1 Video Games and Higher Cognition

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Over the past several decades, technological advancements in entertainment systems have given rise to a multibillion-dollar video gaming industry. Today, video games are one of the most ubiquitous forms of entertainment around the world, with an estimated 2.7 billion video game players worldwide (Statista, 2020). In the United States, 65% of adults play video games, spending an average of 4.8 hours per week playing computer, console, or mobile video games (Entertainment Software Association, 2019). Given the large amount of time individuals throughout the population spend playing video games, scientists have sought to examine the effects of video game exposure on a host of human behaviors and abilities. Such inquiries have spanned the entirety of psychological sciences, from educational psychology (e.g., Clark et al., 2016; Mayo, 2009), to clinical psychology (e.g., Biagianti & Vinogradov, 2013; Eichenbaum et al., 2015), to social psychology (Gentile et al., 2009; Greitemeyer & Osswald, 2011), to the focus of this chapter, cognitive psychology. Within cognitive psychology, the majority of work to date has examined the impact of video game play in domains such as executive functions (e.g., inhibition, cognitive control, selective attention), cognitive flexibility (e.g., multitasking, task switching), and perceptual capabilities (e.g., peripheral vision, multisensory integration; Bavelier et al., 2018, 2012). Yet, a growing body of research has focused on what might be considered "higher level cognition," in particular, intelligence, problem solving, and creativity. These latter three domains will be the focus of this chapter.

Definitions of Intelligence, Problem Solving, and Creativity

Before considering the relations between video game play and intelligence, problem solving, and creativity, it is first important to describe how each of the various cognitive constructs has been operationally defined and measured. Indeed, as cognitive constructs become part of higher level cognition, it is very frequently the case that there is increasing ambiguity and inconsistency, even within the scientific community, with regard to what exactly the constructs mean and how they can be quantitatively measured. As such, we note from the outset that while we offer a set of definitions below, in practice, these higher cognitive constructs have been conceived of in tens, if not hundreds, of distinct ways throughout the literature.

We begin with what is likely the broadest construct—intelligence. Here the most classic definition may be from Binet and Simon (1916) who described intelligence as, "the faculty of adapting oneself to circumstances… To judge well, to comprehend well, to reason well" (pp. 42–43). Such a definition is also very much in line with that of Wechsler's (1944), which stated "the aggregate or global capacity of the individual to act purposefully, to think rationally, and to deal effectively with his environment" (p. 3). Given these descriptions—encompassing learning, judgment and decision making, integration of information, rational choice, etc.—it should be immediately obvious how broad the set of abilities and cognitive functions that fall under the label of "intelligence" can be.

Over the past century, a host of more detailed theories of intelligence have been proposed. Of particular note is that of Spearman (1927), who proposed a two-factor theory of intelligence, which included general intelligence (g), which can be thought of as the shared capacity to perform well (or poorly) in a wide variety of subtasks in a test battery, and specific intelligence, which describes aspects of performance that are specific to each subtest within a test battery. In this sense, as we will see below, the constructs of problem solving and creativity would all fall under the general intelligence factor. Expanding on Spearman's g, Cattell (1971) defined two major abilities, crystallized (Gc) and fluid (Gf) intelligence, and Horn (1988) further added visual, auditory, quantitative, processing speed, long-term memory, and short-term memory abilities. Carroll (1993) then proposed a hierarchical model—the Cattell-Horn-Carroll model—with general intelligence at the top in Stratum III; broad group factors in Stratum II, which include fluid intelligence (Gf), crystallized intelligence (Gc), general memory and learning (Gy), broad visual perception (Gv), broad auditory perception (Gu), broad retrieval ability (Gr), cognitive speediness or processing speed (Gs), and simple reaction time (Gt); and narrow group factors (e.g., the ability to perform specific individual tasks) in Stratum I (Sternberg, 2020). This chapter will focus on the effects of video games on intelligence in Stratums II and III, as defined by this model.

Examples of intelligence test batteries include the Stanford-Binet Intelligence Scale, the Cattell Culture Fair Intelligence Test, and the Wechsler Adult Intelligence Scale (WAIS). These scales are then typically divided into more specific subscales. For instance, the WAIS includes four indices: verbal comprehension, working memory, perceptual organization, and processing speed. These subscales are aimed at measuring crystallized intelligence, memory and learning, fluid intelligence, and processing speed, respectively. The verbal comprehension index includes a vocabulary task (e.g., Define "audacious"), a similarities task (e.g., Identify the qualitative relationship between "summer" and "winter"), and a general information task (e.g., Who is the president of the United States?). The working memory index includes an arithmetic task (e.g., A person with $28 spends $0.50. How much does he have left?), a digit span task (e.g., Repeat the following numbers), and a letter-number sequencing task (e.g., Repeat the following letters in alphabetical order and digits in ascending numerical order). The perceptual organization index consists of a picture completion task (e.g., Identify what is missing in a picture), a block design task (e.g., Create a pattern from colored blocks), and a matrix reasoning task (e.g., Identify the missing image to complete a pattern). Lastly, the processing speed index includes a digit symbol-coding task (e.g., Translate associations between symbols and numbers) and a symbol-search task (e.g., Search a set of symbols and indicate whether a target shape is present).

As for problem solving, an early definition stated that "A problem arises when a living creature has a goal but does not know how this goal is to be reached. Whenever one cannot go from the given situation to the desired situation simply by action, then there is recourse to thinking" (Duncker, 1945, p. 1). In other words, the broadest definition of problem solving is the act of moving from an initial state toward a goal state where the path between these is not readily known (Hambrick et al., 2020). Such a definition would then hierarchically fall beneath intelligence (i.e., if one sub-component of intelligence is the ability to "act purposefully, to think rationally, and to deal effectively with his environment," Wechsler, 1944, p. 3).

Tasks used to measure problem solving assess whether one can reason about a situation to reach a (typically single) correct solution. Indeed, the process of problem solving also involves reasoning, or the process of drawing conclusions from, and making inferences about, incoming information (Lakin & Kell, 2019). An example of a problem solving task is Duncker's (1945) classic candle problem, in which a participant is presented with a candle, a box of thumbtacks, and a book of matches (initial state) and asked to fix the candle to the wall and light it without the wax dripping on the floor (goal state). To move from the initial state to the goal state, the participant must come up with an effective solution by problem solving (with the solution being using a thumbtack to attach the box to the wall, putting the candle in the box, and then lighting the candle). Another task that is often nested in the category of problem solving is Raven's Standard and Advanced Progressive Matrices (RPM) or similar matrix-type tasks, in which participants must reason about a pattern that emerges in a matrix of images and select an image that best completes the pattern (Raven, 1960). RPM has long been considered the best single task to measure general cognitive ability (Kyllonen & Kell, 2016). However, according to the Cattell-Horn-Carroll model, only when matrix-type tasks are combined with other tasks should they be considered as part of a Stratum II or III intelligence measure; when used as a single task, they may be considered a Stratum I measure of reasoning or problem solving.

Finally, creativity often hierarchically falls beneath problem solving. However, rather than reflecting a process inherent to all problem solving (as with reasoning), the term creativity is used most commonly in situations where there are multiple possible solutions to a problem, in particular, in situations where there is not one single objectively correct solution. Furthermore, while there may not be an objectively correct solution, creativity nonetheless implies coming to a solution that is, at a minimum, task appropriate (i.e., while there may be not any single correct solution to the problem, there could very well be objectively incorrect solutions; Kaufman & Glăveanu, 2019). In addition, creativity also frequently requires that a solution be novel (Hennessey & Amabile, 2010; Runco & Jaeger, 2012). For instance, consider an individual who is given a roll of duct tape and five sheets of paper and is asked to repair a 6 in. square hole in a wall such that people cannot see or hear through it. There are many possible solutions to this problem. If an individual decides to create a large ball out of the duct tape and presses it into the wall to fill the entire hole, that may be considered a creative solution. If though on the next day, the individual is given the same problem and utilizes the same solution, it would cease to be considered creative.

Creativity is often operationalized alongside divergent thinking, which is the ability to generate as many solutions to a problem as possible (Kaufman & Glăveanu, 2019). Divergent thinking tasks, such as Guilford's (1967) Structure of Intellect Divergent Production Tests (SOI) and Torrance's (1974) Tests of Creative Thinking (TCTT), ask participants to come up with solutions to problems and are typically scored for the number of responses (fluency), number of categories of responses (flexibility), uniqueness of responses (originality), and the extension of ideas within a response (elaboration; Plucker et al., 2019). For example, a participant may be asked to come up with as many uses for a brick as possible. The participant may list several solutions, such as building a house, building a wall, building a bridge, etc. (which may have high fluency, but low flexibility, originality, and elaboration, and therefore low creativity overall), or may list more novel responses, such as use as a paperweight, use as a tire wedge to keep your car from rolling down a hill, use as a potholder because it holds heat well, etc. (which may have higher scores on all measures and thus would be considered more creative). Recent research has integrated convergent thinking into creativity, with tasks involving the integration and synthesis of different pieces of information in an original way. For example, a participant may be presented with different geometric shapes and would be asked to come up with a drawing integrating all the shapes in a meaningful scene. Assessment tools, such as the Evaluation of Potential Creativity (Lubart et al., 2011), include convergent-integrative thinking as well as divergent-exploratory thinking to measure creativity in children and adolescents.

Definitions of Video Games

While at first glance, the term "video game" may seem easier to operationalize than a cognitive construct such as "intelligence"—in practice, the term has similarly been used in very different ways across academic and popular media. Indeed, the term has been used to refer to an extremely broad variety of experiences from Space Fortress, an arcade-style computer game developed in the 1980s with support of the Defense Advanced Research Projects Agency (DARPA) within the United States Department of Defense with the explicit goal of studying skill acquisition, to blockbuster titles such as League of Legends that were developed purely for entertainment purposes. Over the past 20 years, the types of experiences afforded by video games have evolved so rapidly that it has become a challenge to properly categorize video games (Dale et al., 2020). Yet, it makes intuitive sense that a video game that requires individuals to press a button to blow flowers peacefully through a meadow (e.g., as in the meditation video game, Flower) is unlikely to have the same impact on motor execution as a video game that requires individuals to swiftly execute a series of button presses (as in fighting games such as Super Smash Bros.). The same is likely to hold true for cognition; understanding the particular cognitive constructs that are most strongly loaded upon while playing various types of games is likely key to examining the impact of those video games on cognition. In this chapter, we define action video games as we have done in our past work. Specifically, we have used the term action video game to refer to first- or third-person shooter games, which typically involve mechanisms of controlling a single character, aiming, shooting, and running in real-time action from a first- or third-person perspective (Bavelier et al., 2018; Bavelier & Green, 2019; Green et al., 2017). We use the term action-like video games for games that are not first- or third-person shooter games, but nonetheless involve substantial action mechanics. Typical game types that fit into this category are action-adventure games, action-role-playing games (action-RPG), driving games, multiplayer online battle arena (MOBA) games, and real-time strategy games (RTS; Dale & Green, 2017a, 2017b; Dale et al., 2020). Action and action-like games stand in contrast to turn-based strategy games or complex puzzle games, like Portal, where complex decisions have to be made, but under less time pressure than in action or action-like games. Finally, mini-games, with rather repetitive mechanics, stand on their own (note that this category would include various "brain games" which often instantiate specific versions of standard cognitive laboratory tests). While such distinctions are commonly made in the literature focused on perception, attention, multitasking, speed of processing, and other lower level cognitive abilities, this is less commonly true of research focused on higher cognitive functions. As such, when we review existing meta-analyses, all video games may frequently be combined together.

We will do a quick review of video games specifically designed with the goal of impacting higher cognitive abilities. These video games are very commonly composed of a suite of mini-games each designed around a particular Stratum I task. Thus, interventions using these designed-for-impact video games are certainly informative about the possibility of training specific Stratum I skills, but they appear rather misaligned with our goal here of asking whether Stratum II and III measures of intelligence as well as creativity can be impacted by video game play.

In a more extensive section, we then turn to the review of commercially available video games designed solely for entertainment purposes and their impact on higher cognition. It is certainly the case that these games were not developed for the purpose of impacting cognitive skills, but rather for entertainment. Yet, if one were to conduct a cognitive task analysis asking for the richest video games in terms of what Binet or Wechsler called for when defining intelligence, commercially available games would clearly be among the best contenders. Indeed, many types of commercially available games place significant demands on problem solving, reasoning, and creativity, for instance, by combining many different goals and sub-goals at different time scales (in a very similar way to the everyday life challenges we call upon intelligence and creativity to solve). This level of complexity and richness remains unique to the commercial arena, most likely due to the high production cost it entails to design such experiences.

Assessing Relations Between Video Game Play and Higher Cognitive Abilities: Three Main Study Types

Researchers commonly examine the relationship between video game play and cognitive function using one of three types of study designs. First, correlational research aims to establish relationships between some continuous measure of video game experience, such as hours spent playing video games per week, and performance on a cognitive task. Second, cross-sectional studies compare performance on cognitive tasks between extreme groups, such as heavy video game players (e.g., those that play more than 5 hours per week) and non-video game or "casual" video game players (e.g., those that play fewer than 1 hour per week). Such methods have a number of positive aspects. For example, given the prevalence of video game players in the world, it is often easy to obtain a reasonably large sample of individuals. However, for correlational approaches, it is often difficult to get a sufficiently accurate measurement of video game play using self-report measures, particularly when individuals play many types of games concurrently. In cross-sectional studies meanwhile, the boundaries of what constitutes, for instance, a "heavy" player vs. a "non-player" are not consistent in the literature. Finally, for both types of studies, one cannot make any causal claims about video game play. Nevertheless, correlational and cross-sectional studies are often considered a good starting place to first establish whether any relationships exist between game play and cognitive function.

The third and last type of method is by designing experimental studies (sometimes called intervention studies or "true experiments"). In such studies, participants typically first complete an initial pretest of cognitive tasks. They are then assigned to either play an experimental video game or complete a control experience. The length of intervention (number of hours of video game play, total duration of the training) and the nature of the control experience can differ dramatically across studies. Sometimes the individuals in the control group play a different type of video game, sometimes they are asked to do a non-technology activity, such as reading a pamphlet, and sometimes they have no task at all. The massive differences that often exist between control experiences in the literature have been noted as a significant problem in integrating knowledge across studies (e.g., because studies that use weaker control experiences tend to produce larger experimental effects). Following the intervention, participants take a posttest—usually consisting of the same basic tasks as at pretest. Scores between the groups are then compared to determine whether exposure to the experimental game group led to differential improvements in cognitive task performance compared to the control group. Critically, experimental designs allow for causal inferences of video game play in improving (or hindering) cognitive performance.

Previous Analyses Assessing the Relation Between Video Game Play and Intelligence, Problem Solving, and/or Creativity

Several previous meta-analyses have examined the relations between video game play and higher cognition (Adams & Mayer, 2014; Bediou et al., 2018; Powers et al., 2013; Quiroga & Colom, 2019; Sala et al., 2018; Wang et al., 2016). However, the manner in which they have separated the constructs out has frequently varied. For example, Sala et al. (2018, p. 116) defined intelligence as "tests of fluid intelligence/reasoning (e.g., Raven's matrices) and comprehension/knowledge (e.g., verbal fluency)." In correlational studies, based on Cohen's definition of the strength of correlations (Cohen, 1988), they found that there was a small, but significant, positive correlation between reported video game play and intelligence. They also found small, nonsignificant differences between video game players and non-video game players in cross-sectional studies and between trained and untrained participants in intervention studies. Powers et al. (2013) grouped intelligence tests with executive functions tasks and reported a medium effect among cross-sectional studies ($d = 0.44$), and a small effect among intervention studies ($d = 0.16$). When reasoning tasks were separated from executive function tasks, there was a small, negative effect size ($d = -0.11$) of video game play on reasoning (Adams & Mayer, 2014). Bediou et al. (2018) found no significant effect of a specific genre of video game play—action-shooter video game (first- or third-person shooter video game)—on problem solving, despite reporting a robust medium effect size ($g = 0.55$) among cross-sectional studies of action-shooter play when considering all of the cognitive tasks. Similarly, Wang and colleagues (2016) found a medium effect ($d = 0.58$) of action-shooter video games on overall cognition among adults; as in Bediou et al., few of the studies included measures of intelligence, problem solving, or creativity. Finally, in a more recent work, Quiroga and Colom (2019) reported positive correlations between video game play and Stratum II indices of intelligence.

This chapter expands on these previous meta-analyses by further examining the effects of video games on intelligence, problem solving, and creativity. The following sections explore the extant correlational, cross-sectional, and experimental research between 2008 and 2020 on the effect of video games in each of these three domains. We provide first a brief overview of the research on video games specifically designed to target a specific higher cognitive skill (Stratum I), such as "brain training" or educational games. Video games with such focused design are theorized to produce only near transfer of cognitive skills; for example, a brain training game designed to train problem solving skills by improving performance on a gamified cognitive task is expected to transfer only to similar tasks (Mayer, 2014). We then focus on studies that used commercially available video games designed for entertainment to examine the impact of such rich experiences on Stratum II and III of intelligence measures, as well as on creativity. Video games that may be classified as both a brain training game and an entertainment game (e.g., Big Brain Academy by Nintendo) are included in the second section. While this second section includes all genres of commercial video games, it is important to note that video games vary greatly in terms of their content and gameplay mechanics, such as quick motor execution in action games or slower decision making in turn-based strategy games, which in turn, require the use of, or load onto, different cognitive skills. Thus, we should not expect the rich and complex experiences provided by the entertainment video game industry to have homogenous impact; rather, we will consider carefully lessons from the different game genres when it comes to enhancing intelligence, problem solving, and creativity with an eye toward informing the design of the next generations of games for impact.

Additionally, though problem solving ability could be argued to be involved in any tasks that fit in Stratum I of the Cattell-Horn-Carroll model of intelligence, such as those measuring attentional or perceptual abilities (Quiroga & Colom, 2019), we focus on problem solving tasks that fit within Stratum II categories of fluid intelligence, crystallized intelligence, and more complex visual perceptual tasks, such as mental rotation. As noted above though, the types of measures that researchers have considered as measuring aspects of intelligence, problem solving, and creativity differ enormously. We thus similarly took a broader view of possible measures in the review below, including, for instance, measures such as school grade point average (GPA) or standardized academic exams, like the Scholastic Aptitude Test (SAT), which may be impacted by video game play through the rather different mechanism of displacement whereby time spent on homework or test preparation is reduced due to video game play (Gnambs et al., 2020; Weis & Cerankosky, 2010).

Video Games Designed to Load on Stratum I Skills

Commercial brain training games are designed with the specific intention to improve certain cognitive skills. For example, Lumosity is composed of a set of mini-games focused on skills such as processing speed, memory, attention, and problem solving, many of which are based on existing cognitive tasks used to measure higher cognition (Simons et al., 2016). Though evidence of brain training video games tends to fall short of the claim that it will improve cognition in general, there is some evidence that these games can improve performance on tasks that are similar to those used in the training program. For example, Kesler and colleagues (2013) found that 20 hours of gameplay in Lumosity improved performance on the Wisconsin Card Sort Test, letter-fluency task, and a symbol-search task. In another study, participants who played Mind Frontiers for 40 hours improved on an n-back task and composite measures of perceptual speed and reaction time (Baniqued et al., 2015). However, other studies have found that brain training programs do not improve performance even on tasks similar to the training tasks (Bainbridge & Mayer, 2018; Owen et al., 2010). A review of brain training games concluded that though there is extensive evidence for improving performance within the games themselves, there is less evidence that such interventions improve performance on closely related tasks, and very sparse evidence for improvements on distantly related tasks (Simons et al., 2016).

Another set of focused video games that may seem more promising are educational video games, which are also intended to improve a specific set of skills, such as problem solving in a specific academic domain. For example, a large body of research on web-based games made by PBS KIDS has shown that the targeted skills within specific games have improved those skills on tasks outside of the game (Roberts et al., 2016, 2019). One PBS KIDS game called Fish Force, which was designed to teach physics concepts about force and trajectories, improved children's performance on physics problems outside of the game (Redman et al., this volume). In another example, a game called Measure Up! improved children's mathematical reasoning about measurement concepts (Schenke et al., 2020). In addition, a review of the effect of educational computer games found that video games improved skills particularly related to science and second language learning (Mayer, 2014). In sum, research on focused video games designed to train specific Stratum I skill shows that they can indeed improve the game's targeted skills, but there is less evidence suggesting that the games produce transfer beyond the particular skills utilized in the games themselves.

Entertainment Video Game Research

In contrast to focused video games, entertainment video games are not designed to improve a specific cognitive skill. Rather, the wide-ranging processing demands of commercial video games are predicted to train and improve higher cognitive skills to the extent that the game taps into those skills. In the sections below, we review the extant literature on the effects of commercial video game interventions on higher cognition.

Entertainment Video Games and Intelligence

Studies that examined the effects of video games on intelligence show mostly nonsignificant effects across correlational, cross-sectional, and experimental studies. First, for correlational studies, two out of six studies showed any significant correlation between a measure of video game experience and a measure of intelligence (Boot et al., 2013; Ferguson et al., 2013; Fikkers et al., 2019; Hambrick et al., 2010; Hartanto et al., 2016; Unsworth et al., 2015). For example, Unsworth et al. (2015) found that reported time spent playing what we label above as action games (e.g., Halo, Call of Duty) as well as what we label action-like games (e.g., God of War, Mario Kart) was significantly correlated with fluid intelligence (r = .23 for both types of games), which in this case was measured by a latent score of performance on the Raven's Advanced Progressive Matrices, letter sets, number series, and paper folding. However, time spent playing other specific genres or all genres was generally not related to intelligence as assessed by those same measurements (Boot et al., 2013; Ferguson et al., 2013; Hambrick et al., 2010; Hartanto et al., 2016).

In seven cross-sectional studies, evidence was split on whether there was an advantage for video game players over non-players on intelligence measures (Gnambs & Appel, 2017; Hartanto et al., 2016; Hisam et al., 2018; Latham et al., 2013; Llamas-Alonso et al., 2019; Strobach et al., 2012; Unsworth et al., 2015). Three studies showed that video game players had significantly higher fluid intelligence scores, measured by Raven's Advanced Progressive Matrices, letter sets, and number series (Unsworth et al., 2015) and general intelligence scores, measured by the Wonderlic Cognitive Ability Test and a composite score of a Raven-type task, Peabody Picture Vocabulary Test (PPVT, Salzburg Reading Screening, and a picture symbol test (Gnambs & Appel, 2017; Hisam et al., 2018), but four studies showed that there was no difference between video game players and non-players. Interestingly, studies that defined video game players as playing a minimum time of 7 or more hours per week showed a lower proportion of comparisons favoring video game players on intelligence measures (one of three studies) than studies that defined video game players as playing a minimum time of 1–6 hours per week (two of three studies). The other study, which found no difference between video game players and non-players, defined video game players based on the age of onset of play.

In intervention studies, four out of ten studies showed at least some benefit of a video game intervention on a measure of intelligence (Ang, 2016; Baniqued et al., 2014; Boot et al., 2013; Colom et al., 2012; Cujzek & Vranic, 2017; Libertus et al., 2017; Maillot et al., 2012; Marra, 2016; Minear et al., 2016; Shute et al., 2015). For example, Shute et al. (2015) found that playing Portal 2 led to improved performance on fluid intelligence, which included performance on the Remote Associates Test (RAT), Raven's Progressive Matrices, and an insight test, and improved performance on broad visual perception, which included performance on a mental rotation task, a spatial orientation task, and a virtual spatial navigation assessment, compared to Lumosity. Though some researchers consider the RAT a creativity task, in this study it was included in the composite score for fluid intelligence. In another study, playing a suite of Wii games for 24 hours improved performance on fluid intelligence and processing speed compared to playing no game (Maillot et al., 2012). Similar results found that playing Belote improved general intelligence (Cujzek & Vranic, 2017), and playing a mix of web-based games improved the intelligence construct of visual perception (Ang, 2016). Of the four studies that showed significant differences between groups, three used training lengths of 8 hours or shorter, while one study used a 24-hour training length.

Previous research has shown that intelligence is highly heritable and is relatively stable over the lifespan (Deary, 2014; Sauce & Matzel, 2018). However, intelligence is also malleable, and thus prolonged altered environmental experiences are likely to also contribute to intelligence. Although it may seem counterintuitive that a construct could be both strongly heritable while also being malleable through experience, consider, for instance, height, which is exceptionally heritable (on the order of 80%), and yet over the past 30 years, the average height of Japanese men has increased by around 4 inches (largely attributed to changes in diet; Grasgruber et al., 2016; Hermanussen et al., 2015). And indeed, theories of transfer that posit that cognitive skills learned in one setting should transfer to new situations that require similar cognitive skills in essence posit that intelligence can be enhanced (Mayer, 2014). Entertainment video games combine two key requirements to affect intelligence: they are typically played for extended periods of time, providing the necessary time on task for plastic changes to be expressed, and they immerse the player in a rich and complex experience in which “the faculty of adapting oneself to circumstances …. To judge well, to comprehend well, to reason well” are essentials (Binet & Simon, 1916, pp. 42–43). While entertainment video games have the potential to impact intelligence, the available literature remains scarce and documents only mixed evidence. In Unsworth et al. (2015), most reported measures of video game experience were not related to intelligence, except for the times spent playing action-like and action-shooter games which were specifically and positively correlated with fluid intelligence. The extent to which this relationship may be mediated by the faster processing speed witnessed as a result of action-shooter video game play remains unknown (Dye et al., 2009; Green et al., 2010).

Entertainment Video Games and Problem Solving

The findings from correlational, cross-sectional, and experimental research on video games and problem solving are discussed below. Overall, eight out of 12 studies that examined correlations between previous video game experience (as measured by number of hours per week or frequency of play on a Likert-type scale) and performance on a problem solving task found at least one significantly positive correlation whereby greater gaming experience was associated with better problem solving performance (Adachi & Willoughby, 2013; Blanco-Herrera et al., 2019; Dindar, 2018; Gnambs & Appel, 2017; Hambrick et al., 2010; Jackson et al., 2011; Lieury et al., 2016; Przybylski & Wang, 2016; Richardson et al., 2011; Rodán et al., 2016; Suziedelyte, 2015; Unsworth et al., 2015). For example, Gnambs and Appel (2017) found that the number of hours reported playing strategy video games was significantly correlated with performance on a vocabulary task ($r = 0.10$) and Raven's Advanced Progressive Matrices ($r = 0.10$), both of which were also used as subtasks of composite intelligence scores. Interestingly though, five studies found at least one significantly negative correlation (i.e., more gaming experience associated with worse problem solving performance). For example, Jackson and colleagues (2011) found that the number of hours reported playing video games of all genres was negatively correlated with school GPA ($r = -0.20$ and $r = -0.24$ at two timepoints), which can be considered a Stratum I task nested under crystallized intelligence in the Cattell-Horn-Carroll model. Across the total number of correlations, there were 18 significant positive relationships, nine significant negative relationships, and 72 nonsignificant results. Such a pattern suggests that video game experience, broadly construed, may be related to a few problem solving tasks, but is not strongly related to problem solving at large.

The pattern of results above, though, is an apt illustration of two major issues with many previous examinations of the literature. First, a great deal of previous work in this sphere has considered all video games to be equivalent, which is clearly not appropriate. Indeed, no theoretical framework in the field would predict that time spent playing the video game Flappy Bird (an arcade game where one should press a single button in order to move a bird up or down on the screen) would have the same relations with problem solving as time spent playing the video game Portal 2 (widely recognized as one of the best commercial puzzle/problem solving video games of all time). Yet, many studies have made this critical error (i.e., they have asked individuals about the amount of time they "spend playing video games"). Second, because the cognitive constructs themselves are poorly and inconsistently defined, the measures that are purported to assess "problem solving" may not in fact load together (e.g., number series task and school GPA).

Consistent with these suppositions, the pattern of relationships between video game play and problem solving appears to differ based both upon the type of problem solving tasks used as well as the type of video games considered. For example, the most common problem solving measures were matrix-type tasks (22), such as Raven's Progressive Standard and Advanced Matrices. These had the highest proportion of significantly positive correlations with gaming experience (23%; $r = 0.10–0.26$). On the other hand, academically related measures, such as grades or knowledge tasks, were only occasionally positively correlated with previous game experience (10%, $r = 0.13$), and were more often negatively related to previous game experience (40%, $r = -0.17$ to -0.10) than other problem solving tasks (0–18% negative correlations; $r = -0.16$ to 0.02). The detrimental effect of video game play on grades or knowledge task is well aligned with work documenting that the presence of video game systems in the household often serves to displace homework or other academically-oriented after-school activities (Gnambs et al., 2020; Weis & Cerankosky, 2010). Such a displacement hypothesis may explain why school-related measures may show a negative relation with video game play while measures of more core cognitive functions, that would not be similarly impacted by such simple time displacement, show a positive relation (e.g., fluid intelligence and problem solving). Similarly, the proportion of positive/null/negative relationships also differed based on specific genre of video game experience. For example, 38% of the correlations between previous experience with strategy games and problem solving were significantly positive ($r = 0.10–0.22$), compared to 27% for mixed or unspecified genres ($r = 0.02–0.45$), and 29% for shooter games ($r = 0.14–0.18$). Gambling, sports, and music video games had the highest proportions of significant negative relationships with problem solving (50–66%; $r = -0.16$ to -0.10).

Similarly, performance in specific games or game genres was sometimes correlated with performance on problem solving tasks (Adams & Mayer, 2012, Adams et al., 2016; Buford & O'Leary, 2015; Foroughi et al., 2016; Shute et al., 2015). For example, a player's rank in League of Legends was correlated with deductive reasoning as measured by an odd-one-out task, in which participants found the set of shapes that was the most different from the others (Large et al., 2019), as well as a matrix reasoning subtest of the WAIS (Kokkinakis et al., 2017). Note that the researchers considered this single matrix task to measure fluid intelligence, rather than problem solving, exemplifying the often tenuous distinction between these terms—intelligence and problem solving—in the existing literature. Additionally, performance in the game Portal 2 was positively correlated with more problem solving tasks (50%) than Unreal Tournament (25%), Tetris (11%), and TextTwist (0%), in line with the view that not all video games equally impact problem solving.

Relative to the correlational studies, cross-sectional studies had a smaller proportion of positive results; across 14 studies, only five found at least one comparison showing that video game players significantly outperformed non-players on some measures of problem solving, and two showed the opposite results (Boot et al., 2008; Colzato et al., 2013; Colzato et al., 2010; Foroughi et al., 2016; Gnambs & Appel, 2017; Novak & Tassell, 2015; Özçetin et al., 2019; Ruiz et al., 2010; Schenk et al., 2017; Schubert et al., 2015; Steenbergen et al., 2015; Strobach et al., 2012; Unsworth, et al., 2015; Zaparyniuk, 2006).

Across all studies, there was a greater proportion of positive comparisons favoring video game players over non-players on a problem solving task (40%), such as a mental rotation task in which participants identified figures that were a rotated version of the target figure, and the Peabody Picture Vocabulary Test (Gnambs & Appel, 2017; Novak & Tassell, 2015), than negative comparisons (8%), such as the California Verbal Learning Test, which involved learning and remembering a list of words (Özçetin et al., 2019), but about half were nonsignificant (52%). Video game player definitions differed substantially between these studies however. Critically, and consistent with many of the observations above reporting correlations between reported length of game play and problem solving, studies that defined video game players as playing a minimum of 7 or more hours per week showed a higher proportion of comparisons favoring video game players on problem solving tasks (38%) than studies that defined video game players as playing a minimum of 1 to 6 hours per week (29%).

In experimental studies, eight out of 19 studies found that a video game intervention led to more improvements on at least one problem solving task compared to active or passive control groups (Adams et al., 2016; Baniqued et al., 2014; Basak et al., 2008; Bejjanki et al., 2014; Boot et al., 2008; Buelow et al., 2015; Colom et al., 2012; Emihovich et al., 2020; Libertus et al., 2017; Maillot et al., 2012; Marra, 2016; Masson et al., 2011; Minear et al., 2016; Nouchi et al., 2013; Novak & Tassell, 2015; Pilegard & Mayer, 2018; Shute et al., 2015; Valadez & Ferguson, 2012; Whitlock et al., 2012). However, out of 60 comparisons across these studies, 44 resulted in no differences between experimental and control groups across all problem solving tasks. Puzzle games tended to improve problem solving skills more often than other genres. For instance, in eight studies that included at least one puzzle game, four studies (50%) showed that playing a puzzle game improved problem solving more than another game or passive control group. For example, Shute and colleagues (2015) found that playing Portal 2 for a total of 8 hours improved performance more than playing a brain training control game on an insight test, mental rotation task, and the virtual spatial navigation assessment, in which participants must find a set of gems within a 3D environment. However, another study found that playing Tetris for 4 hours led to worse improvement on a card rotation task and number comparison task than an inactive control group (Pilegard & Mayer, 2018). Studies using strategy (33%) and shooter (20%) game interventions showed lower proportions of significant improvements of those game groups compared to control games or passive controls. Interestingly, based on training length, the eight studies that provided evidence of video game play improving problem solving used an intervention length of either 8 or fewer hours or 21.5 or more hours; training lengths between 10 and 20 hours of training did not lead to significant differences between groups. Such a U-shaped curve as a function of training duration is at odds with most, if not all, theoretical framework about cognitive interventions. While some researchers have found a positive linear relationship between video game intervention duration and effect size (Bediou et al., 2018), others have found a negative relationship (Wang et al., 2016).

In sum, our review suggests that the base question, "Is video game playing related to problem solving ability?" is ill-posed; it has no unique solution. Instead, several patterns of moderating factors, such as type of task and game genre, emerged. Video game experience was more often positively correlated with problem solving when measured by matrix-type tasks, and when considering strategy game play specifically. Strategy games, such as StarCraft and Rise of Nations, may tap into abilities related to problem solving more so than other game genres. Video game players who reported playing more than 7 hours a week were also more likely to outperform non-player controls compared to video game players who play fewer hours per week, and puzzle game interventions such as Portal 2, were more likely to improve problem solving compared to other genres. It is important to note that the puzzle genre varies significantly, and it is unclear whether the effects would be similarly seen across puzzle games.

Entertainment Video Games and Creativity

The effect of video games on creativity has been seldom addressed. The evidence is mixed across all types of research. Between two correlational studies, the number of self-reported hours of playing video games was positively correlated with performance on the Torrance Test of Creative Thinking (TTCT) in one study (Jackson et al., 2012), but was largely negatively correlated with the TTCT in another study (Hamlen, 2009). Blanco-Herrera and colleagues (2019) found that while frequency of video game play was correlated with self-reported problem solving ability, it was not related to performance on the Alien Drawing Task (in which participants are asked to draw an alien from another planet and given a score based on the extent to which their drawings differ from creatures on earth across several dimensions—e.g., number/location of sensory organs), the Alternate Uses Task, and the Remote Associates Task (in which three words are presented and the participant must determine the fourth word that links the first three words). Additionally, performance in Portal 2 was not related to performance on the Remote Associates Task (Shute et al., 2015). Only one cross-sectional study was identified, which found that video game players performed better than non-players on one subtest of TTCT (Gackenbach & Dopko, 2012).

Among the four intervention studies available at this point in time in the literature, two studies report a null effect and two a positive effect of the experimental video game. Importantly, each of these studies used an active control group also required to play video games but of different genres. Shute and colleagues (2015) found no group differences in creativity between Portal 2 and Lumosity. Similarly, Moffat and colleagues (2017) found no group differences in creativity between groups that play Portal 2, Serious Sam, and Minecraft. These two studies indicate equal impacts of the experimental and control games on creativity. However, overall, participants improved their creativity from pretest to posttest after playing Portal 2, Serious Sam, and

Minecraft (Moffat et al., 2017). On the other hand, Yeh (2015) found that playing Light Heroes improved creativity more than playing Clusterz on the Idea Generation Task, and Blanco-Herrera and colleagues (2019) found that playing Minecraft improved creativity more than playing NASCAR on the Alien Drawing Task and on one measure in the Alternate Uses Task. The specificity of these effects prevents any form of conclusion, but already makes clear the potential for different video game titles to have different impact on creativity, calling for a differentiated and more granular approach to the issue.

Discussion and Future Directions

The literature reviewed revealed mixed findings of the effects of video game play on intelligence, problem solving, and creativity. When considering all video games and all possible measures of the higher-level constructs together, relations were frequently weak or null. Yet, across all three types of studies considered—correlational, cross-sectional, and experimental—patterns of heterogeneity in the study design suggest that more nuanced work may be warranted in the future.

One clear area of need is for studies examining relations between video game play and higher cognitive abilities to differentiate between types of games played, rather than considering all games together. This has been a key aspect of the literature that focuses on the impact of video game play on perceptual and attentional abilities (Dale & Green, 2017a). It has been strongly argued that game-types that load on pacing, divided attention, and swift shifts in attentional states are those that are most likely to produce long-term enhancements in perception and attentional abilities. This has led researchers to differentiate between "action video games" (which do strongly load upon these capabilities) and other game types that load less or not at all on those abilities (Cardoso-Leite et al., 2020; Green et al., 2017).

There is currently less existing theory linking particular types of game mechanics with intelligence, problem solving, and/or creativity. But it appears key to move forward the field to ask what types of game elements strongly load upon intelligence/problem solving/creativity and which video game titles or genres possess those elements. The existing literature does point in some directions that may be useful when building such theory. For instance, while correlational studies that considered all games together frequently found null relations with problem solving, self-reported previous experience with one particular type of game, strategy games, appeared more likely to be positively related to problem solving. Strategy games, such as StarCraft and Rise of Nations, which often require decision tree-type thinking that highly influences the outcome of the game, may tap into abilities related to reasoning and decision making, processes involved in problem solving, to reach a correct solution more so than other game genres. Similarly, Unsworth et al. (2015) found that while time spent playing most game types was not related to measures of intelligence, the time spent playing action and shooter video games specifically was correlated with fluid intelligence. This may reflect either the known relation between speed of processing and intelligence or the ability to extract patterns from statistical data and intelligence, as both of these are known outcomes of action video game play (Bejjanki et al., 2014; Dye et al., 2009; Green et al., 2010). Finally, in intervention studies, both puzzle games (such as Portal 2) and what are known as "MOBA" games (multiplayer online battle arena games; which are a hybrid of action games and real-time strategy games) were the most likely to be associated with improved problem solving and intelligence. Here is it important to note that the term "puzzle games," while commonly used in both research examining links between video game play and cognitive function, and more generally when describing video games, may not in fact be an appropriate category in terms of load upon cognitive constructs. Indeed, many of the effects attributable to "puzzle games" utilized the specific game Portal 2. It is thus, in many cases, unclear whether similar effects would be seen for all puzzle games, which is an extremely broad category that in many categorization schemes includes logic games (like Minesweeper), physics/collision games (like Angry Birds), and tile-matching games (like Candy Crush).

Specifying hypotheses about the very video game mechanics needed, starting with game elements that load upon the key higher cognitive constructs, and moving to games that strongly instantiate or possess those elements would allow for a considerably stronger test of theory. In particular, the theory of general transfer of specific skills posits that repeated practice of a cognitive skill in one situation, such as a specific video game, should transfer to other non-video game situations, such as tasks measuring problem solving, to the extent that the video game and task require the use of the same underlying cognitive skill (Mayer, 2014). Therefore, it is important to examine the specific elements within each game or genre and the cognitive skills they should load onto. It is simply not sensible to lump all games together, as few researchers would put forth the hypothesis, for example, that playing Solitaire on a computer would increase intelligence (despite Solitaire nominally being a "video game").

A second major direction in need of future work is more specification in terms of the links between measures and the constructs they are meant to represent. For example, with respect to intelligence, there were significant inconsistencies in outcomes between studies that utilized matrix tasks or letter/number set tasks as their measure of intelligence (where positive relations with game play were often found) as compared to studies that utilized academic-based measures (where nulls or even negative relations were often found). Similarly, in at least one case within the same study, researchers found that video game experience was related to one problem solving task, but not others (e.g., Unsworth et al., 2015). Making clear the links between measures and constructs is of particular importance when the measures are likely to be impacted by the simple fact that video game play is known to displace time spent elsewhere, such as on schoolwork or test preparation.

When interpreting results, it is also important to consider the validity, reliability, and fairness of the various measures of higher cognition used (American Educational Research Association, American Psychological Association, & National Council on Measurement in Education, 2014). Research on video games and higher cognition is still an emerging field, and the field is lacking in these three aspects so far. Regarding validity, task developers and researchers should establish clear intended uses of tasks and provide theoretical bases for the cognitive constructs they are measuring. For example, as mentioned throughout the chapter, Raven's Progressive Matrices is sometimes used as a measure of problem solving and other times as a measure of fluid intelligence, which may not be in line with how the Stratum II construct of fluid intelligence is presented in the Cattell-Horn-Carroll model. Establishing construct validity for this task would be important in continuing with research on examining higher cognition. Additionally, reliability of tasks should be assessed and provided; this is not yet systematically so when new measures of intelligence, problem solving, or creativity are introduced in the context of cognitive studies, calling for a greater collaboration with experts in the domain of intelligence. Finally, in ensuring fairness of testing these higher cognitive constructs, steps should be taken during test design, validation, administration, and scoring to minimize barriers to valid score interpretation for the intended population. For example, intelligence battery subtests that rely on prior knowledge, such as vocabulary, are often critiqued as not being culturally fair.

A number of other areas related to methodology diverged significantly across studies, which may be useful for future meta-analyses to consider (i.e., in examining the impact of the heterogeneity), but may also call for some consensus to be reached in the field. For instance, in cross-sectional studies, there is currently no agreed-upon definition for what constitutes a "video game player" or a "non-player." Definitions of video game players in the literature considered ranged from playing "action or fast-paced games on a weekly basis" (Novak & Tassell, 2015) to playing video games for a minimum of 8 years and 20 hours per week for the last 6 months (Latham et al., 2013). Furthermore, the way that video game experience has been measured also differs considerably across studies (e.g., in some, the number of hours played across all video games combined was measured, while in other cases, time spent playing was separated out by genres defined by the researcher). Moving from self-report measures of game play to quantitative measures (e.g., given by gaming systems) may significantly improve the accuracy of measures along with more standardization in scales (Dale et al., 2020).

Within intervention research, a host of reasonably key methodological elements differed across studies. These include the length of video game training, whether an active or passive control group was used, random assignment, and participant/experimenter blinding (Green et al., 2019). The effect of the length of the intervention studies reviewed here interestingly suggests a U-shaped curve in which shorter and longer training lengths improve cognitive task performance, whereas lengths in the middle do not. However, these patterns were based on very few studies in both intelligence and problem solving literature and would require purposefully designed intervention studies to confirm. Intervention studies reviewed here may have also been underpowered. Based on previous meta-analyses of the effect of video games on higher cognition, with effect sizes ranging from $d = 0.16–0.58$, a minimum of 47 participants per comparison group would be needed to confidently detect effects. However, almost all intervention studies reviewed had fewer than that. This is particularly pertinent in the case of null results, as many nulls could simply reflect the fact that the study was underpowered. Additionally, only a handful of studies have examined long-term effects of video game play and higher cognition with follow-up tests after the intervention has concluded; for example, Cujzek and Vranic (2017) found that the improvements of playing a card game, Belote, were sustained 4 months after training. Long-term effects of cognitive interventions would have strong practical implications, particularly in populations that could benefit the most, such as older populations, so it would appear crucial to examine these effects in future works.

In sum, the time is ripe to unravel the impact of video game play on higher cognition. Existing research makes clear that a careful consideration of the different video game genres most likely to load upon intelligence, problem solving, and/or creativity during game play is in order. The rich and complex video games available in the entertainment industry provide the most promising guidelines as to the factors a video game experience should encompass to enhance higher cognition. In the years to come, the study of game mechanics specifically in terms of how they place load upon high cognitive skills should continue guiding the development of a theoretical framework about the game design factors that foster higher cognition. The existing literature also highlights the importance of considering separately outcomes at the level of Stratum II and III of intelligence that rest firmly upon transfer from outcomes at the Stratum I level, where time training on similar tasks appears sufficient to cause improvements. For such Stratum I outcomes, we illustrated how video games can either act as providing time on task, or on the contrary, distract from time on task as illustrated by the displacement hypothesis. These opposite results are theoretically predicted once the exact relationships between expected outcomes and higher cognitive skills loaded by the video game experience are properly specified. It is only by incorporating these more fine-grained considerations that future research can help elucidate the relationships between video game play and higher cognition.

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