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Comparison of Mental Rotation Ability, Attentional Capacity and Cognitive Flexibility in Action Video Gamers and Non-Gamers

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Abstract

Nowadays, video games have become the most popular form of entertainment. For this reason, it is crucial to investigate the positive and negative consequences of gaming. The action genre is the most played amongst gamers and is interesting for cognitive psychology research because gaming requires many perceptual and cognitive abilities. The present study examined the association between playing action video games and the ability to mentally rotate objects, track multiple objects, and switch between tasks. Using a sample of emerging and young adults (18–37 years old), we compared non-gamers (N = 81) and action video gamers (N = 82). Results showed that playing action video games was related to better mental rotation ability and higher attentional capacity. Although gamers switched between tasks faster than non-gamers, the groups did not differ in switching costs, which are an important indicator of cognitive flexibility. The results suggest that playing action video games is positively associated with information processing speed, attention, and visuospatial abilities, and suggest a possible use of such games to improve these abilities.

Keywords: action video games; cognition; mental rotation; cognitive flexibility; attention

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Introduction

Video games are becoming more prevalent and embedded in our daily lives. According to recent reports, there are 2.7 billion video game players worldwide, playing either on a computer, console or phone (Newzoo, 2020). These numbers are expected to increase in the future. Statistics show that 67% of American adults play video games. Contrary to popular belief that most video gamers are younger men, U.S. statistics show that the average gamer is over 31 years old and 45% of them are female (Entertainment Software Association, 2021).

The popularity of video games is increasing every year, as is the interest in researching the effects of gaming. In 2021, two of the best-selling video game genres, aside from casual games, were action and shooter games (Entertainment Software Association, 2021). The widespread use of video games and the discovered associations between playing video games and cognition make video games a potential candidate for enhancing cognition. The present study examined the associations between playing action video games and selected cognitive skills. Special emphasis was placed on important aspects that have often been overlooked before, such as a carefully defined action genre and strict and precise inclusion criteria in the non-gamer and action gamer groups with a larger number of participants.

The Promising Effects of Action Video Game Play on Cognition

Video games take place in realistic and relevant environments that allow for the exploration of limits and different possibilities, with clearly defined rules, goals, and outcomes. An important feature that distinguishes video games from other media (e.g., movies, books) is their interactivity, meaning that individuals are active during gameplay and their activity influences the course of the game (Granic et al., 2014). Video games can be differentiated by the device on which they are played (computer, phone, tablet, and console), the features (e.g., collaborative or competitive, for one or more players, more or less complex, with or without social interaction), and the genres.

Previous research shows that playing different video games has differential effects on cognitive abilities (Powers et al., 2013; Powers & Brooks, 2014). The most promising genre in this aspect is action (Bediou et al., 2018). In exploring the relationship between action video games and cognition, it is important to clearly define the action genre and determine which video games fall into this genre. The popular media definition is more general, but even among researchers there is disagreement on definitions. We followed the leading researchers in the field (Bediou et al., 2018; Green et al., 2016) and defined action video games as games released after 2000 with the following characteristics: (i) fast pace of play, requiring rapid processing and responses; (ii) high attentional demands (requiring distributed and focused attention); (iii) frequent distractions, requiring the ability to select relevant information and ignore irrelevant stimuli; (iv) complex motor responses; (v) perceptual and cognitive load (e.g., requiring working memory, switching, planning). The most common examples of action video games are first-person and third-person shooter games, although other video games may also have some action elements.

Due to the popularity of action video games and their promising properties, many researchers have attempted to prove their usefulness in developing cognitive skills. To date, several meta-analyses have examined the overall effect of games on various cognitive skills, but only some of them focused on the specific action genre (see Bediou et al., 2018; Powers et al., 2013; Powers & Brooks, 2014; Sala et al., 2018; Wang et al., 2016). Bediou et al.'s (2018) meta-analysis of correlational studies showed a moderate association between playing action video games and cognitive functioning (g = 0.55). The effect varied with the different cognitive domains. Large effects were found for visual perception, top-down attention, and spatial cognition. Medium to small effects were found for multitasking, inhibition and verbal cognition. The only cognitive domain in which no significant effect was found was problem solving. A meta-analysis of experimental studies showed a small to moderate effect size for all cognitive abilities (g = 0.34), with significant effects for spatial cognition and top-down attention. Another meta-analysis published the same year (Sala et al., 2018) showed smaller effects of action video game play compared to Bediou et al. (2018). Meta-analysis of the quasi-experimental data revealed a smaller overall effect size (g = 0.40), statistically significant for visual attention/processing, spatial ability, memory, and cognitive control. Meta-analysis of experimental training data revealed a small effect size of playing action video games for visual attention/processing; for all other outcome measures (spatial ability, cognitive control, memory) the effect was not significant. Such differences in the results of two similar meta-analyses published in the same year, with similar inclusion criteria and definition of action video games, are surprising and indicate that further research is needed.

Two theoretical explanations for the mechanisms of video game play transfer to other contexts were introduced. The first one is "learning to learn" theory (Bavelier et al., 2012), which suggests that the effects of video gaming on improving cognitive abilities are due to improvement at a single, more general level. The second is the "common demands" theory (Oei & Patterson, 2015), which suggests that transfer depends on similar requirements and common demands of video games and cognitive tasks, and is therefore expected only for certain cognitive abilities.

Mental Rotation

Spatial skills are required to be successful when playing action video games, especially mental rotation, wayfinding, and navigation. Action games have complex and often cluttered three-dimensional settings with a high degree of realism, and novice players can experience motion sickness (Spence & Feng, 2010).

To date, few researchers have specifically addressed the relationship between playing action video games and mental rotation. Quite a few studies focused on general spatial ability rather than mental rotation and on general computer use or playing all genres of video games rather than the action genre. Two studies compared the mental rotation ability of action video game players (AVGPs) and non-video game players (NVGPs). Quaiser-Pohl et al. (2006) found that men who played action and simulation video games had better mental rotation ability than men who did not play video games, while there were no significant differences between the female groups. These results show that playing certain types of video games is related to mental rotation ability (small positive effect), and that this relationship varies by gender. It is important to keep in mind that the study had some shortcomings, in particular the unequal gender distribution in the AVGP and NVGP groups and the use of subjective self-ratings on the frequency of video game playing ("never", "rarely", "often", "very often"). When examining mental rotation, considering gender differences is essential, as males have consistently performed better than females (Linn & Petersen, 1985; Voyer et al., 1995).

Santone (2009) compared the spatial abilities of gamers who played different types of video games. The "generalist" group performed best on all tests, suggesting a correlation between playing different video games (from first- and third-person perspectives, in three- and two-dimensional environments, with high and low levels of realism and detail) and spatial abilities. A positive correlation was also found between the frequency of game play and the ability to change perspective.

A meta-analysis of experimental studies (Uttal et al., 2013) showed that playing video games (of all genres) was the cause of improved spatial abilities. When comparing different types of training, the effect size was largest for playing video games ($g = 0.54$), but was not significantly different from other types of training. Experimental studies that included training with a specific action video game provide some evidence that playing this genre improves mental rotation ability (Cherney, 2008; Feng et al., 2007), although some do not confirm this (Choi & Lane, 2013).

Attentional Capacity

When playing action video games, attention is of key importance. Action video games require the distribution of attention across the entire field of view and relocating it from one location to another. Players must track multiple events and moving objects at once. The focus is usually in the centre, but they must also pay attention to multiple relevant stimuli in the periphery, far from the central focus. The distribution of attention over a wide field of view is crucial, because unnoticed events in the periphery can be the reason for losing the game (Spence & Feng, 2010).

In research on attentional capacity, the multiple object tracking paradigm is most commonly used. Attentional capacity is limited, and most people can attentively track 4 ± 1 objects at a time. There are differing opinions about the limit of attentional capacity (Bettencourt & Somers, 2009) – some argue that it is limited to four objects, while others believe that it is more flexible, ranging from two to eight objects, depending on the demands of the task and the person's experience. Bettencourt and Somers (2009) found in their study that attentional capacity is significantly affected by the characteristics of the stimuli (speed and size) and the distractors (number and density).

To date, several studies have confirmed that AVGPs have higher attentional capacity than NVGPs. This has been demonstrated with the multiple object tracking task (Boot et al., 2008; Dale et al., 2020; Dye & Bavelier, 2010; Green & Bavelier, 2006b; Trick, Jasper-Fayer et al., 2005), the flanker task (measuring the effect of a to-be-ignored distractor on a target task; Dye et al., 2009; Green & Bavelier, 2003, 2006a), and the enumeration task (Green & Bavelier, 2003, 2006b). Nevertheless, some studies do not confirm the difference in attentional capacity between groups (Boot et al., 2008; Irons et al., 2011; Murphy & Spencer, 2009). It should be noted that flanker tasks are not the best measure of attentional capacity, as we cannot be sure whether the effect of distractors is high due to multiple available sources of attention or due to poorly directed attention (Dye et al., 2009).

Some experimental studies provide evidence that playing action video games is the cause of higher attentional capacity (Cohen et al., 2008; Green & Bavelier, 2006b; Oei & Patterson, 2013, 2015), although Boot et al. (2008) did not confirm this.

Cognitive Flexibility

The name of the action genre says a lot about its main feature, mainly there is a lot of action. A variety of events, challenges and changes happen in rapid succession, even unexpectedly, so the player must react quickly and switch between tasks. The player may be focused on a navigation task when a sudden attack occurs. To be successful in such circumstances, cognitive flexibility, a quick disengagement from the current task and a quick engagement with the new task are required (Spence & Feng, 2010).

People with high cognitive flexibility can think creatively outside of established frameworks, see things from different perspectives, and adapt quickly to changing circumstances. Cognitive flexibility is often tested through task or set switching tests (Diamond, 2013), which measure the time needed to switch (the switching cost) – the less time and errors, the greater the cognitive flexibility. To test this ability, the alternating or random switching paradigms can be used. In the first case, switching between tasks is predictable, which means that one can prepare for the switch in advance, so the switching cost is lower. Random task switching, on the other hand, leads to greater cognitive conflict and thus higher switching costs (Monsell, 2003).

Studies with different paradigms, tasks, and stimuli show that AVGPs have greater cognitive flexibility compared to NVGPs and can switch between tasks more quickly and with similar or fewer errors (Boot et al., 2008; Cain et al., 2012; Colzato et al., 2010; Green et al., 2012; Kowal et al., 2018; Strobach et al., 2012). Some studies focused on cognitive judgment, such as distinguishing between even and odd numbers (Boot et al., 2008; Colzato et al., 2010; Green et al., 2012), while others focused on perceptual judgment about the shape, color, or orientation of arrows (Cain et al., 2012; Green et al., 2012). Tasks also differed in terms of predictability (Colzato et al., 2010; Green et al., 2012; Kowal et al., 2018) and unpredictability (Boot et al., 2008; Cain et al., 2012; Green et al., 2012) of task switching. Green et al. (2012) also used different response modalities (motor or verbal response). Despite all the differences in the methods used in the different studies, AVGPs had lower switching costs than NVGPs. In contrast, Karle et al. (2010) found no advantage in task switching for VGPs compared to NVGPs when proactive interference between tasks was increased, which is why they suggested that gamers show a better ability to switch between tasks due to better control and distribution of selective attention rather than other higher cognitive control processes on which switching relies.

Research using training with an action video game shows promising results, with lower switching costs in the trained group (Green et al., 2012; Strobach et al., 2012). However, not all studies confirm the positive effects of such training (see e.g., Boot et al., 2008).

The Present Study

Many researchers have focused on the effects of playing any type of video games or computer use in general, which are much broader than playing video games of a specific action genre. Even the studies that examined the effects of action video game play often defined genre very loosely, and as a result, individuals who frequently played other genres were also included in the AVGP group. Many cross-sectional studies also included small samples. The results of some studies are conflicting, and meta-analyses show varying effect sizes. Therefore, further research is needed to avoid these shortcomings.

The aim of the present study was to examine the differences in cognitive abilities between AVGPs and NVGPs using a larger sample and applying strict criteria for inclusion in the AVGP group. We focused on three abilities – mental rotation, attentional capacity, and cognitive flexibility. Based on previous research, we hypothesized that AVGPs would perform better than NVGPs on all three tests. Due to the correlational nature of the study, we cannot draw conclusions about the causal effects of playing action video games. Experimental studies are needed to confirm causal effects. Nevertheless, it seems crucial that this type of correlational research be conducted at this time, as it will be difficult to find participants in the future who have no experience with video games. Since video games are already so embedded in our daily lives, we expect that in the future everyone, at least at some point in their lives, will play video games, including the action genre, which is one of the most popular. At that point, it will be difficult to narrow down the impact of playing different types of video games, and it will also be impossible to compare gamers to non-gamers.

Methods

Participants

A statistical a priori power analysis was performed for sample size estimation, based on the average effect sizes from two meta-analyses: g = 0.55 (Bediou et al., 2018) and g = 0.40 (Sala et al., 2018). With an α = .05 and 1-β = .80, the projected sample size needed with this effect size was approximately 53-100 participants per group. Data were collected online in April and May 2019. Invitation for participation was posted on multiple websites, Discord and Facebook groups. Participants were overtly recruited (i.e., the invitation mentioned playing video games and not playing video games, so they could assume that the purpose of the study was related to their gaming habits). A total of 452 individuals gave informed consent and participated in the study, but not all met the inclusion criteria. Only adult participants up to 40 years of age were included, as cognitive functions decline with age (Iachini et al., 2019; Kray & Lindenberger, 2000; Politakis et al., 2022; Statsenko et al., 2020; Trick et al. 2009; Trick, Perl, et al., 2005; Wasylyshyn et al., 2011). They also had to meet the specific AVGP or NVGP group criteria presented below. The final sample included 163 participants aged 18–37 years; the mean age of AVGPs was 24.3 years (*SD* = 4.2), and the mean age of NVGPs was 25.5 years (*SD* = 4.4). On average, NVGPs had a higher education than AVGPs. Comparing the current status of NVGPs, 53 of them were university students, 25 were employed, and 3 were unemployed. Of the AVGPs, 36 were university students, 34 were employed, 8 were high school students, and 4 were unemployed.

The number of participants varied slightly between tests (Table 1). Not all participants completed all the tests, so the first test (Mental Rotations Test) had the most participants. For the Multiple Object Tracking Test, we excluded the results of 21 participants whose objects' moving speed deviated from the usual (number of draw calls were lower than 288 or higher than 542). The number of draw calls of the remaining participants was similar (Min = 350, Max = 365) and their objects moved at approximately the same speed. There was a 4% difference between the objects' speed, indicating that these differences were not noticeable and were below the threshold (de Bruyn & Orban, 1988). We also excluded one additional participant from this test because his score was significantly different from the AVGP group average (–3.07 *SD*). In the Feature Switching Task, we excluded two participants who reported (partial) color blindness.

Table 1. *The Final Number of Participants in the AVGP and NVGP Group and Their Gender.*

Group	Altogether	Mental Rotations Test	Multiple Object Tracking Test	Feature Switching Test
AVGP (male, female)	82 (70, 12)	81 (69, 12)	58 (46, 12)	81 (69, 12)
NVGP (male, female)	81 (37, 44)	81 (37, 44)	69 (32, 37)	75 (36, 39)

Participants were classified into one of the groups based on the adapted Video Game Questionnaire - version March 2018 and the criteria developed by Bavelier Lab at the University of Geneva (Bediou, 2019). We slightly updated the questionnaire (we added the games most played in each category at the time of the study) and criteria. The criterion for inclusion in the AVGP group was playing at least 5 hours of action video games (either first or third person shooters or action role-playing games/adventure games) per week and minimal playing (at most 1–3 hours per week) of non-action genres (such as non-action role-playing, turn-based strategy, life simulation, puzzle, music games). Participants were also assigned to the AVGP group if they played action first or third person shooters 3–5 hours per week and action role-playing games/adventure games 3–5 hours per week as well as at least 5 hours per week of real-time strategy/multiplayer online battle arena or sports/driving games. All of these genres also have some action features. Playing non-action video games had to be kept to a minimum (at most 1–3 hours per week). The criterion for inclusion in the NVGP group was little or no playing of action video games during and before the past year (at most 0–1 hour per week) and minimal experience with other video game genres (at most 0–1 hour per week for sports/driving games, at most 0–1 hour per week for real-time strategy/multiplayer online battle arena, and at most 1–3 hours per week for games with non-action features, such as non-action real-time strategy, fantasy, turn based strategy, puzzle, music games). Some exceptions were allowed, namely if the participant played 3–5 hours of non-action video games before the past year (e.g., Solitaire, The Sims, puzzle games, Candy Crush). Most often played action first/third person shooter games were Counter-Strike: Global Offensive, Overwatch, Call of Duty and Fortnite. Most often played action role-playing games/adventure games were The Witcher, Grand Theft Auto and Assassin's Creed.

Measures

Mental Rotations Test

We developed a computerized online version of the Mental Rotations Test (MRT; Vandenberg & Kuse, 1978) to test mental rotation ability. The test was divided into two parts, each consisting of 10 tasks. Each task had a base object on the left and four alternatives on the right (Figure 1). There were only two correct answers representing two objects identical to the base object, the only difference being the angle of rotation. Time was limited to 6 minutes (3 minutes for each part) and participants could see the timer in the upper right corner of the screen. The maximum score was 40 points; 2 points were awarded for both answers, 1 point for only one correct answer, and 0 points if both correct and incorrect answers were chosen or only incorrect answers were chosen.

Figure 1. *An example of a task from the Mental Rotations Test.*

Multiple Object Tracking Test

The Multiple Object Tracking Test (MOT) was used as a measure of attentional capacity. It requires active attention allocation to successfully track multiple target stimuli among distractors. The test was developed following the guidelines of Yung et al. (2015). Participants were required to direct their attention to 16 randomly moving yellow circles. After two seconds, a certain number of circles (1–5) turned blue and they had to track them. After four seconds of tracking, all circles returned to their original yellow color. Then, only one of the 16 circles was given a question mark and the participant had to answer whether it was the tracked stimulus (colored blue) or not. The test consisted of 6 practice items followed by 45 trials divided into three sets (15 trials each). Yung et al. (2015) applied their version of the test online with 1,744 participants, and the results were comparable to standard laboratory tests.

Feature Switching Test

To measure cognitive flexibility, we used the Feature Switching Test (FST) and programmed it as it is available in the open-source software program PEBL (Mueller, 2012). The test measures the ability to switch flexibly between tasks with different rules. Participants saw a screen with ten randomly arranged objects on a black background that differed in color, shape, and letter inside the object. Each object matched another object in only one dimension (color, shape, or letter). At the beginning of each task, an object was circled, and a rule was written on the screen, which the participant had to follow by selecting the next matching object. The three rules were 'color', 'shape' and 'letter'. For example, if the rule was 'shape', the participant had to find an object that matched the shape of the circled object. The test was divided into three parts with three switching levels; the first alternated two rules, the second alternated three rules consistently, and the third alternated three rules randomly so that the next feature could not be anticipated prior to making the response. Each switching level contained three sessions of nine rules. Reaction times and the number of errors were measured.

Procedure

The tests were administered online. All tests were written in JavaScript on the Node.js runtime environment, using the Express 4 web framework and the MongoDB database. In the browser, we used the jQuery library and the CSS bootstrap framework. We used a freely available project code with PHP technology and MySQL database for Multiple Object Tracking Test (Yung, 2017).

The requirement for starting the experiment was access from a computer with a large enough screen. If someone accessed the website from a phone or tablet, or if the browser window was not large enough, the message "Enlarge your browser window or try a larger screen" would appear and the participant could not proceed with the test. Each participant was automatically given their own code, which was displayed at the top right of the screen. If someone accessed the site more than once from the same computer, they were automatically redirected to the last part of the test in the previous session. Everyone had the option of starting a new session in which a new code was assigned (e.g., if two people wanted to participate from the same computer).

First, we administered the demographic and video game questionnaires. The video game questionnaire included seven video game genres with examples of popular video games, adapted from Bediou (2019). For each genre, participants indicated how many hours per week they played it in the last year and before. The options given were: never, 0 to 1, 1 to 3, 3 to 5, 5 to 10 and more than 10 hours. Participants were asked to list the games they had played in each genre to ensure the accuracy of their answers. At the end, participants had the option to indicate the hours of playing video games that they felt did not fall into any of the seven genres. The video game questionnaire was followed by three cognitive tests, administered in the same order to all participants: Mental Rotations Test, Multiple Object Tracking Test, and Feature Switching Test. Before the Multiple Object Tracking Test, participants were asked to calibrate the screen according to the instructions of Yung et al. (2015).

After participants completed all the tests, they were asked if anything affected their performance. Some participants reported that objects moved too quickly in the MOT test, and some reported that their color blindness affected their performance in the FST. We excluded the test results of these participants. Some participants gave less specific reasons, such as internet connection problems, distractions, and illness. These participants were as well not included in the final sample.

Data Analysis

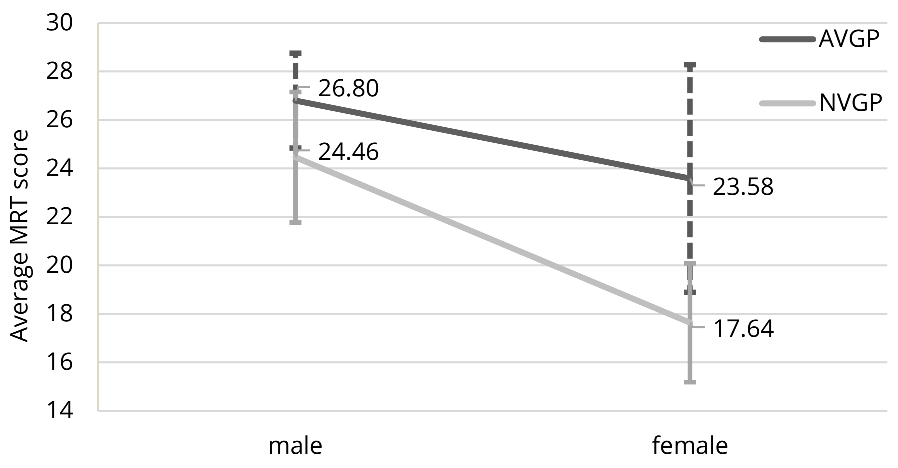
For Mental Rotations Test, the two-way repeated-measures analysis of variance was used, with gender and video game playing as factors. Controlling for gender effect was necessary because research shows that males have better mental rotation ability compared to females (Linn & Petersen, 1985; Voyer et al., 1995). However, since there was unequal gender representation in the AVGP and NVGP groups (Table 1), the interpretation of our results should be cautious, since this represented a confounding variable in our study. The observation that the proportion of both genders were different in the AVGP and NVGP groups should be addressed in future studies that would examine the motivation of the two genders for playing videogames and other factors affecting their decision to play. Multiple Object Tracking Test results were analysed using 2 (group [AVGP, NVGP], independent samples) x 4 (number of tracking objects [two, three, four, five], repeated measures) mixed ANOVA. For *post-hoc* comparisons of groups under different conditions, we used the *emmeans* package in R (Lenth et al., 2021) and the FDR method for *p*-value adjustment. Feature Switching Test results were analysed using 2 (group [AVGP, NVGP], independent samples) x 3 (switching level [first, second, third], repeated measures) mixed ANOVA. If Mauchly's test showed that the data violated the assumption of sphericity, the Huynh-Feldt correction was used. To test for reaction time differences between groups at different switching levels, we used independent-samples *t*-tests, and for differences in the number of errors, we used the Mann-Whitney *U* test, Monte Carlo procedure.

Results

Mental Rotations Test

On the Mental Rotations Test, AVGPs (M = 26.32, SD = 8.17) scored on average 5 points higher than NVGPs (M = 20.75, SD = 8.95). This difference was statistically significant, $F(1, 158) = 6.86$, $p = .010$, $\eta_p^2 = .04$. Mental rotation was statistically significantly associated with gender, $F(1, 158) = 10.07$, $p = .002$, $\eta_p^2 = .06$. Males scored higher (M = 25.98, SD = 7.99) than females (M = 18.91, SD = 9.00). The interaction between group and gender was not statistically significant, $F(1, 158) = 1.30$, $p = .255$, $\eta_p^2 = .01$. That is, the effect of playing action video games on mental rotation ability was similar for males and females. The results of the test are shown in Figure 2.

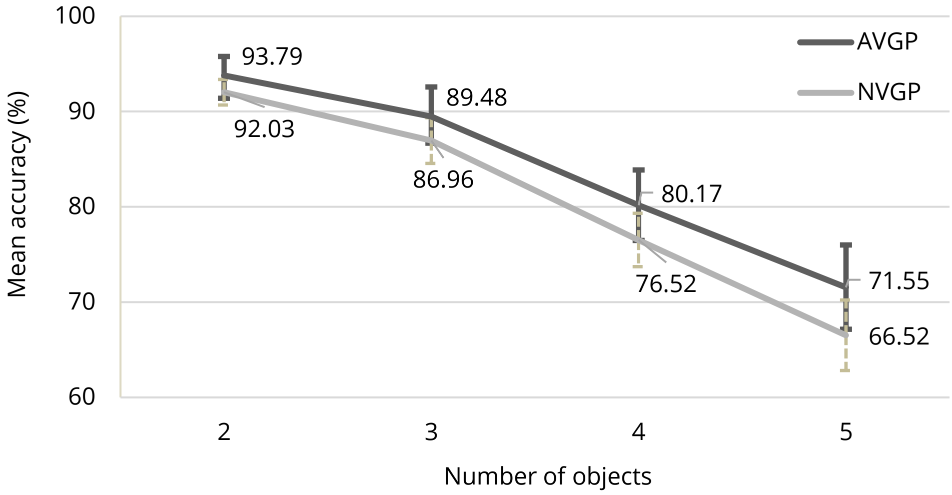
Figure 2. *Average Scores (With 95% Confidence Intervals for the Mean of the Group of Participants) of AVGPs and NVGPs in Mental Rotations Test.*



Multiple Object Tracking Test

In the Multiple Object Tracking Test, the accuracy of AVGPs (M = 83.75%, SD = 7.73%) was statistically significantly higher from the accuracy of NVGPs (M = 80.51%, SD = 8.77%), $F(1, 125) = 4.80$, $p = .030$, $\eta_p^2 = .04$. Accuracy was also statistically significantly affected by the number of objects tracked, $F(2.60, 324.50) = 88.34$, $p < .001$, $\eta_p^2 = .41$ (see Figure 3). Although the interaction between group and number of objects tracked did not reach statistical significance, $F(2.60, 324.50) = 0.40$, $p = .728$, $\eta_p^2 < .01$, additional comparisons showed that the difference between the two groups increased slightly with the number of objects tracked. The difference between the average accuracy of the two groups was 1.76% (p = .473, d = 0.14), 2.53% (p = .304, d = 0.20), 3.65% (p = .138, d = 0.29), and 5.03% (p = .041, d = 0.40) for the conditions with two, three, four, and five tracked objects, respectively.

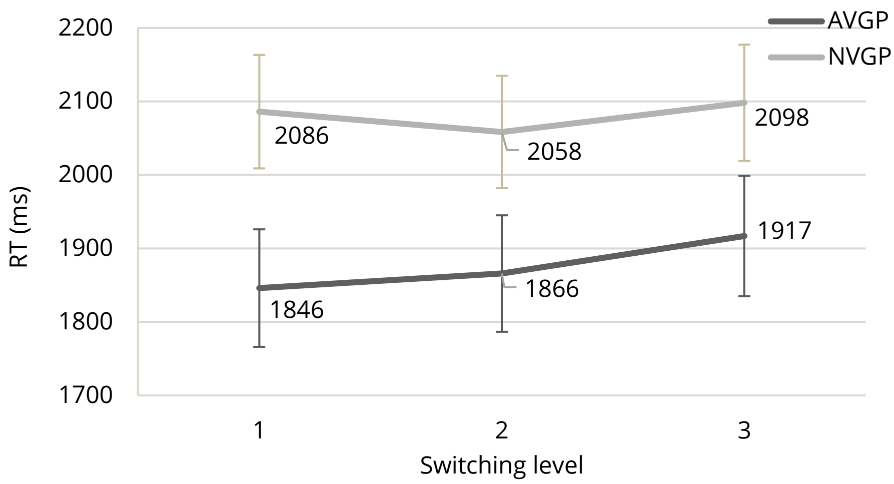
Figure 3. *Average Percentage of Correct Answers (With 95% Confidence Intervals for the Mean of the Group of Participants) of AVGPs and NVGPs in the Multiple Objects Tracking Test for Different Numbers of Tracked Objects.*



Feature Switching Test

Figure 4 shows that AVGPs had faster reaction times than NVGPs in all conditions of the Feature Switching Test. The difference between groups was statistically significant, $F(1, 141) = 15.68$, $p < .001$, $\eta_p^2 = .10$. Reaction times were also statistically significantly affected by switching level, $F(2, 282) = 3.23$, $p = .041$, $\eta_p^2 = .02$. On average, reaction times increased with switching level. The interaction between group and switching level was not statistically significant, $F(2, 282) = 1.24$, $p = .291$, $\eta_p^2 = .01$, indicating that the effect of video game playing was similar across switching levels.

Figure 4. *Average Reaction Times (With 95% Confidence Intervals for the Mean of the Group of Participants) of AVGPs and NVGPs at Three Different Switching Levels.*



However, a better indicator of cognitive flexibility is the comparison of reaction times at different switching levels, which provides us with information about switching costs. AVGPs and NVGPs did not differ significantly in switching costs. The difference in reaction times for switching of different complexity was similar in both groups. The differences between reaction times for conditions with two (Level 1) and three rules alternating in a consistent order (Level 2) were similar for AVGPs and NVGPs, $t(141) = 1.19$, $p = .237$, $d = 0.20$, as were the differences in reaction times for random (Level 3) and consistent (Level 2) alternation between the three rules, $t(142) = 0.30$, $p = .766$, $d = 0.05$. Although AVGPs were faster than NVGPs at all switching levels, they did not make statistically significantly more errors (see Table 2).

Table 2. *Results of the Mann-Whitney U Test of Differences in the Average Number of Errors in the Feature Switching Test Between Groups of AVGPs and NVGPs*.

	AVGP errors *M* (*SD*)	NVGP errors *M* (*SD*)	*U*	*z*	*p*	*d*
ERRORS FOR SWITCHING LEVEL 1	0.39 (1.00)	0.45 (1.25)	2584.50	–0.02	.984	–0.00
ERRORS FOR SWITCHING LEVEL 2	0.49 (1.13)	0.43 (0.90)	2586.00	–0.01	.997	–0.00
ERRORS FOR SWITCHING LEVEL 3	0.55 (1.13)	0.43 (0.85)	2536.50	–0.26	.787	–0.02

Note. Values were calculated using a non-parametric Mann-Whitney U test based on 10.000 samples.

Discussion

Men scored significantly higher than women on the Mental Rotations Test, which was to be expected since previous researchers have found a difference in mental rotation ability between the genders since the 1970s. The moderate effect size is also consistent with the results of meta-analyses (Linn & Petersen, 1985; Voyer et al., 1995). Both male and female AVGPs showed better mental rotation abilities than male and female NVGPs. The effect size related to playing action video games was small (and smaller than the gender effect), but statistically significant. We can conclude that playing action video games is associated with higher spatial abilities, especially mental rotation, supporting our first hypothesis. This is consistent with previous research findings, although two recent meta-analyses (Bediou et al., 2018; Sala et al., 2018) showed larger effect sizes. The reason could be that we examined a specific mental rotation ability, whereas the meta-analyses included a general spatial ability, of which mental rotation is only a part. Our version of the test was also time limited, which could affect the results. Time pressure is an additional stressor in solving cognitive tests, to which people respond differently. Action video games are often played under time pressure, and research shows that gaming is associated with faster processing and shorter reaction times (Dye et al., 2009), which could give AVGPs an advantage when solving the Mental Rotations Test. In the future, it would be interesting to compare the differences between the groups in time limited and time unlimited mental rotation tests.

The effect of playing action video games did not differ between men and women. However, the interpretation must be cautious, as the gender representation in the AVGP and NVGP groups was unequal. There were more male gamers in the AVGP group, which was to be expected as statistics also show that in the 18–34 age group, males are most likely to play the action genre and females are most likely to play casual games (Entertainment Software Association, 2020). There were more female non-gamers in the NVGP group, about three times as many as in the AVGP group. We attempted to account for the problem of unequal gender distribution at the participant search stage and later controlled for gender effect in the analysis. Although our study was not experimental, we could hypothesise that playing the action genre might lead to a parallel improvement in mental rotation in male and female gamers. This is consistent with the conclusions of Uttal et al. (2013), although some researchers (Cherney et al., 2014; Feng et al., 2007) found that training had a greater impact on females. In another correlational study (Quaiser-Pohl et al., 2006), the relationship between playing video games and mental rotation was found only in male players. The reasons for the different results could be due to a more even gender distribution in the groups of AVGPs and NVGPs in our sample. Quaiser-Pohl et al. (2006) also used a slightly different test and scoring.

In our study, we did not examine what strategies participants used when solving the mental rotation tasks. In the future, it would be interesting to include eye-tracking and self-report information about the strategies used. This would provide more in-depth information about how the test is solved by AVGPs with better mental rotation ability compared to NVGPs.

We used the Multiple Object Tracking Test to measure attentional capacity. Previous research (Green & Bavelier, 2006; Yung et al., 2015) has shown that as the number of objects to be tracked increases, the average percentage of correct responses decreases, which is also reflected in our results. The average score of AVGPs was significantly higher than that of NVGPs when tracking two, three, four, and five objects, although the effect size was small. AVGPs appear to have higher attentional capacity, which supports our second hypothesis and is consistent with previous findings (Bediou et al., 2018; Boot et al., 2008; Dale et al., 2020; Dye et al., 2009; Dye & Bavelier, 2010; Green et al., 2016; Green & Bavelier, 2003, 2006a, 2006b; Sala et al., 2018; Trick, Jaspers-Fayer et al., 2005). Researchers using the object tracking paradigm as a measure of attentional capacity found significantly better tracking abilities in AVGPs in all cases (Boot et al., 2008; Dye & Bavelier, 2010; Green & Bavelier, 2006b; Trick, Jaspers-Fayer et al., 2005), but the effect sizes were larger than in our study. This could be due to the smaller sample sizes (Boot et al., 2008; Green & Bavelier, 2003, 2006a, 2006b; Trick, Jaspers-Fayer et al., 2005) or to a specific property of the test we used. In our study, the interaction between playing action video games and the number of objects tracked did not reach statistical significance, even though we observed a trend of increasing advantage of AVGPs with the increase in the number of objects tracked. Using the same test, Green and Bavelier (2006) found the largest differences between AVGPs and NVGPs when tracking four and five objects, similar to our results. It would be preferable in the future to include tracking six and even seven objects to determine the potential differences in attentional capture between the two groups and whether the trend of increasing differences between the groups continues as the number of tracked objects increases. It is also important to note that some participants had the problem that the stimuli moved too fast due to the higher monitor refresh rate. For this reason, we had to exclude data of 11 AVGPs. We assume that they had very good monitors, and precisely individuals with better monitors in particular are likely to be frequent and competent video gamers, so it is possible that the effect size would be higher if these gamers were included. This could also be the case if the amount of action properties of action video games were controlled for in the AVGP group. The intervention study by Oei and Patterson (2015) showed that attentional capacity was only affected by playing the video game Modern Combat, which had the most action properties, while playing the other three video games had no effect, even though we would classify them as action video games by definition.

The results of the Feature Switching Test showed significant differences between AVGPs and NVGPs in reaction times at all three switching levels. The effect size was moderate to large, with AVGPs being faster at predictable switching between two and three rules as well as at and random switching. Although they responded faster, they did not make significantly more errors than NVGPs. Thus, this speed effect was not influenced by a speed-accuracy trade-off. These results are consistent with previous findings showing that gamers are faster than non-gamers while their accuracy is comparable (Dye et al., 2009; Kowal et al., 2018). It is important to consider that the faster absolute reaction times of AVGPs could indicate better visual processing, attention, and possibly task switching, but this speed could also be the result of better computer equipment or a generally faster motor response when handling the mouse. Comparing reaction times between switching levels provides more information about switching costs than do reaction times at individual switching levels. We expect higher switching costs for random switching than for predictable switching (Monsell, 2003). Strobach and Schubert (2016) suggest that selective attention and working memory updating are crucial in the predictable switching task, and therefore the differences between AVGPs and NVGPs might be smaller in the random switching task. Individuals cannot prepare for switching, so top-down processes are less important. However, AVGPs and NVGPs did not differ in switching costs. The number of rules (two or three) and the (un)predictability of switching affected the performance of the two groups equally. This is inconsistent with other studies showing – regardless of the paradigm used – that gamers have lower switching costs (Boot et al., 2008; Cain et al., 2012; Colzato et al., 2010; Green et al., 2012; Kowal et al., 2018; Strobach et al., 2012). Our results are more in line with Karle et al. (2010), who assume that gamers switch faster due to better control over selective attention, but this does not indicate better developed executive functions and greater cognitive flexibility.

The effect of the switching levels was small but significant. Given the complexity of switching, one would expect the shortest reaction times in the first switching level and increasing reaction times in the second and third levels. This was the case for the AVGP group, while the NVGPs were fastest at the second switching level. This could be because they needed more time to figure out the requirements of the task and the most optimal way to solve it, so they were slower on the first switching level, which was at the beginning of the test.

The Feature Switching Test was used as a measure of task switching, but the test itself may not be the best choice for measuring this ability. The simplest task consists of two alternating rules instead of a single rule. This means that we get no information about the time it takes to respond to tasks without switching. Also, there is lack of information about the validity of the test. Furthermore, since participants had to follow the rules at the top of the screen, this suggests that a verbal component may be involved in the successful completion of the test. In the first and second levels, the switching rules were predictable, allowing participants to memorize the switching pattern. In this case, it can be assumed that verbal working memory was involved. Participants could remember the order of the two or three rules they had to follow. In the third level, the switching rules were unpredictable, so participants could not memorize the switching pattern. In the meta-analysis by Bediou et al. (2018), verbal working memory was classified as part of verbal cognition, where the effect sizes were small to medium (smaller than for task switching/multitasking). If this cognitive component (verbal working memory) was predominant in solving this task, it would have a large effect on performance, possibly even more so than task switching. It is possible that the group differences in switching costs would be more pronounced if more established tests (e.g., Trail Making Test or Wisconsin Card Sorting Test) were used.

One limitation of this study is that the order of the cognitive tests was not counterbalanced. Although we tried to avoid potential fatigue effects by allowing and encouraging breaks between tests, it seems reasonable to point out that this may still affect the results. On the other hand, the same test order allowed us to more easily administer and manage online testing, where participants were able to continue the test at the same point where they had left off, even if they had closed the browser window in the meantime.

We expect that in the future there will be fewer gamers who exclusively play the action genre. At the same time, features of different genres will be present in most video games and the distinction between different video game genres will become less clear. For these reasons, it would be interesting to focus on the specific characteristics of video games rather than genres in the future. Based on the characteristics of video games that contribute to higher cognitive skills, researchers could also more easily design a video game for the purpose of training specific skills.

Finally, we would like to point out that, based on the results of our study, the conclusion that excessive playing of action video games contributes to the improvement of cognitive skills would not be justified for two reasons. First, in our study, the criterion for inclusion in the AVGP group was playing action video games more than 5 hours per week. This does not exclusively cover individuals who play video games throughout the day or devote most of their free time to gaming. It would be interesting to study how the effects of gaming on cognitive abilities change with the number of hours spent playing video games. The results of some studies show better performance of heavy/professional action gamers compared to moderate/amateur action gamers (Benoit et al., 2020; Kowal et al., 2018; Mallik et al., 2020). Second, our study was quasi-experimental. The comparison between regular AVGPs and NVGPs does not allow us to draw conclusions about whether gaming is the cause of more advanced cognitive abilities. It could be that individuals with better cognitive abilities play more action video games because they perform well in such games. Carefully designed and controlled longitudinal experimental studies are needed to determine whether playing action video games is indeed the cause of improvement. However, based on the research to date, this seems plausible.

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Conflict of Interest

The Authors declare no conflict of interest.

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