Is Computer Gaming Associated with Cognitive Abilities?

A Population Study among German Adolescents

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Abstract

Playing commercial computer games supposedly trains cognitive abilities. The present study investigated linear and nonlinear associations between the time spent on computer and video games each day and cognitive abilities in a representative sample of $N = 12{,}459$ German adolescents (51% girls). Piecewise polynomial regression analyses revealed that computer gamers scored higher on standardized tests of reasoning and receptive vocabulary than non-gamers, but the difference was small in size. Among gamers, the time spent on computer games exhibited very modest associations with the cognitive scores: Reasoning and receptive vocabulary showed a slight (non)linear increase, whereas perceptual and reading speed were largely unrelated to gaming times. Analyses that did not account for the gender of the respondents created spurious effects that might wrongly indicate associations of gaming times with cognitive abilities. This is the first large-scale assessment showing that linear as well as nonlinear associations between playing commercial computer games and different cognitive abilities are weak to nonexistent.

Keywords: computer games, video games, intelligence, reading, perceptual speed

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Computer gaming is one of the most popular pastime activities for adolescents and young adults alike. About half of all Americans (Duggan, 2015) and Europeans (Ipsos MediaCT, 2012) report playing computer games at least occasionally. Among teenagers computer gaming is even more widespread. According to a nationally representative study 72% of US teenagers (84% of boys and 59% of girls) play computer games (Lenhart, Smith, Anderson, Duggan, & Perrin, 2015), more than half of them for two hours or more each day (Brooks et al., 2015). Whereas playing popular computer games has been connected to maladaptive thoughts, feelings, and behavior (e.g., Greitemeyer & Mügge, 2014; see also Ferguson, 2015) other research outlined its positive psychological ramifications (for an overview see Granic, Lobel, & Engels, 2014). Among others, playing computer games on a regular basis was linked to a variety of cognitive skills including processing speed and problem solving (e.g., Basak, Boot, Voss, & Kramer, 2008; Drew & Waters, 1986; Stroud & Whitbourne, 2015; for a recent review see Green & Seitz, 2015). However, several failures to replicate these findings (e.g., Colzato, van den Wildenberg, Zmigrod, & Hommel, 2013; Hambrick, Oswald, Darowski, Rench, & Brou, 2010; Unsworth et al., 2015) alongside a number of methodological weaknesses of many studies (see Boot, Blakely, & Simons, 2011; Green, Strobach, & Schubert, 2014; Latham, Patston, & Tippett, 2013) cast doubts on the current evidence. Therefore, the present study examined the association between basic cognitive abilities and the time spent on computer games each day in a large, representative sample of adolescents. Notably, this study is among the first to highlight linear as well as nonlinear relationships between cognitive abilities and computer gaming including moderating influences thereon.

Computer Gaming and Cognitive Abilities

Repeated practice can considerably improve people's performance on a given task; this also applies to the cognitive domain. For example, cognitive training programs have been shown to improve working memory (e.g., Kelly et al., 2014). However, their benefits appear to be limited to tasks closely related to the training program, with non-significant transfer to other tasks. Harrison and colleagues (2013) showed that training in working memory tasks lead to improvements in other working memory tasks, but not in tests of fluid intelligence. Moreover, the effectiveness of cognitive training for the improvement of everyday, real-world performance has not yet been convincingly demonstrated (see recent reviews by Melby-Lervåg, Redick, and Hulme, 2016, and Simons et al., 2016). Many of these training programs come in the form of computerized, game-like applications that were explicitly constructed to practice specific cognitive domains. Similarly, many commercial computer and video games exhibit features that might incidentally train cognitive skills. Although primarily developed for fun and entertainment, many of these games are rather complex and require the use of multiple cognitive abilities (Baniqued et al., 2013; Quiroga et al., 2015). At the same time, commercial computer games are intrinsically motivating; people play them voluntarily without any obligation to do so and frequently dedicate a substantial amount of their free time to playing these games (Duggan, 2015; Lenhart et al., 2015). Therefore, it has been suggested that by playing computer and video games on a regular basis people casually train their cognitive abilities. Consequently, computer gamers should yield higher scores on standardized tests of intelligence than non-players. In line with this assumption, playing computer games has been linked to various cognitive domains such as improved spatial skills (Murias, Kwok, Castillejo, Liu, & Iaria, 2015; Sanchez, 2012; Shute, Ventura, & Ke, 2105; Uttal et al., 2013), better perceptual speed and attentional capacity (Chiappe, Conger, Liao, Caldwell, & Vu, 2013; Stroud & Whitbourne, 2015), and increased fluid intelligence (Basak et al., 2008; Drew & Waters, 1986; Shute et al., 2015). Intensive computer gaming might even induce neural changes associated with these cognitive skills (Kühn, Gleich, Lorenz, Lindenberger, & Gallinat, 2014). A meta-analysis estimated that, on average, computer gaming was associated with cognitive gains corresponding to Cohen's *d* between .48 to .61 (Powers, Brooks, Aldrich, Palladino, & Alfieri, 2013). However, the meta-analysis also highlighted substantial heterogeneity between the published effects. Although many studies documented cognitive benefits of playing computer games, a number of studies were unable to replicate these effects (e.g., Colzato et al., 2013; Hambrick et al., 2010; Unsworth et al., 2015). The meta-analysis also highlighted a potential publication bias in this field. Small effects and nonsignificant results tended to be underrepresented in the published literature. Importantly, most of the published gaming studies are plagued by severe methodological shortcomings (see Boot et al., 2011; Green et al., 2014; Latham et al., 2013; Unsworth et al., 2015), similar to research on the effectiveness of cognitive training programs (see Simons et al., 2016). Thus, the credibility of many available research findings is questionable at best.

Shortcomings of Previous Research

Despite a substantial body of research on computer gaming and cognitive abilities, a number of methodological shortcomings make the available findings rather difficult (if not impossible) to evaluate (see Table 1). For one, most previous research adopted group comparisons that contrasted computer gamers and non-gamers. This can be problematic for a number of reasons (see Unsworth et al., 2015): For example, computer gamers are all treated equally although there is likely to be a large variability in the time spent on computer games (from less than 6 hours per week to more than 20 hours; cf. Latham et al., 2013). Although moderate amounts of computer gaming might benefit cognitive abilities, it is likely that excessive gaming can also yield detrimental consequences—for example, excessive gaming has been linked to dependency symptoms and psychiatric disorders (Schou Andreassen et al., 2016). So far, even when computer gaming time was examined continually (e.g., Hambrick et al., 2010; Unsworth et al., 2015) predominantly linear trends were acknowledged. In addition, extreme group comparisons between heavy gamers and non-gamers are likely to overestimate effect sizes and thus increase the likelihood of Type I errors (cf. Preacher, Rucker, MacCallum, & Nicewander, 2005). Another shortcoming pertains to different demand characteristics between gamers and non-gamers that might have contributed to between-group differences (see Boot et al., 2011; Boot, Simons, Stothart, & Sutts, 2013; Green et al., 2014). If gamers are recruited to a study because of their gaming experience and they are aware that their gaming skills are the focus of the investigation, they might expect to perform well on the cognitive tasks and thus might also be strongly motivated to do so. In contrast, there are no respective expectations for non-gamers. Thus, placebo effects might account for many of the documented cognitive benefits of computer gaming (see Foroughi, Monfort, Paczynski, McKnight, & Greenwood, 2016). Finally, most gaming research suffers from pronounced sampling biases. The average sample size of most available gaming studies is extremely small. According to a recent meta-analysis (Powers et al., 2013) the average sample size was about 48 for quasi-experimental studies and even less ($N = 35$) for true experiments. As a consequence, the power of the average study in this field to detect the small effects that are expected in this line of research was only about .40. To make matters worse, most gaming research relied on convenient samples dominated by undergraduate students. However, undergraduates are typically a rather peculiar group (Sears, 1986). On average, they exhibit stronger cognitive abilities. Moreover, the cognitive skills of college and university students typically exhibit a rather restricted range. Consequently, potential associations between cognitive abilities and computer gaming might be underestimated. In addition, in computer gaming research cognitive differences are frequently confounded with gender differences: Men tend to engage more strongly in computer gaming activities than women (Greenberg, Sherry, Lachlan, Lucas, & Holmstrom, 2010). As a result, the group of computer gamers is frequently dominated by male participants, whereas non-gamers typically exhibit a more balanced gender ratio. Consequently, it is unclear whether documented between-group differences reflect effects of computer gaming or rather gender differences in cognitive abilities (see Hyde, 2014; Irwing & Lynn, 2004).

Present Investigation

The general aim of the present study was to examine the relationship between playing computer and video games (i.e., gaming intensity) and basic cognitive abilities. In doing so, we tried to overcome three major limitations of previous studies: First, we examined computer gaming activities as a continuum, thereby including non-gamers, casual gamers, and heavy gamers. This allowed us to analyze not only linear but also potential nonlinear relationships between computer gaming and cognitive abilities. Second, we relied on a large, representative sample of adolescents with heterogeneous cognitive skills to overcome limitations due to sampling error and range restriction. Moreover, the topic of computer and video games was not made salient to respondents during the study to guard against different demand characteristics for gamers and non-gamers. Rather, the questions on computer gaming activities were embedded in a larger research project on competence development across the life course. Third, we explicitly accounted for the respondents' gender to disentangle the effects of computer gaming activities from gender differences in cognitive skills. In conclusion, the present study provides a more exhaustive and more nuanced investigation of the relationship between computer gaming and basic cognitive skills than is available so far.

Method

Sample

The study draws on a representative sample of German students from the National Educational Panel Study (NEPS). The NEPS is a large-scale, longitudinal, multi-cohort study that examines the development of competencies and educational trajectories across the lifespan (Blossfeld, Roßbach, & von Maurice, 2011). For this study, we analyzed responses from N = 12,459 students (51% girls) in 988 classes attending 536 different secondary schools in ninth grade in the school year 2010/2011. All major school types across the country were included (for more information on the sampling procedure see Aßmann et al., 2011). On average, these students were $M = 14.70$ ($SD = 0.71$) years old.

Instruments

Computer gaming intensity was assessed with three items asking about how long students played (a) online role-playing games (e.g., World of Warcraft, Gild Wars), (b) games of skill or strategy, and (c) other computer or video games on a normal school day. The responses were recorded on five-point scales with 1 = *never*, 2 = *up to 1 hour*, 3 = *1 to 2 hours*, 4 = *2 to 4 hours*, 5 = *more than 4 hours*. The average gaming time per day (in hours) was approximated by recoding the five response options into values of 0.0, 0.5, 1.5, 3.0, and 4.5, respectively (i.e., representing the average hours playing computer games) and summing up the three item scores. On average, the students played about $M = 1.96$ ($SD = 2.46$) hours of computer games during a regular school day[1]. In addition, we calculated the relative proportion of the total gaming time per day spent on each type of computer game. Thus, we derived the relative time dedicated to online role-playing games ($M = 0.09$, $SD = 0.22$) and the relative time playing games of skill or strategy ($M = 0.19$, $SD = 0.28$).

Basic cognitive skills were measured with two tests assessing reasoning and perceptual speed that were specifically constructed for administration in the NEPS. The adopted theoretical framework for these tests is described in Brunner, Lang, and Lüdtke

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[1] We conducted two kinds of sensitivity analyses to examine the stability of the results with regard to the chosen scoring scheme. First, we used the ordinary sum score of the *untransformed* item responses as an indicator of gaming intensity. Second, an additional item asked how long on average students played computer games or console and video games on a day when there was no school (weekend, vacation). Therefore, we also calculated a composite score of the average computer gaming time *per week*. However, both alternative scoring schemes replicated the reported pattern of effects. Therefore, we only present the results for the more intuitive score representing the average hours playing computer games per day.

(2014), whereas details on the construction process are presented in Lang, Kamin, Rohr, Stünkel, and Williger (2014). *Reasoning* was measured with a Raven (1977)-type test including 12 items. Each item consisted of a number of fields including geometrical elements that followed various logical rules. Participants had to identify these rules to select the correct element from a series of available response options (example items are given in Lang et al., 2014). The number of correctly solved items represented the focal indicator of students' reasoning abilities. On average, the participants correctly solved M = 8.72 (SD = 2.41) items. The omega hierarchical reliability (Rodriguez, Reise, & Haviland, 2016) of this measure was ω_h = .84. *Perceptual speed* was measured with a picture symbol test that required participants to match a series of numbers with graphical symbols (example items are given in Lang et al., 2014). The test included three sets each containing 31 items that had to be solved within 30 seconds. The number of correctly scored items across the three sets represented the focal indicator of perceptual speed for each student. On average, the participants correctly solved M = 59.24 (SD = 13.72) items. The reliability was ω_h = .80.

Basic reading skills were measured with two tests assessing receptive vocabulary and reading speed. *Receptive vocabulary* (i.e., the understanding of spoken word meanings) is a central indicator of language competence and also crystallized intelligence (e.g., Perfetti, 2010). In the NEPS it is measured with a version of the Peabody Picture Vocabulary Test (Dunn & Dunn, 2004; see also Berendes, Weinert, Zimmermann, & Artelt, 2013) including 89 items. For each item the respondents had to select one out of four pictures that corresponded to a spoken word. The sum score of correctly answered items represented the measure of receptive vocabulary. The average score of the respondents was M = 57.33 (SD = 10.52) and the reliability amounted to ω_h = .95. *Reading speed* (i.e., automated reading processes such as decoding) represents an elemental prerequisite for competence development across the life course. The administered test for reading speed followed the Salzburg Reading Screening (Auer, Gruber, Mayring, & Wimmer, 2005) and included 51 short sentences (e.g., "There is a bath tub in every garage.") that had to be rated as either true or false within two minutes. The sum score of correctly answered items represented the indicator of students' automatized reading processes. On average, the participants correctly solved M = 34.26 (SD = 8.56) items. The scale had a reliability of ω_h = .96.

Statistical Analyses

The associations between computer gaming intensity and cognitive abilities were examined with piecewise polynomial regression analyses using a maximum likelihood estimator that specified either reasoning, perceptual speed, receptive vocabulary, or reading speed as criterion. Potential nonlinear relationships were studied by recoding computer gaming intensity into two components that reflected the intercept and change of cognitive abilities associated with computer gaming: On the one hand, separate intercepts for computer gamers and non-gamers were modeled by including a dichotomous predictor in these regressions that indicated whether the respondent played computer games at least occasionally (coded 1) or never played computer games at all (coded 0). This variable reflected qualitative differences in cognitive abilities between gamers and non-gamers. On the other hand, potential differences in cognitive abilities between computer gamers associated with the time spent on computer games were acknowledged by including orthogonal higher-order polynomials (see Cohen, Cohen, West, & Aiken, 2003) of computer gaming intensity as predictors in these regression models. The appropriate number of higher-order terms was identified by selecting the best fitting regression model in terms of the Bayesian Information Criterion (BIC; Schwartz, 1978) from different models that included polynomials of degree 1 to 10. These polynomials reflected the change in gamers' cognitive abilities related to the time dedicated to computer games each day. Because the adolescents were sampled from different classes located in different schools, these dependencies were acknowledged by estimating a three-level mixed-effects regression model. Although the higher-order structure is not of focal interest for the present investigation, inclusion of the respective random variance components results in more precise estimates of the regression parameters and their standard errors (Snijders & Bosker, 2012). Model fit was evaluated using the BIC (with smaller values indicating a better fit) and the probability of a particular model given the data (see Wagenmakers, 2007). Subsequently, the univariate regression analyses were replicated in latent variable analyses. These models were estimated using a maximum likelihood algorithm (Yuan & Bentler, 2000) and heteroskedasticity-robust standard errors (Hays & Cai, 2007). In line with conventional standards (Schermelleh-Engel, Moosbrugger, & Müller, 2003) models with a comparative fit index (CFI) > .95, a root mean square error of approximation (RMSEA) < .08, and a standardized root mean square residual (SRMR) < .10 are interpreted as ”acceptable”, whereas CFI ≥ .97, RMSEA ≤ .05, and SRMR ≤ .05 are evaluated as ”good” fitting.

Statistical Software and Open Data

Univariate analyses were conducted with the *lme4* software version 1.1-12 (Bates, Maechler, Bolker, & Walker, 2015) in *R* version 3.3.1 (R Core Team, 2016). Multivariate models were estimated in M*plus* 7 (Muthén & Muthén, 1998-2012). The raw data is available at http://www.neps-data.de.

Results

Descriptive Analyses

More than two thirds of the sample indicated playing computer and video games at least occasionally, whereas about 28 percent never played computer games at all (see Figure 1). These findings are similar to prior results from representative teenage samples from the US (e.g., Lenhard et al., 2015). About half of the students showed moderate gaming behavior and played up to about three hours each day. The remaining students could be characterized as heavy gamers that played for four hours and longer each day. As expected, boys (M = 3.08, SD = 2.77) spent significantly, t(9,212.74) = 55.07, p < .001, d = 0.99, more time on computer games than girls (M = 0.88, SD = 1.48). Moreover, boys dedicated on average 15.40 percent

(SD = 26.13) of their gaming time to role-playing games such as World of Warcraft or Gild Wars; the respective proportion was significantly, $t(9{,}453.37) = 31.17$, $p < .001$, d = 0.56, smaller for girls (M = 3.51, SD = 14.59). With regard to games of skill and strategy the respective difference between boys (M = 21.47, SD = 25.68) and girls (M = 16.75, SD = 28.95) was considerably smaller, $t(12{,}389.16) = 9.63$, $p < .001$, $d = 0.17$. The zero-order correlations between the time spent on computer games and the four ability scores (see Table 2) did not support the hypothesis of enhanced cognitive abilities for computer gamers. Computer gaming intensity exhibited small negative associations with reasoning, $r = -.02$ (p = .02), perceptual speed, $r = -.07$ ($p < .001$), and reading speed, $r = -.14$ ($p < .001$), and a small positive correlation with receptive vocabulary, $r = .02$ ($p < .001$). However, these correlations might be misleading if there are nonlinear relationships between computer gaming intensity and cognitive abilities.

The Relationship Between Computer Gaming and Cognitive Abilities

The associations between computer gaming and the cognitive ability scores were examined by regressing either reasoning, perceptual speed, receptive vocabulary, or reading speed on the dichotomous indicator distinguishing gamers from non-gamers and higher-order polynomial terms of computer gaming intensity. Model comparisons using the BIC indicated that the best fitting model for receptive vocabulary included linear and quadratic effects, whereas for reasoning, perceptual and reading speed only linear effects of computer gaming intensity were indicated. The respective mixed-effects regression model for reasoning (Model 1 in Table 4) yielded a significant difference between gamers and non-gamers, $\beta = .09$, $p <$ .001. Moreover, for gamers reasoning showed a slight linear increase with the time spent on computer games each day, $\beta = .02$, $p = .01$. As shown in Figure 2 (left plot in first row), in terms of Cohen's d the difference in reasoning abilities between non-gamers and students that played approximately one hour per day represented a $d = .20$. In contrast, there was only a minor difference between moderate gamers playing one hour each day and heavy gamers that played for about five hours each day, $d = .04$. A similar albeit slightly curvilinear trajectory resulted for receptive vocabulary (see Table 4). Again, receptive vocabulary was significantly larger for gamers than for non-gamers, $\beta = .10$, $p < .001$. Moreover, for gamers it significantly ($p < .001$) increased for students dedicating more time to playing computer games (see right plot in first row of Figure 2). In terms of Cohen's *d*, the difference in receptive vocabulary between non-gamers and students that played approximately one hour per day was $d = .19$. Moreover, for gamers receptive vocabulary increased by $d = .22$ between moderate gamers playing about one hour each day and heavy gamers that played about five hours per day. We were unable to identify similar differences between gamers and non-gamers for perceptual and reading speed (see Model 1 in Table 5). Rather, the regression models showed only a continuous decline ($p < .001$) in the two speed measures with the time spent on computer games. In terms of Cohen's *d*, this decline represented a $d = -.09$ and $d = -.11$ between moderate gamers that played about one hour per day and heavy gamers playing about five hours (see first row of Figure 3).

Moderating Effects of Gender and Game Type

We expected that boys, the group that in general engages in computer games more frequently, might benefit more strongly from playing computer games than girls. In addition, we also explored whether cognitive abilities might benefit more from different types of games (i.e., games of skill and strategy). These moderating influences were examined by estimating four mixed-effects regression models for each cognitive measure: First, we extended the previous regression models to additionally include the main effects of gender, the proportion of gaming time spent on games of skill or strategy, and the proportion of gaming time spent on role-playing games (Model 2 in Table 3). Second, we added the interactions between gender and the computer gaming measures (Model 3) or the interactions between the proportion of gaming times spent on each type of game and computer gaming (Model 4). Finally, Model 5 included all main effects and higher-order interactions between these variables. Model comparisons using the BIC indicated that for all four cognitive measures the model including only the main effects but no interactions (Model 2) had the smallest BIC and, thus, exhibited the best fit. Moreover, the probability of Model 2 given the data (see Wagenmakers, 2007) exceeded 99 percent in all four cases (see Table 3). Therefore, our interpretations focus on Model 2.

Reasoning and receptive vocabulary were significantly ($p < .05$) larger for boys, $\beta = .03$ and $\beta = .14$, and for students who dedicated more time to games of skill and strategy, $\beta = .05$ and $\beta = .04$, than to other games (see Model 2 in Table 4). However, these factors did not moderate the association between computer gaming intensity and reasoning or receptive vocabulary; rather the respective effects remained unaffected by gender and the type of game (see Figure 2). For perceptual and reading speed these analyses identified pronounced ($p < .001$) gender differences, $\beta = -.18$ and $\beta = -.12$, respectively (see Table 5). On average, girls achieved higher scores on both speed measures than boys. After accounting for this effect perceptual speed was more or less invariant across different levels of gaming intensity and did not change, whereas reading speed exhibited a small decline between moderate gamers that played about one hour each day and heavy gamers playing about five hours, $d = -.04$ for boys and girls (see last row of Figure 3).

Latent Variable Analyses

Because the four cognitive measures were moderately correlated to each other (see Table 2), we estimated a latent variable model with a bifactor structure that accounted for these intercorrelations (see Figure 4). Following the CT-C(M-1) approach (cf. Geiser, Eid, & Nussbeck, 2008), the bifactor structure included a general factor for all four cognitive measures (*g*-factor) and a specific factor (*s*-factor) for the two speed measures. In this model the *g*-factor can be interpreted as general intelligence as measured by reasoning and vocabulary, whereas the *s*-factor accounted for the *residual* variance due to perceptual and reading speed. In line with the previous analyses, the two latent factors were regressed on the dichotomous indicator distinguishing gamers from non-gamers, computer gaming intensity (linear and quadratic terms), and the covariates (i.e., gender, gaming type). The respective model exhibited a good fit to the data, $\chi^2(df = 12) = 207.02$, CFI = .96, SRMR = .02, RMSEA = .036 (90% CI = [.032, .041]). The estimated model parameters are summarized in Figure 4. Gamers exhibited a significantly larger *g* than non-gamers, $B = 0.08$, $SE = 0.02$, $p < .001$, $\beta = .07$; in contrast, there was no significant difference on the specific factor, $B = 0.02$, $SE = 0.02$, $p = .28$, $\beta = .02$. Moreover, there were significant linear relationships between gaming intensity and the general factor, $B = -0.02$, $SE = 0.01$, $p = .01$, $\beta = -.10$, as well as the specific factor, $B = -0.02$, $SE = 0.01$, $p = .04$, $\beta = -.10$. Non-linear associations were not significant for neither factor, $B = 0.00$, $SE = 0.00$, $p = .88$, $\beta = .00$, and $B = 0.00$, $SE = 0.00$, $p = .55$, $\beta = .02$, respectively.

Discussion

The popularity of computer gaming has fuelled questions regarding its implications for individuals and societies. Whereas much of the psychological research on computer games has been focused on negative effects such as aggression, compulsive behavior, and addiction (e.g., Greitemeyer & Mügge, 2014; Kuss & Griffith, 2013), some recent research highlighted more positive relationships and effects (Granic et al., 2014). Several studies point at a positive link between computer gaming and cognitive abilities (Basak et al., 2008; Glass, Maddox, & Love, 2013; Sanchez, 2012) which is reflected in press headlines such as “Playing video games could make children MORE intelligent, scientists claim” (Waghorn, 2016), “Playing online video games may boost teenagers' intelligence“ (Griffiths, 2016), or “Video games may improve children's intellectual and social skills, study finds” (Bolton, 2016). Others, however, identified null effects (e.g., Unsworth et al., 2015).

The aim of the current study was to examine the association between playing computer games and different cognitive skills, thereby overcoming frequent shortcomings in the empirical literature. Our analyses were based on a large, representative sample of adolescents, which reduces the risk of underestimating effects sizes due to a range restriction typically found in convenience samples (cf. Sears, 1986) and the risk of inducing placebo effects among gamers specifically targeted for a study (Foroughi et al., 2016; Green et al., 2014). Gaming was measured continuously, allowing us to take into account gaming intensity variations among gamers, in addition to comparing non-gamers and gamers. Importantly, our study also tested the possibility that gaming–cognition associations might be nonlinear, and thus missed by traditional linear analyses. Our results showed that reasoning abilities and receptive vocabulary were larger for gamers (vs. non-gamers), for those who preferred games of skill and strategy, and for male (vs. female) participants. Among gamers, the time spent on computer games was only weakly associated with reasoning scores. In contrast, for receptive vocabulary linear and quadratic relationships were observed. We identified a nonlinear increase of receptive vocabulary with gaming intensity, suggesting that the increment is smaller at high scores of gaming intensity. Our results further show that perceptual and reading speed did not differ between non-gamers and gamers. For neither of the two variables substantial linear or nonlinear (quadratic) associations with gaming intensity could be observed. Initially, we identified linear, negative associations between gaming intensity and the two speed measures. However, once gender was included in the model these relationships disappeared. Moderation effects of gender or game type could not be identified for any of the examined cognitive domains.

In sum, our findings suggest no to very modest relationships between video gaming and cognitive abilities. The largest effects in our models, with an effect size ranging around Cohen's d = .20, pertained to comparisons between gamers and non-gamers with lower scores for reasoning and receptive vocabulary among adolescents who did not play computer games. Whether adolescents played up to one hour per day or more than four hours per day had little impact on the cognitive abilities with one exception: we found a nonlinear increase of receptive vocabulary with gaming, indicating a more pronounced increase at lower gaming intensities than at higher gaming intensities. These results also replicated in a latent variable analysis that distinguished a general factor of intelligence from an independent speed factor: gaming intensity was only weakly associated with both factors. Our findings – based on a representative sample of German adolescents and incorporating nonlinear relationships – are consistent with recent cross-sectional research that focused on linear relationships, pointing out weak to nonexistent associations between video gaming and cognitive abilities among two samples of undergraduate US students and community volunteers (Unsworth et al., 2015). Our research did not address the field of computerized training programs that are specifically created to improve cognitive abilities. A recent systematic review on the effectiveness of so-called "brain-training" programs for the enhancement of cognitive performance also painted a somewhat skeptical picture (Simons et al., 2016). Most of these trainings show modest effects at the most that rarely transfer to everyday real-life performance outside the training context. Overall, these and our results suggest that (non-pathological) use of computer games does not seem to have a sizeable association with cognitive abilities, neither in the positive nor in the negative direction.

Limitations and Direction for Future Research

The limitations and caveats of our study point at intriguing opportunities for future research. As a first limitation, we need to emphasize that the reported study was based on a cross-sectional design. The associations could reflect cognitive training effects of playing commercial videos games, effects of selective exposure to computer games by individuals with high cognitive abilities, or combinations of these causal effects over time. Moreover, we cannot rule out the possibility that unobserved third variables influenced our findings. Large-scale longitudinal studies seem warranted to examine linear and nonlinear associations over time.

Second, our research is silent on social interactions during or in the context of video gaming. Gaming is oftentimes a social activity (e.g., Lenhard et al., 2015). Parent and peer communication can be particularly relevant for children and adolescents. Conversations with parents and peers about the game and the challenges during gaming could foster practicing cognitive abilities by suggesting alternative solutions and providing the opportunity for meta-cognitive processing. We are unaware of any studies on cognitive abilities that explicitly examined gaming-related interactions with parents and peers, interactions that likely influence the relationship between playing video games and cognitive abilities.

Third, we observed the age group of adolescents aged 14 to 15 years. For other age groups the assumed positive association between gaming and cognitive abilities might be more pronounced. We envisage future research to address computer gaming and cognitive ability in the group of older adults. Little research to date has focused on this age group with the available studies pointing at larger positive effects than in any other age group (Powers et al., 2013). Likewise, studies with older samples focusing on non-gaming digital media activities, such as using the Internet and e-mails, or engaging in social networking sites, identified positive effects (e.g., Morton et al., 2016; Xavier et al., 2014).

Fourth, we focused on the time spent on gaming as our indicator of activity. Previous lab studies also used measures of game success as an alternative activity measure because many recreational computer and video games seem to tap into similar cognitive processes as required by broad range tests of intelligence (e.g., Baniqued et al., 2013; McPherson & Burns, 2008; Quiroga et al., 2015). Therefore, prior research identified gaming performance as a valid diagnostic of gamers’ cognitive skills (see Foroughi, Serraino, Parasuraman, & Boehm-Davis, 2016). Our research does not provide additional evidence for or against the link between gaming performance and cognitive abilities. However, if recreational computer games substantially stimulated cognitive developments, systematic (non)linear relationships between the time spent on computer and video games and scores on standardized tests of intelligence would be expected. Given the small associations identified in our study (see also

Unsworth et al., 2015) we can conclude that the results from video gaming performance studies do not translate to the time spent playing commercial video games. This implies that commercial computer and video games are likely no efficient training programs for cognitive abilities. Beyond both approaches a closer observation of the actual behavioral patterns of players in computerized gaming worlds seems warranted. Commercial open world video games, such as the best-selling *Grant Theft Auto* video game series, allow individuals to roam around in a virtual world, to choose their game objectives and to tackle their goals in their own ways. Researchers are encouraged to track this virtual world behavior and to investigate associations with cognitive abilities.

Conclusion

Cognitive training studies and computer gaming research suggested a positive association between playing commercial computer games and cognitive abilities. However, various methodological shortcomings made the available findings difficult to evaluate. The present study on a large representative sample of German adolescents did not identify a substantial link between the time spent on computer games and cognitive abilities. Although the cognitive abilities of gamers differed in part from non-gamers, the respective effects were small. More importantly, among gamers computer gaming time was largely unrelated to most cognitive abilities. Thus, it is unlikely that playing commercial computer games on a regular basis can boost cognitive performance.

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Table 1.

Six Shortcomings in Computer Gaming Research on Cognitive Abilities

	Shortcoming	Consequences
1.	Group comparisons between gamers and non-gamers	- Ignores variability among gamers (Latham et al., 2013; Unsworth et al., 2015) - Overestimation of effect sizes if only non-gamers and heavy gamers are considered but moderate gamers are ignored (Preacher et al., 2005) - Increased likelihood of Type I errors due to overestimated effect sizes (Conway et al., 2005; Preacher et al., 2005)
2.	Linear analyses	- Ignores potential nonlinear effects if different levels of computer gaming intensity result in different cognitive benefits
3.	Confounds due to gender differences	- Cognitive differences between gamers and non-gamers might reflect gender differences because computer gaming activities are more prevalent among men than women (e.g., Greenberg, Sherry, Lachlan, Lucas, & Holmstrom, 2010)
4.	Overt participant recruitment	- Different demand characteristics for non-gamers and gamers increase the likelihood of Placebo effects (cf. Boot et al., 2011, 2013; Green et al., 2014; Foroughi et al., 2016)
5.	Small sample sizes	- Low power for the identification of small effects that are to be expected in this line of research (cf. Powers et al., 2013)
6.	Student samples	- Underestimation of effect sizes as a result of range restriction in cognitive abilities (cf. Sears, 1986)

Table 2.

Descriptive Statistics and Correlations between Study Variables

				Correlations						
	M	*SD*	ω_h	1.	2.	3.	4.	5.	6.	7.
1. Reasoning	8.72	2.41	.84							
2. Perceptual speed	59.24	13.72	.80	.12*						
3. Receptive vocabulary	57.33	10.52	.95	.42*	.06*					
4. Reading speed	34.26	8.56	.96	.19*	.27*	.32*				
5. Computer gaming intensity	1.96	2.46	-	-.02*	-.07*	.02*	-.14*			
6. Relative role-playing time	0.09	0.22	-	-.02	-.04*	-.01	-.08*	.41*		
7. Relative time playing games of skill or strategy	0.19	0.28	-	.10*	.01	.10*	.00	.19*	-.07*	
8. Gender	-0.02	1.00	-	.03*	-.16*	.14*	-.16*	.45*	.27*	.09*

Note. N = 12,459. ω_h = Omega hierarchical reliability (see Rodriguez et al., 2016). Gender was coded -1 for girls and 1 for boys.

* $p < .05$

Table 3.

Fit Statistics for Mixed-Effects Regression Models

	Model 0	Model 1	Model 2	Model 3	Model 4	Model 5
			Reasoning			
Deviance	54,759	54,595	54,550	54,545	54,537	54,525
Parameters	4	6	9	11	11	17
BIC	54,797	54,651	54,635	54,649	54,650	54,686
Pr_{BIC}	.0000	.0002	.9986	.0007	.0004	.0000
			Perceptual speed			
Deviance	98,681	98,631	98,249	98,249	98,248	98,226
Parameters	4	6	9	11	11	17
BIC	98,719	98,687	98,334	98,352	98,352	98,386
Pr_{BIC}	.0000	.0000	.9997	.0001	.0002	.0000
			Receptive vocabulary			
Deviance	89,058	88,601	88,305	88,302	88,281	88,246
Parameters	4	7	10	13	14	23
BIC	89,096	88,667	88,399	88,425	88,413	88,463
Pr_{BIC}	.0000	.0000	.9991	.0000	.0009	.0000
			Reading speed			
Deviance	86,215	86,141	85,948	85,946	85,948	85,944
Parameters	4	6	9	11	11	17
BIC	86,253	86,197	86,033	86,050	86,052	86,104
Pr_{BIC}	.0000	.0000	.9997	.0002	.0001	.0000

Note. N = 12,459 students nested in 988 classes nested in 536 schools. BIC = Bayesian information criterion (Schwarz, 1978), Pr_{BIC} = Probability of the model given the empirical data (see Wagenmakers, 2007). Predictors in models: Model 0 = none, Model 1 = main effects of computer gaming intensity, Model 2 = main effects of computer gaming intensity, gender, and relative gaming times, Model 3= main effects of computer gaming intensity, gender, relative gaming times, and interaction between computer gaming intensity and gender, Model 4 = main effects of computer gaming intensity, gender, relative gaming times, and interactions between computer gaming intensity and relative gaming times, Model 5 = main effects of computer gaming intensity, gender, relative gaming times, and all higher-order interactions.

Table 4.

Parameter Estimates of Mixed-Effects Regression Models for Reasoning and Receptive Vocabulary

		Reasoning						*Receptive Vocabulary*					
		Model 1			Model 2			Model 1			Model 2:		
		B	*SE*	β	*B*	*SE*	β	*B*	*SE*	β	*B*	*SE*	β
	Fixed effects:												
	Intercept	8.08*	0.07		8.12*	0.07		54.92*	0.34		55.41*	0.34	
1.	Gaming intensity: intercept	0.48*	0.05	.09	0.32*	0.05	.06	1.63*	0.19	.07	0.65*	0.21	.03
2.	Gaming intensity: linear	0.02*	0.01	.02	0.02	0.01	.02	114.76*	9.37	.10	67.18*	10.34	.06
3.	Gaming intensity: quadratic							-47.89*	8.83	-.04	-24.78*	8.91	-.02
4.	Gender				0.06*	0.02	.03				1.43*	0.09	.14
5.	Relative role-playing time				0.02	0.10	.00				-0.85*	0.38	-.02
6.	Relative time playing games of skill or strategy				0.48*	0.08	.05				1.66*	0.30	.04
	Variance components:												
	Classes	0.24			0.24			5.89			5.83		
	Schools	1.54			1.52			43.81			43.30		
	Residual	4.17			4.17			61.99			60.49		
	Pseudo-R^2	0.02			0.02			0.04			0.06		

Note. N = 12,459 students nested in 988 classes nested in 536 schools. Gender was coded -1 for girls and 1 for boys. Gaming intensity and relative gaming times were centered. B = Unstandardized regression weight, SE = Standard error for B, β = Standardized regression weight. Predictors in models: Model 1 = main effects of computer gaming intensity, Model 2 = main effects of computer gaming intensity, gender, and relative gaming times.

* $p < .05$

Table 5.

Parameter Estimates of Mixed-Effects Regression Models for Perceptual and Reading Speed

		Perceptual speed						*Reading speed*					
		Model 1			Model 2			Model 1			Model 2:		
		B	*SE*	β	*B*	*SE*	β	*B*	*SE*	β	*B*	*SE*	β
	Fixed effects:												
	Intercept	59.47*	0.34		57.93*	0.35		33.94*	0.23		33.28*	0.23	
1.	Gaming intensity: intercept	-0.21	0.27	-.01	0.86*	0.31	.03	-0.26	0.17	-.01	0.23	0.19	.01
2.	Gaming intensity: linear	-0.33*	0.05	-.06	0.00	0.06	.00	-0.23*	0.03	-.06	-0.08*	0.04	-.02
3.	Gender				-2.48*	0.13	-.18				-1.06*	0.08	-.12
4.	Relative role-playing time				0.56	0.57	.01				-0.06	0.35	.00
5.	Relative time playing games of skill or strategy				0.84	0.45	.02				0.34	0.27	.01
	Variance components:												
	Classes	22.90			22.60			6.04			5.81		
	Schools	23.60			23.70			14.45			14.43		
	Residual	142.90			138.40			52.27			51.49		
	Pseudo-R^2	0.00			0.04			0.00			0.04		

Note. N = 12,459 students nested in 988 classes nested in 536 schools. Gender was coded -1 for girls and 1 for boys. Gaming intensity and relative gaming times were centered. B = Unstandardized regression weight, SE = Standard error for B, β = Standardized regression weight. Predictors in models: Model 1 = main effects of computer gaming intensity, Model 2 = main effects of computer gaming intensity, gender, and relative gaming times.

* $p < .05$

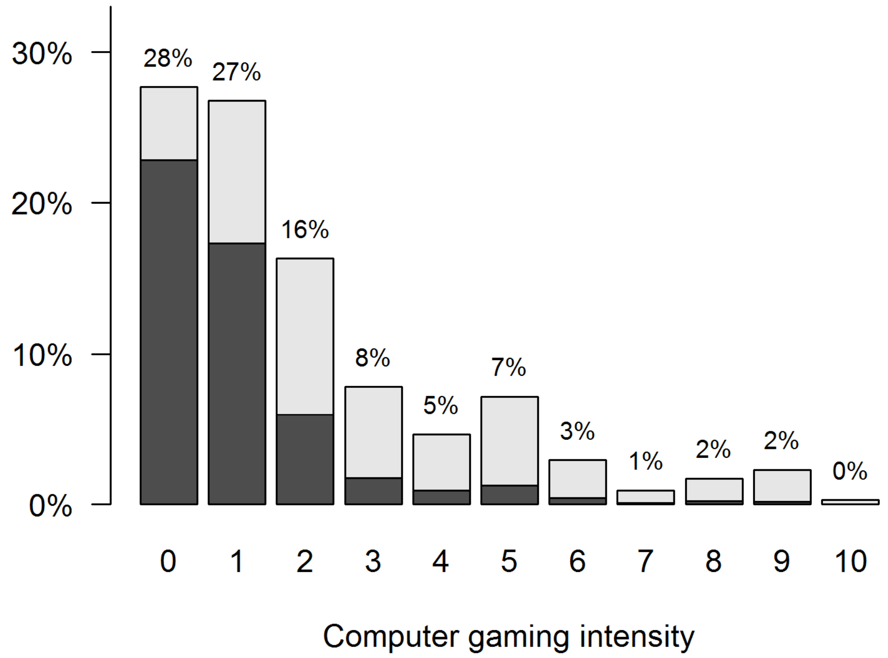

Figure 1. Distribution of computer playing intensity among youths. Dark bars indicate girls, whereas light bars represent boys.

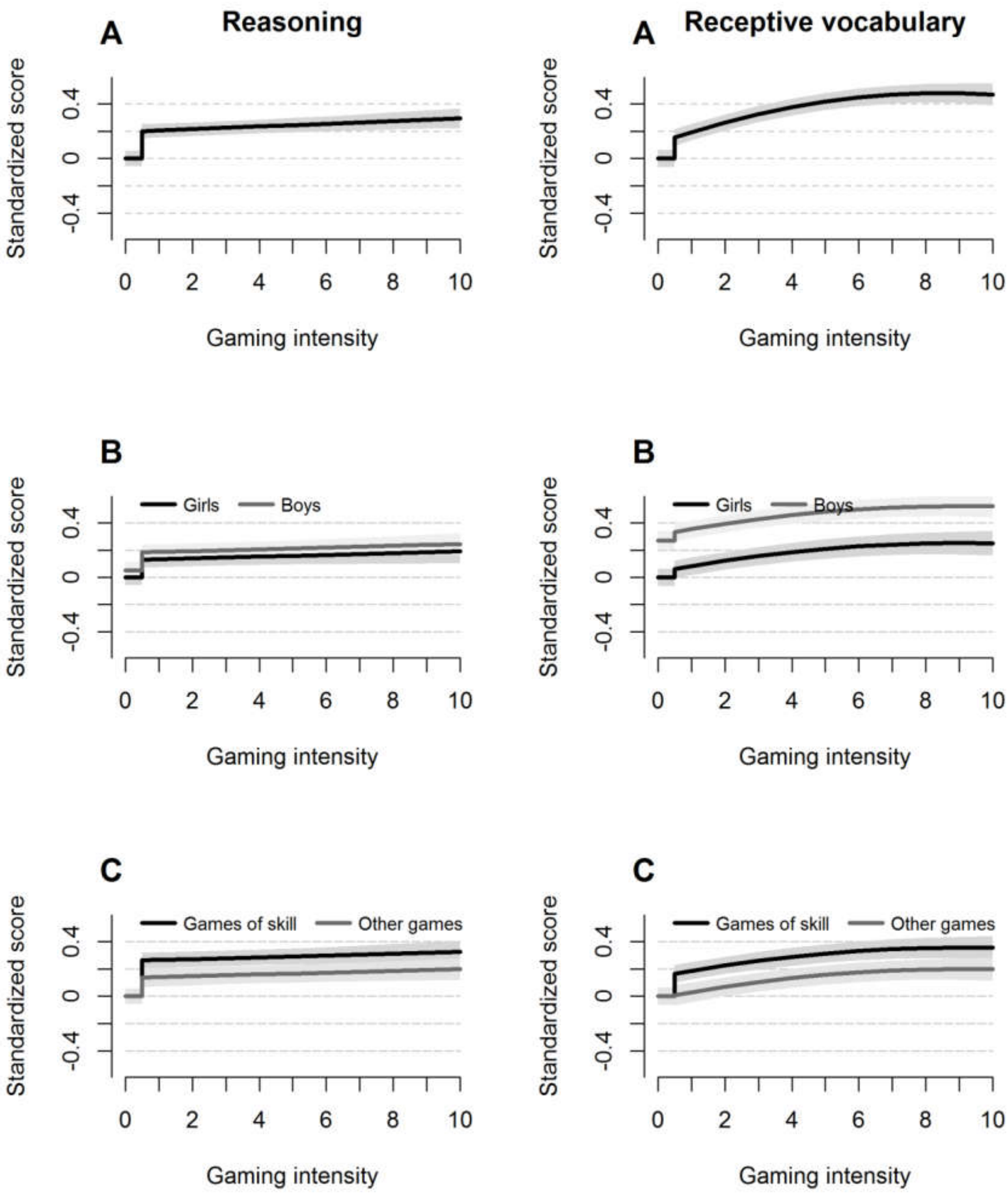

Figure 2. Effects of computer gaming intensity on reasoning and receptive vocabulary (with 95% confidence interval). A: without moderators, B: by gender, C: by game type

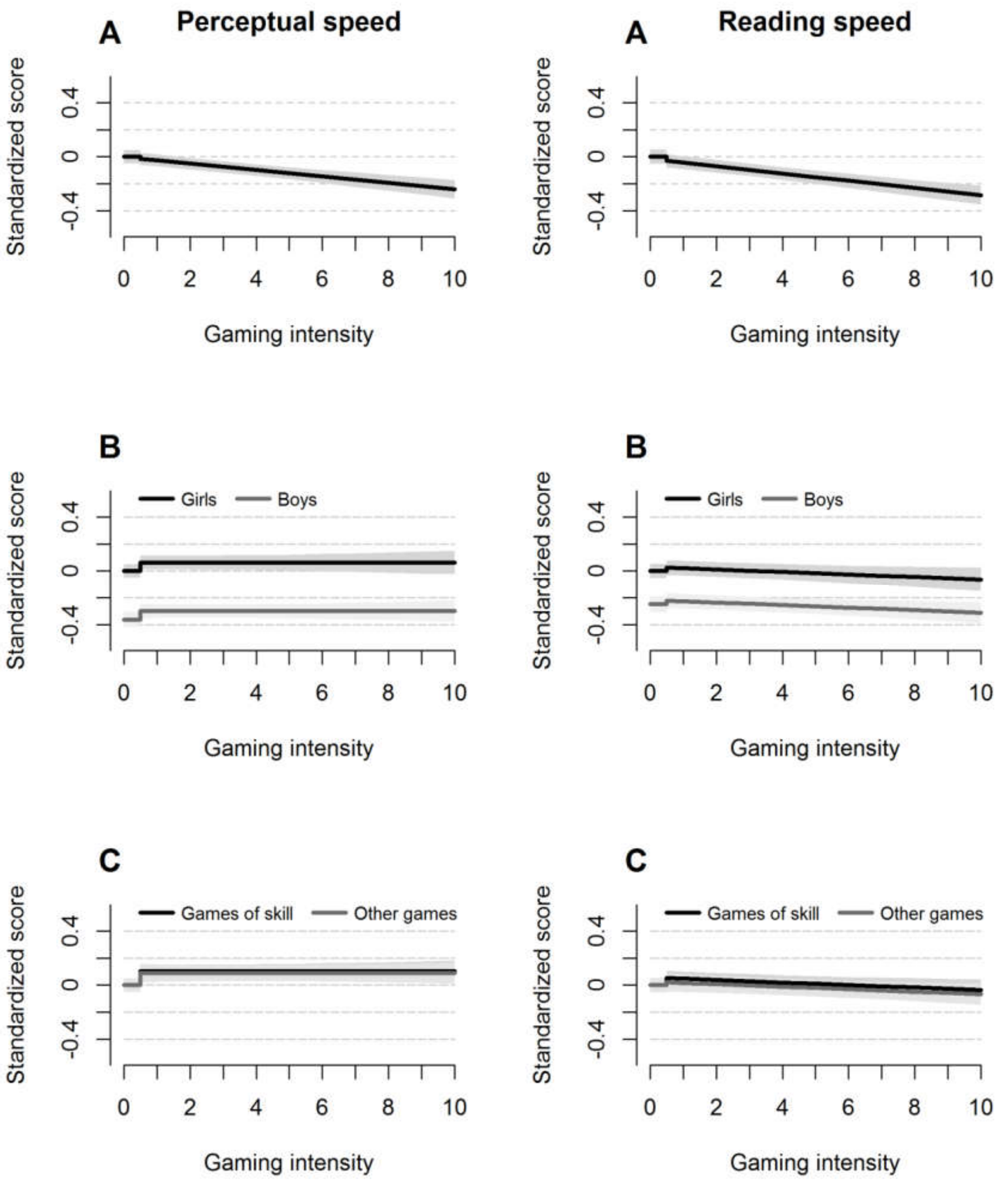

Figure 3. Effects of computer gaming intensity on perceptual and reading speed (with 95% confidence interval). A: without moderators, B: by gender, C: by game type.

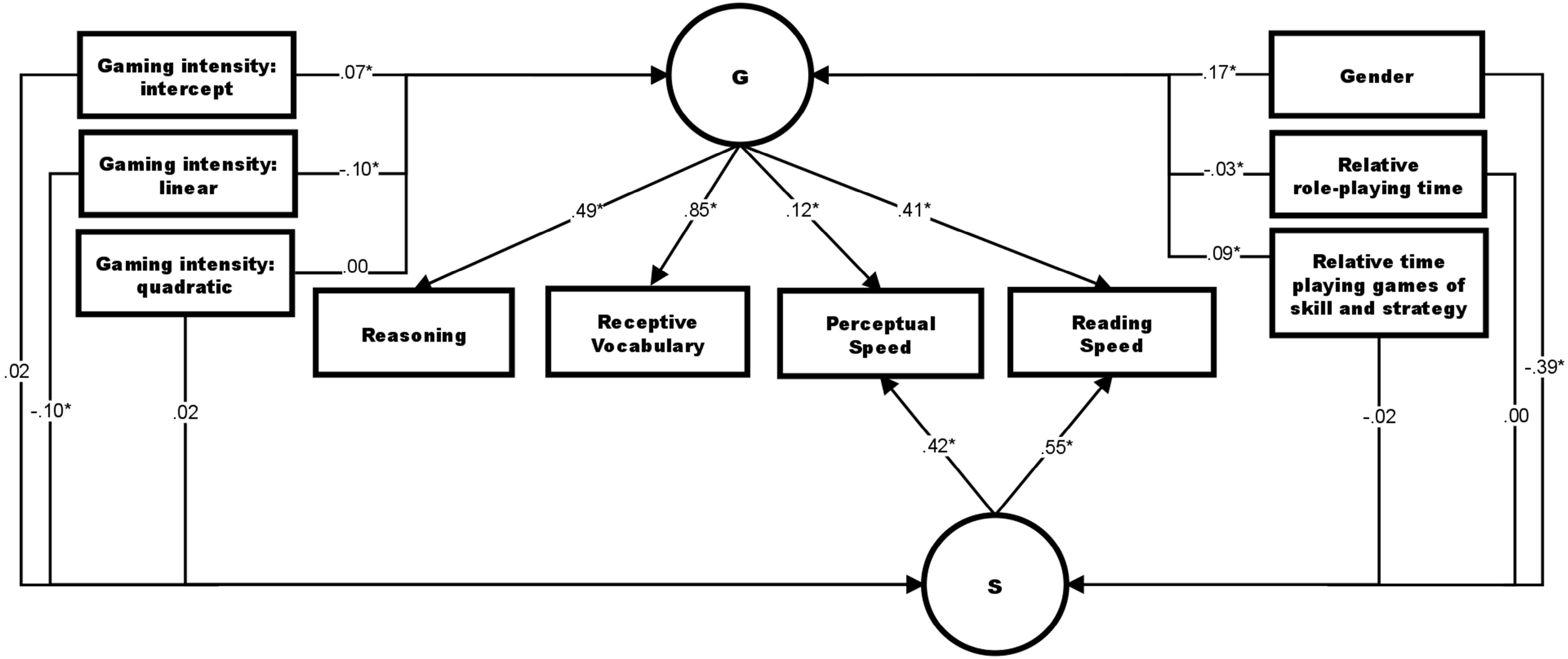

Figure 4. Structural equation model (with standardized regression weights) predicting the latent general (G) and residual speed (S) factors by gaming intensity and covariates ($^{*}p < .05$).