ISSN 1846-6168 (Print), ISSN 1848-5588 (Online)
https://doi.org/10.31803/tg-20220427170715

Preliminary communication
Received: 2022-04-27, Accepted: 2022-10-20

Influence of Video Games on Cognitive Abilities and Intelligence

Dorja Hatlak, Andrija Bernik*, Igor Tomičić

Abstract: This paper gives an overview of development in research concerning the influence of video games on cognitive development and intelligence. The first part of the paper mentions three categories used by different researchers in their research: generally speaking, the development of constructs and commercial games. StarCraft is mentioned in the paper, one of the most complex strategical games of all time, and its influence on professional players in eSport. Additionally, it presents a taxonomy of strategy games compared to real world situations, such as crisis management and control. The papers indexed in Scopus and Web of Science databases are chosen for this research since they are based on the cognitive relations between the games and players. One of the conclusions is that games can influence the enhancement of cognitive abilities in both directions.

Keywords: cognitive abilities; cognitive stimuli; computer games; intelligence; memory

1 INTRODUCTION

Entertainment Software Association reports in their 2020 research that 75% of American have at least one video game player in their household who plays (further on in the text - people who occasionally or often play video games). [1] Out of that percentage 65% of video gamers play with others (multi-player), while the average age range of video gamers is between 35 and 44 years old.

The same type of research in 2017 shows 67% of households has at least one video game player (that amounts to 16% more than in 2014), which indicates to further growth trend in the popularity of video games and their integration in daily lives.

To what extent is intelligence determined by genes, and to what extent is the development of intelligence susceptible to external conditions? There has been a lot of research on genetics up to date. Certain genes that play a role in intelligence and academic performance have even been identified. It is without a doubt that intelligence is primarily determined by genes. However, there are some significant factors that can influence cognition, especially at early age. A research team from King's College London shows nine general groups of hereditary traits (out of 83 possible ones) that are connected to GSCE (General Certificate of Secondary Education) or academic performance. Identical twins have a high probability of sharing these 9 traits. In research "Sources of Human Psychological Differences: The Minnesota Study of Twins Reared Apart" from 1990 Thomas J. Bouchard et al. [2] studies monozygotic twins reared apart after birth in order to explain environmental and genetic influences on traits. It concludes that twins reared apart can share 70% of genes. Differences in IQ results can be found in about 25% of the variance at adult age in twins with the same genetic predispositions.

Along with the change in trends, new discoveries in the field of psychology, cognition and increased quality, quantity and possibilities that games offer, a lot of new questions arise. One of the most controversial ones is perhaps "Do video games influence our intelligence?" Can cognitive ability and general intelligence be extended beyond the genetic framework? If they can, could the games assume the role in these efforts of a means that serves to develop certain cognitive abilities?

2 LITERATURE OVERVIEW
2.1 Pioneer Studies

This research paper includes research that:

a) Measures the correlation of success in playing video games and the results of standard intelligence tests using the Pearson correlation coefficient
b) Research that confirms but also refutes the thesis
c) Research that relies on medical instruments (MRI) or otherwise measures neuroplasticity of the brain and thus proves the effects (positive or negative) of playing video games on the human brain.

The first official effort to use video games in a cognitive processes study dates back to the 80s of the 20th century when Jones et al. [3] calculated correlation values between intelligence tests and cognitive measurement factors that varied between 0.18 and 0.50. The mentioned research examines the relationship between video games and determined dimensions of individual differences in cognitive and perceptual functioning performed on 63 male students with more than 2 hours of experience playing Atari video games, 5 games and 12 ETS (Educational Testing Service) intelligence paper-and- pencil tests; Hidden patterns (CF-2), copying (CF-3), Gestalt tasks of synthesizing an image elements into a whole picture (SC-1), addition and subtraction (N-4), searching for letter A (P-1), meaningless syllogisms (RL-1), card rotation (S-1), comparing cubes (S-2), map planning (SS-3), advanced vocabulary (V-5) and paper folding (VZ-2). From the mentioned tests, 3 were general intelligence tests and four spatial ability tests, since spatial perception is present in the chosen games. Games were not randomly chosen, but for specific reasons such as: quick reaction, fantasy elements, spatial and perceptual abilities. Almost all the tests have at least some positive correlations, except for advanced vocabulary and meaningless syllogisms whose correlations has a minus sign. It should be taken into account that both tests refer to general intelligence. This means that 11 tests in total are in some type of relationship with the video games. The conclusion is brought that video games have a cognitive ability variability which is not included in classical intelligence tests, and that different intelligence test would most likely give different results. It is also suggested that video games could fill in for the disadvantages of classical intelligence tests.

As a continuation of the research, Rabbit et al. [4] obtain higher values (from 0.27 to 0.68) by applying a similar method and using AH4 intelligence test and Space Fortress game. This study takes a step further by using Space Fortress game made in association with cognitive psychologists as a tool for studying learning strategies. It requires more advanced motor and memory abilities, multi-tasking with visual components, many of which are directly copied from cognitive and psychology literature. The experiment included 56 participants 18 to 36 years old. The conclusion is that the game could be used as a tool that it can, with a precision similar to psychometric tests, determine individual differences in intelligence.

Haier et al. [5] report a correlation value of 0.39 and 0.41 using Tetris game and RAPM intelligence test and conclude that the performances of playing video games are not automated even after a higher number of repeated playing. This research methodology was innovative. There were 8 male volunteers, 19 to 32 years old, who were scanned using PET (CT) device before and after being given a complex task. The focus in this research is not really on video games and their influence on intelligence but on the changes in brain glucose metabolic rate (GMR) which occur after studying. In other words, the research aims to prove that learning and intelligence share the same factor g, and that GMR, which is responsible in parts of brain for attention and/or memory, is connected to RAPM results. All 8 participants were reported to have significantly improved their performances when playing Tetris, after the practice phase, by 69.45% (an average of the whole group). The discussion states that the higher the intelligence quotient, the greater the reduction in GMR level is, which was proved in all the participants. It concludes that learning and intelligence share the same factor g, and that g is not localized in the brain although the working memory and g are highly connected and greatly contribute to individual differences when solving RAPM tests. Also, after practicing Tetris, the only significant change in the brain occurs in the hippocampus (primary area for memory), which shows increased GMR. That means that there is an inverse correlation between GMR and PIQ (visual-spatial abilities) since Tetris requires attention and speed, however, it is not an adequate tool for researching working memory (which is highly connected to g factor).

Pioneer studies researching the relation between cognition and video games have low to medium correlation values and most often have narrow character in the questioning methodology. Some of the reasons for their probably flawed, however not insignificant results, are insufficient number of participants as well as insufficient homogeneity in favor of one sex, unautomated performance measurements which could lead to less precise results. There is also the fact that, although the video games back in the day were very popular, they were not as intuitive, realistic, mechanically and physically advanced as they are today, and the console control itself could present a great mental effort.

2.2 Constructs

The term refers to computer tasks and games made or constructed with the aim of measuring and testing cognitive performance. In this sense, the constructs are tests similar to computer games that measure specific aspects of cognitive abilities such as Gs (Space Code) or WM (Space Matrix) or VSNA (Ventura et al.) to examine the connection between visuospatial abilities and students' success in STEM fields.

Guided by the new studies that research Gs (Processing Speed) and WM (working memory), which continues the thesis that these two domains are the most responsible for complex cognitive tasks and the proposition that the Gs and WM measuring tools could be constructed by using verbal, numerical and spatial stimuli which can be presented visually and auditory, as well as that Gs and WM measures can greatly be confused with psychological effects such as anxiousness and weakened motivation, Jason McPherson and Nicholas R. Burns, together with other researchers suggest that computer tasks or games can provide an ambient that causes less anxiety and encourages motivation in people who get tested, what is particularly important with children who are usually familiar with computers and control them easily, as well as because of the experience they have with video games [6]. Further on, they explain how computer games can embody a whole range of specific features that stir motivation, such as instant positive or negative response (using graphics, sound and results), as well as a feeling of progress through levels.

McPherson and Burns designed Space Code game using DSST (Digit Symbol Substitution Test) reference for Gs and Space Matrix (2008) for WM and Gf (fluid intelligence). The first experiment included 70 psychology students, 19.6 years old, from the University of Adelaide; 20 participants male, and 40 female. Participants solved tests in a particular order; Space Code, Space Matrix, Visual Matching, Picture Swaps, APM-DF, Space Code, Space Matrix. The order was chosen to maintain participants' motivation and allow as much time distance as possible between the first and second playing of the Space Matrix and Space Code games.

Space Matrix game is an "improved" version of the Space Code game from 2008, where the player must destroy the spaceship and at the same time memorize the space "sector" in which the enemy operates. This sector was presented as a dot placed on 5 × 5 network, similar as in Dot Matrix task. Space Code game showed median correlation values (between 0.45 and 0.60) but had no correlations with visual processing results (Gv).

The second experiment included 94 participants out of which 42 male and 52 female. The experiment aimed to use Scape Matrix and Space Code games for predicting school achievements using Gs and WM measures. It is especially intended for subjects such as English language, Mathematics and Science. More accurate results were predicted for grades in English language for Gs than for Mathematics and Science; Gf measures for Mathematics were higher than for English and Science. GW measures should refer to general cognitive abilities. The experiment is based on an extensive study in which Gs and Wm measures could predict academic success of an individual equally successfully as Gs (crystallized intelligence) and Gf (fluid intelligence). However, the primary goal was to establish a direct comparison of external validity and reliability that tests similar to computer games have. Mean measuring values for Space Matrix and Space Code were very high. In both experiments, Space Matrix showed more consistent psychometric characteristics and a higher degree of similarity to traditional WM and Gf measures. On the other hand, it determined that Space Code probably requires abilities for mixed measures, and not primary for Gs as intended, since it leaned more on Gf, and to a certain degree on Gv. Correlation was set up between Space Matrix and RAPM test (taking data from both experiments) from 0.44 to 0.53 for Gf. Potential was shown for correlation with g. Additionally, taking into account the results and experience of the subjects in both experiments, the conclusion can be made that computer cognitive abilities tests with gamified elements are more accurate for students with gaming experience, which is true for both Gf /WM and Gs.

Ventura et al. [7] created a video game for virtual spatial navigation assessment (VSNA) in which the participants had to navigate four virtual spaces in search for jewels. The link between the time it took to collect all the objects and the different spatial abilities ranged from 0.18 to 0.37. Moreover, indoor video game spaces correlated with STEM categories containing self-assessing measures of spatial-temporal abilities.

Based on some other previous studies, which shows that spatial abilities can be a significant predictor of a degree of achievement in STEM field, and arguing that playing 3D games can improve spatial abilities, Ventura et al. [7] want to set up correlation connections in an experiment between VSNA, cognitive abilities and success in STEM field. Other encouraging references included in this study refer to the following: Feng et al. [8] discovered that playing action video games improves performances and abilities of mental rotation tasks; Uttal et al. [9] in their meta-analysis containing 206 papers, found a total of 24 papers that are video-game based. On the other hand, there is research that came across results that lacked transfer effects between playing action video games and basic cognitive functions and skills [10].

Research [11] discover that the experience with video games correlates with the ability of a person to plan routes for autonomous vehicles in 3D virtual simulations. Schuster et al. put forward a hypothesis that more frequent video game playing leads to better spatial abilities. Ventura et al. put together 323 volunteers (129 male and 194 female), all psychology students. The participants solved tests while playing games: SBSOD - Santa Barbara Sense of direction scale [12]; SOT - Spatial orientation test [13] for evaluation of perspective abilities, MRT - Mental rotation test [14] for figural abilities, and a questionnaire on general experience with video games, and experience with games that share similarities with VSNA space. The results showed high reliability for SBSOD (0.89), MRT (0.76) and SOT (0.87). A correlation was found between indoor performance and STEM performance (10.13), between indoor VSNA spaces and SBSOD of 0.37, between VSNA and MRT (0.24), and between VSNA and SOT (0.18). The first set hypothesis (more correlations between VSNA and SBSOD) was confirmed by concluding that VSNA could be used as a measurement of spatial abilities (more for indoor and less for outdoor virtual spaces). The second hypothesis was also confirmed since VSNA results had higher correlations with mathematical than with verbal skills. The third STEM-related hypothesis was only partially confirmed as well as the fourth (playing video games improves spatial abilities at all levels), since no significant correlations were found between VDSNA and SAT for outdoor spaces, only for the indoor ones.

2.3 Commercial Video Games

By arguing that exposing an organism to changing visual environments often results in modifications in the visual system, and that the field of perceptual learning offers many examples of increased performance due to learning, Green and Bavelier [15] explain that perceptual learning tends to remain task-specific and can rarely be generalized or transferred to new tasks or other fields. They conducted 4 experiments in order to prove the hypothesis. People who took the test were placed into one of 2 groups.

The first group video game players (VGP) who played a set of video games for the previous 6 months a minimum of one hour per day, 4 days a week; GTA3, Half-Life, Counter Strike, Crazy Taxi, Team Fortress Classic, 007, Spider-Man, Halo, Marvel vs Capcom, Rogue Spear, and Super Mario Cart.

The second group was composed of people who preferably had no or very little experience playing similar games (non video game players - nVGP), and they were instructed not to play games during the determined time. The participants were between 18 and 23 years old. The first out of four conducted experiments used the "flanker compatibility" effect, a standard experimental paradigm in attention studies (Fig. 1, up). The task confirming the effect consisted of 6 circles and a minimum of 1 distractor. The participants were asked to confirm compatibility of the requested and given shapes, where the distractor element can but does not have to be compatible with the one that was displayed.

An interesting fact is that the more difficult the task and the more distractors it has, the more processing speed increases. This is because the more difficult the task, the fewer mental resources are provided to the distractor. In the second experiment, two groups had to answer the questions on how many square outlines they saw on a briefly presented image. The first group had an accuracy of 78% while the average accuracy in the second group was 65%.

Although these two experiments indicate that playing video games could increase attention capacity at least in the "training" area, it does not answer the question whether frequent game playing is responsible for processing beyond the range of the trained task. In order to test the possibilities, the results of two groups were compared in the task "useful field of view" (Fig. 1) for distribution of visual attention on three locations; one within the training range (0 degrees), the second at the border (20 degrees), and the third outside the training range (30 degrees). This test does not correlate well with standardized tests for visual acuity. However, it provides a measure of attention resources and their spatial distribution. The participants had to localize the target (a triangle within a circle outline) on a given screen location. VGP group showed improvement in localization abilities in the tasks outside the training range (30 degrees), which proves that spatial attention in this population is not limited only to the training tasks, at least not in this case.

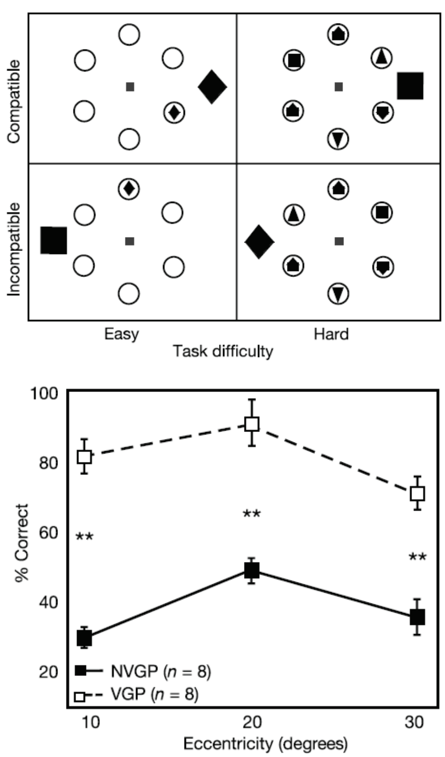

Figure 1 Testing Flanker compatibility effect (up) useful field of view (down)

The fourth experiment measured attention over time using a "blink" test in which the participants were shown consecutive multiple images in a very short time period. The possibility to forget the content of the first image after the second was shown was being checked. The test enabled visual attention distribution over time. In the beginning, the VGP group showed better results; however, after training and repetition, those results leveled with the second group (nVGP). This proves that attention over time can be trained.

Baniqued et al. [16] chose twenty casual videogames and compare the achieved performances with twenty-five psychometric tests, were correlation similarities were determined from 0.19 and 0.65 between the games and different psychometric tests. The connection between the games and latent factors varied between 0.17 and 0.65. Heterogeneity in their performance measurements may represent different aspects of mental abilities.

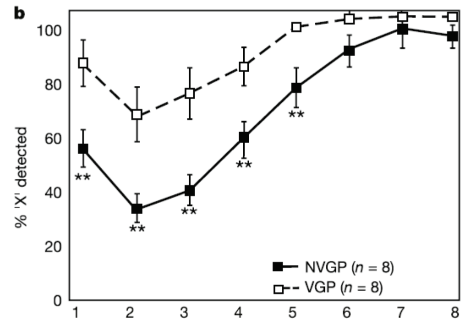

Figure 2 Results of blink test for VGP and nVGP group

Baniqued decided to find out whether commercial games could influence cognitive aspects, and whether they require more advance cognitive abilities. Up to that point, it has been proven that cognitive training protocols can improve visual attention, inhibition or attention related to conflict, working memory and general judgment. However, these abilities are limited to specific tasks and rarely applicable in a wider range of cognitive abilities. Additionally, many similar programs have methodological issues such as [17] and are unsuccessful in replications [18].

Encouraged by the earlier study, Baniqued et al. [16] set a similar hypothesis stating that maintaining challenges and motivation through "cross-training" can produce greater gains in targeted abilities, and that greater diversity in process integration can lead to larger improvements in cognitive abilities; perhaps even in executive functions necessary in daily life, school, and the workplace. A total of 209 young adults (18 to 30 years old) who participated in the study were paid 10 dollars per session and were "motivated" by the fact they would be paid twice less per session if they failed to perform the tasks. The average age was 21.7, with 33% of participants being male. Out of all the examinees who firstly responded to participate in the study, all those that played games for 10 hours or more per week were excluded, as well as those with mental or psychological conditions. This was done in order to homogenize the group.

The protocol consisted of three cognitive testing sessions, which included: (1) fluid intelligence, spatial reasoning, processing speed, episodic memory and vocabulary, (2) ANT, VSTM (Visual Short Term Memory), task switching and Stroop test, and (3) AB (Attentional blink), n-back, SPWM, Digit Span and Trail Making. The participants played a total of 20 casual video games divided in 5 sessions, all of which were freely available on the web: (1) Silversphere, Filler, Memotri, Digital Switch; (2) Crashdown, Simon Says, Blaxorz, Enigmata, (3) Dodge, Sushi-Go-Round, 25 Boxes, Memocubes, (4) Round Table, Phange Wars, Cathode, Blobs; (5) Music Catch, Two Three, AlphaAttack, Oddball. Each session was done on different days, and each game playing time was limited to 20 minutes. Mutual correlations were calculated for all games at all 5 levels. Connections were also established between the levels - a connection was found between working memory and perceptual speed of 0.295, between working memory and fluid intelligence of 0.5, between perceptual speed and fluid intelligence 0.19, between fluid intelligence and episodic memory 0.17; no correlation was found between these four categories and cognitive attention. Further on, the following values were obtained among these 5 components in video games and factor tasks: from 0.24 to 0.59 for working memory (with the highest correlations in working memory, spatial reasoning and object tracking), from 0.27 to 0.65 for fluid intelligence, from 0.23 to 0.36 for perceptual speed, and low significance correlations in episodic memory and ANT.

Quiroga et al. [19], conduct research in 2019 in which they want to confirm the correlations between intelligence and video games (the first research was conducted in 2009). They additionally want to prove that genre does not influence the correlations between the gaming performance and the results of intelligence standardized tests. There were 134 people, all students from the Faculty of Psychology in Madrid (105 female and 29 male) in an age range between 18 - 30, who initially played all games up to a certain level for training purposes (the number of levels varied depending on the complexity of the game). After that, in the testing phase, they had to solve as many levels as possible in a given time period. For each of the video games, reliability coefficients were calculated referring to either the number of levels completed, or the number of deaths or errors (depending on the game) that ranged from 0.77 to 0.92. Three positive correlations were found between video game performance quality and cognitive tests. Lower correlation was found with video games in Gs tests than in Gf and Gv tests. This was unexpected as most games required response speed and taking action. However, speed is a multifaceted construct with four aspects: psychomotor speed, decision speed, cognitive speed and search fluidity. Therefore, it is understandable that the speed expected in psychomotor tests may differ from the speed required in a particular game. AT - AR (abstract reasoning) was the only test with positive correlations in all games (from 0.19 to 0.60). This suggests that all these games require intelligence since DAT - AR holds a higher coefficient for g factor. Overall results suggest that even simple games require intelligence to some extent. In order to solve problems effectively, the ability to quickly adapt to a new environment is needed. The main goal was to analyze the potential of games to measure intelligence, which was confirmed with positive correlations. Commercial video games have the potential to measure certain aspects of cognitive abilities and intelligence. This study is very relevant, not only because it is a more recent one, but also because the authors have researched the same topic several times over the years (2009 and 2016). The calculations are clearer, with extensive descriptive statistics, factor models and a variety of reference games than in previous research by same and different authors.

3 INFLUENCE OF VIDEO GAMES ON COGNITIVE ABILITIES AND INTELLIGENCE

StarCraft is a strategy game developed by Blizzard Entertainment studio. It does not only require forward thinking but also a lot of remembering and memorizing of multiple units and structures, multi-tasking and high attention and concentration levels. Compared to chess, the "playing filed" can never be seen at one time since it is so big. In order to be successful in the game and win, the person who plays should constantly check what is happening on the map. All this suggests that this game definitely requires general intelligence, in addition to processing speed, general memory and fluid intelligence, at least from the logical point of view.

However, this argument lacks empirical statical data evidence, which is understandable given how difficult it would be to conduct such a study. Still, in 2013 a study was conducted in which Korean scientists used MRI to scan the brains of 23 experienced and successful, professional StarCraft players, and came to an interesting conclusion. The brain is a flexible organ prone to the formation and physical growth of certain more stimulated areas. As a result, thickenings were observed in certain parts of frontal cortex responsible for decision making and the parietal lobe responsible for redirecting attention. The research was conducted in association with Chung-Ang University Medical Centre in Korea. All the participants were members of KeSPa (Korea eSports Association). None of the participants suffered from depression, brain trauma, hyperactivity or drug abuse. The daily group average number of hours of playing StarCraft was 9.2.

The results showed positive correlations between career length and cortical thickness in three brain regions: superior frontal gyrus, parietal gyrus, and precental gyrus, all to the right of the frontal lobe. Additionally, increased cortex thickness in prefrontal cortex correlated with professional league's victory rates. These thickenings were also associated with higher performance in the WCST (Wisconsin Card Sorting Test) test.

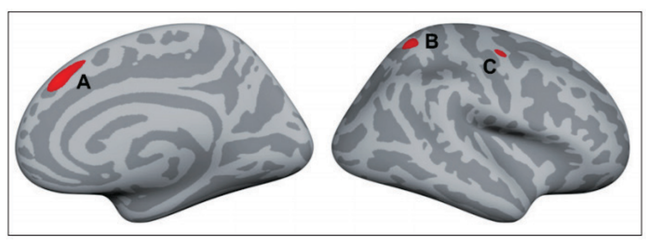

Figure 3 Brain region associated with professional career length in eSport; A: Right superior frontal gyrus, B: Right superior precental gyrus and C: Right precental gyrus

The correlations between cortical thickness and career length of the pro-gamers were 0.57 for A, 0.67 for B, and 0.63 for C. Considering not everyone in the group played StarCraft professionally or unprofessionally for the same length of time, it was determined that the right medial frontal cortex was thicker in professional gamers with longer careers and higher winning rather than losing odds. This particular region is associated with attention span change, executive functions and inhibitory action control. The parietal cortex is responsible for movement control and is associated with spatial attention. The superior parietal cortex is responsible for working memory (it was previously mentioned that working memory is largely associated with general intelligence). Hyun et al. [20] concluded that long-term, online game playing of this type (without addiction) increases cortical thickness.

Lewis et al. [21] developed a referent partial taxonomy of games so they could compare StarCraft with other types of games using 4 characteristics; stochasticity, incomplete information, unlimited opportunity and asymmetry. They argued stochastic games might restrict player actions based on the outcome of random events; incomplete information enable assumption since they do not give the player full information on state of game or situation of the opponent; unlimited opportunities allow constant modification of the game state through action (bringing decisions); asymmetry provides players with distinct materials, action repertoires, and higher territory variability. According to this classification, the representation of all characteristics in a particular game determines its difficulty, and it also requires optimal distribution of one's attention through tasks with different criteria. Accordingly, StarCraft resonates better that most other games to all the four criteria. It holds its place in a unique branch of game taxonomy, and the game complexity can be compared to real-world situations such as undergoing and managing a crisis situation.

Games & Tasks	Stochastic	Incomplete Information	Unlimited Opportunity	Asymmetry
Chess				
Backgammon	✓			
H.H. Hippos	✓		✓	
Mastermind	✓	✓		
Poker	✓	✓		✓
Tennis	✓		✓	✓
Starcraft	✓	✓	✓	✓
Disaster Management	✓	✓	✓	✓
Air Traffic Control	✓	✓	✓	✓
Military Command	✓	✓	✓	✓

Figure 4 A representation of strategic game taxonomy

Relationship between the measure of reaction speed and spatial variance of action was taken into account. It was concluded that quick reactions and quick attention distribution are characteristic for efficient cognitive abilities. Showing those abilities can play a role in predicting whether a player will lose or win. The question that arises whether people with a natural ability to distribute attention are simply inclined and attracted to demanding games such as StarCraft, or can games really "train the brain" and make an individual more intelligent by extending their cognitive abilities beyond genetic innateness. What was crucial for successfulness of the analysis is the replay file, a StarCraft feature that allows users to re-watch games after they have concluded playing.

Regarding methodology, the following was recorded: APM number (Action per Minute), SVA (Spatial Variance of Action) - moving units and placing objects, (3) Macro action count (production and building), (4) Micro action count - a total number of actions connected to managing units during battle, scouting or positioning, and (5) Win state, 1 or 0 depending on whether the player won. It was determined that the players who can perform an action quicker (have higher APM) have a higher tendency of winning.

It was determined for SVA to be an indirect measure of the distribution of attention, for scouting opponent's base, gathering resources from the other part of the map, all which leads to success-winning actions. This indicates better multi-tasking abilities and attention distribution that can provide a good insight into the learning processes. APM and SVA numbers are not useful and do not correlate with winning/ losing rates in less stochastic games without unlimited opportunities (for example, chess). It was concluded that in undergoing a crisis situation, a high APM can lead to increased success in maintaining stability in real-world situation.

Unsworth et al. [22] conducted 2 experiments in 2015. In the first experiment they reanalyzed their own results from an unpublished study conducted a year earlier [23], which included typical inconsistencies: lack of information on previous experience of playing video games, giving financial awards to participants, dismissing the participants who did not complete all the cognitive ability tests, and so on. There were 252 subjects (recruited for the Oregon University), 18 to 35 years old, who were group tested in 6 sessions lasting 2 hours max. According to the results, VGP group outperformed the second group on some working memory tests (symmetry span), all the fluid intelligence tests, and some of the attention-control tests. Better WM results were not all that significant, although the results were still better and in favor of the VGP group. The same testing was repeated in the second phase, but with 198 participants where VGP did not include first-person shooter players but other genre players. This experiment of applying different statistical methods showed how relative and susceptible to manipulation the results obtained for the purpose of getting higher correlations can be. Although none of these studies were methodologically inaccurate, where Quiroga et al. [19] produced the most extensive study proving correlations on a latent level, this experiment only showed that extreme groups always show greater correlations in favor of the desired hypothesis.

In order to correct the limitations from the first experiment, Unsworth et. al. conducted a second experiment where they reanalyzed the data from research done by Redick [24] with the purpose of expanding the results form experiment 1. A total of 586 subjects (226 male and 354 female), between the ages of 18 and 30, were tested at four different universities. It was concluded that more research and experiments were needed for determining to what extent video games could enhance cognitive abilities, giving a recommendation to use higher and full range of participants and research the established relationships through constructs that include latent variables.

The research from 2018 [25] used behavioral and electrophysiological measures for examining the plasticity of

Visual Selective Attention (VSA) linked to action video games and effects they have on VSA after one hour of practicing. The research included both VGP and nVGP so that a comparison within a group could be made. All the participants were students of the University of Electronic Science and Technology of China (UESTC). The group with gaming experience included n = 15 participants, and the group without gaming experience included n = 14 participants.

Research results indicated to: (a) improvement in response time in both groups after one hour of LOL playing, (b) improvement in neurological plasticity in the second group after one hour of playing: short-term effect, and (c) long-term effect of playing this type of game on neurological plasticity which was proved by cross comparing the results in the two groups.

Stojanoski et al. [26] conducted research aimed at denying the claims that video games enhanced cognitive functions that can be transferred to other tasks. There were 72 participants, some students from the University of Ontario and others workers in Amazon Mechanical Turk, separated into two groups. The results showed that extensive repetition of the gamified task improved the outcome in the performance test group by 18% on average. However, there was no evidence that subjects performed significantly better on cognitive tests (after the training phase) in some other tasks.

Stojanoski et al. also conducted a second experiment using a similar procedure with 24 new participants for the test group and the same group of people for the control group. Performances improved up to 60% after the training phase, but there was no improvement in transfer of acquired knowledge on special and new tasks.

West et al. [27] managed to prove, in their 2017 research, the negative effects first person shooting-games have on brain, such as reducing grey matter within the hippocampus, which brings increased risk of Alzheimer disease, in participants using non-spatial memory strategies, i.e. the mechanisms that are not hippocampus-dependent.

Reynaldo et al. [28] showed that there are several types of games (RPG, RTS, FPS) that could influence different cognitive categories. They have analyzed 27 experimental and literature review articles with the concludions that video games do improve cognitive skills and decision-making.

In the case of mentaly disabled individuals, Suárez-Iglesias et al. [29] have shown that some type of games (exergaming vs sedentary) could stimulate cognitive functions. They have analyzed 17 cases and concluded that videogames can improve health-related outcomes in people with intellectual disabilities.

Also Franceschini et al. [30] have conduct an experiment on visual perception, sensorimotor and reading skills in children with developmental coordination disorder and dyslexia. They used shooting and puzzle video-games and came to interesting conclusions that any type of videogame can be a useful clinical tool for the prevention and treatment of multiple cognitive disorders.

4 DISCUSSION AND CONCLUSION

Although it could sound pretentious to conclude that video games can make us smarter and expand our cognitive abilities, given the results of the referenced research described, such a claim cannot be denied. Since there is a small amount of empirical evidence, it can only be concluded with certainty that video games definitely have huge potential for further research on the topic as well as that they have, as proven in several studies, the potential to be used for medical, educational and research purposes. It is also a fact that certain games, or the mechanisms within, can determine individual differences in cognitive abilities between individuals, perhaps not to the same extent that intelligence tests do, but to a certain degree they can. This is understandable since it would not be realistic to expect that something which was not primarily designed as a tool for measuring cognitive abilities could match the intelligence tests that have been developed for decades. What games could do in future is to extend the classic tests to spheres, which cannot be measured.

While some of these studies support the hypothesis, others fail to find significant correlations between improving cognitive ability and playing video games. Some of the reasons are the use of different methodologies, too small participant groups, the use of games that are not demanding enough or simply do not relate to the required cognitive abilities. One of the reasons could be using too simple, or at the other end, too aggressive and stressful games. From all the above-mentioned research, the best results were shown by emotionally neutral or positive video games. This especially refers to certain strategy, action and puzzle games. The research that carries the most weight is probably that including changes in the hippocampus and frontal cortex after training, especially in professional and experienced players. Taking the assumption that intelligence can be expanded, video games should never replace physical activity, as well as no other form of cognitive training, healthy eating and other basic prerequisites for proper brain function. Instead, video games should be considered as a possible tool for developing cognitive flexibility with great potential in sharpening processing speed, multi-tasking, fluid intelligence, visual-spatial capabilities and working memory (which is uf Gf in high correlation with the g factor).

This paper does not include all the research that exists on the topic, but only that which is methodologically accurate and most elaborate. One relatively certain conclusion can be made: different games, depending on the genre, can have influence in both directions in terms of improving cognitive abilities. Therefore, aggressive games can definitely have a negative psychological influence, and subsequently a cognitive or neurological one. We believe that further research should not pose the question "Do video games have an influence on the enhancement of cognitive abilities?" Future research should focus on finding specific mechanisms in video game design that have short-term and long-term effects on intelligence and cognition, which, after sufficient evidence, could consequently be projected onto game developments with the aim of (a) measuring intelligence, and (b) increasing certain g factor branches. The paper does not describe serious video games, as they involve increased crystallized intelligence (learning new information) or specific ability trainings (not necessarily cognitive).

5 REFERENCES

[1] ESA, E. (2020). Essential facts about the video game industry.

[2] Bouchard Jr, T. J., Lykken, D. T., McGue, M., Segal, N. L., & Tellegen, A. (1990). Sources of human psychological differences: The Minnesota study of twins reared apart. *Science, 250*(4978), 223-228. https://doi.org/10.1126/science.2218526

[3] Jones, M. B., Dunlap, W. P., & Bilodeau, I. M. (1986). Comparison of video game and conventional test performance. *Simulation & Games, 17*(4), 435-446. https://doi.org/10.1177/0037550086174001

[4] Rabbitt, P., Banerji, N., & Szymanski, A. (1989). Space Fortress as an IQ test? Predictions of learning and of practised performance in a complex interactive video-game. *Acta psychologica, 71*(1-3), 243-257. https://doi.org/10.1016/0001-6918(89)90011-5

[5] Haier, R. J., Siegel, B., Tang, C., Abel, L., & Buchsbaum, M. S. (1992). Intelligence and changes in regional cerebral glucose metabolic rate following learning. *Intelligence, 16*(3-4), 415-426. https://doi.org/10.1016/0160-2896(92)90018-M

[6] McPherson, J. & Burns, N. R. (2008). Assessing the validity of computer-game-like tests of processing speed and working memory. *Behavior Research Methods, 40*(4), 969-981. https://doi.org/10.3758/BRM.40.4.969

[7] Ventura, M., Shute, V., Wright, T. J., & Zhao, W. (2013). An investigation of the validity of the virtual spatial navigation assessment. *Frontiers in psychology, 4*, 852. https://doi.org/10.3389/fpsyg.2013.00852

[8] Feng, J., Spence, I., & Pratt, J. (2007). Playing an action video game reduces gender differences in spatial cognition. *Psychological science, 18*(10), 850-855. https://doi.org/10.1111/j.1467-9280.2007.01990.x

[9] Uttal, D. H., & Cohen, C. A. (2012). Spatial thinking and STEM education: When, why, and how? *Psychology of Learning and Motivation, 57*, 147-181. https://doi.org/10.1016/B978-0-12-394293-7.00004-2

[10] 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*(3), 387-398. https://doi.org/10.1016/j.actpsy.2008.09.005

[11] Richardson, M., Abraham, C., & Bond, R. (2012). Psychological correlates of university students' academic performance: a systematic review and meta-analysis. *Psychological bulletin, 138*(2), 353. https://doi.org/10.1037/a0026838

[12] Hegarty, M., Richardson, A. E., Montello, D. R., Lovelace, K., & Subbiah, I. (2002). Development of a self-report measure of environmental spatial ability. *Intelligence, 30*(5), 425-447. https://doi.org/10.1016/S0160-2896(02)00116-2

[13] Waller, D., Montello, D. R., Richardson, A. E., & Hegarty, M. (2002). Orientation specificity and spatial updating of memories for layouts. *Journal of experimental psychology: Learning, Memory, and Cognition, 28*(6), 1051. https://doi.org/10.1037/0278-7393.28.6.1051

[14] Vandenberg, S. G. & Kuse, A. R. (1978). Mental rotations, a group test of three-dimensional spatial visualization. *Perceptual and motor skills, 47*(2), 599-604. https://doi.org/10.2466/pms.1978.47.2.599

[15] Green, C. S., & Bavelier, D. (2003). Action video game modifies visual selective attention. *Nature, 423*(6939), 534-537. https://doi.org/10.1038/nature01647

[16] Baniqued, P. L., Lee, H., Voss, M. W., Basak, C., Cosman, J. D., DeSouza, S., ... & Kramer, A. F. (2013). Selling points: What cognitive abilities are tapped by casual video games?. *Acta psychologica, 142*(1), 74-86. https://doi.org/10.1016/j.actpsy.2012.11.009

[17] Boot, W. R., Blakely, D. P., & Simons, D. J. (2011). Do action video games improve perception and cognition?. Frontiers in psychology, 2, 226. https://doi.org/10.3389/fpsyg.2011.00226

[18] Chooi, W. T. & Thompson, L. A. (2012). Working memory training does not improve intelligence in healthy young adults. *Intelligence, 40*(6), 531-542. https://doi.org/10.1016/j.intell.2012.07.004

[19] Quiroga, M. A., Diaz, A., Roman, F. J., Privado, J., & Colom, R. (2019). Intelligence and video games: Beyond "brain-games". *Intelligence, 75*, 85-94. https://doi.org/10.1016/j.intell.2019.05.001

[20] Hyun, G. J., Shin, Y. W., Kim, B. N., Cheong, J. H., Jin, S. N., & Han, D. H. (2013). Increased cortical thickness in professional on-line gamers. *Psychiatry Investigation, 10*(4), 388. https://doi.org/10.4306/pi.2013.10.4.388

[21] Lewis, J., Trinh, P., & Kirsh, D. (2011). A corpus analysis of strategy video game play in starcraft: Brood war. *Proceedings of the Annual Meeting of the Cognitive Science Society, 33*(33).

[22] Unsworth, N., Redick, T. S., McMillan, B. D., Hambrick, D. Z., Kane, M. J., & Engle, R. W. (2015). Is playing video games related to cognitive abilities? *Psychological science, 26*(6), 759-774. https://doi.org/10.1177/0956797615570367

[23] Unsworth, N., & McMillan, B. D. (2014). Similarities and differences between mind-wandering and external distraction: A latent variable analysis of lapses of attention and their relation to cognitive abilities. *Acta psychologica, 150*, 14-25. https://doi.org/10.1016/j.actpsy.2014.04.001

[24] Redick, T. S. (2014). Cognitive control in context: Working memory capacity and proactive control. *Acta psychologica, 145*, 1-9. https://doi.org/10.1016/j.actpsy.2013.10.010

[25] Qiu, N., Ma, W., Fan, X., Zhang, Y., Li, Y., Yan, Y., ... & Yao, D. (2018). Rapid improvement in visual selective attention related to action video gaming experience. *Frontiers in human neuroscience, 47*. https://doi.org/10.3389/fnhum.2018.00047

[26] Stojanoski, B., Lyons, K. M., Pearce, A. A., & Owen, A. M. (2018). Targeted training: Converging evidence against the transferable benefits of online brain training on cognitive function. *Neuropsychologia, 117*, 541-550. https://doi.org/10.1016/j.neuropsychologia.2018.07.013

[27] West, G. L., Konishi, K., Diarra, M., Benady-Chorney, J., Drisdelle, B. L., Dahmani, L., ... & Bohbot, V. D. (2018). Impact of video games on plasticity of the hippocampus. *Molecular psychiatry, 23*(7), 1566-1574. https://doi.org/10.1038/mp.2017.155

[28] Reynaldo, C., Christian, R., Hosea, H., & Gunawan, A. A. (2021). Using video games to improve capabilities in decision making and cognitive skill: a literature review. *Procedia Computer Science, 179*, 211-221. https://doi.org/10.1016/j.procs.2020.12.027

[29] Suárez-Iglesias, D., Martínez-de-Quel, Ó., Marin Moldes, J. R., & Ayan Perez, C. (2021). Effects of videogaming on the physical, mental health, and cognitive function of people with intellectual disability: a systematic review of randomized controlled trials. *Games for Health Journal, 10*(5), 295-313.

[30] Franceschini, S., Bertoni, S., Lulli, M., Pievani, T., & Facoetti, A. (2022). Short-term effects of video-games on cognitive

enhancement: The role of positive emotions. *Journal of Cognitive Enhancement, 6*(1), 29-46. https://doi.org/10.1007/s41465-021-00220-9

Authors' contacts:

Dorja Hatlak, mag. ing. techn. graph.
University North,
104. brigade 1, 42000 Varazdin, Croatia
dahatlak@unin.hr

Andrija Bernik, PhD, Assistant Professor
University North,
104. brigade 1, 42000 Varazdin, Croatia
andrija.bernik@unin.hr

Igor Tomičić, PhD, Assistant Professor
Faculty of Organization and Informatics,
Pavlinska ul. 2, 42000 Varazdin, Croatia
tomicic.igor@gmail.com