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Timesplitters: Playing video games before (but not after) school on weekdays is associated with poorer adolescent academic performance. A test of competing theoretical accounts

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A B S T R A C T

Video games are a common pastime for adolescents. There has been a relatively enduring concern that time spent playing video games might undermine students' academic performance. Hartanto, Toh, and Yang (2018) suggested that frequent gameplay, particularly frequent weekday video gameplay, might displace students' homework; reducing academic performance, albeit by a small amount. Although some evidence has been presented supporting this view, the emerging evidence is mixed. Significant theoretical flaws have also limited our understanding of the relationship between video game play and adolescent academic performance. Here we show that, across approximately 219,000 students, the frequency of video gameplay does not appear to have a systematic relationship with academic performance, confirming the results of earlier research (Drummond & Sauer, 2014). Moreover, although there is a small-moderate reduction in academic performance for some weekday players, this reduction only occurs for players who play in the mornings *before* school. Players who play in the evenings after school show no meaningful difference in academic performance to non-users. As no existing theoretical accounts of the relationship between gameplay and academic performance adequately explain this finding, we propose that the results most likely support a third variable explanation. That is, video game play does not appear to affect academic results per se. The results further suggest that media psychologists and educational researchers analysing large datasets must be especially diligent when specifying and testing theory, especially with regards to what evidence would effectively falsify such theory. Failing to do so increases the risk of false discovery.

Video games are a common pastime for adolescents around the world. The Entertainment Software Association (2017) estimates there are 2.6 billion gamers worldwide, including an estimated 424 million minors. With any evolving technology, there tends to be debate, public and academic, about the potential benefits and risks associated with new technology for society in general, and for particular subsets thereof. So has it been with video games, with relatively enduring concerns surrounding the psychological effects of adolescents' video game play on a range of factors. Although concern has focussed primarily on the effect that violent game content may have on players' aggression and post-game violence (Anderson et al., 2010; Drummond, Sauer, & Garea, 2018; Ferguson, 2015; Hilgard, Engelhardt, & Rouder, 2017; Sauer, Drummond, & Nova, 2015), the concern that video games might be damaging to adolescent academic performance is also prominent (Drummond & Sauer, 2014, 2015; Ferguson, 2015; Hartanto, Toh, and Yang, 2018). Here we replicated Drummond and Sauer's (2014) multilevel model analysis of Programme of International Student Assessment (PISA) data using newer data to investigate (a) whether there is a negative relationship between academic performance and video game use amongst adolescents, (b) whether the relationship has changed from that observed in the 2009 PISA data (Drummond & Sauer, 2014), and (c) extend this analysis to investigate whether the timing of video game play moderates any effects of gameplay on academic performance – that is, do effects on students' academic performance vary depending on whether students are playing

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video games before versus after school?

The empirical evidence on whether video game play results in poorer adolescent academic performance is mixed. Drummond and Sauer (2014) showed no consistent relationship between video game use and adolescent academic performance, a finding replicated both in smaller empirical samples (Dindar, 2018), and also in meta-analyses (Ferguson, 2015). However, several more recent investigations have yielded divergent results. Somewhat counterintuitively, Concepcion, Nales-Torres, and Rodriguez-Zubiaurre (2016) found that US students may actually achieve higher Grade Point Averages when spending more time playing video games. Conversely, one study suggested that reading performance from physical texts (but not digital sources) was negatively associated with video game play (Borgonovi, 2016). Paradoxically, a recent study suggests that although video game use is not associated with a decline in basic educational competencies (e.g., reading and mathematical ability), grades are slightly lower for more frequent users (Gnambs, Stasielowicz, Wolter, & Appel, 2018). Thus, the evidence for the relationship between academic performance and video game use remains unclear.

The relationship between video game play and educational outcomes, if one exists, is currently poorly understood. A recent meta-analysis on the issue estimated that the plausible range of effect sizes is between $r = .02$ and $r = 0.20$, explaining somewhere between 0.04% and 4% of variance in academic performance scores (Ferguson, 2015). Thus, the proposed relationship appears to be trivial-to-small in size (Cohen, 1988, 1992; Ferguson, 2015). However, three further considerations illustrate the limits of our current understanding. First, due to the general dearth of studies in this area, Ferguson et al.'s meta-analysis includes relatively few studies. Second, there is a lack of standardization of measures and research foci across studies: Different studies focus on different aspects of educational attainment and measure key constructs in different ways.

Third, and the focus of the current paper, the divergent results in the literature may partly reflect an under-developed consideration of potential moderating factors. Hartanto et al. (2018) suggest that one such factor is the timing of gameplay; more specifically, whether gameplay takes place during the school week or on the weekend. Citing evidence that adolescents undertake more homework on weekdays than weekends (Yeung, Sandberg, Davis-Kean, & Hofferth, 2001), Hartanto et al. (2018) postulate that weekday video game play may be more disruptive to adolescent academic performance than weekend play. Combining a range of data sources, the authors demonstrate that weekday gameplay is indeed associated with small reductions in academic performance in a US sample, with students who play video games more frequently during the week (cf. less frequently during the week) having slightly lower performance in science, mathematics and reading, while no such decline is evident for their peers who play more frequently on weekends (cf., less frequently on weekends). Here we tested these findings, by replicating and extending Drummond and Sauer's (2014) analysis using newer PISA data.

Updated analyses are important for three reasons. First, replication is one of the cornerstones of good scientific practice. Replication is even more important when undertaking correlational analyses as in the present project. Correlational analyses, through their very nature, allow limited inference about causation, and therefore require numerous replications to ensure their conclusions are reliable and valid. Additionally, Hartanto et al. (2018) study examines only one country (the US) and results may not generalize to other contexts. Moreover, Hartanto et al. (2018) suggest that Drummond and Sauer (2014) analyses were flawed in that they did not explicitly control for gender and socioeconomic status. We include these controls in our updated analyses. Second, as one might imagine, video games have changed substantially between 2009 and 2015. In addition to graphics improvements, new gaming hardware and technical advancements of other forms, a general increase in the length of games is evident over this time. For example, the top 3 critic rated games in 2009 would take approximately 20 h to play through, and about 147 h to fully complete, while the top 3 rated games in 2015 would take approximately 41 h to play through and 404 h to fully complete.[1] This suggests that the playtime required to complete the most popular games has increased over the last half-decade, and may imply a greater time-commitment for gamers in general, and potentially increasing the likelihood that gameplay may displace other activities (if the displacement hypothesis is true). Last, and perhaps most importantly, more nuanced analyses may allow us to distinguish between potential theoretical mechanisms underpinning differences between the effects of weekday and weekend video game play (Hartanto et al., 2018).

1. Theoretical frameworks

Concerns that video games might have deleterious effects on adolescent academic performance, though relatively intuitive, are theoretically underdeveloped. The mechanisms by which adolescent academic performance might be affected by gameplay are, in general, not well specified, and often lacking plausible mechanisms by which gaming might affect learning. There are, so far as we can discern, at least three plausible theoretical pathways that *might* support a negative relationship between academic performance and increased time spent playing video games. Time spent gaming might negatively affect academic performance via a *displacement* mechanism, via *attentional* mechanisms, and/or via *reduced sleep efficiency* mechanisms. Alternatively, as is always a possibility in correlational research, the relationship between academic performance and gameplay may represent a spurious or third variable association.

First, and most intuitively, is the *displacement* mechanism (Esteban-Cornejo et al., 2015; Hartanto et al., 2018). Time spent gaming is time not spent studying. Thus, according to this account, adolescents who spend time playing video games are not engaging with other, more academically beneficial activities (Esteban-Cornejo et al., 2015; Hartanto et al., 2018). While the *displacement* mechanism may have a high degree of face validity, it does not withstand closer scrutiny. Specifically, the *displacement* mechanism suggests that adolescents are spending time playing video games instead of engaging in academically beneficial activities. By assuming that a

[1] Top games sourced from www.metacritic.com and gameplay times sourced from www.howlongtobeat.com.

meaningful proportion of the time spent gaming would otherwise have been spent on academic pursuits, this mechanism ignores the possibility that the activities displaced by gameplay may be other forms of leisure, and thus gameplay may exert only a minimal effect, if any, upon academic performance. Moreover, this mechanism tends to pathologize video game use: it implies that video games fall into a special category of leisure activities that will damage academic performance in a manner inconsistent with other leisure activities such as sport, reading, or art. In other words, the displacement hypothesis implies that video games will displace academic activities to a greater degree than other kinds of leisure pursuits.

A second mechanism by which video game use might negatively affect academic performance is via the alteration of *attentional* mechanisms. According to this account, repeated exposure to exciting stimuli within video games might result in students developing a preoccupation with video games (diverting attention away from less interesting tasks), or alter students' attentional mechanisms leaving them less capable of sustaining attention for less-engaging tasks (Chan & Rabinowitz, 2006; Swing, Gentile, Anderson, & Walsh, 2010). Previous studies have found that more frequent gameplay is associated with increased reports from teachers of student attention problems (Swing et al., 2010), and Drummond and Sauer (2015) found that children with the highest frequency of gameplay had poorer metacognitive knowledge about effective learning strategies. This, by extension, may imply that such children were engaging in less rigorous evaluation of their learning experiences and learning strategies, and that students who played games more frequently were more likely to use less effective learning strategies in their day-to-day lives. At first glance, this evidence may appear consistent with the proposed deleterious effects on attention. However, when considering these speculations, two point must be borne in mind. First, the correlation between teachers' reports of students' attentional problems and students' attentional problems is unclear (Rosenthal & Jacobson, 1968). Second, although Drummond and Sauer found a negative association between gameplay frequency and metacognitive knowledge, there was no concordant decrease in academic performance in this sample (Drummond & Sauer, 2014).

A third potential mechanism relates to *reduced sleep efficiency*. Playing fast-paced action games for long periods immediately prior to bed may result in poorer sleep efficiency (the proportion of time spent asleep compared to the total time spent in bed, King et al., 2013). The mechanism for this effect is unclear however, with participants experiencing no physiological differences in arousal prior to bed, and no corresponding increase in sleep onset latency (implying that the reduction was not due to melatonin inhibition). Nonetheless, given the importance of sleep for attention (Sanders & Reitsma, 1982), cognitive performance (Blagrove, Alexander, & Horne, 1995) and the consolidation of memory (Maquet, 2001), this reduction in sleep efficiency could potentially translate to poorer learning and academic performance, especially if games are played in the evening immediately prior to bed.

A final possibility that requires consideration is the potential for a third variable explanation for the association between academic performance and video gameplay. It may not be the case that video games cause poorer academic performance, but rather that excessive video game use is symptomatic of broader issues which, themselves, might be related to poorer academic performance. These issues may reflect intrinsic or extrinsic motivational factors. For instance, an intrinsic motivational mechanism may manifest as underperforming students disengaging with a variety of important activities (including schoolwork; Fröjd et al., 2008), and simultaneously engage in high levels of video game play as a mood management tool (Olson, 2010). Alternatively, as an example of an extrinsic influence on motivation, some parenting strategies (e.g., laissez-faire parental attitudes) may simultaneously result in a lack of parental controls around screen time and a lack of promotion or incentivising of schoolwork (leading to reduced motivation to study). Thus, rather than video game play *causing* a reduction in academic performance, high levels of video game play may instead be an indicator of other issues associated with poorer academic performance (e.g., intrinsic or extrinsic motivational factors associated with both lower academic performance and high levels of video game play). A third variable explanation would suggest that the purported association between video game play and adolescent academic performance was spurious (i.e., caused by extraneous variables). This would support a more traditional science of learning approach which suggests that for learning to be influenced by a factor, the factor must be directly related to the learning activity, and that learning is unlikely to be influenced by everyday leisure activities (Alexander, Schallert, & Reynolds, 2009).

2. Distinguishing between theoretical accounts

By operationalising the mechanisms through which video game play may affect adolescent behaviour, we may identify methods capable of differentiating between such mechanisms. Based upon the extant evidence, it is relatively easy to make some inferences about the likelihood of various mechanisms. Specifically, *attentional* accounts of video game play do not appear to explain the extant data, especially the differential associations of weekday and weekend video game play with adolescent academic performance. The theoretical reduction of either attentional mechanisms or metacognition do not postulate (nor contain plausible moderation pathways which would predict) that the timing of gameplay would differentially affect attention or metacognition. Thus, we can already be relatively confident that this theoretical account does not explain the data. Moreover, any further data which shows differential timing effects would also effectively falsify this theoretical account.

The remaining theoretical accounts of *displacement* and *reductions in sleep efficiency* are both consistent with the available data. The *displacement* mechanism would require that students were playing games on weekdays in place of study activities, while weekend play displaced non-study activities (Hartanto et al., 2018). In contrast, the *sleep efficiency* mechanism proposes that games during weekday evenings disrupt sleep, negatively influencing academic performance, but allows for the possibility that lost sleep during weekends due to evening play may be recovered during rebound sleep on Sunday night (King et al., 2013). Thus, the extant data do not distinguish between these theoretical accounts. Crucially, however, it is possible to conceive of data that could test predictions drawn from, and thereby differentiate, these accounts. Specifically, by investigating whether there are systematic differences in academic performance for children who play video games in the morning before school or evenings after school we can provide

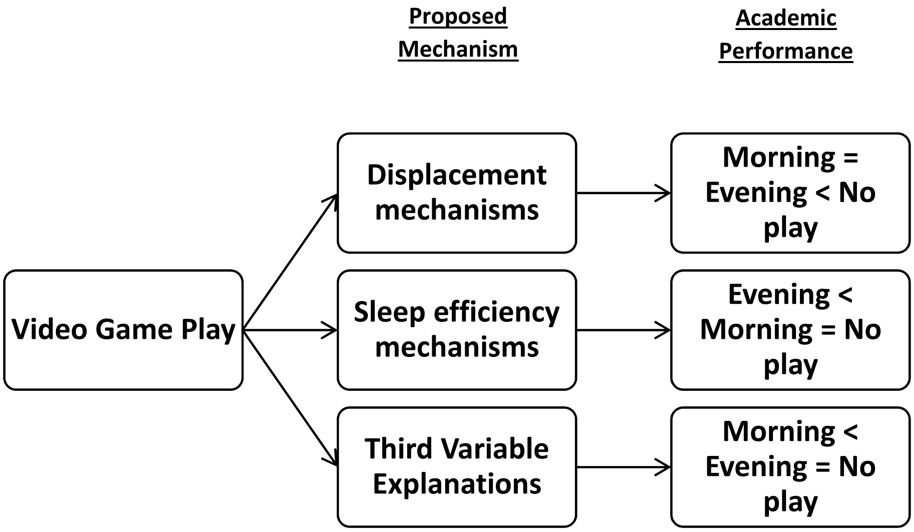


Fig. 1. Competing hypotheses drawn from potential theoretical models explaining effects of gameplay on adolescent academic performance. Equals symbols (=) imply that academic performance will be equivalent for the two groups listed, while less than symbols (<) imply lower academic performance for the preceding group.

information about the likely mechanisms underlying effects of gameplay on academic performance. The *sleep efficiency* mechanism suggests that evening play is responsible for a reduction in sleep efficiency and thus a reduction in learning. Thus, if students playing video games in the evening after school display lower academic performance than their peers who play in the morning or do not play games, this would provide evidence for the *sleep efficiency* mechanism.

In contrast, the *displacement* mechanism rests upon the assumption that there is a finite amount of time to undertake all activities, and time spent gaming reduces time devoted to academic tasks and, consequently, academic performance. Thus, if adolescents who play in the morning or the evening on school days display lower academic performance than their peers who do not play before or after school, this would be evidence for the *displacement* mechanism. Although it might be tempting to assume that students do not typically undertake homework in the morning, the 2015 PISA dataset provides clear evidence against this assumption – 111,023 students of 225,789 (49.2%) who answered the question about studying in the morning indicated that they had studied prior to school. Thus, there is clearly a high proportion of students studying prior to school whose study activity could be disrupted by morning gameplay if the *displacement* mechanism is accurate.

Finally, neither the *displacement* or *sleep efficiency* mechanisms predict that morning play should selectively be associated with lower adolescent academic performance. Thus, if adolescents who play games in the morning before school have lower academic performance than their peers who play after school or not at all, this would offer evidence against current theoretical accounts, but might be consistent with a third variable explanation such as general disengagement or laissez-faire parenting. A summary of the competing hypotheses drawn from these theoretical frameworks is depicted in Fig. 1.

Here we test these mechanisms by examining the 2015 Programme of International Student Assessment data to investigate the relationship between frequency of gameplay, patterns of gameplay before and after school, and adolescent academic performance.

3. Research questions and hypotheses

Based on the theoretical frameworks reviewed in the present manuscript, we explored the following research questions.

1. Is there is a negative relationship between academic performance and the frequency of video game use amongst adolescents, and has this relationship changed from that observed in the 2009 PISA data (Drummond & Sauer, 2014)?
2. Do adolescents who play during the week exhibit lower academic performance than their peers who do not play, and is the size of any such effect comparable to that observed by Hartanto et al. (2018)?
3. Does the morning/afternoon timing of video game play moderate the relationship of gameplay with academic performance – that is, do effects on students' academic performance vary depending upon whether students are playing video games in the morning before versus in the evening after school? In the context of the existing theoretical frameworks, what do these findings imply about the likely mechanism of any observed reduction in academic performance associated with video gameplay?

With regard to research question 3, we anticipate that any differences between morning and evening video game play will also alter the size of the observed effects. Where theory would predict that the effect is similar for morning and evening gameplay, we would expect that both effect sizes were similar to Hartanto et al.'s data, which demonstrated a small reduction in academic performance associated with weekday gameplay ($0.2 < ds < 0.5$). However, where theory predicts differential effects of morning and evening game play, we expect that the size of the effect would be altered. Where one effect (e.g., morning gameplay) increases to a moderate sized effect ($0.5 < ds < 0.8$), we would expect the corresponding effect (e.g., evening play) to decline to a trivial effect ($ds < 0.2$).

Therefore, based upon our review of the literature we generated the following 4 hypotheses:

H1. There will be no substantial reduction in adolescents' academic performance in science, mathematics and reading ability associated with more frequent (c.f. less frequent) video game play. Specifically, we expect that the differences in academic performance in science, mathematics and reading will be trivial in terms of effect size ($ds < 0.2$; Cohen, 1988)

H2. The differences in academic performance in science, mathematics and reading ability between frequencies of video game play will be similar in size to those observed by Drummond and Sauer (2014).

H3. Based upon the findings of Hartanto et al. (2018) we expect that adolescents who play video games during the week will have lower academic performance in science, reading and mathematics than adolescents who do not play video games during the week. This effect size will be small ($0.2 < ds < 0.5$).

H4. We expect that the effect of weekday video game play observed in hypothesis 3 will be clarified by distinct differences between adolescents who play in the morning before school versus players who play in the evening after school, such that:

a. If displacement of homework is the mechanism of action for this effect that both morning and evening players will perform poorer academically in science, reading and mathematics than adolescents who do not play during the week. Concordant with Hartanto et al., we expect these effects will be small in size ($0.2 < ds < 0.5$).
b. If reductions in sleep efficiency is the mechanism of action for this effect that adolescents who play video games in the evening will exhibit poorer academic performance to those who play in the morning or not at all. These effects will be moderate in size ($0.5 < ds < 0.8$). Adolescents who play video games in the morning will not appreciably differ in academic performance to those who do not play during the week ($ds < 0.2$).
c. If third variable explanations are the mechanism of action for this effect that adolescents who play video games in the morning before school will exhibit poorer academic performance in science, reading and mathematics than students who play in the evening or not at all. These effects will moderate in size ($0.5 < ds < 0.8$). Adolescents who play video games in the evening will not appreciably differ in academic performance to those who do not play during the week ($ds < 0.2$).

4. Method

4.1. Dataset

The PISA is an ongoing Organization for Economic Cooperation and Development (OECD) initiative that assesses students in a large number of countries on their academic performance on reading, mathematics and science as well as a range of other variables. The programme focuses upon the performance of ~15 year old adolescents (some variability in ages is evident due to the timing of student's birthdays and differences in grade levels across countries) and is repeated every three years to examine the performance of secondary students across countries. Once the programme has prepared their report, the data are made available to the public.

4.2. Participants

We reanalysed data from students who undertook the Programme for International Student Assessment test in 2015. We limited our analyses to students in OECD countries due to the higher prevalence of video game use in western industrialized countries, and to be consistent with previously reported samples (Drummond & Sauer, 2014). Questions assessing morning and afternoon video game play occurred on a different questionnaire than questions assessing frequency of video game play (see below). Not every participant answered every question (students could skip some questions if desired), and some countries or schools administered only a subset of the background questions. Additionally, some students did not complete enough of the assessments to generate valid academic performance estimates. This resulted in slightly different participant numbers for each of these variables. For the analyses of frequency of single player video games, participants were 184,567 students nested within 7,541 schools, nested within 31 countries who also had academic performance estimates. For the analyses of frequency of multiplayer video games, there were 183,531 participants nested within 7,545 schools, nested within 31 countries who also had academic performance estimates. For the analyses of morning and afternoon video gameplay, there were 219,113 participants nested within 9,201 schools, nested within 35 countries who also had academic performance estimates. Due to the large number of participants we opted to ignore statistical significance (which is relatively meaningless in large samples; Lin, Lucas Jr, & Shmueli, 2013) and instead focus upon effect size. We indexed effect size using Cohen's *d*. We consider any effect smaller than Cohen's *d* of 0.2 as trivial, as suggested by Cohen (1992). Table 1 presents demographic characteristics and descriptive statistics for the variables used in the reanalyses in this paper.

4.3. Video game use

The PISA 2015 data contain four items assessing video game use. Two items assessed the general frequency of video game play: "How often do you use digital devices [to play one-player games; to play collaborative online games] outside of school?" (Never or

Table 1
Demographic characteristics and descriptive statistics for PISA variables analysed in the present paper.

	Mean (*SD*)	Mode (Frequency)	Range
Sex	N/A	Male (50.3%)	1(Female) – 2(Male)
Birth Year	1999.11 (0.31)	1999 (80.7%)	1999–2000
Economic, Social and Cultural Status (ESCS)	−0.01 (1.00)	N/A	−7.05 - 4.18
Single Player video game frequency	2.39 (1.41)	1 (30.4%)	1(Never or hardly ever) – 5(Every day)
Multiplayer video game frequency	2.29 (1.48)	1 (36.2%)	1(Never or hardly ever) – 5(Every day)
Video games before school	N/A	0 (73.5%)	0(Did Not Play) – 1(Played)
Video games after school	N/A	0 (54.8%)	0(Did Not Play) – 1(Played)
Science Achievement	494.84 (97.65)	N/A	106.66–889.77
Mathematics Achievement	491.02 (92.64)	N/A	83.84–862.23
Reading Achievement	493.60 (98.03)	N/A	98.03–869.02

hardly ever; Once or twice a month; Once or twice a week; Almost every day; Every day). Two further items assessed video game play in the morning and evening: “On the most recent day you attended school, did you play video games [before going to/after leaving] school?” (Yes, No). While this measure may miscategorise some students who usually play and did not on the latest morning or evening (or some students who usually do not play and did on the latest morning/evening), given that adolescent weekday behaviour typically involves a high degree of structure in Industrialized Nations (Huston, Wright, Marquis, & Green, 1999; Larson & Verma, 1999), it is expected that questions about activity on the latest school day, being an average weekday, should correctly classify the typical behaviour of the majority of students.

4.4. Academic achievement

We examined the latest PISA data available at the time of writing (the 2015 dataset). This dataset contains standardized test scores on science, mathematics, and reading ability, all on psychometrically validated instruments. For reading assessments, students answer comprehension questions after reading a short section of text (e.g., interpreting, summarizing, or applying the information contained within the text). Students answer questions requiring mathematical calculation and interpretation (e.g., calculating the area of objects or accurately interpreting graphs) to determine their score in mathematics. Students must apply scientific thinking such as interpreting the results of scientific experiments, deciding upon the best design for potential experiments, and determining causal factors in particular scenarios for the test of science academic performance.

Each of these tests yields a score for each student which is then subjected to a Rasch model estimation procedure to yield a set of 10 plausible values for each of these constructs for each student. These estimates are standardized to a scale with an average of approximately 500 and a standard deviation of 100. Higher scores are evidence of higher academic performance in that particular academic domain. As per OECD recommendations of best practice, we examined each of the ten plausible values separately and averaged the results across these figures to obtain the most reliable analyses. Analyses on each of the individual plausible values offered qualitatively similar results.

4.5. Economic, social and cultural status (ESCS)

The OECD PISA generates an index of ESCS which combines a variety of measures in the PISA. Specifically, this measure indexes a combination of the International Socio-Economic Index of Occupational Status, the highest level of education achieved by a student's parents, family wealth, educational resources available in the student's home and the number of possessions related to classical culture in the home (e.g., Shakespearian literature). We employed this as a measure of socio-economic status to ensure that results were conflated by sociocultural or socioeconomic differences between students. Analyses not including this measure were qualitatively similar to the results presented here.

4.6. Data analyses

We tested our hypotheses through the use of iterative generalized least squares (IGLS) linear mixed-models using the MLwiN analysis program. For each of the models we nested students within schools, and schools within countries, and allowed the model to vary the intercept and slope of the linear regression equation between these hierarchical variables. Thus, the nesting of variables in this analysis allowed the model to fit a different relationship between video game play and academic performance between countries and schools. This results in a model with an average regression line, and a standard deviation of that line for school and country level variance which we report in the results section.

For the analysis of frequency of video game use, because the scale students reported upon was ordinal, we recoded the categorical variable as a series of dummy variables to determine the association each magnitude of frequency had upon academic performance. We also included student sex and ESCS in the model. This resulted in three models (one for science performance, one for mathematics performance, one for reading performance) for the frequency of single player games and three models for multiplayer games specified by the following equations.

$$\text{AcademicPerformance}_{jk} = \beta_{0jk} + \beta_{1jk}\text{SingleplayerMonthly} + \beta_{2jk}\text{SingleplayerWeekly} + \beta_{3jk}\text{SingleplayerAlmostDaily} + \beta_{4jk}\text{SingleplayerDaily} + \beta_{5jk}\text{Sex} + \beta_{6jk}\text{ESCS} + e_{jk} \quad (1)$$

$$\text{AcademicPerformance}_{jk} = \beta_{0jk} + \beta_{1jk}\text{MultiplayerMonthly} + \beta_{2jk}\text{MultiplayerWeekly} + \beta_{3jk}\text{MultiplayerAlmostDaily} + \beta_{4jk}\text{MultiplayerDaily} + \beta_{5jk}\text{Sex} + \beta_{6jk}\text{ESCS} + e_{jk} \quad (2)$$

where e denotes residual error, j denotes the value was allowed to vary by school site and k denoting that the value was allowed to vary by country.

For the analysis of the relationship between before and after school video game play, the independent variables were already in a binary response option format, and thus dummy coding was not required. This resulted in three models (one for science performance, one for mathematics performance, one for reading performance) which are specified by the following equation.

$$\text{AcademicPerformance}_{jk} = \beta_{0jk} + \beta_{1jk}\text{BeforeSchoolPlay} + \beta_{2jk}\text{AfterSchoolPlay} + \beta_{3jk}\text{Sex} + \beta_{4jk}\text{ESCS} + e_{jk} \quad (3)$$

5. Results

5.1. Video game use

26.4% of students indicated that they had played video games before school on their latest school day. Almost half of the sample (45.1%) indicated they had played video games after school on their most recent school day. For those who had played games at some time on their most recent school day, 44.1% had played only after school, 4.6% had played before school but not after school, and 51.3% had played both before and after school.

5.2. Frequency of video gameplay

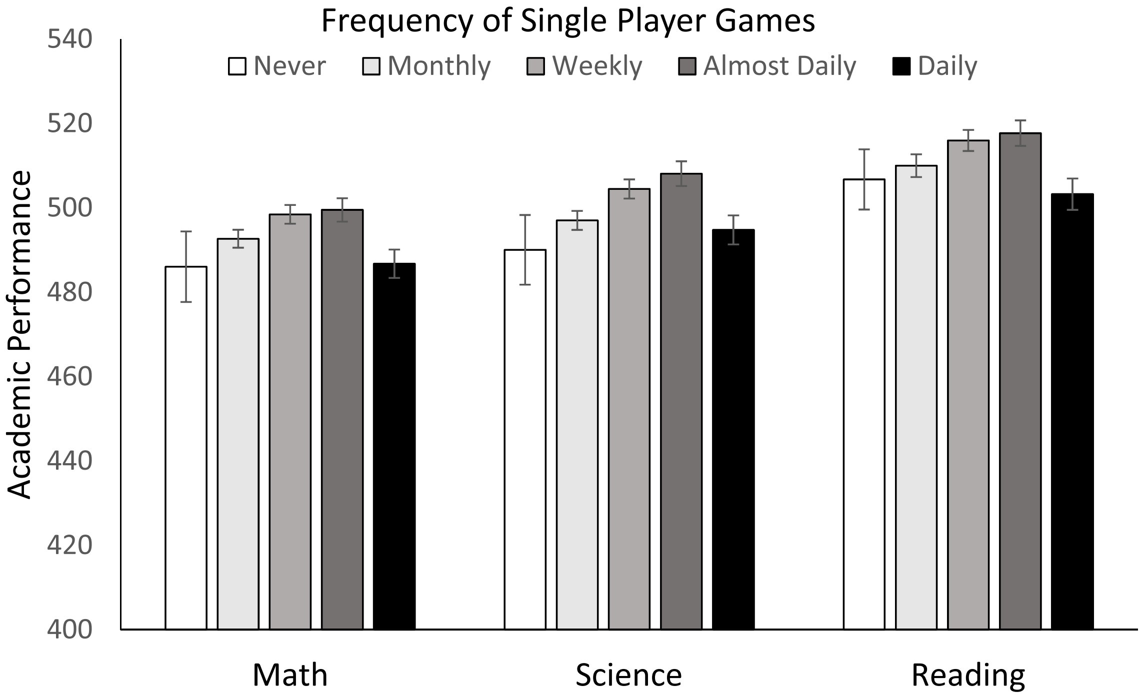
The relationship between the frequency of video game play and academic performance was examined in two sets of multi-level models – one for single player gameplay and one for multiplayer gameplay. The multilevel models allowed the intercept and slopes to vary by school and country, thus allowing the relationship between gameplay and academic performance to differ between countries and schools. The average relationships between the frequency of video gameplay and adolescent academic performance in mathematics, science, and reading are displayed in Fig. 2. Two models failed to converge – one plausible value in science and one plausible value in mathematics, both for the models estimating the relationship between academic performance and frequency of single player video game use. For these models we obtained averages based on the remaining 9 models. Only one relationship exceeded Cohen's (1992) recommendations for the smallest interpretable effect size – a small increase in science performance was observed for students who played video games almost every day as compared to those that never played. No other relationships exceeded a Cohen's d of 0.2. In sum, there were no non-trivial reductions in academic performance associated with the frequency of gameplay.

The multilevel models showed that the results were relatively consistent across countries and schools. Table 2 shows the standard deviation of the slopes across countries and schools for both single player and multiplayer games. While there is considerable variance in the never played group, it is important to note that this is the *intercept* and indicates expected high degrees of variance (and hence differences) in the average academic performance of students in different countries and schools. In contrast, the low variances of the *slopes* indicate that the relationship between gameplay and academic performance was relatively consistent irrespective of which country or school students were located within. Indeed, these variances suggest that the school a child is educated in has a greater effect on performance than frequency of gameplay.

5.3. Before/after school play

Our third research question was: Does the morning/afternoon timing of video game play moderate the relationship between gameplay and academic performance – that is, do effects on students' academic performance vary depending upon whether students are playing video games in the morning before, versus in the evening after, school? Here, we were particularly interested in the patterns of academic performance associated with morning/evening play as they provide valuable information about the likely mechanisms of action underlying any relationship between gameplay and adolescent academic performance.

As with the frequency of gameplay, the relationship between the timing of video game play and academic performance was examined in a multi-level model. Here we compared academic performance for students who played video games on before and/or after school against students who did not play video games on weekdays. Again, the multilevel models allowed the intercept and slopes to vary by school and country. There was a tendency for students who reported playing during the week (either before or after school) to report lower academic performance than their peers who did not play during the week in science, $d = 0.21$, mathematics, $d = 0.20$, and reading, $d = 0.26$, replicating the core finding of Hartanto et al., 2018, in both direction and effect size. However, this effect was clarified by substantive differences in the relationship between before and after school video game play and academic performance. Specifically, the relationship was primarily due to students who played before school, irrespective of whether they also played after school. Fig. 3 shows the relationship between before and after school video game play and adolescent performance in mathematics, science, and reading. Before school video game play was associated with a drop in academic performance between 35



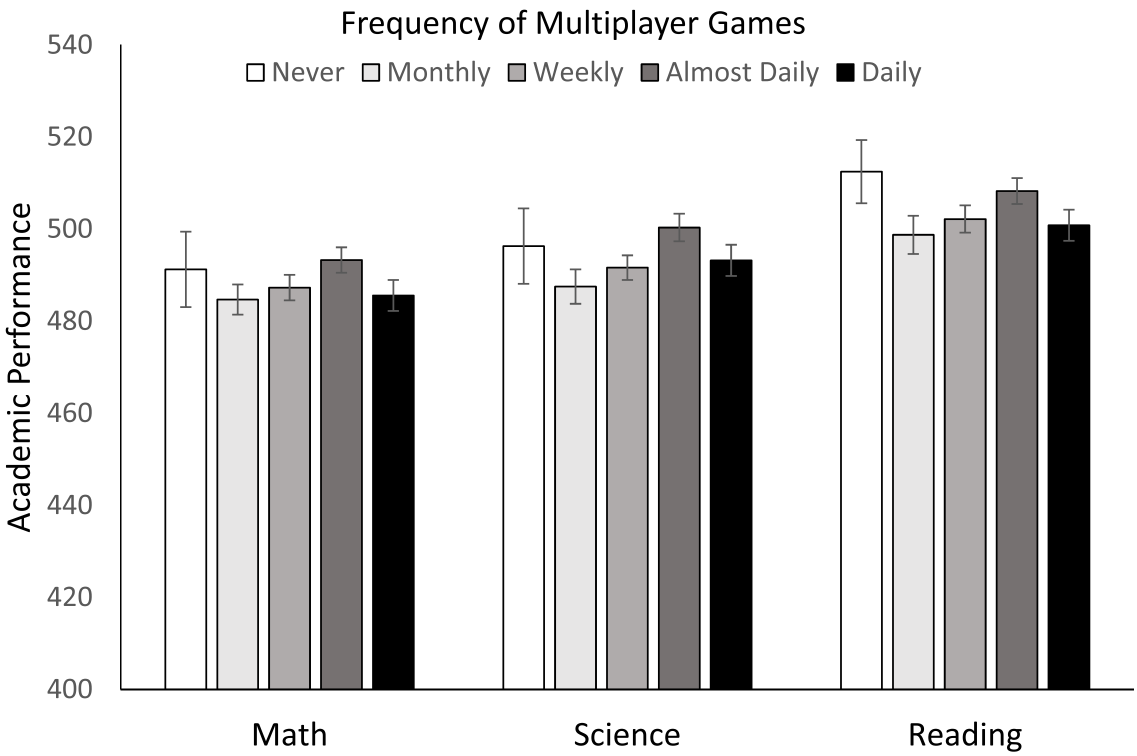


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Fig. 2. The relationship between frequency of single player video game use and adolescent academic performance (top) and multiplayer video game use and adolescent academic performance (bottom). The full contents of these models are specified by equation (1) (top) and 2 (bottom). Academic performance is assessed on a scale with an international average of 500 and a standard deviation of 100. Error bars represent 95% confidence intervals. As MLWin does not produce 95% confidence intervals, these were computed manually as 1.96 times the standard error of the slope. The only difference which exceeded a Cohen's *d* of 0.2 (a small effect) was an increase in science performance for students who played single player games almost every day (c.f., those that never played). The observed reduction in reading performance for weekly players of multiplayer games approached, but did not reach a *d* of 0.2 ($d = 0.17$) which is similar to the size of the increase in mathematics performance for players of single player games almost every day or the increase in science performance for players of single player games weekly ($ds = 0.18$). Note that higher frequencies of video game play showed better reading performance than monthly multiplayer game users.

Table 2
Standard deviations of slopes for the multilevel models.

	Mathematics		Science		Reading	
	Country	School	Country	School	Country	School
Single player						
Never (Intercept)	23.29	32.90	22.97	34.06	19.60	35.05
Monthly	5.10	4.27	5.41	3.34	6.82	3.33
Weekly	5.47	4.79	5.64	1.78	6.38	1.41
Almost Daily	7.00	8.87	7.48	8.07	7.70	7.56
Daily	8.57	10.70	8.66	12.10	9.51	12.63
Multiplayer						
Never (Intercept)	22.82	32.29	22.78	33.36	18.95	34.10
Monthly	8.61	6.62	9.91	5.97	11.09	8.84
Weekly	6.99	6.95	6.58	7.25	7.57	7.06
Almost Daily	6.75	9.92	7.37	12.48	6.84	11.25
Daily	8.65	10.82	8.59	12.52	8.52	12.23

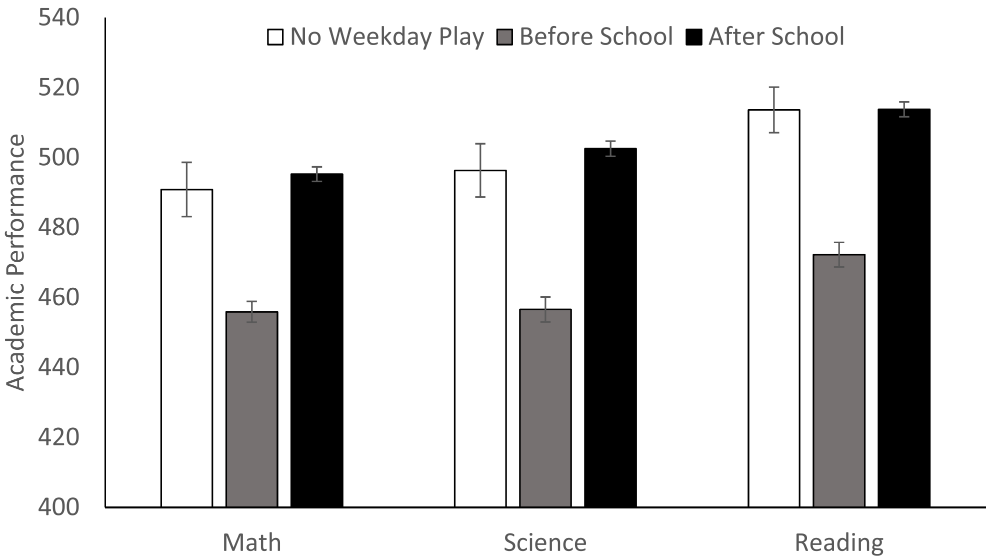

Fig. 3. The relationship between before and after school video game play and adolescent academic performance. The full model is specified in equation (3). Academic performance is assessed on a scale with an international average of 500 and a standard deviation of 100. Error bars represent 95% confidence intervals. As MLWin does not produce 95% confidence intervals, these were computed manually as 1.96 times the standard error of the slope. The decline in academic performance associated with before school play (c.f. no gameplay) approached a moderate size for mathematics ($d = 0.47$), and moderate in size for science ($d = 0.50$) and reading ($d = 0.52$). Compared to after school play, adolescents who played before school performed moderately worse on mathematics ($d = 0.52$), science ($d = 0.57$) and reading ($d = 0.52$). Differences between no video game play and after school play were negligible, and counter to predictions: For all three indicators, academic performance was, if anything, negligibly higher for students who played games after school.

and 41 points on the PISA assessment of mathematics, science, and reading performance ($Ms = 500$, $SDs = 100$). No reduction in academic performance in any domain was evident for after-school gamers.

There was little variance in the slope of the relationship by country or school. For the relationship between before school gameplay and academic performance, the variance in slope of the relationship by country was similar and relatively small compared to the effects ($SD_{Mathematics}$ = 8.33, $SD_{Science}$ = 10.13, $SD_{Reading}$ = 10.00). Variance of the slope of the relationship by school was also small compared to the effects ($SD_{Mathematics}$ = 8.61, $SD_{Science}$ = 9.45, $SD_{Reading}$ = 10.37). Commensurate with the smaller effects, for the relationship between after school gameplay and academic performance, variance of the slope by school were tightly clustered around the average slope ($SD_{Mathematics}$ = 5.55, $SD_{Science}$ = 5.77, $SD_{Reading}$ = 5.18). Variance of the slope of the relationship by school was also small compared to the effects ($SD_{Mathematics}$ = 7.09, $SD_{Science}$ = 7.84, $SD_{Reading}$ = 8.83). This implies that the relationships were relatively consistent across countries and schools.

Perhaps students who played before school were typically more likely to also play after school. This total increase in gameplay may be enough to displace academic activities, even if playing either before or after school is not. If this were true, we would expect this to be evidence in a non-trivial interaction term indicating that effects on academic performance varied for players who played *both* before and after school, compared to players who played *either* before or after school. However, including the interaction term for the interaction between before and after school play in the model did not alter these results. In fact, the interaction yielded trivial effects in the opposite direction for all measures. That is, people who played both before and after school had trivially higher scores than students who played *only before school.* This implies that the observed reduction for students who play before school is not due to a higher amount of total gameplay split between before and after school play, and that observed reductions in academic performance are specific to the effects of before school gameplay.

6. Discussion

The present study investigated three research questions. First, do adolescent students who play video games more frequently exhibit lower academic achievement scores than their peers who play less frequently and are the effects similar in size to those observed by Drummond and Sauer (2014)? Second, do adolescents who play video games on weekday's exhibit lower academic achievement scores than their peers who do not play on weekdays, and are the effects similar in size to those observed by Hartanto et al. (2018)? Third, are there systematic differences in the timing of weekday play which can expand our knowledge of the theoretical mechanisms which account for any observed reductions in weekday play?

In response to the first question, our analyses replicate Drummond and Sauer's (2014) findings: There did not appear to be a systematic reduction in academic performance based on the frequency of gameplay. Indeed, the only observed effect larger than the minimum recommendation for a small effect Cohen (1992) was a small *increase* in science performance for adolescents who played games almost daily (cf. those who never played). We would suggest interpreting this relationship with caution for two reasons. First, the relationship borders the smallest interpretable effect size suggested by Cohen (1992). Second, and more importantly, there appears to be no theoretically plausible explanation as to why almost daily gameplay would increase science performance compared to other frequencies of play.

To the second question, we were able to replicate Hartanto et al. (2018) general finding that students who play games on weekdays (cf. those who did not play during the week) showed slightly lower academic performance across reading, mathematics, and science. However, it is critical to note that this effect is only properly interpretable alongside findings relating to timing of gameplay. Specifically, and in consideration of the third research question, students who played video games in the morning prior to attending school exhibited moderately lower academic performance across the three academic domains compared to students who played video games after school whose academic performance, in turn, was no poorer than for students who did not play games on weekdays.

To our knowledge, no extant theory of the effects of video games on academic performance can properly account for these findings. Sleep displacement would predict the precise opposite of what we observed: that evening (but not morning) play would produce a reduction in academic performance. Similarly, displacement mechanisms would require that gameplay that occurred at any time a student may be undertaking homework to result in lower academic performance. Even if one rejects the PISA data presented herein suggesting a substantial number of students study in the morning, the theory still requires evening play to reduce academic performance as it displaces evening study, something we did not observe. Finally, changes in the attentional mechanisms of students would require no difference in the relationship between weekday/weekend play and academic performance to materialise. This was not the case in the present data, nor in Hartanto et al. (2018) data. Given these theoretical accounts, we suggest that the data most likely indicate a third variable explanation. These data suggest that video game play does not have a veridical impact upon academic performance, and instead the association is spurious and due to un-modelled variables.

We are hesitant to speculate much on the exact nature of this third variable, as it requires substantial conjecture beyond the available data. In our view, a number of explanations may account for the findings. For example, laissez-faire parenting may include relaxed controls on students' before-school behaviour *and* less oversight of homework, thus accounting for the differences observed. Similarly, playing games in the morning prior to school might be an indicator of poor impulse control, or broader problematic gameplay behaviours. It may also be the case that depressed, anxious, or disengaged students engage in morning gameplay as a form of escapism, and thus the reduction in academic performance may be more indicative of underlying mental health or educational engagement issues rather than the effects of video games per se. Further research, testing theoretically-motivated hypotheses, is clearly required to disentangle the effects of gameplay (and other forms of media) from confounds that may explain differences in educational performance.

More broadly, these results highlight the need for the careful specification of theory in the media psychology and education research domains. It is not enough to theoretically examine relationships in large datasets. For instance, a similar analysis might be performed on whether students perform worse academically when they play a greater amount of soccer each week, yet without a plausible theory to explain how playing soccer would affect academic performance this analysis would at best be meaningless and at worst (if a significant negative relationship were observed) spark undue moral panic about the effects of an activity unrelated to learning. Much has been made of the apparent significant relationships between video game use and academic performance observed in past studies, yet here we show that they cannot be adequately explained by plausible theory and thus appear to be non-veridical factors. Media psychologists need to specify the supposed theoretical mechanisms underpinning potential media effects, and then diligently test theoretically-motivated hypotheses. Given the higher probability of false discovery when datasets are reanalysed for relationships they were not designed to test (Simmons, Nelson, & Simonsohn, 2011), researchers should be especially certain to specify *a-priori* the patterns of results that would effectively falsify such theories and ensure that these falsification conditions are extensively tested. To effectively advance this important area of inquiry, a more nuanced understanding of the effects of specific kinds of media, and specific kinds of engagement, upon more stratified groups is required to inform an important and pressing discussion of the appropriateness of specific content for specific audiences. In other words, researchers need to employ a great deal of care to (a) ensure that, when considering what factors may affect learning, there are plausible pathways by which these factors could legitimately influence learning and (b) clearly specify what analysis outcomes would confirm or falsify their predictions.

6.1. Future research

The present research suggests that the association between academic performance and video game play is unlikely to be causal. No plausible theory of video game play on academic performance adequately explains why lower academic performance scores should be observed for morning players but not evening players. Thus, as we have stated earlier, we believe the findings most likely represent a third variable explanation. Though we have speculated that it may be that students with *laissez-faire* parents may simultaneously lack encouragement of school work and boundaries around appropriate video game play, or that disengaged students may play video games as a coping strategy, these explanations are, presently, untested. Future research should investigate what the third-variable driving the observed differences in academic performances observed for morning players is to better understand the true reason for this observed correlation.

One potentially interesting area for future research relates to whether the genre of games that students are playing has any bearing on their academic performance. Many have attempted to construct serious games for the purposes of learning, with mixed results (Michael & Chen, 2005). Some research suggests that expert players of games with historical simulation elements (e.g., Civilization) exhibit better subsequent learning of history than expert players of similar games without history elements (Hammer & Black, 2009). Similarly, students who played a game about genetics showed greater subsequent engagement in genetics classes than a control group (Annetta, Minogue, Holmes, & Cheng, 2009), and computer science taught via game appears to increase student memory for computer science concepts compared to students in a non-game control (Papastergiou, 2009). It therefore may be that players of certain genres of games (e.g., science-based puzzle games, learning games) may show increases in academic performance compared to those who play non-educational games. Future research should examine the genre and context of gaming to determine whether there are any veridical influences of particular game-types upon learning.

6.2. Conclusion

In sum, weekday gameplay does appear to be associated with a moderate reduction in academic performance for adolescent users, but only for those users who engage with video games in the morning before school. Further, no existing theoretical account of video game play effects on academic performance appear to account for these data. As such, it appears safest to conclude that video game play per se does not negatively influence adolescent academic performance. For the majority of gamers, who do not engage in before school play (73.5%), the present findings support existing evidence that playing video games is unlikely to be a risk factor for poor academic performance. These data suggest that interventions beyond existing parental controls to control game time are, *for academic purposes*, unnecessary. The lower academic performance of morning players, while unlikely to be caused by video games, might be an indication of broader third-variable issues for students, such as disengagement or laissez-faire parenting. Parents who have teens who engage in morning video game play prior to school however, may therefore be wise to consider this a possible warning sign for poorer academic performance and seek strategies to increase student engagement.

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