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Intelligence and video games: Beyond “brain-games”

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ABSTRACT

Video games are among the most popular leisure activities in current Western societies. Psychology research has shown correlations, at the latent level, between intelligence and video games ranging from 0.60 to 0.93. Here we analyze whether video games genre can account for this range of correlations by testing one hundred and thirty-four participants playing ten video games of different genres for iPad® and WiiU® (Art of Balance®, Blek, Crazy Pool, EDGE®, Hook, Rail Maze, SkyJump, Space Invaders, Splatoon® and Unpossible) within a controlled playing environment. Gaming performance was correlated with standard measures of fluid reasoning, visuospatial ability, and processing speed. Results revealed a correlation value of 0.79 between latent factors representing general intelligence (*g*) and video games general performance (*g*VG). This finding leads to conclude that: (1) performance intelligence tests and video games is supported by shared cognitive processes and (2) brain-games are not the only genre able to produce performance measures comparable to intelligence standardized tests. From a theoretical perspective, the observed result supports the principle of the indifference of the indicator that has been addressed in intelligence research across decades.

1. Introduction

1.1. Video games in everyday life

In 2017, the Entertainment Software Association (Ipsos, 2017) reported that 67% of USA households owned a device to play video games (16% more than in 2014). Further, there was a usual player – playing for three or more hours per week– in 65% of the families. Trends in video games usage and gamers profile have also been changing (Interactive Software Federation of Europe, 2017). The number of women who play video games has almost equated or surpassed that of men in the USA (41% women players on average), Spain (44%), UK (46%), Germany (48%), or France (52%). By 2017, the majority of players in USA used multiplayer mode (53%) and the most widely used genres were shooters (29%), casual (28%), and action (27%) video games. Most casual games are puzzle type and they require varied cognitive abilities (Quiroga & Colom, 2019). These data show that leisure time has become more cognitively demanding and that video games are important for our daily lives.

1.2. First studies relating cognition and video games performance

The first attempt to use video games to study cognitive processes dates back to the 80s (Jones, Dunlap & Bilodeau, 1986; Rabbitt, Banerji, & Szymanski, 1989). Jones et al. (1986) administered intelligence tests from the *Factor-Referenced Cognitive Tests* by R.B. Ekstrom and colleagues, as well as video games of the Atari console (Air Combat Maneuvering, Breakout, Race Car, Slalom, and Antiaircraft). The correlation values ranged from 0.18 (for the Slalom game) to 0.50 (for the Race Car game). In Rabbitt et al. (1989), correlations between participants' performance in *Space Fortress* and AH4 test's scores increased across sessions (from 0.28 to 0.68) showing greater associations between video game performance and intelligence tests' scores with increased practice. Haier, Siegel, Tang, Abel, and Buchsbaum (1992) reported a higher correlation between Tetris and the *Raven Advanced Progressive Matrices (RAPM)* test with increased practice (from 0.36 to 0.41), reinforcing the conclusion that some video games are not automated even after extensive practice.

1.3. Task and constructs

Since those pioneer studies, there has been more research aimed at correlating video games with intelligence performance at the task (Lim & Furnham, 2018; McPherson & Burns, 2007, 2008; Ventura, Shute, Wright, & Zhao, 2013) and construct levels (Baniqued et al., 2013; Foroughi, Serraino, Parasuraman, & Boehm-Davis, 2016; Quiroga et al., 2015).

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McPherson and Burns (2007) designed the game *Space Code* using the Digit Symbol subtest from the WAIS-III as a reference. The goal of this video game was to destroy enemies' spaceships appearing at the window of participants' cockpit. Each of the enemies' spaceships was represented at the bottom of the cockpit along with a single digit. Participants had to press the corresponding number in the keyboard in order to destroy the spaceships. Participants' performance on *Space Code* showed medium correlations (between 0.45 and 0.60) with Gs but not with visual processing scores (Gv).

In 2008, McPherson and Burns developed *Space Matrix* based on their previous game. Here, participants had to destroy the spaceships, as in *Space Code*, whilst trying to memorize the "sector" of space where they operated. The sector was represented as dots located on a 5 × 5 grid resembling the Dot Matrix task (Miyake et al., 2000). Results revealed correlations between *Space Matrix* and Gy measures ranging from 0.53 to 0.66. *Space matrix* was also associated with English and Mathematics preparatory school grades (0.32 to 0.35) and high school Mathematics grades (0.32 to 0.34), suggesting that video games performance could potentially be used to predict academic achievement.

Ventura et al. (2013) created a video game for estimating visual-spatial ability in which participants had to navigate four virtual spaces in search of gems. Correlations between the time taken to collect all objects and different estimates of spatial ability ranged from 0.18 to 0.37. Moreover, indoor spaces of the video game correlated 0.22 with STEM majors and 0.37 with self-report measures of environmental spatial ability.

These three studies are examples of video games specifically tailored to assess cognitive differences by taping abilities at the second stratum level of the CHC model (Gs and Gv). Since this tailored-design approach is highly expensive, many researchers started using commercial video.

1.4. Commercial video games

Baniqued et al. (2013), selected twenty casual video games and correlated achieved performance levels with twenty-five psychometric tests. They found correlations ranging from 0.19 to 0.65 between games and a wide range of psychometric tests. The correlations between games and ability latent factors ranged from 0.17 to 0.65. Heterogeneity of their performance measures may account for the disparate correlations found in this study.

Some commercial video games also provide players with platforms, like Portal 2 Mod, to modify the pre-existing layout of the video games. Such flexibility allows researchers to stretch video games potential. Buford and O'Leary (2015) used Portal 2 Mod to create a test with fifteen levels called 'chambers'. Test reliability was 0.92 and correlations between game execution and Gf tests ranged from 0.34 to 0.49. Foroughi et al. (2016) also used Portal 2 Mod to produce 15 chambers with a reliability value of 0.80 and correlations between videogame performance and intelligence at test (0.61 to 0.63) and construct level (0.78). Finally, Lim and Furnham (2018) compared performance (measured as time taken to complete each level) in four Portal chambers with scores obtained on the Raven Advanced Progressive Matrices test (RAPM), computing a correlation of $r = 0.61$.

With the exception of Baniqued et al.'s (2013) research, these studies focused on Gf. Batteries of video games aimed at tapping several second stratum abilities are not as common but may provide useful insights about the relationship between video game performance and intelligence test's scores. In this regard, Quiroga et al. (2015) described the creation of the first video game test battery devised to tap a wide range of cognitive abilities. Participants completed a comprehensive battery of games for Computer and for the Wii® console, along with a set of intelligence tests. A general factor was computed from both batteries and the correlation between the general factor of intelligence (*g*) and the general video games factor (VG*g*) was $r = 0.93$. This high correlation was close to the reported by Foroughi et al. (2016) but differed considerably from the values obtained in most studies mentioned above. It is of interest to find out why there is such a disparity of research results and video game genre is worth testing explanation.

1.5. The present study

The games administered by Quiroga et al. (2015) fell into the *Brain Games* genre and, therefore, they would share both superficial and underlying cognitive requirements with intelligence tests. From this perspective, the reported correlation may not be very surprising.

In order to move beyond these brain games, we created another video games battery for the present study using ten non-brain games of different genres for either Wii-U® or iPad®. Due to the current widespread use of tactile response devices, we decided to include iPad® games to test whether or not response format makes a difference.

Measures of video game playing habits were also included for testing for possible confounding effects in performance. Foroughi et al. (2016) did not find confounding effects of previous experience over game performance, whereas Buford and O'Leary (2015) found an interaction between experience, performance, and sex. The latter finding suggests differential influence of experience according to gaming-ability level. It is important to emphasize that equating video games' experience and video game performance is inappropriate and may account for some discrepancies in research findings.

Our main prediction is that the correlation between video-game performance and standard intelligence tests will not be affected by video game genre. This prediction is based on Quiroga et al.'s (2009) criteria for selecting and designing appropriate video games aimed at tapping core cognitive processes required for intelligent performance: (a) moderate levels of complexity, (b) low consistency across items (or game screens), and (c) no transfer keys.

According to the principle of the indifference of the indicator (Jensen, 1998; Spearman, 1904) the superficial characteristics of problems appropriately tapping the intelligence construct should be irrelevant. What is relevant is how these problems are designed (or selected) from a psychological perspective. In fact, this principle explains why intelligence, as assessed by standardized tests, predicts a heterogeneous set of behavioural differences across real life settings (Strenze, 2015). If life is (a) a very long intelligence test battery, as proposed by Gottfredson (1997) and Gordon (1997), (b) there are problems/items in life with smaller and greater levels of cognitive complexity, and (c) video games are now present in our lives, then it is reasonable to assume that intelligence might be properly assessed choosing and designing adequate video games, those aimed at tapping the cognitive processes key for recruiting intelligence regardless of their superficial appearance.

2. Method

2.1. Participants

Participants were recruited from the Faculty of Psychology at *Universidad Complutense de Madrid* (UCM) and *Centro de Enseñanza Superior Cardenal Cisneros* (CESCC). They were given extra-credits for their participation. A total of 147 participants started the experiment and 136 completed all three sessions. Of those, two had to be excluded from the analysis due to missing data for some game or test. Among the 134 undergraduates that were finally included in the analysis, there were 105 women and 29 men ($M = 21.04$; $SD = 2.23$; range 18–30).

2.2. Materials

2.2.1. Video games

Over thirty video games were reviewed. Several features were considered for selecting the most appropriate video games. In order of increased relevance these were: a) the video game (VG) measures

Table 1
Video games selected.

Video game	Cognitive factor	Description	Device	Playing time	Training and real levels	Measures
Art of balance ®	Gf/Gv	The aim of this game is to pile up several pieces over a platform	Wii-U®	12 min	Training trials: levels 1–2 from world A Real trials: selected number of levels from different worlds	Number of completed levels
Blek	Gf	Participants have to draw a line to destroy certain elements keeping in mind that when they lift the finger from the screen, the line will continuously repeat the movement they have just traced	iPad®	10 min	Training trials: 3–7 Real trial: From level 8 onwards	Number of completed levels
Crazy pool	Gv	The purpose is to throw the red balls to the moat that surrounds the table without touching the yellow balls	iPad®	12 min	Training trials: 3 Real trials: From level 23 onwards	Number of completed levels
EDGE®	Gv	Participants have to guide the character across visually ambiguous platforms while collecting prisms	Wii-U®	12 min	Training trials: 1–3 of normal levels Real trials: From level 10 onwards, from the extended levels	Number of completed levels,
Hook	Gf	The object of this game is to discover the order on which the elements have to be selected so that they can be free and erased	iPad®	12 min	Training trials: 4–7 Real trials: From level 16 onwards	Number of completed levels
Rail maze	Gf	Players have to set certain rail tracks in the correct position so that the train can continue its journey	iPad®	12 min	Training trials: 6–9 Real trials: From level 14 onwards	Number of completed levels
Space invaders	Gs	An arcade game on which players have to move a spaceship sideways to destroy enemy ships	iPad®	5 min	Training trials: Playing to level 1 for 2 min Real trials: Playing to level 2 for 5 min	Total points
Splatoon®	Gv	Players have to guide the character whilst collecting balls and shooting ink to the monsters in order to move from one platform to the next one	Wii-U®	20 min	Video game's tutorial and History mode	Number of completed levels,
Sky jump	Gs	The aim is to make the character jump in the exact moment so that it does a proper long jump	iPad®	5 min	One jumping trial and three real jumps	Meters mean across the three trials
Unpossible	Gs	The point is to tilt the iPad® to avoid the obstacles as fast as possible to keep the ship moving forward	iPad®	5 min	Training trials: Playing *Daily Simplicity* level for 2 min Real trials: Playing *Simplicity* level for 5 min	Number of deaths

achievement (accuracy) and response time (speed); b) VG goals; c) VG content; d) playing devices; e) genres; and f) costs.

Controlling for the speed and accuracy trade-off (SATO) is crucial for studying individual differences because it allows equating performance of participants devoting more time to ensure correct answers to those sacrificing accuracy for higher speed. This control also ensures homogeneity in performance measures across video games.

Regarding video games' goals, only those games in which lexicon or memory played a major role were excluded from the study. Games content could be diverse but under no circumstances, violent or explicit. Video games were also selected according to their genres to assure they were equally represented. Video games and devices (i.e. Wii-U®, the iPad®) were also chosen on the bases of their handling: their use had to be intuitive and should not require mainly psychomotor skills.

Applying these criteria, the final set included ten video games (Table 1), three for Wii-U® and seven for iPad®. A short clip showing the video games can be found in the following link. These 10 games represent different genres: shooters (Space Invaders and Splatoon); Sports (Sky Jump, Unpossible, and Crazy Pool); Platform (Edge); Strategy (Rail Maze and Art of Balance) and Puzzles (Blek and Hook). Therefore, only 2 out of 10 video games belong to the puzzle category.

Members of the research group played all video games extensively to select the appropriate levels. The number of training levels varied depending on game complexity and time requirements for level completion. Training levels were untimed. Once these levels were completed, participants had a specific amount of time to progress in the game and complete as many levels as possible (Table 1). Performance and time invested within each level allowed controlling for SATO.

Two issues must be noted regarding floor effects detected for two video games at the beginning of the study. In Art of Balance®, 19 participants (14.17%) played an excessively complicated version which was later substituted by a different set of levels. In order to preserve the data of the first participants, within group standard scores were computed to equate their performance to that of the rest. In another video game, Unpossible, 42 participants (31.34%) completed a harder version. Another level was chosen for the following participants and, again, within group standard scores were computed to equate data form all participants.

Two groups of examiners were selected. One group was trained to administer Wii-U® video games and another group was trained to administer iPad® video games. All were trained to administer psychometric tests, but they never administered the psychometric tests to the participants they had administered the video games. An SPSS syntax file was written to score the psychometric tests. The scoring process was run by the lab research-assistant who had not participated in the testing sessions.

2.2.2. Devices

There were two main devices used in the present research, a Wii-U® wired to a 40 in. flat screen (Toshiba, 1920 × 1080 resolution) and the iPad Mini 2® (7.9 in. screen of 2048 × 1536 resolution at 326 pixels per inch).

The Wii-U® (2012) has an IBM Power®-based multi-core processor and an AMD Radeon™-based High Definition GPU. All its games were played using the GamePad as the remote control, which has a 16:9 LCD touch screen of 6.2 in. In Splatoon®, this small screen helped participants to navigate by providing them a map of the platforms. This screen was also used in Art of Balance® to arrange the pieces. However, the GamePad's screen was covered while participants played EDGE®, to ensure that they were all looking to the flat screen.

2.2.3. Intelligence/ability measures

Psychometric tests (Table 2) were selected according to the video games' characteristics and the abilities they presumably tapped: fluid reasoning (Gf), visuospatial ability (Gv), and processing speed (Gs). Two tests were selected for each ability. The screening version of *Abstract Reasoning Subtest* from DAT-5 (Bennett, Seashore, & Wesman, 1990; Colom, Abad, Quiroga, Shih, & Flores-Mendoza, 2008) and the D48 (Anstey & Pichot, 1963) for Gf. The screening version of DAT-5 *Spatial Reasoning Subtest* and the *S Factor Subtest* from the Primary Mental Abilities (PMA) battery (Thurstone & Thurstone, 1968) for Gv. Finally, the Reviewed Toulouse-Piéron (Toulouse & Piéron, 1972, 2013) and the *Perceptual Speed and Accuracy (PSA) Subtest* from DAT-5 for Gs.

The testing session lasted 90 min and the tests were always administered in the same order: (1) DAT-*Abstract Reasoning*; (2) Toulouse-Piéron-Revised; (3) DAT-*Spatial Reasoning*; (4) DAT-*PSA*; (5) D-48; (6) and PMA-*S*.

2.3. Procedure

There was a total of three ninety minutes sessions carried out in a strictly controlled lab environment. The first two were individual playing sessions, one for Wii-U® and another for iPad® games. During these sessions, the experimenter registered participants' performance. Splatoon® was also recorded to ensure the accuracy of the registers.

In the first session, participants completed their demographic data, informed consent form and Video Games Habits Scale (VGHS; Quiroga et al., 2011), to control for extensive playing habits and previous experience with the video games. Then, participants started playing the Wii-U® or the iPad® games according to the group where they were randomly allocated when they signed up for the experiment. Participants always played video games following the same order within each session, but sessions' order was counterbalanced. Wii-U® games' order was: Splatoon®, Art of Balance® and EDGE®. iPad® games' order was: Hook, Unpossible, Rail Maze, SkyJump, Blek, Space Invaders, and Crazy Pool. Participants were required to complete training trials for each video game. Moreover, all games settings, screens' brightness, and volume were the same for all participants.

Once both video games' sessions were completed, participants chose a date for psychometric testing. Up to five participants could complete the psychometric tests battery at the same time.

2.4. Analyses

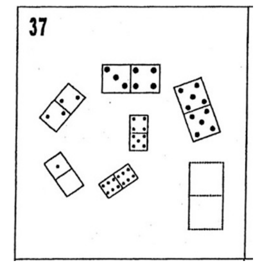
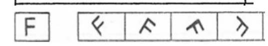
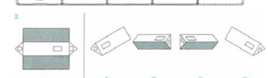
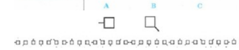
First, we computed the descriptive statistics for each video game and intelligence measure. Second, a Confirmatory Factor Analysis (CFA) was run for the video games and for the intelligence batteries. Regarding the former, we tested two different models: a one-factor model and a hierarchical model. In the hierarchical model, a higher-order factor (*g*VG) was obtained from four first-order factors: *Puzzles* (Blek, Hook, and EDGE®), *Strategy* (Art of Balance® and Rail Maze), *Sports* (Crazy Pool, Sky Jump, and Unpossible) and *Shooters* (Space Invaders and Splatoon®). The one-factor model was computed for the intelligence tests. The hierarchical model would have not been appropriate due to the relative low number of measures defining each first-order factor (Gf, Gv, and Gc), as pointed by Ding, Velicer, and Harlow (1995). Finally, Structural Equation Modelling (SEM) analyses were computed for testing the association between intelligence and video games latent factors.

3. Results

3.1. Experience with video games

Participants' playing experience was evaluated using the Video Games Habits Scale (VGHS; Quiroga et al., 2011). 98.51% of the participants had played at least once with a video game console and 82,84% had a video game console at home (67.91% had between 1 and 3 gaming devices). Only 28 participants (21%) played > 5 h per week with a video console. Therefore, the whole group was predominantly non-experienced video game players (the current cut-off for high experience is 6–7 h per week, West et al., 2017). For iPad, only 8 (1,5%)

Table 2
Psychometric tests.

Test	Intelligence factor	Description	Example
D-48	Gf	The aim is to identify the domino piece that would continue the series	
Spatial factor (PMA-S)	Gv	The purpose is to mark all models that resemble the sample	
Perceptual speed and accuracy (DAT-PSA)	Gs	The point is to localize the sets of letters that resemble the provided sample	
Abstract reasoning subtest (DAT-AR)	Gf	The object is to select the figure that continues the series	
Spatial Reasoning Subtest (DAT-SR)	Gv	The purpose is to select among four options the figure that could be reconstructed from the given unfolded model	
Toulouse-Piéron - Revised	Gs	The aim is to select the figures that resemble one of the two samples as fast as possible.	

Abstract Reasoning Subtest from DAT-5 (Bennett et al., 1990; Colom et al., 2008) and the D48 (Anstey & Pichot, 1963). To estimate Gs, the reviewed Toulouse-Piéron (Toulouse & Pieron, 1972, 2013) and the *Perceptual Speed and Accuracy (PSA) Subtest* from DAT-5. Finally, for Gv, was the screening version of DAT-5 *Spatial Reasoning Subtest* and the *S Factor Subtest* form the primary mental abilities (PMA) battery (Thurstone & Thurstone, 1968).

participants played > 5 h per week. Over 90% of the participants were unfamiliar with the video games considered in the present study, and just 1.49% had already played some of these games. The best-known game was Space Invaders (far from surprising because the original version was released in 1978).

In short, all participants had played video games, but they were not experienced gamers and the games administered in the present study were new to them. Nevertheless, partial correlations between intelligence tests and video games performance were computed, controlling for experience playing video games. Results were closely similar (not statistically different) to the raw correlations. Therefore, video game experience was no longer considered in the remaining analyses.

3.2. Descriptive statistics

Table 3 shows the descriptive statistics for the video games and the intelligence tests. Reliability coefficients were appropriate for all games (from 0.77 to 0.92).

The dependent variable for the video games was the number of completed levels with three exceptions: Space Invaders (number of total points), SkyJump (mean meters across the three trials) and Unpossible (number of deaths during game performance). Performance scores were normally distributed for half of the games. However, participants found Hook, Rail Maze, Space Invaders and Unpossible too difficult (positive asymmetry), contrary to SkyJump that was easy (negative asymmetry).

All intelligence measures were normally distributed, except D-48. In this latter instance, the test was easier than expected under the assumption of a normal distribution. Cronbach's Alpha coefficients for the psychometric tests were satisfactory (from 0.74 to 0.84).

Table 4 shows the correlations between video games performance and intelligence tests. Overall, positive correlations were found among all measures, except for Unpossible in which the performance measure was the number of deaths so higher scores implied worse performance. Gs tests (DAT-PSA and Toulouse-Piéron – Revised) showed lower correlations with video games performance than Gf and Gv measures, even with video games requiring fast responses. This result was unexpected.

Table 3
Mean, SD, skewness and kurtosis for ability tests and for video games (N = 134). PMA-S = PMA- Spatial factor; DAT-PSA = DAT- Perceptual speed and accuracy; DAT-AR = DAT-Abstract reasoning; DAT-SR = DAT-Spatial reasoning.

Tasks	Mean	SD	$Z_{skewness}$	$Z_{kurtosis}$	α
Video games battery					
Art of balance®	6.15	3.36	−0.49	−2.29	NA
Blek	11.50	4.22	1.67	0.24	0.908
Crazy pool	5.77	2.77	1.38	0.50	0.856
EDGE®	3.01	1.06	1.91	−1.33	NA
Hook	13.02	3.23	2.74	−0.63	0.923
Rail maze	5.72	2.18	3.71	2.74	0.813
Space invaders	2173.13	355.91	3.18	1.85	NA
Splatoon®	7.44	4.52	−0.20	−2.56	0.920
Sky jump	96.52	34.77	−3.68	0.32	0.772
Unpossible	12.35	11.25	7.55	5.51	NA
Psychometric tests					
D-48	15.35	3.26	−2.56	0.03	0.741
PMA-S	22.16	11.64	0.54	1.07	0.836
DAT-PSA	56.65	13.22	0.56	−1.09	NA
DAT-AR	11.87	3.54	−0.83	−0.30	0.734
DAT-SR	12.85	4.68	−0.03	−1.30	0.833
Toulouse-Piéron-Revised	209.65	51.37	1.36	−0.26	NA

NA = Not available.

However, speed is a multi-faceted construct with four broad abilities: Psychomotor speed, Decision speed, Cognitive speed, and Retrieval Fluency (Schneider & McGrew, 2018). Therefore, speed tapped by psychometric tests might be different from that required by video games. Video games could require decision or psychomotor speed, but not cognitive speed, as shown by the results reported here.

DAT-AR was the only test correlating with all the video games (from 0.19 to 0.60, $p < .01$), which suggests that all these video games require intelligence (DAT-AR shows the higher coefficient on the *g* factor, please see Fig. 1).

Five video games were specially related with other video games and intelligence tests: Hook, EDGE®, Rail Maze, Splatoon® and Crazy Pool.

Table 4
Pearson's correlation for video games and psychometric tests. B = Balance; Invd = Invaders; Unposs = Unpossible; PMA-S = PMA- Spatial factor; DAT-PSA = DAT- Perceptual speed and accuracy; DAT-AR = DAT-Abstract reasoning; DAT-SR = DAT-Spatial reasoning; TP: rvd = Toulouse-Piéron – Revised (95% Confidence intervals in BRACKETS).

Video game	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.
1. Art of B. ®	1	0.19* (0.02 0.35)	0.05 (−0.12 0.22)	0.29** (0.13 0.44)	0.33** (0.17 0.47)	0.30** (0.14 0.45)	−0.10 (−0.26 0.07)	0.24** (0.07 0.39)	0.06 (−0.11 0.23)	−0.02 (−0.19 0.15)	0.30** (0.14 0.45)	0.34** (0.18 0.48)	−0.05 (−0.22 0.12)	0.33** (0.17 0.47)	0.37** 0.21 0.51)	0.03 (−0.14 0.02)
2. Blek		1	0.23** (0.06 0.38)	0.43** (0.28 0.56)	0.57** (0.44 0.67)	0.42** (0.27 0.65)	0.16 (−0.01 0.32)	0.26** (0.09 0.41)	0.27** (0.10 0.42)	−0.15 (−0.31 0.02)	0.34** (0.18 0.48)	0.23** (0.06 0.38)	0.05 (−0.12 0.22)	0.51** (0.37 0.63)	0.36** (0.20 0.50)	0.22* (0.05 0.38)
3. Crazy pool			1	0.45** (0.30 0.58)	0.39** (0.24 0.52)	0.38** (0.22 0.52)	0.32** (0.16 0.46)	0.51** (0.37 0.63)	0.33** (0.17 0.47)	−0.21* (−0.37–0.04)	0.31** (0.15 0.46)	0.17* (0.0 0.33)	0.15 (−0.02 0.31)	0.37** (0.21 0.51)	0.22** (0.05 0.38)	0.32** (0.16 0.46)
4. EDGE®				1	0.68** (0.58 0.76)	0.49** (0.35 0.61)	0.23** (0.06 0.38)	0.60** (0.48 0.70)	0.47** (0.33 0.59)	−0.27** (−0.42–0.10)	0.38** (0.22 0.52)	0.37** (0.21 0.51)	0.13 (−0.04 0.29)	0.43** (0.28 0.56)	0.30** (0.14 0.45)	0.23** (0.06 0.38)
5. Hook					1	0.69** (0.59 0.77)	0.19* (0.02 0.35)	0.53** (0.40 0.64)	0.31** (0.15 0.46)	−0.20* (−0.36–0.03)	0.55** (0.42 0.66)	0.50** (0.36 0.62)	0.08 (−0.09 0.25)	0.60** (0.48 0.70)	0.47** (0.33 0.59)	0.24** (0.07 0.39)
6. Rail maze						1	0.15 (−0.02 0.31)	0.51** (0.37 0.63)	0.31** (0.15 0.46)	−0.19* (−0.35–0.02)	0.32** (0.16 0.46)	0.38** (0.22 0.52)	0.01 (−0.16 0.18)	0.55** (0.42 0.66)	0.40** (0.25 0.53)	0.10 (−0.07 0.26)
7. Space invd.							1	0.27** (0.10 0.42)	0.10 (−0.07 0.26)	−0.21* (−0.37–0.04)	0.03 (−0.14 0.20)	0.14 (−0.03 0.30)	0.05 (−0.12 0.22)	0.19* (0.02 0.35)	0.00 (−0.17 0.17)	0.08 (−0.09 0.25)
8. Splatoon®								1	0.38** (0.22 0.52)	−0.37** (−0.51–0.21)	0.32** (0.16 0.46)	0.40** (0.25 0.53)	0.05 (−0.12 0.22)	0.41** (0.26 0.54)	0.27** (0.10 0.42)	0.18* (0.01 0.34)
9. Sky jump									1	−0.21* (−0.37–0.04)	0.17* (0.00 0.33)	0.17* (0.00 0.33)	0.10 (−0.07 0.26)	0.30** (0.14 0.45)	0.15 (−0.02 0.31)	0.21* (0.04 0.37)
10. Unposs.										1	−0.13 (−0.29 0.04)	−0.16 (−0.32 0.01)	−0.02 (−0.19 0.15)	−0.26** (−0.41–0.09)	−0.20* (−0.36–0.03)	−0.07 (−0.24 0.10)
11. D-48											1	0.36** (0.20 0.50)	0.13 (−0.04 0.29)	0.54** (0.41 0.65)	0.51** (0.37 0.63)	0.31** (0.15 0.46)
12. PMA-S												1	0.02 (−0.15 0.19)	0.51** (0.37 0.63)	0.44** (0.29 0.57)	0.10 (−0.07 0.26)
13. DAT-PSA													1	0.22* (0.05 0.38)	0.21* (0.04 0.37)	0.57** (0.44 0.67)
14. DAT-AR														1	0.56** (0.43 0.67)	0.29** (0.13 0.44)
15. DAT-SR															1	0.20* (0.03 0.36)
16. TP: rvd																1

* $p < .05$.
** $p < .0$.

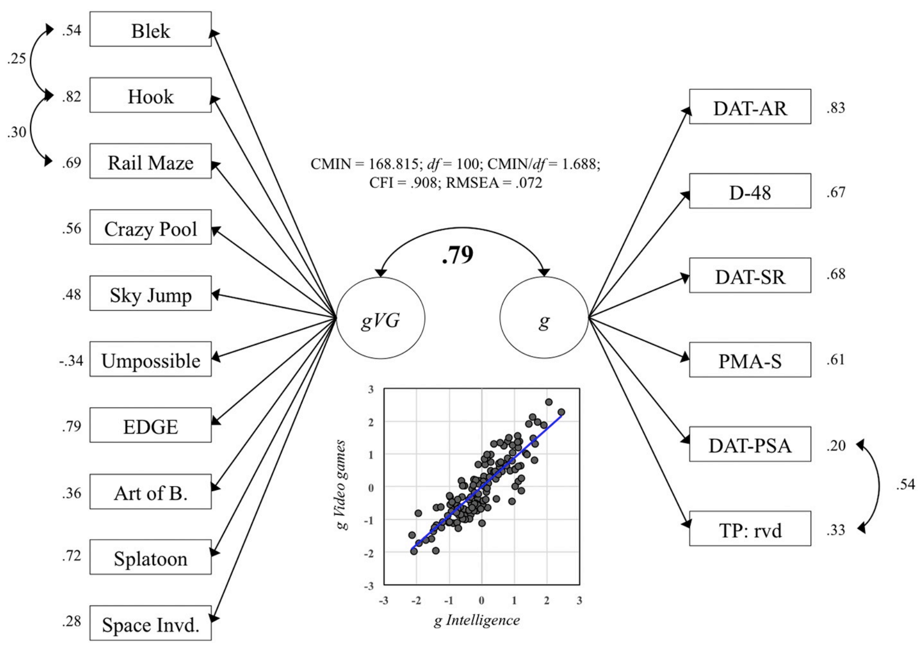


Fig. 1. Top panel shows factor-loadings for the SEM model. Bottom panel depicts the scatterplot for general factors of intelligence and video games. B = Balance; Invd = Invaders; PMA-S = PMA- Spatial Factor; DAT-PSA = DAT- Perceptual Speed and Accuracy; DAT-AR = DAT-Abstract Reasoning; DAT-SR = DAT-Spatial Reasoning; TP: rvd = Toulouse-Piéron – Revised.

Note that, EDGE® and Splatoon® are platform games in which participants must take decisions as they progress across levels (dynamic tasks). In contrast, the information displayed while playing Hook, Rail Maze and Blek does not change (static tasks), and therefore, participants can evaluate the different courses of action before moving forward. This may explain why correlations between these later games and DAT-AR (Gf) are higher than for the platform games.

The camera angle can change in Splatoon® and Crazy Pool, but not in EDGE®. However, EDGE® environment is designed to be spatially ambiguous. These characteristics should make these video games more demanding with regards to spatial reasoning. However, results did not support these hypotheses. Correlations between Gf tests and Splatoon®, Crazy Pool or EDGE® were weak, but slightly higher than with Gv measures. Art of Balance® showed a similar pattern of correlations. This game was supposed to load heavily in mental rotation but it showed similar weak correlations with Gf and Gv.

Unpossible and SkyJump are easy video games in which a fast reaction time is crucial to succeed. They were expected to correlate with Gs, but they only correlated weakly with Gf measures. This result suggests that, even for very simple games, intelligence (conceived in this regard as the ability for fast adaptation to novelty) is required for solving the problems efficiently.

3.3. Confirmatory factor models (video games)

Maximum Likelihood Mean adjusted method (MLM) was employed for computing the confirmatory factor analyses (CFA) because of the asymmetry values for some video games (Satorra & Bentler, 1994).

Table 5A shows the fit indices for the video games one-factor and hierarchical models. The fit for the one-factor model was unacceptable (CFI = 0.887; RMSEA = 0.100). The Modification Indices (M.I.) suggested the inclusion of the correlation between three games (Rail Maze, Hook, and Blek) to improve fit. The inclusion of the correlation between Rail Maze and Hook (M.I. = 13.97 increased the fit values (Table 5A; model 1.1). This correlation was reasonable because both games theoretically tap fluid intelligence (Table 1). The second step was the inclusion of the correlation between Hook and Blek (M.*I* = 12.423). Both games are measures of the *Puzzles* factor and, therefore, this correlation was considered adequate. The fit of this model was good (CFI = 0.944; RMSEA = 0.073; see model 1.2 of Table 5A).

Regarding the hierarchical model, the fit of the conceptual framework was unsatisfactory (model 2; CFI = 0.898; RMSEA = 0.101). The M.I. suggested the inclusion of the correlation between *Sport* and *Shooters* factors (M.I. = 16.712). The inclusion of this correlation improved the fit values (CFI = 0.940; RMSEA = 0.079; model 2.1 of Table 5A). However, the correlation between *Sports* and *Shooters* was higher than 1 (Heywood case). The presence of this Heywood case could mean that there were not enough participants to provide stable estimations. Therefore, we decided to merge the games of *Shooters* and *Sports* factors into one single factor of *Action Games* (model 2.2). This model showed good fit indices (CFI = 0.944; RMSEA = 0.074).

Finally, we compared the best solutions for the one-factor model (1.2) and the hierarchical model (2.2) using CFI and Chi-squared comparison because they were nested-models. Both models showed the same CFI value [ΔCFI = CFI (One Factor) − CFI (Hierarquical) = 0.944–0.944 = 0.000 (< 0.010)]. Regarding chi-squared comparison, both models revealed similar fit (ΔChi-squared = 1.142 (56.390–55.242), Δdf = 1 (32 − 31); $p = .284$), and, therefore, they summarized the data properly. Nevertheless, the one-factor model was selected as the best representation of video games' performance.

3.4. Confirmatory factor models (intelligence tests)

Table 5B shows the statistics for the one-factor model of the intelligence battery (CFI = 0.780; RMSEA = 0.199). Fit values were poor. A high Modification Index was found (M.*I* = 38.934). This M.I suggested the inclusion of the covariation between the two Gs measures (DAT-PSA and Toulouse-Piéron – Revised). After adding the covariation between speed measures, the fit of this model was appropriate (CFI = 0.981; RMSEA = 0.062; model 1.2 of Table 5B).

3.5. Structural equation model

Finally, we combined the previous measurement models in a Structural Equation Model (SEM) to test the magnitude of the covariation between the two general factors: video games (*g*VG) and intelligence (*g*). Fig. 1 displays the standardized results of the SEM model. Model fit was acceptable (CFI = 0.908; RMSEA = 0.072) and the correlation value between the two general factors was high ($r = 0.79$; $p < .001$).

Table 5
Statistics for video games CFA (A) and cognitive tests' CFA models (B). DAT-PSA = DAT-Perceptual speed and accuracy; TP = Toulouse-Piéron – revised.

	Cmin	*df*	Cmin/*df*	*p*	*CFI*	*RMSEA*
A. Video games' models						
1. One-factor	82.032	35	2.34	< .001	0.887	0.100
1.1. One-factor: Rail Maze with Hook	68.532	34	2.02	.000	0.917	0.087
1.2. One-factor (1.1) & Hook with Blek	56.390	33	1.71	.007	**0.944**	**0.073**
2. Hierarchical factor	73.307	31	2.36	< .001	0.898	0.101
2.1 Hierarchical factor: Sports with Shooters	54.868	30	1.83	.004	0.940	0.079
2.2 Hierarchical factor: Sports & Shooters combined	55.242	32	1.73	.007	**0.944**	**0.074**
B. Cognitive tests' models						
1. One-factor	56.615	9	6.29	< .001	0.780	0.199
1.1. One-factor: DAT-PSA with TP	12.138	8	1.52	.145	**0.981**	**0.062**

Numbers in bold indicate the best solution.

4. Discussion

Video games are now part of our lives. Here we have shown that video games from different genres can serve as proper measures of intelligence at the latent level –as assessed by standard psychometric tests. The correlation observed at the latent level between general intelligence (*g*) and non-brain video games general performance (*g*VG) was 0.79.

Research studies separate participants according to their gaming experience (Bediou et al., 2018) especially in those focusing on action video games (Green, Pouget, & Bavelier, 2010). However, this approach was irrelevant here because, unlike other studies, we did not test for the training effects of playing specific genres (action games, etc.). The main goal was to analyze their potential as measures of intelligence. In this regard, and as previously shown by Quiroga et al. (2009, 2011) extensive practice with video games does not alter their correlation with intelligence, as long as the video games adhere to three features: (a) moderate levels of complexity, (b) low consistency across items or screens, and (c) no transfer keys. Furthermore, video games with these features show measurement invariance related to video games experience, as shown by Foroughi et al. (2016).

4.1. Correlations among tests and tasks

Correlations among tests and tasks varied in magnitude, but they were all positive. This is in line with the positive manifold and the principle of the indifference of the indicator for tasks comprising mental requirements (Spearman, 1904). We have seen that cognitively challenging video games are remarkably related to intelligence. The overlap of indicators reflecting video game performance can be represented by a common factor (*g*VG), in the same sense that the overlap of indicators reflecting intelligence can be represented by a common factor (*g*). These two common factors are highly correlated (0.79).

The highest correlations were found between abstract reasoning tests (D-48 and DAT-AR) and five video games, specifically: Hook (0.55 and 0.60), EDGE® (0.38 and 0.43), Rail Maze (0.32 and 0.55), Splatoon® (0.32 and 0.41) and Crazy Pool (0.31 and 0.37). These five games belong to very different genres and, therefore, we can conclude that video games correlate with intelligence regardless of their genre.

Another interesting conclusion is that none of the video games showed statistically significant correlations with DAT-PSA (Gs), and just three correlated with Toulouse-Piéron-Revised (Gs): Crazy Pool ($r = 0.32$), EDGE® ($r = 0.23$) and Hook ($r = 0.24$). Both intelligence tests tap speed, but The *Toulouse-Piéron Test* is a cancellation test measuring selective and sustained attention, not just perceptual speed. SkyJump and Unpossible were uncorrelated with DAT-PSA or the *Toulouse-Piéron*. This might seem surprising because good performance in both games seems to heavily rely on response time. However, it could be that video games mainly tap on decision or psychomotor speed whilst psychometric tests measure cognitive speed. Schneider and McGrew (2018) highlighted the need to enrich the speed construct within the CHC model. Interestingly, both games showed moderate correlations with DAT-AR (Gf), which suggests that, even for very simple games, intelligence, as quick adaptation to novelty, is required for solving the problems efficiently. As underscored by Jensen (1998), page 52) there are 2 criteria for defining a cognitive ability: (1) an ability is cognitive if the receptor and effector mechanisms are nonspecific, if the individual's performance is not essentially dependent on any particular sensory or motor system, and (2) an ability is cognitive if individual differences in the ability are insignificantly correlated with measures of sensory acuity, physical strength, endurance, agility, or dexterity (as independently assessed). Following these criteria, we can state that the ability required for playing some video games is clearly cognitive.

It is important to emphasize that the answer device (fingers for the iPad® and a remote control for the Wii®) made no difference for measurement purposes in this group of participants. Correlation values were similar for iPad and WiiU games, e.g.: Splatoon correlates 0.40 with the PMA-S and Rail Maze correlates 0.38 with PMA-S. Answers given by this sample of young people did not seem to differ from paper and pencil tests to touch screens or remote-control devices. Therefore, the results observed are in tension with Hunt and Pellegrino's (1985) prediction: "responding to computerized tests evidently does require a specialized ability to deal with the test format. While definitive studies have not been done, there is some evidence that this is the case" (p. 210). However, as observed by Quiroga, Román, Fuente, Privado, and Colom (2016): "[…] two different types of video games, two different intelligence tests' batteries, but the same conclusion: intelligence can be measured with commercial video games. The hypothesis by Hunt and Pellegrino (1985) regarding the influence of the device used for presenting the items (paper and pencil or computer) fails to substantiate" (p. 3). Results from the present study supports the previous conclusion raised by Quiroga et al. (2016) (Supplementary Material reports details of a formal test of Hunt and Pellegrino's hypothesis using the dataset considered in the present study).

4.2. Factor models

The one-factor model was acceptable to summarize video games' performance, although two correlations had to be incorporated to achieve appropriate model's fit. At the latent level, the correlation between intelligence and video games was high ($r = 0.79$). Therefore, non-brain video games ordered participants in a way closely similar to standard intelligence tests. Our results were consistent with those of Rabbitt et al. (1989) and Quiroga et al. (2015): the superficial characteristics of video games are not particularly relevant. What is crucial is their underlying cognitive requirements.

The correlation between the factors representing video games and intelligence performance was higher here than in other studies also using commercial video games. Thus, for instance, Lim and Furnham

(2018) tried to incorporate games of different genres using Taboo (by Hasbro®) board game, but they found small correlations at the construct level with *Portal* video game and standard intelligence tests. The limited control over some performance variables and the lack of consistency across games' measures might contribute to explain the discrepancies between our results and those of Lim and Furnham's (2018) or Baniqued et al. (2013). The results reported here resemble those found by Foroughi et al. (2016), which used the commercial video game Portal 2. They also observed a substantial correlation at the latent level (r = 0.78), but only for Gf.

4.3. The 'true' correlation between video games and intelligence performance

Regarding the difference between the correlation value reported by Quiroga et al. (2015) (r = 0.93) and the observed here (r = 0.79), we can suggest that the underlying (hidden) cognitive requirements are far from trivial. The difference between these correlation values might result from at least two sources: (1) breadth of the *g* factor: Gc and Gy measures were not included in this study and this may contribute to lower the association; (2) cognitive loadings of the chosen videogames: *g* has to do with cognitive complexity and perhaps the average complexity levels of the set of videogames played here are not high enough. The breath of the *g* factor obtained in the present study is closer to Gf than the *g* factor obtained by Quiroga et al. (2015).

Still another issue that must be highlighted is that designing video games from the outset aimed at testing the key facets of intelligence would refine the obtained estimates of the construct of interest. Commercial video games are limited in this regard.

4.4. Variations across studies

There are some issues that may help to explain the disparate findings reported by different studies relating intelligence and video game performance.

First, we chose video games with neutral emotional content. In this regard, Santostefano and Rieder (1984) showed that aggressive participants did better with aggressive than with neutral cognitive control tasks. Baniqued et al. (2013) also selected non-aggressive video games and the obtained correlation values between cognitive factors and video games were closely similar to those observed in the present study. In clear contrast, Bonny, Castaneda, and Swanson (2016) used DOTA II (an action real time strategy video game with aggressive content in which two teams of five players compete to destroy a large structure defended by the opposing team) and the computed correlations with memory tasks were low (from 0.03 to 0.24). Also, Kokkinakis, Cowling, Drachen, and Wade (2017) used DOTA II together with LOL (League of Legends) and computed a correlation of 0.44 with the Matrix subtest from the WASI. We suggest that these low correlation values may be due to an attenuation effect evoked by the emotional content of the games.

Second, we controlled for speed-accuracy trade-off (SATO) that accounts for individual differences when approaching a task— some people would invest more time to avoid errors, while others would sacrifice accuracy to gain speed. When correcting for SATO, game scores are more fine-grained and they provide better representations of people's performance. Usually, researchers take this point into account. However, Kokkinakis et al. (2017) used a broad measure of performance MMR (ratio of historical wins to losses) that failed to control for SATO and they obtained a lower correlation between video game performance and reasoning (0.44).

Third, video game performance is the appropriate video games measure, not the amount of previous experience playing video games. Quiroga and Colom (2019) have shown that the amount of playing hours provides low, medium or high correlations with intelligence. However, these correlation values refer to the correlation between 'motivation' to play video games (hours per week) and intelligence, not to the correlation between 'ability' revealed when performing video games and intelligence. Studies relying on experience playing video games depart from the best scenario required for obtaining the dependent variable of interest.

Finally, participants played in a highly controlled environment with well-trained examiners. Failing to do so may increase measurement error, which would attenuate the correlations computed between video game and intelligence performance. In this regard, Baniqued et al. (2013) used a specific web designed for their research where participants completed the games. While testing in the lab increases control, using online platforms helps to recruit greater numbers of participants. It is up to researchers to balance this trade-off.

4.5. Limitations

There are two main limitations in the study reported here. First, the floor effects of Art of Balance® and Unpossible. To overcome this limitation, we computed within group standard scores to equate all participants' performance. Second, the data collection procedure could have been a source of measurement error. Although the examiners were well trained, performance measures might be more accurate if registered and computed automatically by the video games' software. However, this is still not possible with available commercial video games. The design of these games from the outset by informed psychologists is strongly required.

4.6. Concluding remarks

Video-games performance is remarkably related to intelligence regardless of their genre when the chosen video games adhere to three key features: (a) moderate levels of complexity, (b) low consistency across items or screens, and (c) no transfer keys. Still, three important questions remain unanswered: (1) Can we adapt commercial video games for assessing intelligence on a regular basis? (2) What is the nature of the three-way relationship between game mechanics, cognitive abilities, and cognitive processes? It might be important to know which game mechanics are better suited for measuring (a) distinguishable cognitive abilities (Gf, Gc, Gv, Gy, Gs, Gt, Gy), and (b) specific cognitive processes (executive functions such as updating, inhibition, and shifting). Perhaps "shooters games" are better for testing cognitive speed and visual attention, whereas "puzzle games" are better for testing reasoning; (3) Can we identify the essential ingredients of the video games for achieving the most efficient assessment of intelligence and related cognitive abilities? Once the best video games mechanics for testing a given cognitive ability are identified, the next step will be to design a video game that parallels the essence of an intelligence battery, grouping several video games using distinguishable mechanics and tapping different second stratum abilities. Here we have shown that a video games battery disparate games, including puzzles games (Hook and Blek), platform games (Edge), shooter games (Splatoon and space invaders), strategy games (Rail Maze and Art of Balance) and sport games (Crazy Pool, Sky Jump and Unpossible) can provide reliable measures of intelligence differences. Now the challenge is to design from the outset a battery of video games including the key underlying ingredients.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.intell.2019.05.001.

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