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EMPIRICAL RESEARCH

More Than Just Fun and Games: The Longitudinal Relationships Between Strategic Video Games, Self-Reported Problem Solving Skills, and Academic Grades

Paul J. C. Adachi · Teena Willoughby

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Abstract Some researchers have proposed that video games possess good learning principles and may promote problem solving skills. Empirical research regarding this relationship, however, is limited. The goal of the presented study was to examine whether strategic video game play (i.e., role playing and strategy games) predicted self-reported problem solving skills among a sample of 1,492 adolescents (50.8 % female), over the four high school years. The results showed that more strategic video game play predicted higher self-reported problem solving skills over time than less strategic video game play. In addition, the results showed support for an indirect association between strategic video game play and academic grades, in that strategic video game play predicted higher self-reported problem solving skills, and, in turn, higher self-reported problem solving skills predicted higher academic grades. The novel findings that strategic video games promote self-reported problem solving skills and indirectly predict academic grades are important considering that millions of adolescents play video games every day.

Keywords Problem solving · Academic performance · Video games · Adolescent development

Introduction

Video games are the fastest growing form of entertainment in the world, with a global market value of $67 billion in 2010 and a predicted value of $112 billion by 2015 (Biscotti et al. 2011). In fact, video game play has become ubiquitous among adolescents as 97 % of American adolescents aged 12–17 years play computer, web, portable or console video games (Lenhart et al. 2008; see also Gentile 2009). In terms of frequency, 31 % of adolescents play video games every day and another 21 % play games 3–5 days a week. In spite of the importance of video game play to adolescents, however, over the past few decades psychologists have focused primarily on the link between video game use and negative outcomes, such as addiction and aggression (see Anderson et al. 2010, but also Ferguson and Kilburn 2010 for criticisms of this work), at the expense of research on positive outcomes (see Adachi and Willoughby 2012).

Only recently have researchers begun to investigate some positive outcomes of video game play. For example, researchers have examined the relationship between video games with prosocial content and subsequent prosocial behavior in experimental (e.g., Greitemeyer and Osswald 2010), and correlational studies (e.g., Ferguson and Garza 2011; Gentile et al. 2009). In addition, some researchers have argued that, although most video games are not designed to be educational mediums, they possess many good learning principles (Gee 2008; Squire 2007). For example, researchers recently have shown that video games may be effective cognitive training tools (i.e., video games can encourage the practicing of certain cognitive skills) for executive control functions and visual and attentional skills among both young (Green and Bavelier 2006) and older adults (Basak et al. 2008) (see Green and Bavelier 2008 for a review). Furthermore, Gee (2005) suggests that video games can promote problem solving skills, such as when games encourage players to stop, thoroughly explore different possibilities, and consider new strategies and goals before moving on, rather than simply progressing toward

P. J. C. Adachi (✉) · T. Willoughby
Department of Psychology, Brock University, St. Catharines, ON L2S 3A1, Canada
e-mail: pa08fg@brocku.ca

their goal as fast as possible. Problem solving is important, as it is related positively to academic performance (e.g., D'Zurilla and Sheedy 1992). To date, however, empirical research on the link between video game play and problem solving skills is limited. Specifically, no studies exist in which researchers have examined whether video game play predicts higher problem solving skills. Furthermore, considering that problem solving skills may be slow to develop and require repetitive practice (Kinney 1952), it is important to examine this association longitudinally. Indeed, we need to address questions of whether video game play at one point in time predicts problem solving skills at a later point in time, and whether sustained video game play over many years is associated with faster increases in problem solving skills over time than less sustained game play. Moreover, the direction of effects between video game play and problem solving skills has not been investigated (Boot et al. 2011). That is, it is not clear whether video games predict higher problem solving skills (i.e., cognitive training effect) or whether individuals who have better problem solving skills are more likely to play video games (i.e., the selection hypothesis).

It also is important to test whether video games indirectly predict higher academic performance over time through elevations in problem solving skills. To date, researchers have focused mainly on a negative relationship between time spent playing video games and academic performance (e.g., Weis and Cerankosky 2010), while research demonstrating a positive link between video games that involve problem solving and academic performance is scarce (note that this does not include research focusing on the link between educational or serious games and academic performance). Thus, the goal of the present study was to examine the predictive relationship between playing video games that involve problem solving and problem solving skills among adolescents over the four high school years, as well as to test an indirect association between video game play, problem solving skills and academic performance.

Video Game Play and Cognitive Training

Recently, video games have been recognized as an effective cognitive training paradigm for executive control functions (Basak et al. 2008) as well as several visual and attentional skills (Green and Bavelier 2003, 2006). Cognitive training is thought to lead to an improvement in cognitive performance over time (Green and Bavelier 2008). Furthermore, improvements in cognitive performance are usually specific to the particular domain that was trained (e.g., Ball et al. 2002). For example, cognitive training that targets attentional skills may improve attentional, but not memory or problem solving skills. Evidence for the benefits of video game play for cognitive training come from Green and Bavelier (2006) who conducted a series of experiments with young adults in which they examined differences between video game players versus non-video games players on a multiple object tracking task, which required participants to attend to several objects over time. Green and Bavelier found that video game players were able to attend to more objects than non-video game players, and they concluded that this difference in attentional skills may be mediated by elevations among video game players in their visual short-term memory skills. In contrast, research on video games as cognitive training tools for problem solving skills has not been explored. Moreover, any research to date on the link between video game play and cognitive skills has been solely concurrent, and thus the direction of effects (i.e., cognitive training effects versus selection effects) is unclear (Boot et al. 2011). Thus, longitudinal research is needed to elucidate the direction of long-term effects.

Video Game Play and Problem Solving

To date, only a few studies have addressed the link between video game play and problem solving. For example, Steinkuehler and Duncan (2008) examined whether discussion forums for the role playing video game *World of Warcraft* (*WoW*) showed evidence of scientific thought. They found greater evidence of "social knowledge construction" than social banter, as well as evidence of systems-based reasoning and even a small amount of model-based reasoning. However, due to the nature of the study, it was unclear whether playing the role playing game *WoW* in particular was related to higher levels of scientific thought, or whether discussion forums for different genres of games such as first-person shooters or action games also contain similar content. Furthermore, if playing *WoW* was related to higher levels of scientific thought, then it is unclear whether playing *WoW* led to higher levels of scientific thought (cognitive training effect), or whether people with higher levels of scientific thought are more likely to play *WoW* (selection effect).

Researchers also have found a relationship between video game play and persistence when solving problems. Ventura et al. (2013) had undergraduate participants self-report about their video game playing behaviors, and then complete a performance-based measure of persistence, which entailed a series of anagrams and riddles. Persistence was operationalized as the amount of time spent on unsolved anagrams and riddles. Ventura et al. (2013) found that frequent video game players spent significantly longer amounts of time working on unsolved anagrams and riddles, compared to infrequent video game players. Thus, they concluded that persistence during video game play also may be applied to other forms of problem solving. However, the direction of effects is unclear, as it is equally plausible that people who tend to persist longer in problem solving tasks are more likely to play video games.

In terms of evidence of strategy use during video game play, Blumberg et al. (2008) conducted a study in which they told adult video game players to think aloud when playing the adventure video game, *Sonic the Hedgehog 2*. Blumberg et al. found that frequent video game players were more likely to make comments reflecting insight (e.g., discovering a novel method or approach) and game strategies (e.g., which specific moves to use to defeat certain types of enemies) compared to non-frequent video game players. However, although frequent video game play may be related to greater insight and strategy use when playing video games, it is unclear whether such insight and strategy use during video game play predicts higher levels of problem solving skills in general.

Video Game Play and Academic Performance

The majority of research regarding video game play and academic performance has been focused on the link between time spent playing video games and negative academic outcomes. For example, Anderson and Dill (2000) conducted one of the first studies on this relationship and found that the overall amount of time spent playing video games was related negatively to academic achievement among undergraduate students (but also see Ferguson 2011 for a concurrent study that did not find an association between video game play and academic performance). Similarly, Skoric et al. (2009) found a concurrent negative association between pathological video game play (i.e., addiction tendencies) and academic performance among elementary school students, although they did not find a significant association between time spent playing and academic performance, or between video game engagement and academic performance (see also Willoughby 2008). In addition, Weis and Cerankosky (2010) conducted an experiment with a sample of elementary school students who did not own a video game system. Half of the participants were given a video game system, while the other half were not, and then follow-up measures were completed 4-months later. They found that participants who received the video game system spent more time playing video games and less time in after-school academic activities than the participants who did not receive the video game system. Furthermore, participants who received the video game system had lower reading and writing scores as well as more teacher-reported academic problems at follow-up than participants who did not receive the video game system. Thus, people who spend more time playing video games may have less time to engage in academic activities (e.g., studying), and thus may perform worse academically compared to people who spend less time playing video games. In contrast, video games that involve problem solving may indirectly predict greater academic performance, because they may predict higher levels of problem solving skills, and, in turn, higher levels of problem solving skills may predict greater academic performance.

The Current Study

Strategic Video Games and Problem Solving

Consistent with research showing that cognitive training may only improve skills that are specific to the cognitive domain that was trained (Ball et al. 2002), we hypothesized that only certain types of video games may predict increases in problem solving skills. Strategy games may teach the player to first gather information and think of a strategy before attempting to solve a problem. For example, in *Splinter Cell* the main character is a black-ops agent and the goal is to use stealth and remain undetected by enemies when completing missions. Unlike most action and shooter games in which the player rushes toward enemies with guns blazing, in *Splinter Cell* the player often must remain hidden by moving slowly and carefully in the shadows and creating diversions to distract enemies. For example, when approaching enemies, the player must study the scene, gather information about how the enemies move, and formulate a plan regarding when and how to attack without being detected. Such a strategy often involves waiting to attack once the enemy has moved to a remote location, and then hiding the enemy's body in the shadows. Considering that this form of problem solving (i.e., gain information, weigh different options, and formulate a strategy before acting) is repeated at every level of the game, sustained playing over time may increase the player's problem solving skills.

Role playing games also may increase problem solving skills by teaching players to first gather information and think of a strategy before trying to solve a problem. For example, in *WoW*, when a group of players battle a large monster called a "boss," their initial goal is often to gain as much information about the boss as possible, such as specific fighting abilities and how the boss maneuvers during combat. Then, the players discuss this information and formulate a battle strategy prior to attacking. Because this problem solving sequence is repeated every time the player battles a different boss, sustained playing of role playing games over time also may increase players' problem solving skills.

Fast-Paced Video Games and Problem Solving

In contrast to strategic video games, more fast-paced games such as fighting, action, and racing games may not predict increased problem solving skills over time. For example, fighting and action games involve immediately attacking enemies with little down time between battles, and racing games encourage constant fast-paced driving and maneuvering throughout each race. Although players can formulate or adapt a strategy while playing these games in a more spontaneous trial-and-error fashion, there is little to no opportunity to gather information and strategize *before* a battle or a race. In other words, fast-paced games may not contain the same problem solving sequence that can be found in strategic video games (i.e., encouraging the player to stop, thoroughly explore different possibilities, and consider new strategies and goals before moving on), and thus playing fast-paced video games may not increase players' problem solving skills.

It is especially important to examine cognitive training effects of video game play on problem solving skills among adolescents, as the executive function of inhibitory control is still developing during adolescence (Kuhn 2009). Specifically, when faced with a problem, adolescents may have more difficulty inhibiting their initial response in order to carefully consider different strategies compared to adults, and thus they may be more likely to use the first strategy that comes to mind. In contrast, adults tend to have more developed inhibitory control, and thus may be more likely to inhibit their initial response so that they can weigh different options, and then choose the most effective strategy (see Kuhn and Pease 2006). Thus, it is crucial to identify activities that predict higher problem solving skills among adolescents in order to promote the development of inhibitory control.

To address our hypotheses, we examined whether sustained playing of strategic games (i.e., role playing and strategy), but not fast-paced games (i.e., fighting, action, and racing), predicted an increase in self-reported problem solving skills across the high school years. Next, we simultaneously assessed cognitive training and selection effects. In addition, we examined whether strategic video games were indirectly related to academic grades through self-reported problem solving skills. Three demographic variables (gender, parental education, and number of computers in the home) were included as covariates. Finally, given that boys are more likely to play video games than girls, we also assessed whether gender was a significant moderator of the results. This question was exploratory and thus we did not have specific predictions.

Method

Participants

Students from eight high schools encompassing a school district in Ontario, Canada took part in the study in grades 9, 10, 11, and 12 (*M* age in grade 9 = 13 years, 10 months). This study was part of a larger cohort-sequential project. In the larger study, surveys were completed five times between 2003 and 2008, with some students starting the study in 2003 and others starting the study in 2004. The analyses for the present study are based on the cohort of students who entered the study in Grade 9 in 2004 and completed the survey in Grades 9, 10, 11, and 12, as this was the only cohort that was surveyed on all the measures pertinent to the study (i.e., a Likert-type scale distinguishing between the frequency of strategy and fast-paced video game play was included only in the 2007 and 2008 surveys when this cohort of students was in Grade 11 and Grade 12, respectively).The overall participation rate ranged from 83 to 86 % across the four waves; nonparticipation was due to student absenteeism (average of 13.5 %), parental refusal (average of .06 %), or student refusal (average of 1.4 %). Student absenteeism from class was due to illness, a co-op placement, a free period, or involvement in another school activity. Consistent with the broader Canadian population (Statistics Canada 2001), 92.4 % of the participants were born in Canada and the most common ethnic backgrounds reported other than Canadian were Italian (31 %), French (18 %), British (15 %), and German (12 %). Data on socioeconomic status indicated mean levels of education for mothers and fathers falling between "some college, university or apprenticeship program" and "completed a college/apprenticeship/technical diploma." Furthermore, 70 % of the respondents reported living with both birth parents, 12 % with one birth parent and a stepparent, 15 % with one birth parent (mother or father only), and the remainder with other guardians (e.g., other relatives, foster parents, etc.).

Only students who completed the survey at a minimum of 2 time points over the four waves were included, resulting in 1,492 participants (50.8 % female), or 84 % of the total sample of 1,771 adolescents. Participants who completed the survey only in grade 9 reported significantly lower academic grades than the longitudinal participants ($p < .001$; mean difference of .41; $r^2 = .21$, 95 % CI [.17, .24]. There were no other significant differences between the two groups. Missing data resulted from absenteeism and because some students did not finish the entire questionnaire (10.6 % of the data, consistent with other longitudinal survey studies; e.g., Ciarrochi et al. 2009; Feldman et al. 2009; Hyde and Petersen 2009). We included three versions of the survey at each time period so that the same scales were not always near the end of the survey. As missing data were not dependent on the values of the study measures, it is reasonable to assume that this data is missing at random (Little and Rubin 2002; Schafer and Graham 2002), and maximum likelihood estimation (MLE) was used to estimate the models in AMOS 19 (Arbuckle 1995–2012).

Procedure

Active informed assent was obtained from the adolescent participants. Parents were provided with written correspondence mailed to each student's home prior to the survey administration outlining the study; this letter indicated that parents could request that their adolescent not participate in the study. An automated phone message about the study also was left at each student's home phone number. This procedure was approved by the participating school board and the University Research Ethics Board. At all time periods, the questionnaire was administered to students in classrooms by trained research staff.

Measures

All measures were assessed across all four grades of high school (i.e., grades 9 through 12) except for the demographic variables that only were assessed in grade 9.

Demographic Factors

Single-item questions were used to assess participants' sex and the number of computers in the home. Parental education was an average of two items (one per parent, $r = .58$). Higher scores indicated female gender, more computers, and greater parental education (1 = did not finish high school to 6 = professional degree).

Strategic and Fast-Paced Video Game Play

Prevalence of strategic video game play was assessed at each of the four time periods. Participants were asked to indicate *yes* or *no* to whether they played strategic (average of two items, i.e., role playing, strategy) and fast-paced (average of three items, i.e., fighting, action, racing) video games. An index of sustained play was created for both strategy and fast-paced video games by calculating the ratio of number of waves in which the participant reported playing strategic and fast-paced video games to the total number of waves that the participant completed (see Willoughby et al. 2011). This index ranged from 0 (e.g., never played strategy games during any of the high school grades) to 1 (played strategy games during all of the high school grades). For example, of participants who completed 4 waves, those who indicated playing strategic video games during 3 waves received a sustained play score of .75. When participants were in grades 11 and 12 only, frequencies of both strategic (i.e., role playing, strategy) and fast-paced (i.e., fighting, action, racing) video game play also were assessed (1 = *not at all* to 5 = *5 or more* hours on an average day).

Self-Reported Problem Solving Skills

Self-reported problem solving skills were assessed using 5 items (e.g., "I think hard about what steps to take" and "I think about the choices before I do anything" and "I tell myself 'Stop and think before you do anything'") based on a 5-point scale (1 = *never* to 5 = *usually*), and adapted from Wills et al. (1996). Cronbach's alpha ranged from .87 to .93 across the four grades.

Academic Grades

Participants were asked to report their typical school grades for the past year based on a 5-point scale (1 = below 50 % to 5 = 80 % or higher).

Results

Preliminary Analyses

Table 1 outlines the means and standard deviations for the study variables. All measures showed acceptable skewness and kurtosis. In terms of the demographics, half of the participants were female, and participants averaged three computers in the home. In addition, the average parent of participants had completed some college, university or apprenticeship program. A significant multivariate main effect for gender was found at each grade (all Wilks λs $< .001$, r^2 ranging from .20, 95 % CI [.16, .24] in grade 9 to .28 95 % CI [.24, .32] in grade 12). Overall, boys reported more strategic and fast-paced video game play than girls, while girls reported higher academic grades than boys.

Long-Term Association Between Sustained Strategic Video Game Play and Self-Reported Problem Solving Skills

Univariate Growth Trajectory of Self-Reported Problem Solving Skills

Latent growth curve modeling in AMOS 19 (Arbuckle 1995–2012) was used to estimate individual trajectories of self-reported problem solving skills across the four grade

Table 1 Means and standard deviations of study measures and demographic variables

Variable	Scale Range	Grade 9 M (SD)	Grade 10 M (SD)	Grade 11 (SD)	Grade 12 M (SD)
Gender	1–2	50.8 % female			
Parental Education	1–6	3.27 (1.03)			
Number of computers in home		3.09 (0.91)			
Self-reported problem solving	1–5	3.36 (0.94)	3.31 (0.93)	3.25 (0.95)	3.38 (0.97)
Academic grades	1–5	3.40 (0.87)	3.42 (0.89)	3.45 (0.91)	3.57 (0.85)
Sustained strategic vg play	0–1	.33 (0.37)			
Sustained fast-paced vg play	0–1	.51 (0.39)			
Strategic vg play	1–2	1.21 (0.34)	1.20 (0.34)	1.43 (0.41)	1.46 (0.39)
Fast-paced vg play	1–2	1.33 (0.37)	1.29 (0.35)	1.49 (0.38)	1.48 (0.38)
Frequency of strategic vg play	1–5	n/a	n/a	1.80 (0.97)	1.88 (1.01)
Frequency of fast-paced vg play	1–5	n/a	n/a	1.84 (0.87)	1.83 (0.87)

vg video game; Strategic and fast-paced video game play were measured as *1* do no play, *2* play

levels. Two latent factors were estimated: intercept or starting point, and slope or rate of change over time. We first identified a linear growth model, which provided an excellent fit for the data $\chi^2(5) = 9.51$, $p > .05$; CFI = .99; RMSEA = .025 (.00–.048), indicating a linear increase in self-reported problem solving skills over time, as well as significant variability in the slope ($p < .001$). We also tested a non-linear model but it did not significantly improve the fit for the data.

Association Between Self-Reported Problem Solving Skills and Sustained Strategic Video Game Play

To assess whether sustained strategic and/or fast-paced video game play across the high school years independently predicted self-reported problem solving skills, we specified paths from sustained strategic video game play and sustained fast-paced video game play to the slope of the self-reported problem solving trajectory, while simultaneously controlling for gender, parental education, and number of computers in the home (see Fig. 1). Note that the direction of effects between sustained video game play and self-reported problem solving skills could not be ascertained in this model as sustained play was not clearly occurring prior to changes over time in self-reported problem solving skills. The covariances among sustained strategic game play, sustained fast-paced game play, and the intercept of self-reported problem solving also were estimated. Model fit was excellent, $\chi^2(15) = 14.55$, $p > .05$; CFI = 1.00, RMSEA = .000 (.00–.024). Sustained strategic video game play significantly predicted the slope of self-reported problem solving, $\beta = .18$, 95 % CI [.02, .34], $p < .05$, such that participants who reported higher sustained strategic video game play also reported steeper increases in self-reported problem solving scores over time than participants who indicated less sustained strategic video game play (the indexes of sustained video game play did not account for the frequency with which participants played the games; however, we obtained similar results when controlling for overall video game play by adding a growth trajectory for frequency of overall video game play). Sustained fast-paced video game play, in contrast, did not significantly predict self-reported problem solving skills, $\beta = .01$, 95 % CI [−.17, .19], $p > .05$.

Assessment of Cognitive Training and Selection Effects

Our second and third set of analyses simultaneously assessed cognitive training (playing strategic video games precedes an increase in self-reported problem solving skills) and selection (self-reported problem solving skills precedes an increase in strategic video game play) effects, as well as the indirect relationship between strategic video game play and academic grades, using autoregressive cross-lagged models. We first tested cognitive training and selection effects with our Likert scale measure of the frequency of strategic and fast-paced video game play in grades 11 and 12. Second, we tested these effects, as well as the indirect relationship between strategic video game play and academic grades with our dichotomous measure of strategic and fast-paced video game play (i.e., yes or no) from grades 9 through 12.

Association Between Self-Reported Problem Solving Skills and Frequency of Strategic and Fast-Paced Video Game Play in Grades 11 and 12

This model involved a 2-wave autoregressive cross-lagged path analysis in which bidirectional paths were estimated

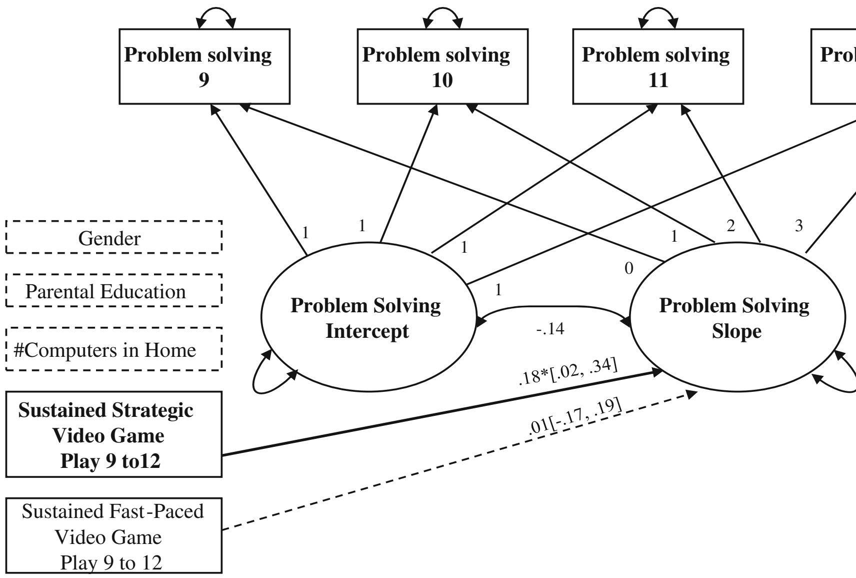

Fig. 1 Final model results for analysis assessing the long-term association between sustained strategic video game play and self-reported problem solving. 9 = grade 9; 10 = grade10; 11 = grade 11; 12 = grade 12. Covariates are indicated with dashed lines. Note that the direction of effects between sustained strategic video game play and problem solving can not be ascertained in this model as sustained strategic video game play is not clearly occurring before changes over time in problem solving. Not shown are paths from control variables to slopes of problem solving; covariancesamong exogenous variables, and intercepts. Standardized coefficients (95 % confidence intervals are in brackets) are reported. *<.05. Results for covariates and covariancescan be obtained from the first author

between frequency of strategic video game play and self-reported problem solving skills, and between frequency of fast-paced video game play and self-reported problem solving skills (see Fig. 2). Stability paths across grade within each variable also were specified, as well as covariances among the variables within each grade. Model fit was excellent, $\chi^2(2) = .67$, $p > .05$, CFI = 1.00, RMSEA = .00 (.00–.037). Frequency of playing strategic video games in grade 11 significantly predicted self-reported problem solving skills in grade 12, $\beta = .17$, 95 % CI [.04, .30], $p < .05$, after controlling for stability of self-reported problem solving skills, such that higher frequency of playing of strategic video games in grade 11 predicted higher self-reported problem solving skills in grade 12. In contrast, frequency of playing fast-paced video games in grade 11 did not significantly predict self-reported problem solving skills in grade 12, after controlling for stability of self-reported problem solving skills, $\beta = -.05$, 95 % CI [−.19, .09], $p > .05$. Self-reported problem solving skills in grade 11 also did not significantly predict greater frequency of strategic or fast-paced video game play over time ps > .05. Therefore, a cognitive training effect was uniquely supported for strategic, but not fast-paced video game play, and no support was found for a selection effect.

Association Between Self-Reported Problem Solving Skills and Strategic Video Game Play, and the Indirect Association Between Strategic Video Game Play and Academic Grades, from Grades 9 Through 12

This model involved a 4-wave (grade 9–12) autoregressive cross-lagged path analysis in which bidirectional paths were estimated across each adjacent grade between both strategic and fast-paced video game play (yes/no) and self-reported problem solving skills, as well as academic grades, and between self-reported problem solving skills and academic grades (see Fig. 3). We used dichotomous measures (yes/no) of strategic and fast-paced video game play because we did not have frequency measures in all four waves. Stability paths across grade within each variable also were specified, as well as covariances among the variables within each grade in order to control for common method variance.

We first assessed whether the pattern of results was invariant across grade. Invariance was tested by comparing a model in which all cross-lagged paths were constrained to be equal across grade to the unconstrained model in which all structural paths were free to vary. The Chi square difference test of relative fit indicated that the unconstrained model was

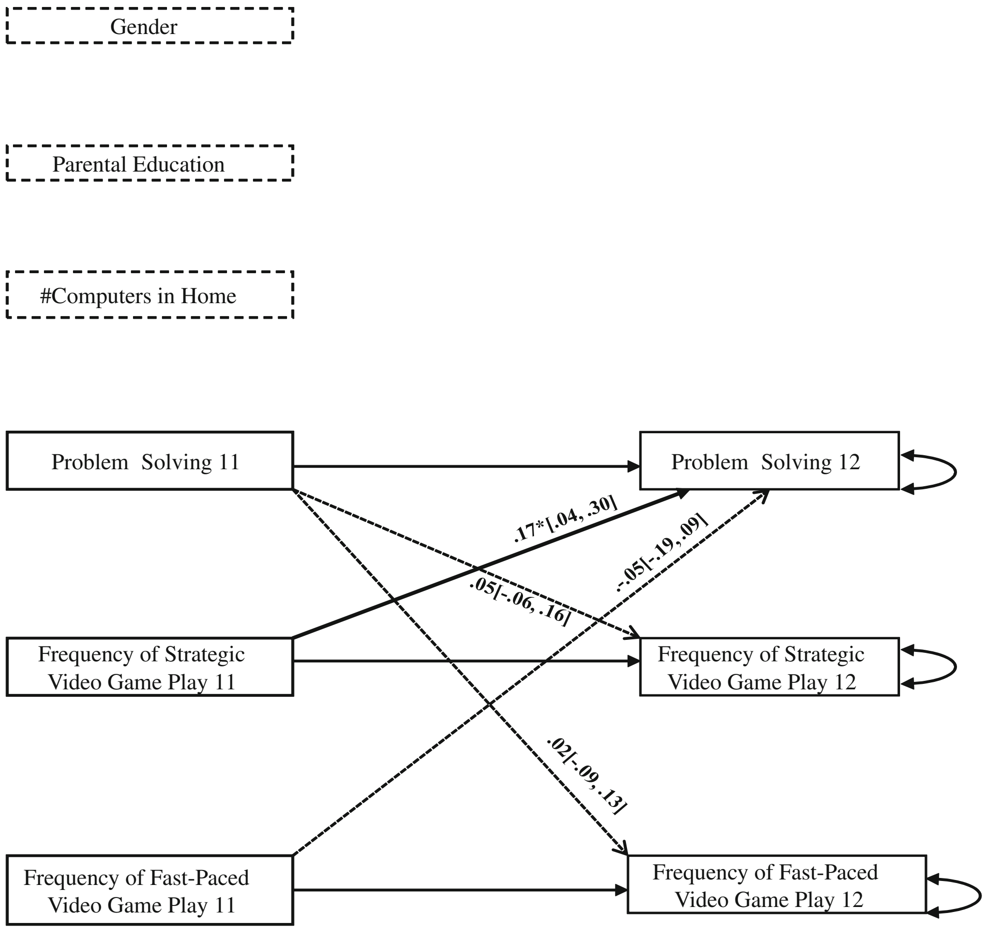

Fig. 2 Final model results for analysis assessing cognitive training vs selection effects with frequency of strategic video game play in grades 11 and 12. 11 = grade 11; 12 = grade 12. Covariates are indicated with *dashed lines*. Not shown are covariancesamong variables within each grade, or paths related to covariates. Standardized coefficients (95 % confidence intervals are in brackets) are reported. *<.05. Results for covariates, covariances, and stability paths can be obtained from the first author

not a significant better fit than the constrained model, suggesting that the patterns of associations among the measures were consistent across the high school years, $p > .05$. As the constrained model was the most parsimonious model, all further interpretations were based on the constrained model. Model fit was good, $\chi^2(62) = 117.53$ $p < .001$, CFI = .99, RMSEA = .025 (.018–.031). Figure 2 summarizes the significant path estimates. Consistent with a cognitive training effect, playing strategic video games significantly predicted higher self-reported problem solving skills over time ($\beta = .09$, 95 % CI [.05, .13], $p < .001$), after controlling for stability of self-reported problem solving skills. In contrast, playing fast-paced video games did not significantly predict self-reported problem solving skills over time ($\beta = -.01$, 95 % CI [−.06, .04], $p > .05$), after controlling for stability of self-reported problem solving skills. No support was found for a selection effect, as self-reported problem solving skills significantly predicted *less* strategic video game play ($\beta = -.04$, 95 % CI [−.07, −.001], $p < .05$), after controlling for stability of strategic video game play.

Consistent with past research (D'Zurilla and Sheedy 1992), self-reported problem solving skills significantly predicted higher academic grades over time ($\beta = .07$, 95 % CI [.04, .10], $p < .001$), after controlling for stability of academic grades. Academic grades also predicted self-reported problem solving skills ($\beta = .10$, 95 % CI [.06, .14], $p < .001$), after controlling for stability of self-reported problem solving skills. Strategy and fast-paced video game play, however, did not directly predict academic grades, *ps* > .05. Given the significant direct effect between strategy video game play and self-reported problem solving, and between self-reported problem solving and academic grades, we assessed the indirect effect between strategic video game play and academic grades through self-reported problem solving. Using bias-corrected bootstrapping (bootstrap samples = 1,000), we found a significant indirect effect, $\beta = .05$, 95 % CI [.01, .06], $p < .01$. Thus, the results provide support for an indirect mediation model (MacKinnon et al. 2007; Zhao et al. 2010) in which playing strategic video games

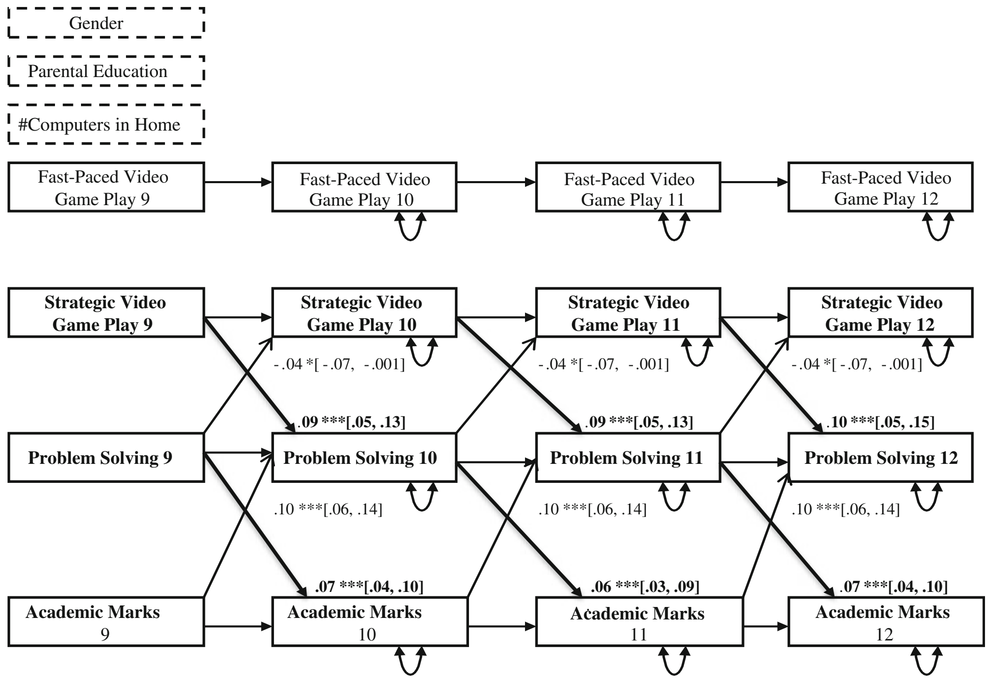

Fig. 3 Final model results for analysis assessing cognitive training vs selection effects with dichotomous measure of strategic video game play and indirect association between strategic video game play and academic grades. Strategic and fast-paced video game play were measured as 1 = do no play; 2 = play; 9 = grade 9; 10 = grade 10; 11 = grade 11; 12 = grade 12. Covariates are indicated with *dashed lines*. Only significant paths are shown. Cross-lagged paths of greatest interest are *bolded*. Not shown are covariancesamong variables within each grade, or paths related to covariates. Standardized coefficients (95 % confidence intervals are in brackets) are reported for significant paths. ***<.001, **<.01, *<.05. Results for covariates, covariances, and stability paths, can be obtained from the first author

predicted higher self-reported problem solving skills, and in turn, higher self-reported problem solving skills predicted higher academic grades.

Gender as a Moderator

Gender also was included as a moderator in each analysis and there were no significant differences in the pattern of findings as a function of gender (*p*s > .05 in χ^2_{diff} tests between constrained and unconstrained models).

Discussion

Although researchers recently have demonstrated that video games are an effective tool for training a variety of cognitive skills such as executive control functions as well as several visual and attentional skills (e.g., Basak et al. 2008; Green and Bavelier 2006), no researchers have examined the link between strategic video game play and problem solving skills. It is especially important to examine this association among adolescents, because the executive function of inhibitory control is still developing during adolescence (Kuhn 2009), and activities that encourage players to stop and consider different strategies when faced with a problem, instead of simply using the first strategy that comes to mind, are critical during this stage of development. In addition, to our knowledge no longitudinal studies exist in which researchers have examined the bidirectional relationship between video game play and cognitive skills (i.e., cognitive training versus selection effects). Thus, using a 4-wave dataset of adolescents, we investigated the longitudinal association between strategic and fast-paced video game play and self-reported problem solving skills. In addition, we tested the hypothesis that strategic video game play may indirectly predict academic grades through self-reported problem solving skills.

The current study is the first to discover a relationship between strategic (but not fast-paced) video game play and self-reported problem solving skills, and to demonstrate this relationship longitudinally. We also demonstrated a positive indirect relationship between strategic video game play and academic grades. The first analysis revealed that adolescents who played strategic video games across many years of high school also reported steeper increases in self-reported problem solving skills over time compared to participants who reported less sustained play. Next, we found support for cognitive training effects in that greater *frequency* of strategic video game play in grade 11 predicted greater self-reported problem solving skills in grade

12, after controlling for previous levels of self-reported problem solving skills. In addition, playing strategic video games (but not fast-paced video games) predicted greater self-reported problem solving skills across the four high school years, after controlling for previous levels of self-reported problem solving skills. In contrast, no support was found for a selection effect, as self-reported problem solving skills in an earlier grade predicted *less* playing of strategic video games in a later grade. Perhaps adolescents who have higher problem solving skills are more likely to focus on academic achievement instead of playing video games. Specifically, adolescents who have higher problem solving skills may self-select into academic activities to a greater extent than those who have lower problem solving skills, and thus may have less time to play video games. More research on this relationship is needed to elucidate why higher problem solving skills predicts less playing of strategic video games over time.

Finally, we found support for an indirect relationship between strategic video game play and academic grades. Specifically, strategic video game play predicted higher self-reported problem solving skills after controlling for previous levels of self-reported problem solving skills, and in turn, higher self-reported problem solving skills predicted higher academic grades after controlling for previous academic grades. This finding is unique, as longitudinal research to date has been focused mainly on whether video game play might lower academic performance. Overall, these findings suggest that over the four high school years, playing strategic video games may enhance adolescents' self-reported problem solving skills, which in turn may help adolescents perform better in school. In addition, academic grades also predicted self-reported problem solving skills over time, which suggests that people who have higher grades tend to have higher self-reported problem solving skills than their peers at a later time point. Furthermore, this finding suggests that participants may learn or develop problem solving skills at school.

Results also support our hypothesis that a unique relationship exists between *strategic* video game play and self-reported problem solving skills, as fast-paced video game play was not related to self-reported problem solving skills in any of the analyses. Specifically, strategic video games often involve gaining information and thinking of a strategy before trying to solve a problem, which may enhance players' problem solving skills. In contrast, fast-paced video games encourage immediate action while providing little to no opportunity to stop and think of a strategy. Examining strategic and fast-paced video game play separately is necessary in determining whether strategic video games are uniquely related to problem solving skills, and is a major strength of the present study. Importantly, gender did not moderate the results, suggesting that the pattern of results among strategic video game play, self-reported problem solving skills, and academic grades did not differ between boys and girls.

The current findings have important implications for educators. Specifically, strategic video game play may predict higher problem solving skills because video games possess good learning principles (Gee 2005; Green and Bavelier 2008). For instance, the level of difficulty in almost all video games increases throughout the games in small incremental steps, so that players do not advance to the next level of difficulty too early—but only once they have developed the skills necessary to complete the current level. Video games, therefore, involve individualized skill development, which likely leads to enhanced motivation (Green and Bavelier 2008). In contrast, this high level of individualized skill development is more difficult to replicate in the average classroom where there often are more than 30 students per class, potentially contributing to the finding that many adolescents report feeling bored and unmotivated in school (Larson 2000). As we have shown, mainstream "popular" video games that involve problem solving are associated with increased self-reported problem solving skills, and thus educational video game developers (i.e., video games created specifically for educational purposes) should focus more on including problem solving tasks in educational games.

The present study is not without limitations. For example, one limitation was that our measure of sustained strategic and fast-paced video game play was not clearly occurring prior to changes over time in self-reported problem solving skills, limiting our ability to assess the direction of effects between these variables. Our auto-regressive cross-lagged models, however, directly tested the direction of effects. Another important limitation stems from the reliance on self-report measures. Although we specified covariances among all of the variables within each time period in all models, thus accounting for common method variance, reports of video game use would benefit from corroboration from other informants (e.g., friends, parents). It is not clear, however, whether anyone other than the adolescent can provide an accurate assessment of their video game use given that much of the activity may be conducted alone. It also may be beneficial for future studies to include objective measures of problem solving skills or academic performance. For example, in the current study it may be that playing strategic video games predicted participants' perceptions of their problem solving skills, but not their actual objective solving skills. Also, the structural paths that were significant in the present study were all small in magnitude. However, these effect sizes are common in longitudinal cross-lagged models when accounting for stability between adjacent waves of data and for concurrent associations among variables at each grade. Finally, although the participants in the present study included a large sample of enrolled students from a school distinct, findings may not generalize to other geographic regions, including those with differing ethnic and/or demographic populations.

In the future, researchers should continue to investigate the relationship between strategic video game play and problem solving skills, especially with experimental designs to directly test causation. However, considering that problem solving develops slowly with repetitive practice, it may be difficult to demonstrate short-term effects of strategic video game play on problem solving in the laboratory. Thus, a randomized and controlled study that spans several months, such as in Weis and Cerankosky (2010), may be more informative than a short-term experiment. In addition, although the measure of strategic video game play in the current study included measures of playing different genres of games (i.e., role playing and strategy), we did not examine the predictive effect of specific video games. For example, perhaps role playing or strategy games that involve more problem solving have stronger predictive effects on problem solving skills than role playing games or strategy games that involve less problem solving. Future research should be focused on identifying which strategic games are most strongly linked to problem solving skills.

In summary, this was the first study to demonstrate a cognitive training effect of strategic video games on self-reported problem solving skills, in that playing strategic video games predicted higher self-reported problem solving skills across the four high school years. Furthermore, we found evidence for an indirect positive relationship between strategic video game play and academic grades. These results, and the fact that millions of adolescents enjoy playing strategic video games for several hours every day (e.g., Lenhart et al. 2008), underscores the need for psychologists to continue to investigate the relationship between strategic video game play and problem solving skills.

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Author's Contributions PA conceived the study, conducted most of the statistical analyses, and drafted the manuscript. TW collected the data and participated in the statistical analyses as well as the drafting of the manuscript. All authors read and approved the final manuscript.

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Author Biographies

Paul J. C. Adachi received his MA degree in psychology from Brock University and is currently a PhD candidate. In terms of research, Paul is interested in the positive and negative effects of video games on adolescent development. He has conducted research examining the relation between video game competition and aggression, and is currently investigating the relation between video game play and cooperation.

Teena Willoughby is a professor in the Department of Psychology at Brock University. She her received her PhD in psychology from Waterloo University. Her research interest is in adolescent development, particularly with regard to risk taking, academic achievement, and media use (e.g., video game play).