on 18 experimental comparisons. A meta-analysis by Bediou et al. (2018) on the cognitive consequences of playing action video games found that playing action video games improved performance on perceptual processing tasks as well, with the strongest effects for spatial cognition tasks with a mean effect size of $g = 0.45$ based on 29 experimental comparisons. A follow-up meta-analysis (Bediou et al., in press) reported similar findings based on more recent studies.

In line with Bediou et al. (2017, in press), the principles underlying the impact of action video games are that they require rapid control of perceptual attention on moving objects in the player’s visual periphery, offer repeated practice with feedback at increasing levels of challenge, and include variation in the context of the game. *Fortnite* was selected as a representative action video game because of its popularity, and because it involved the major characteristics of action video games to some extent.

**Designed Video Games**

Custom-designed video games (Parong et al., 2017) are interactive game experiences designed around a specific objective instead of focusing solely on entertainment (Mishra et al., 2016; Parong et al., 2020; Pellegrini, 2009). According to the cognitive theory of game-based training (Parong et al., 2020), designed or targeted video games are grounded on the following principles:

- **Focus**: the game is focused on a targeted skill
- **Practice**: the game requires repeatedly exercise of the targeted skill
- **Feedback**: the game provides feedback that is rooted in the consequences of the players’ actions
- **Challenge**: the game provides an increasing level of challenge to maintain practice over the targeted skill
- **Variation**: the game changes in context while maintaining focus on the targeted skill
- **Enjoyment**: the game is exciting and appealing for the player

Parong et al. (2017) asked college students to play a design video game focused on the executive function skill of shifting at home for 4 h. The game, called *Alien Game*, consists of following a series of ever-changing rules for shooting up food or drink to space creatures who move from the top to the bottom of the screen. Students who played the game showed greater improvements in executive function skills than a control game group. These results were replicated in Parong et al. (2020) using an updated version called *All You Can ET* in which participants played for 2 h in a lab environment.

Wells et al. (2021) found complementary results for another design video game, *CrushStations*, aimed at improving the executive function skill of updating. The results showed that participants from the experimental group outscored the control group on an updating task (n-back) but not on a visuospatial memory task that required cognitive skills not directly targeted in the game.

Homer et al. (2019) explored the effect of two versions of a design game centered on training the executive function of inhibition called *Gwakkamole* on a teenage population. Their results show that depending on the age of the adolescents, a larger focus on speed (for younger adolescents) or accuracy (for older adolescents) is necessary depending on their stage of neurocognitive development.

Finally, a study by Flores-Gallegos et al. (2021) used a designed video game and an off-the-shelf video game to train cognitive skills in children with a reading learning disorder. The designed game targeted codification and comprehension processes in reading, whereas the commercial videogame targeted visuospatial attention and automaticity. The results showed a significant effect of the training program on motor coordination, reading speed, and visual attention compared to a control (waiting list) group.

**Theory and Predictions**

Do players develop transferable cognitive skills from playing video games? In other words, do people who are assigned to play video games show greater improvements in cognitive skills outside the context of the game than people who are assigned to control groups? Mayer (2014) refers to this as a cognitive consequences question, and the search for transferable cognitive skills based on game playing has a disappointing history in the empirical
In the present study, we seek to determine whether game playing has an impact on any of four skills performed in non-game contexts—the executive function skills of updating (as measured by the n-back task) and shifting (as measured by the letter-number task) and the perceptual processing skills of mental rotation (as measured by a 3D mental rotation task) and perceptual selective attention (as measured by the multiple object tracking task).

Two classic theories of transfer are specific transfer theory and general transfer theory (Singley & Anderson, 1989). Specific transfer theory holds that learning of A will help in learning or performance of B to the extent that A and B have elements in common. Thus, playing a game should result in improved performance in the game, but not on performance outside the game. This theory predicts that game playing will not impact any of the four tasks examined in this study.

In contrast, general transfer theory holds that learning A can help in learning or performing B to the extent that A involves improving the learner’s mind in general (Anderson & Bavelier, 2011; Mayer, 2014; Sims & Mayer, 2002; Singley & Anderson, 1989). Thus, playing a game can serve a brain training function that results in improvements on a variety of cognitive tasks such as those tested in this study. This theory predicts that game playing will positively impact all four of the tasks examined in this study.

As a more nuanced and focused approach, specific transfer of general skills theory holds that students may improve on general skills that are exercised in the game and then be able to transfer that improvement to performing the same general skill outside the game context. This theory predicts that playing designed games will result in improvements in executive function skills (such as tapped by the n-back and letter-number tasks) whereas playing action video games will result in improvements in perceptual processing skills (such as tapped by the mental rotation and multiple object tracking tasks). These predictions are summarized in Table 1 and represent the primary theoretical focus of this study.

| Treatment group         | Target skills                  | Predicted test performance |
|-------------------------|--------------------------------|-----------------------------|
|                         |                                | Executive function tasks    | Executive function tasks |
|                         |                                | n-back | letter-number | mental rotation | multiple object tracking |
| Designed game           | Executive function             | ++ +   | ++ +          | + + +           | + + +                      |
| Action video game       | Perceptual attention           |        |               |                 |                            |

Note: ++ + indicates superior performance as compared to the control group.

### Method

#### Participants and Design

The participants were 60 college students recruited from a subject pool at a university in California. The mean age was 20.02 years (SD = 2.70, range = 18 – 24). There were 43 women, 16 men, and one binary participant. The mean number of hours per week spent playing video games was 1.65 (SD = 1.83, range = 0—6), indicating relatively low game playing. Participants were randomly divided into three groups in a between-subjects design: action game group (n = 15 participants; 12 women, one binary), designed game group (n = 19 participants; 10 women), and control group (n = 26 participants; 16 women). The uneven number of subjects in each group was caused by logistical issues in conducting a study during the pandemic.

#### Materials

The materials consisted of a questionnaire, two video games (i.e., action and designed games), and four cognitive skill tests (i.e., n-back, letter-number, mental rotation, and multiple object tracking). All materials were presented online. The questionnaire solicited information concerning the participant’s age, gender, and time spent playing video games each week.

The action video game is a commercial first-person shooter game called *Fortnite* (Epic Games, 2021). This video game uses an online Battle Royal format in which the main objective during each episode is to be the last remaining player on the map. The player can use different resources such as hiding, building structures, or fighting to achieve the goal. Difficulty in this game is based on the level of experience reflected on the general score of each player, and each battle in battle royal “solo” mode allows 100 players with a similar score, aiming to balance gameplay difficulty for all players. In the present study, participants were asked to play only in solo mode on their own devices for six sessions of 30 min each.
Participants could use different strategies through the game involving attacking other players or hiding. These strategies also were open to different tools, such as building barricades. Although there are different gameplay strategies, all players will have a confrontation during gameplay given that the map size and number of participants reduce over time. After the player wins or dies in the game, there is a possibility to keep watching other players who have not lost; however, participants from this study were instructed to quit the gaming session and start a new one until they had a total gameplay of 30 min; this was monitored by a brief questionnaire after each training session in which participants specified the time they started and ended playing, along with the number of episodes they played.

Reviews of the cognitive consequences of playing action video games such as *Fortnite* show effects on improving perceptual attention skills as compared to a control group (Bediou et al., 2018, Bediou in press; Mayer, 2014).

To follow-up participants’ performance throughout the game, a small survey was applied after each training session. The survey included questions about time of gameplay, highest achieved level achieved after training session, and a motivation item rated in a scale from 1 to 5 that involved the question “In a scale from 1 to 5, how much effort did you put today on the game?” Participants played the game either on a PC (with a system requirement of 8 GB of RAM as minimum, intel Core i5 or equivalent, included graphics card) or a videogame console (Xbox, PlayStation, or Nintendo Switch). Participants were asked to not download or buy any additional game packages during the length of the study.

The designed video games consisted of a suite of three games developed at the Create Lab at New York University based on cognitive principles of skill learning with each game focused on a specific executive function skill (Parong et al., 2020). The games are *CrushStations*, which focused on updating skill (Plass, Mayer & Homer, 2020; Wells et al., 2021); *All You Can ET*, which focused on shifting skill (Parong et al., 2017, 2020); and *Gwakkamole*, which focused on inhibition skill (Homer et al., 2019; Wells, Parong, & Mayer, 2021). All three games are available at the Apple app Store or Google Play app store.

*CrushStations* (shown in the upper left portion of Fig. 1) is a 2D videogame in which the player must remember a series of sea creatures (starfish, jellyfish, etc.) that appear in a bubble of a certain color (green, red, yellow, etc.) in the order of appearance to save them from being eaten by an octopus. Each level increases in difficulty by adding more sea creatures and colors. *All You Can ET* (shown in the upper right portion of Fig. 1) is a 2D video game in which the main objective is to shoot either food or drink up to incoming space creatures based a rule involving their color (yellow or green) and/or appearance (one or two eyes), with some levels changing the rules more than once. Each level increases in difficulty by adding more complexity to the

![Fig. 1 Screenshots of designed games: CrushStations (upper left), 1B: All You Can ET (upper right), Gwakkamole (lower left)](image_url)
rules and requiring faster responses. Gwakkamole (shown in the lower left portion of Fig. 1) is a 2D video game in which the player must smash avocados as they emerge from the ground, except for the ones that have a helmet. On some occasions, the helmet may come off and then the avocado can be smashed. Each level increases in difficulty by requiring faster responses and adding more conditions to avoid. Participants were asked to play each game at home on their own devices for 10 min throughout a 30-min session for a total of six sessions. Participants were asked to play on a smartphone or tablet that had an iOS or Android ecosystem. Participants were also asked to achieve at least three stars to move to the next level; this was instructed to ensure that participants were playing and not skipping levels. Each level in the games has a scoring system that gives player 1 to 3 stars depending on their performance.

Similar to the action video game group, to follow-up participants’ performance throughout the game, a short survey was applied after each training session. The survey included questions about time of gameplay, level achieved after gameplay, and a motivation item rated in a scale from 1 to 5 that involved the question “In a scale from 1 to 5, how much effort did you put today on the game?.”

The four cognitive skill tests were deployed using PsychoPy (version 3.6.8) and were administered on iMac computers with 24-inch screens. To assess updating skill, we used the n-back task. Participants are presented with 8 different abstract figures in yellow color with a black background. The figures are presented in random order and change every 3.5 s. The participant must click on the spacebar every time the presented figure also appeared a specific number (3.5 s. The participant must click on the spacebar every time the presented figure also appeared a specific number (n) of figures back. The task uses n = 2, n = 3, and n = 4 conditions; each condition has 3 blocks that consist of 20 + n stimuli. More detail can be found in Jaeggi et al., (2010, 2014). The score is the percentage of correct responses and the mean response time across the task. This task is targeted by CrushStations (Wells et al., 2021), and to some extent by Gwakkamole (Wells et al., 2021) and All-You-Can ET (Parong et al., 2017, 2020).

To assess shifting skill, we used the letter-number task. This task focuses on shifting between two different tasks, a letter task and a number task. A letter-number pair is presented within one of four quadrants on a white screen every 3.5 s, and the placement of the letter-number pair moves in a clockwise order from trial to trial. For the letter task, the participant has to press a key indicating whether the letter-number pair contains a vowel (A, E, I, U) or a constant (G, K, M, R); for the number task, the participant has to press a key indicating whether the letter-number pair contains an odd number (1, 3, 5, 7) or even number (2, 4, 6, 8). When the letter-number pair occurs in an upper quadrant, the letter task is required; when the letter-number pair occurs in a lower quadrant, the number task is required. A transition from the upper to lower quadrant or vice versa constitutes a switch trial, whereas a transition within the upper or lower quadrants constitutes a non-switch trial. There are 128 stimuli (64 switch and 64 non-switch trials). More detail can be found in Miyake et al. (2000) and Parong et al. (2017). The score is the cost for switching tasks (mean time on switch trials minus mean time on non-switch trials, or percentage correct on switch trials minus percentage correct on non-switch trials). This task is targeted by All You Can ET (Parong et al., 2017, 2020).

To assess selective perceptual attention skill, we used the multiple object tracking task. The task involves showing black or white spheres within a gray rectangle for 15 s. The participants watch a specific number of spheres as they move and bounce at a random speed between 66 and 198 pixels per second within a gray color square. After each block, they must indicate on the keyboard the number of bounces they observed. The task consisted of three conditions, following 4 of 8 targets, following 5 of 10 targets, and following 6 of 12 targets for ten blocks in each condition. The task is adapted from the original task of Wood and Simons (2019); the color of the target spheres is randomly chosen per trial. The score is the mean percentage of approximation to the actual number of bounces from the target across the three conditions. This task is most closely aligned with the action video game, Fortnite.

To assess mental rotation skill, we used the 3D mental rotation task. The participant is presented with a pair of 3D square shape white figures on a black screen and must press a key to indicate whether the figure on the left could be rotated to match the figure on the right. Each pair of figures is presented with a maximum duration of 7 s. To answer same or different, the participant must mentally rotate the figure mentally one of the figures. Three hundred forty-eight stimuli were randomly presented (i.e., 174 same trials and 174 different trials). Different trials used mirrored figures. Stimuli were presented based on a rotation of 0°, 50°, 100°, or 150°. More detail can be found in Ganis and Kievit (2015). The score consisted of the percentage of correct responses and mean response times across the task. This task is most closely aligned with the action video game, Fortnite.

**Procedure**

Participants signed up for the study through an online subject pool at a university on California. All participants were randomly assigned to groups and attended an in-person pretest session that had a duration of 1 h, during which they signed a written consent form, completed the questionnaire, and took each of the four cognitive skill tests. Participants who were randomly assigned to the action game group or the designed game group received instructions in how to play the respective games at home on their own devices. They
played the assigned video games at home for six sessions of 30 min each across 2 weeks. After each session, participants answered a short online survey that asked for the time they started and ended their session, the highest level achieved, and asked them to rate their motivation. Over six training sessions participants demonstrated adherence to training by registering an average of 32 min (SD = 0.0043) for the action group and an average of 33 min (SD = 0.0042) for the designed group. Participants who were randomly assigned to the control group did not play any video games during the 2 weeks. After the 2 weeks, all participants attended an in-person posttest session that lasted 1 h and included the same tasks as the pretest session. After completing the study, participants from the game groups received a $60.00 Amazon gift card after their participation, and participants from the control group received credit toward meeting a class requirement. The study received IRB approval and was conducted in line with guidelines for ethical treatment of human subjects.

Results

Are the Groups Equivalent in Basic Characteristics?

As a preliminary step, we examine whether the groups are equivalent on basic characteristics. There are no significant differences among groups in the proportion of each gender category ($X^2 = 6.946, p = 0.139$), the proportion of participants that played video games ($X^2 = 1.529, p = 0.466$), the proportion of participants that played action video games ($X^2 = 0.230, p = 0.989$), and mean number of hours spent playing video games each week ($F = 1.061, p = 0.137$). There is a significant difference among the groups on age, $F = 3.967, p = 0.024$. The mean ages are 19.93 years ($SD = 1.03$) for the action game group, 21.58 ($SD = 6.22$) for the designed game group, and 18.53 ($SD = 0.86$) for the control group. A post hoc Tukey test shows a significant difference between the design group and control group (mean difference = 3.040, $p = 0.007$) but not between the action group and control group (mean difference = 1.394, $p = 0.395$) or action group and design group (mean difference = 1.645, $p = 0.188$). To control for age, we used age as a covariate in subsequent analyses comparing the groups.

Based on a MANOVA on the cognitive skills before training, there is no significant difference among groups in the multivariate test (Wilk’s Lambda = 0.775, $F = 0.972, p = 0.487$, partial eta$^2 = 0.120$). There is, however, a significant difference in the average of percent correct responses on the multiple objects tracking task, $F(2, 56) = 3.226, p = 0.047$. To control for this differences, prescores were used as a covariate in subsequent analyses comparing the groups.

Do the Action Group Get Better at Playing?

Another preliminary issue concerns changes in performance for the action game group. The highest level reached in the action game group appeared to be greater for the last game session (mean = 12.800, $SD = 11.620$) than the first game session (mean = 8.933, $SD = 8.241$); but this difference does not reach statistical significance, $t = 1.250, df = 14, p = 0.232$.

Is Motivation During Training Stable for Both Training Groups?

Finally, another preliminary issue concerns whether learners are able to maintain equivalent levels of motivation across the sessions. For the action game group, motivation during training sessions is stable, $t = 0.823, df = 14, p = 0.424$, with equivalent ratings on the first (mean = 3.600, $SD = 0.910$) and last (mean = 3.800, $SD = 0.774$) training session. For the designed group, average motivation rating also is stable, $t = 1.556, df = 18, p = 0.137$, between the first (mean = 3.701, $SD = 0.955$) and last (mean = 3.473, $SD = 1.067$) training session. There are no significant differences on the average motivation score, $t = 0.279, df = 34, p = 0.782$, between the action game group (mean = 3.724, $SD = 0.614$) and the designed game group (mean = 3.647, $SD = 0.924$).

Do the Groups Differ on Pretest-to-Posttest Gains?

The first hypothesis based on the specific transfer of general skill theory is that students in the designed game group will show greater gains than the control group on the letter-number test and the n-back test. The second hypothesis based on the specific transfer of general skill theory is that the action game group will show greater gains than the control group on the multiple objects tracking test and the mental rotation test. In contrast, general transfer theory predicts that each of the game groups will show greater gains than the control group on all cognitive skill tests, whereas specific transfer theory predicts each of the game groups will not show greater gains than the control group on any of the cognitive skill tests.

Table 2 shows the means and standard deviations on the pretest, posttest, and gain score on each cognitive skill test for each of the three groups. An ANCOVA analysis shows a significant difference among the three groups for the percent correct on the mental rotation test, $F(3, 55) = 8.178; p = 0.001$; however, a post hoc Tukey test does not show any pairwise significant differences between the action game group and the control group (mean difference = 6.098, $p = 0.062$), the designed game group and the control group (mean difference = 5.250, $p = 0.100$), and the action game group and the designed game group (mean difference = 0.847, $p = 0.805$). In contrast to the two hypotheses based on the specific transfer of general skill theory, there
are not significant differences for any of the other measures in Table 2 as can be seen in Fig. 2.

Before concluding that results do not support our hypotheses, we examined performance on the more difficult trials for each task, which may provide a more sensitive measure and based on the lack of significant difference among groups for the n-back test involving 2-back, $F(2, 55) = 0.372, p = 0.695$, 3-back, $F(2, 55) = 1.822, p = 0.192$, and the mental rotation test involving 50° trials, $F(2, 55) = 2.136, p = 0.553$, and 100° trials, $F(2, 55) = 0.245, p = 0.786$. Table 3 and Fig. 3 show the percent correct on the most difficult trials of the n-back test involving 4-back, and the most difficult trials of the mental rotation test involving 150° trials. We focused on these because they are the most sensitive measures of two key tests—n-back

### Table 2

| Target skills                  | Group             | Pretest $M$ | Pretest $SD$ | Posttest $M$ | Posttest $SD$ | Gain $M$ | Gain $SD$ |
|--------------------------------|-------------------|-------------|--------------|--------------|--------------|----------|-----------|
| n-back (percent correct)       | Designed game     | 75.26       | 9.60         | 77.76        | 10.82        | 2.50     | 7.51      |
|                                | Action video game | 78.07       | 10.39        | 79.67        | 11.69        | 1.59     | 6.38      |
|                                | Control           | 73.38       | 7.17         | 49.10        | 10.63        | 0.10     | 6.70      |
| n-back (response time)         | Designed game     | 0.30        | 0.07         | 0.77         | 0.27         | -0.44    | 0.16      |
|                                | Action video game | 0.21        | 0.05         | 0.86         | 0.32         | 0.08     | 0.18      |
|                                | Control           | 0.22        | 0.04         | 0.93         | 0.25         | 0.02     | 0.25      |
| Letter-number (percent correct of cost) | Designed game | 11.59       | 9.85         | 7.73         | 11.62        | -3.86    | 10.15     |
|                                | Action video game | 9.16        | 7.08         | 7.70         | 12.35        | -1.45    | 12.60     |
|                                | Control           | 13.36       | 12.74        | 6.31         | 14.37        | -7.05    | 16.54     |
| Letter-number (response time of cost) | Designed game | -0.03       | 0.09         | -0.04        | 0.20         | -0.01    | 0.15      |
|                                | Action video game | -0.05       | 0.23         | -0.03        | 0.19         | -0.01    | 0.18      |
|                                | Control           | 0.23        | 0.75         | 0.08         | 0.55         | -0.14    | 0.53      |
| Mental rotation (percent correct) | Designed game | 82.42       | 17.60        | 85.66        | 12.20        | 3.24     | 15.82     |
|                                | Action video game | 82.26       | 18.82        | 87.15        | 11.41        | 4.89     | 14.67     |
|                                | Control           | 78.85       | 12.93        | 79.75        | 14.86        | 0.97     | 14.12     |
| Mental rotation (response time) | Designed game     | 1.96        | 0.59         | 1.57         | 0.59         | -0.30    | 0.63      |
|                                | Action video game | 1.82        | 0.68         | 1.51         | 0.66         | -0.31    | 0.66      |
|                                | Control           | 1.97        | 0.90         | 1.47         | 0.49         | -0.49    | 0.41      |
| Multiple object tracking (percent correct) | Designed game | 80.11       | 9.06         | 82.40        | 9.10         | 2.28     | 6.40      |
|                                | Action video game | 82.99       | 10.71        | 79.65        | 10.19        | -3.33    | 7.18      |
|                                | Control           | 72.71       | 16.98        | 74.05        | 16.97        | 1.39     | 5.15      |

![Fig. 2](image-url)
which we hypothesized would be improved by playing the designed games and mental rotation which we hypothesized would be improved by playing the action video game. ANCOVA analyses show a significant effect on percent correct on the n-back test, 4-back trials, \(F(3, 55) = 3.855; p = 0.014\); and on the mental rotation test, 150° trials, \(F(3, 55) = 6.539; p = 0.001\). Consistent with hypothesis 1, post hoc Tukey tests (at \(p < 0.05\)) show that for the n-back test 4-back trials, the designed group had a higher percentage correct than the control group (mean difference = 3.823, \(p = 0.178\)), and consistent with hypothesis 2, post hoc Tukey tests show that for the mental rotation test 150° rotation trials, the action group had a higher percentage correct than the control group (mean difference = 7.987, \(p = 0.029\)). These are the only significant pairwise differences.

**Discussion**

**Empirical Contributions**

On the positive side, the results are partially congruent with the cognitive theory of specific transfer of general skills in that compared to a control group, the design game training significantly improved a measure of updating skill in working memory (i.e., the most difficult trials in an n-back task), and the action video game training significantly improved a measure of mental rotation (i.e., the most difficult trials in a mental rotation task). On the negative side, there were no significant differences among the groups on most of the

**Table 3** Means and standard deviations on the pretest, posttest, and gain score on most difficult trials of n-back and mental rotation tests by group

| Target skills                  | Group           | Pretest M | Pretest SD | Posttest M | Posttest SD | Gain M  | Gain SD |
|-------------------------------|-----------------|-----------|------------|------------|-------------|---------|---------|
| n-back: 4-back (percent correct) | Designed game   | 69.95     | 9.96       | 72.73      | 9.46        | 2.77    | 9.44    |
|                               | Action video game | 72.03     | 12.79      | 73.14      | 13.42       | 1.11    | 10.97   |
|                               | Control         | 69.28     | 8.46       | 69.87      | 10.61       | 0.58    | 8.64    |
| Mental rotation: 150° rotation| Designed game   | 76.14     | 16.45      | 80.32      | 11.99       | 4.17    | 13.74   |
|                               | Action video game | 76.23     | 16.89      | 82.31      | 10.88       | 6.08    | 15.72   |
|                               | Control         | 72.59     | 12.99      | 72.90      | 16.92       | 0.30    | 8.75    |

**Fig. 3** Gain (post–pre) for percent correct of mental rotation task, 150° trial condition, and n-back, 4-back trial condition for action video game group (light), designed group (medium), and control group (dark), * indicates significant difference among groups at \(p < 0.05\); error bars indicate the standard error of the mean.
measures of cognitive skill, suggesting that the effects are somewhat focused.

Although *Fortnite* may require several cognitive skills (i.e., selective attention, working memory, adaptability), this study highlights the need to rotate a 3D image in a specific space mentally. This assumption makes sense given that the game requires the player to orientate the avatar through a vast world and manipulate objects depending on the avatar’s orientation and the position of the object. The results are congruent with the literature in which action video games affect spatial cognition (Bediou et al., 2018, in press); however, it is more common for first-person shooter games to have a significant effect on perceptual attention skills such as multiple object tracking (Mayer, 2014). In our case, the training did not have a significant effect compared to the control group on multiple object tracking, which is intended to tap perceptual attention. This result brings new evidence showing that the cognitive consequences of playing all games are not alike. Although the mechanics are similar, some games may require different predominant cognitive skills depending on how the player interacts with the game.

For the battery of design games we used in this study, *All You Can ET*, *Gwakkamole*, and *CrushStations*, it is not possible to disentangle the effects of individual games. Each game was targeted toward a specific executive function skill: *All You Can ET* was directed toward task switching (also called adaptability), *Gwakkamole* was aimed toward inhibition (also called attention), and *CrushStations* was targeted for updating working memory. At a first glimpse, it may seem that *CrushStations* caused the more significant effect; however, the results may imply that all three games train updating in working memory. Banich (2009) and Diamond (2013) maintain that executive functions work in an integrated multilevel cognitive process (i.e., solving a problem within a video game may require diverse cognitive skills besides the one that is focalized upon). This would imply that each of the games relied to some extent on updating in working memory. When we analyze the mechanics for each game, we observe that *All You Can ET* needs the player to remember a specific set of instructions and color codes to play each level and adapt to new rules, and *Gwakkamole* requires the player to remember the conditions of when to smash the avocado and when not to (i.e., while the avocado is wearing a helmet) while playing the game. Baddeley’s (Baddeley and Hitch, 1974; Baddeley, 2010) working memory model explains that two short-term memory systems (visuospatial sketchpad and phonological loop) depend on a standard central executive attention system. In our case, all three games may require repeated execution of a working memory updating as tapped by the n-back task.

### Theoretical Implications

On a theoretical level, these results provide partial support for the cognitive theory of specific transfer of general skills in that playing action video games trained a skill that is specifically involved in the game—mental rotation—whereas playing designed games trained a cognitive skill specifically targeted in the games—updating in working memory. Thus, this works suggests that the effects of game playing can be somewhat focused on the cognitive skills targeted in the game, so that playing a video game can help train cognitive skills that are specifically involved in the game, but not skills that are not specifically involved in the game. Importantly, this training can transfer to situations involving the same skill outside of the game context—such as in our cognitive tests.

### Practical Implications

On the practical level, these results suggest that cognitive training with games is best implemented by having students play games that involve repeatedly exercising the target skill, with feedback, with increasing levels of challenge, and with changing game contexts. This means that it does not make sense to assume that video game playing will improve a wide array of cognitive skills, but rather games should be chosen that tap the target skill.

### Limitations and Future Directions

In terms of limitations, the present study involved a relatively low number of participants so there may not be enough power to adequately examine some of the measures that were not significant. We also note that the game playing in this study was done at home on the participants’ own devices, which while increasing ecological validity, does not allow for the same level of experimental control and treatment fidelity as a laboratory study. In addition, it would have been better to have equal numbers of participants in each group. We were hampered by the sample size in conducting more fine-grained analysis such as median splits. Furthermore, a total of 6 30-min sessions may not be enough to produce strong effects.

*Fortnite* is an online game, which means that its difficulty cannot be controlled and players may need instruction and guidance in how to optimize the training benefits of the game. In future studies, more work is needed to ensure that the level of playing is appropriate for the participants.

Future studies on the cognitive effects of action video games may consider the game mechanics and particular characteristics of each game in relation to the targeted training skill. Also, a careful consideration of the relation between cognitive skills is needed to design and apply...
multiple custom designed videogames. Finally, we focused on only two kinds of games that have produced promising results in previous training studies—action video games and games designed to train executive function skills—so it would be worthwhile to determine whether the same pattern of focused effects would occur for other game genres.

Conclusion

The purpose of this study was to explore whether people can learn cognitive skills by playing video games and whether such learning was influenced by the type of game, i.e., action video games and designed games. Our results are partially congruent with the theory of specific transfer of general skills where the designed game training improved updating skill and the action video game training improved mental rotation skill; however, there were no significant differences between the training groups and control group in most of the measures of cognitive skill. The results could be explained by a need of a larger experimental control and treatment fidelity that a study at home could not bring.

Author Contribution Richard E. Mayer supervised the project, managed the subject sign-ups, and assisted in designing the study, interpreting the results, and writing the manuscript. Rodrigo Flores-Gallegos set up the experiment, collected the data, conducted the data analyses, and assisted in designing the study, interpreting the results, and writing the manuscript.

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Data Availability The materials and datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics Approval This project received Institutional Review Board approval from the Human Subjects Committee of the University of California, Santa Barbara, and was performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments or comparable standards.

Consent to Participate Participants provided informed consent to participate.

Consent for Publication Participants consented to have their data published in ways that do not reveal their identity.

Conflict of Interest The authors declare no competing interests.

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