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ORIGINAL ARTICLE

Similar Task-Switching Performance of Real-Time Strategy and First-Person Shooter Players: Implications for Cognitive Training

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Abstract

Computer games have been proposed as effective tools for cognitive enhancement. Especially first-person shooter (FPS) games have been found to yield a range of positive effects, and these positive effects also apply to the domain of executive functioning. Only a particular area of executive functioning has been shown to resist training via FPS games, and this area is task-switching performance. Here, we tested whether games of a different genre, real-time strategy (RTS) games, offer a more promising approach to improve task-switching performance, because RTS games capitalize on precisely this behavior. A high-powered, quasi-experimental comparison of RTS and FPS players indicated reliable costs for task-switching across both player groups—with similar performance on multiple indicators, comprising switch costs, mixing costs, voluntary switch rates, and psychological refractory period effects. Performance of both groups further did not exceed the performance of a control group of Chess and Go players. These results corroborate previous findings on the robustness of cognitive costs of task-switching. At the same time, our results also suggest that the precise characteristics of different computer games might not be critical in determining potential training effects.

Keywords Task-switching · Executive functions · Computer games · Cognitive training · Cognitive enhancement

"Ay-yay-yay, the multi-tasking...the multi-tasking!"
MembTV, Caster (Age of Empires II)

Introduction

Living in a modern Western society comes with constant multitasking. We check for online messages on the PC while talking on the cell phone and still manage to have an occasional look at the video that is playing in the background. Our attention switches back and forth between these different activities, focusing only for a fleeting moment.

Not surprisingly, this behavior comes with cognitive and affective consequences (Becker et al. 2013; Ophir et al. 2009), and we will focus on the cognitive consequences of multitasking in this study. These cognitive consequences include costs that arise from switching back and forth between two or more tasks (Kiesel et al. 2010; Monsell 2003). In light of these robust side effects of multitasking in general, and task-switching in particular, recent research has begun to explore opportunities to reduce task-switching costs by training interventions (Kray et al. 2012; Strobach et al. 2012b, 2014). Because basic cognitive trainings yielded mostly task-specific improvements and only weak transfer effects (e.g., Garner et al. 2014; Salminen et al. 2012), recent research has focused on more holistic training methods (e.g., Colcombe and Kramer 2003; Moradzadeh et al. 2015; Moreno et al. 2011).

One type of intervention that has received particular attention is video game training (Boot et al. 2008; Dale and Green 2016; Strobach et al. 2012a). The use of video games to train cognitive abilities is motivated by numerous findings that suggest video gaming to be associated with benefits for a wide range of cognitive processes as indicated by quasi-experimental comparisons of gamers and nongamers (e.g., Boot et al. 2008; Colzato et al. 2010; Gozli et al. 2014; Green

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and Bavelier 2012; Pohl et al. 2014). Recent reviews and meta-analyses of experimental training studies further concluded that video game training yields positive consequences for a variety of executive functions (Colzato et al. 2014; Green and Bavelier 2015; for a meta-analysis, see Powers et al. 2013).[1] Effect sizes for video game training have been reported in the small to medium range, with the only exception being task-switching costs: Even though quasi-experimental comparisons between video gamers and nongamers suggest a potential benefit for gamers (Andrews and Murphy 2006; Boot et al. 2008; Cain et al. 2012; but compare Karle et al. 2010), experimental studies did not show conclusive evidence for corresponding training effects (see Boot et al. 2008; Green et al. 2012; Olfers and Band 2017; mean effect size of $d = 0.06$, 95% confidence interval = [− 0.33, 0.45] as reported by Powers et al. 2013; but compare Basak et al. 2008; Colzato et al. 2014).

Task-switching costs thus seem to be highly resistant to training-related efforts. One limitation of previous studies on video games, however, is the strong focus on first-person shooter (FPS) games (Powers et al. 2013). Not all games are created equal, though (Cohen et al. 2008; Green 2014; Latham et al. 2013; Powers et al. 2013), and shooter games might not be optimally suited to train task-switching because they tend to pose strong demands on fast reactions rather than on multitasking. We therefore hypothesized that other types of games might yield more promise in this regard. One candidate type is real-time strategy (RTS) games. These games share many characteristics with shooter games, such as fast-paced reactions and high attentional demands, but they also tend to include strong emphasis on rapid and flexible task-switching (such as keeping track of different management tasks, controlling multiple units, etc.). Up to now, only few studies have addressed RTS games so that the database is currently still limited (Basak et al. 2008; Boot et al. 2008; Glass et al. 2013; Kim et al. 2015). First, findings suggest that RTS players outperform FPS players in situations that may draw on comparable functions as task-switching (i.e., multiple object tracking; Dobrowolski et al. 2015). Furthermore, one of the few training studies to report a clear positive effect of video training on task-switching employed a strategy game (Basak et al. 2008).

Direct comparisons of RTS and FPS games are rare, though (for exceptions, see Boot et al. 2008; Dale and Green 2017; Dobrowolski et al. 2015), and especially a high-powered comparison of strategy and shooter players has not yet been conducted to our knowledge. The present study therefore compared regular FPS and RTS players on three behavioral paradigms (Fig. 1): cued task-switching (Meiran 1996), voluntary task-switching (Arrington and Logan 2004), and the psychological refractory period (PRP) paradigm (Pashler 1994). Importantly, we chose to concentrate on principled measures related to task-switching that have been established in basic studies rather than computing efficiency scores for a battery of different tests (Glass et al. 2013). In the *cued task-switching* design, participants were presented with digits and a cue indicated whether they had to perform either a magnitude task (categorizing a number as smaller or bigger than 5) or a parity task (categorizing a number as odd or even). In some blocks, participants performed only one of these tasks throughout (single-task blocks), whereas tasks switched randomly in other blocks (mixed blocks). This setup yields three conditions: task repetitions in single-task blocks, task repetitions in mixed blocks, and task-switches in mixed blocks. A comparison of the former two conditions probes for *mixing costs* due to a concurrent representation of both task sets, whereas a comparison of the latter two conditions probes for *switch costs* (cf. Allport et al. 1994; Rogers and Monsell 1995; Rubin and Meiran 2005). The *voluntary task-switching* design was similar to the cued task-switching design, though participants were free to choose between both tasks on each trial. This setup therefore yields the individual *switch frequency* as a main measure, while also permitting to assess switch costs by comparing voluntary task repetitions and switches (Arrington and Logan 2004; Vandierendonck et al. 2012). Switch frequencies have been shown to be correlated with switch costs (with larger switch costs going along with smaller switch frequencies; Mayr and Bell 2006); however, they also capture additional factors such as working memory load (Demanet et al. 2010), general requirements for flexibility in the current environment (Fröber and Dreisbach 2017), and strategic decisions (Mayr and Bell 2006). Finally, in the *PRP* design, participants had to perform two tasks on each trial. In the first task, they had to categorize a number as odd or even. A colored rectangle surrounding the number either appeared simultaneously with the number or after a stimulus-onset asynchrony (SOA) of 1000 ms, and participants responded to its color (blue vs. red). This setup allows to measure the *PRP effect* by computing the performance difference for the second task between instantaneous and asynchronous stimulus presentation (Pashler 1994; Pashler and Johnston 1989).

Differences between shooter players and strategy players on any of these measures—mixing costs, switch costs, switch frequency, and/or the PRP effect—would be a first indication of whether both types of games promise differential use for active training. We expected

[1] A more recent meta-analysis was published during re-review of the second revision of the present paper (Bediou et al. 2017). This analysis replicated the conclusion that task-switching performance does not profit from video-game training. We thank the editor for drawing our attention to this study.

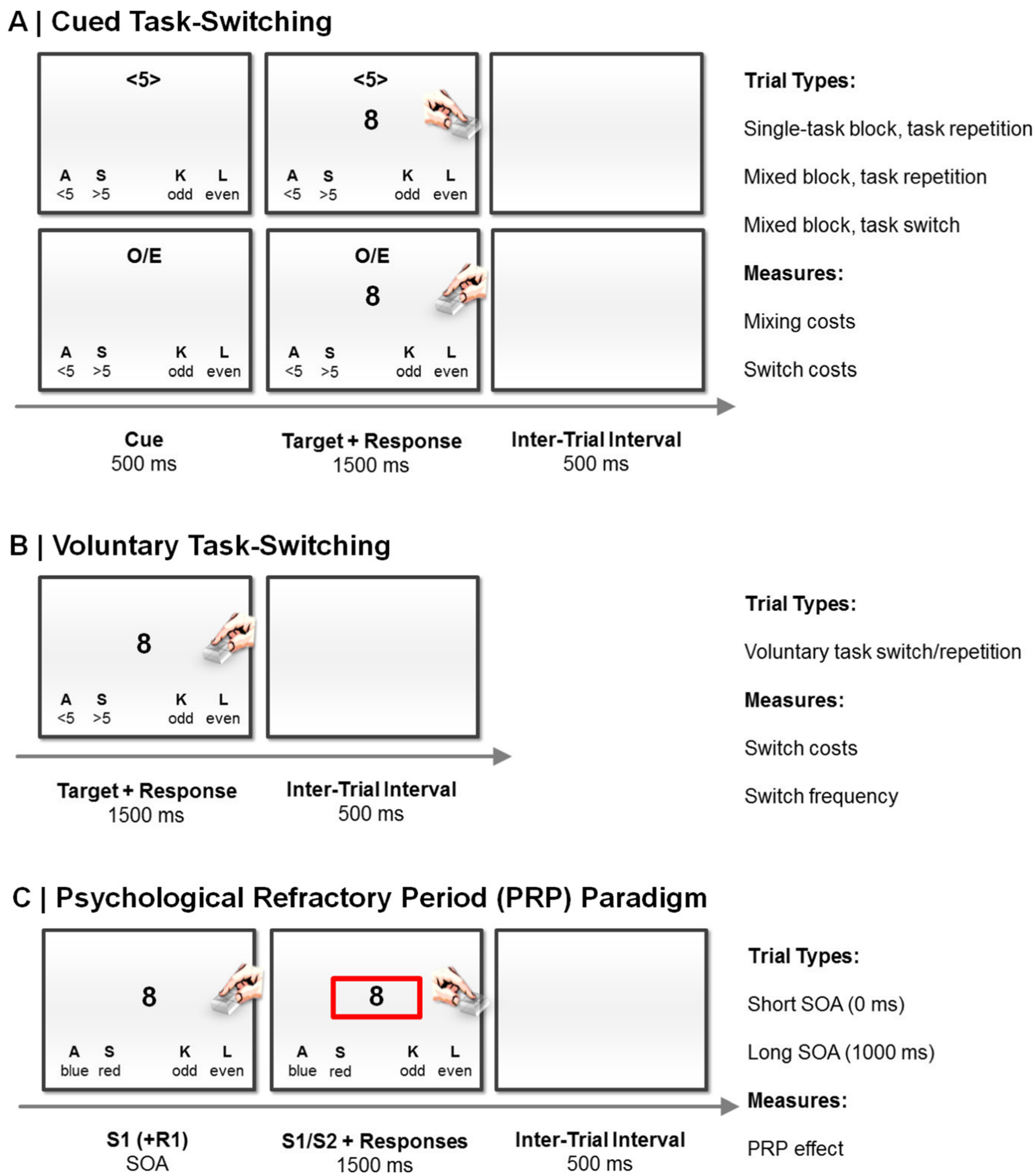

Fig. 1 Trial procedure, conditions, and relevant measures of the applied paradigms. **a** In the cued task-switching paradigm, participants categorized a number according to magnitude (smaller or greater than five) or according to parity (odd or even). Throughout a block of trials, they either performed only one task (single-task blocks) or tasks switched in a random sequence (mixed blocks). Worse performance on task-repetition trials in mixed blocks relative to single-task blocks indicates mixing costs, whereas a comparison of task-repetition and task-switch trials in mixed blocks probes for switch costs. **b** In the voluntary task-switching paradigm, participants were again presented with number stimuli, but they could freely choose whether to perform the magnitude task or the parity task on each trial. This paradigm mainly captures the resulting switch frequency and further allows assessing switch costs by comparing voluntary task-switches to voluntary task repetitions. **c** In the psychological refractory period (PRP) paradigm, participants performed two tasks on each trial. In the first task, they categorized a number as odd or even. The second task was prompted by a red or blue rectangle that surrounded the number and participants had to react to its color. The rectangle appeared with a stimulus-onset asynchrony (SOA) of either 0 or 1000 ms, which allows for assessing the PRP effect by comparing performance in the second task between both SOAs

RTS players to perform at least as well as FPS players throughout. Corresponding results of this quasi-experimental approach would further prepare the grounds for scrutinizing these observations with controlled training interventions.

Methods

Participants

The study was conducted as an online experiment that was hosted on a private domain of one of the authors (kaschwarz.net), linked from a custom webpage on the institutional server of the Department of Psychology, University of Würzburg. We recruited participants via the social platform reddit.com with advertisements placed in game-specific sections (subreddits) of the website. We opted for sample sizes of at least 64 participants for each game type, corresponding to a power of $1 - \beta = 0.8$ to detect at least medium-sized differences between groups. Note that this sample size also ensures sufficient power for small to medium effects within each group.

In a first wave, we posted advertisements in the subreddits of two RTS games, Age of Empires II and League of Legends, and two FPS games, Call of Duty and Counter-Strike. These games were selected among typical installments of both genres according to the authors' personal gaming preferences. Because this first wave resulted in insufficient sample sizes, 3 weeks after posting, we advertised the study in a second wave in the subreddits of DotA 2 and Starcraft 2 as RTS games and Battlefield and CS:GO as FPS games. The games of the second wave were primarily selected for their high number of currently active players (e.g., Linn 2015). Readers of these subreddits, especially those involved in DotA2, proved extraordinarily responsive, resulting in a total of 2785 page visits overall. About half of these visitors produced usable data by finishing at least one paradigm ($n = 1484$). Data of these participants were screened for errors and response omissions, and we excluded 127 participants with the number of errors or omissions exceeding 2.5 standard deviations from the mean of the remaining sample in any of the paradigms. Additionally, we excluded participants who reported playing an equal amount of FPS and RTS games (they checked the same category of hours per week for both genres and thus could not be assigned unambiguously to either group), and ultimately included 1155 participants in the analysis. This procedure resulted in 821 usable data sets for the cued task-switching paradigm, 985 data sets for the voluntary task-switching paradigm, and 859 data sets for the PRP paradigm.

Of the final sample, 1003 participants stated more hours of RTS games played, forming the RTS group, while the remaining participants stated more hours of FPS games (FPS group; see Table 3 in Appendix 1 for the distribution of games in both groups). Participants came from 76 different countries according to their IP addresses (see Fig. 3 in Appendix 1 for a breakdown according to continents); they were 22.2 years on average ($SD = 4.17$; 1147 participants disclosed their age) and predominantly male (1112 of 1143 participants who chose to disclose their gender). There were no significant between-group differences regarding age, gender, and mean gaming experience ($ps > .274$; see Table 4 in Appendix 1 for sample characteristics for each group).

Setup and Procedure

The experiment was mainly programmed with JavaScript (embedded in HTML and styled with CSS) and implemented via the free JavaScript library jsPsych (de Leeuw 2015). Additional server-based scripting was implemented in PHP 5.5; all scripts are available on the Open Science Framework (https://osf.io/c3qad/).

In an initial survey, participants were asked to provide demographic and gaming-related information. More precisely, they were asked about their gender (male, female, "Prefer not to say"), their age (< 14, 14–17, 18–25, 26–30, 30–40, > 40, "Prefer not to say"), and their English language skills ("Beginner," "Intermediate," "Fluent," "Native," "Prefer not to say"). They were further asked about their favorite RTS and FPS games and their gaming habits. Regarding gaming habits, we asked for their overall time spent gaming per week, the weekly time spent on RTS games, and the weekly time spent on FPS games (in hours; 0, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, "more"). Finally, participants were asked to name their all-time favorite games (max. five) in an open-ended question.

The main study consisted of three individual parts: a cued task-switching paradigm, a voluntary task-switching paradigm, and a PRP paradigm. The paradigms were presented in a randomized sequence to control for order effects. Participants responded with the keys "A," "S," "K," and "L" of their computer keyboard. They were instructed to operate "A" and "S" with the middle and index finger of their left hand and to operate "K" and "L" with the index and middle finger of their right hand. A reminder of the different response options was displayed at the lower edge of the screen (see Fig. 1). Data was saved on the server after each paradigm was finished. Each part took about 5–10 min to complete.

Cued Task-Switching

Participants were presented a digit from one to nine (except five) centrally on the screen which they were asked to categorize according to either its magnitude ("A" for smaller than five, "S" for bigger than five) or its parity ("K" for even, "L" for odd; see Fig. 1a). Magnitude-key and parity-key mapping were constant across participants, and both were compatible with typical number-space associations (e.g., Dehaene et al. 1993). Trials began with a cue in the upper center of the display, indicating whether participants were to perform the magnitude task (cue: "<5>") or the parity task (cue: "E/O"; see Fig. 1a). The target stimulus followed 500 ms after the cue and was displayed and stayed on screen for 1500 ms. Correct responses during target presentation completed the trial and the next trial started after an intertrial interval of 500 ms. Errors or response omissions additionally triggered appropriate error feedback that was displayed for 1000 ms. The next trial started after an intertrial interval of 500 ms.

Participants performed 96 trials, divided into six equally sized blocks with each number being featured 12 times as a target across all blocks. In four blocks, participants had to categorize either for magnitude only or for parity only (single-task blocks), whereas in the remaining two blocks, the cue varied randomly from trial to trial (mixed blocks). Block order consisted of two triplets of either single-task (magnitude) ▸ mixed ▸ single-task (parity) or single-task (parity) ▸ mixed ▸ single-task (magnitude). The two possible sequences were randomized across participants. Even though the cue only carried valuable information in the mixed blocks, it was presented in all blocks to equalize visual stimulation.

Voluntary Task-Switching

The setup was comparable to the cued task-switching paradigm with the exception that no cue was presented (Fig. 1b). Instead, participants could decide freely which task to perform but they had to respond within 1500 ms. Response omissions triggered a warning message ("Too slow!") for 1000 ms. The next trial started after an intertrial interval of 500 ms. The part was structured into three blocks with each 32 trials in a random trial sequence without constraints. Participants were instructed to decide spontaneously on each trial which task to perform, and this instruction was repeated between blocks.

Psychological Refractory Period Paradigm

Each trial featured a central number stimulus and a colored rectangular frame around this stimulus (Fig. 1c). The participants had two tasks on each trial. The first task required a parity judgment of the number stimulus (S1) with the right hand (R1), whereas the second task required participants to classify the frame color (S2) with the left hand (R2). Trials differed with regard to the SOA, i.e., the time between presentation of the number and presentation of the colored frame. In half of the trials, number and frame were revealed simultaneously (SOA = 0 ms), while in the remaining trials, the frame was shown 1000 ms after the number (SOA = 1000 ms). Participants were instructed to indicate the number's parity first and categorize frame color afterward (keys: "A" for blue, "S" for red). The stimulus display remained on screen until 2000 ms after S2 onset. A trial was regarded as correct, if both responses were correctly made within this time window and in the correct order. Error feedback was provided for 1000 ms following response omissions or incorrect trials, and the next trial followed after an intertrial interval of 500 ms. Participants worked through three blocks with 32 trials each, and blocks included every combination of number, color, and SOA exactly once.

Hypotheses

We had initially planned to (a) probe for the existence of typical task-switching deficits in participants with RTS experience and (b) to compare their task-switching performance to a group of FPS players. Due to the unexpectedly high responsiveness of the DotA 2 community, we additionally decided to assess the influence of RTS gaming experience in this subsample on task-switching effects in each paradigm.

H1: Cued task-switching. Participants of both groups should show mixing costs as quantified by comparing single-task blocks to repetition trials in mixed-task blocks, and they should also show switch costs as quantified by a comparison of repetition and switch trials in mixed-task blocks.
H1a. Participants in the RTS group should show smaller mixing and switch costs compared to participants in the FPS group.
H1b. Mixing and switch costs should decrease with higher experience with RTS games.
H2: Voluntary task-switching. We expected an overall preference for task repetitions over task switches. Participants in both groups should further show switch costs in terms of worse performance in self-chosen switch trials than in self-chosen repetition trials.
H2a. Voluntary switch rates were suspected to differ between RTS and FPS players (nondirectional hypothesis).
H2b. RTS players should show smaller switch costs for voluntary switches than FPS players.
H2c. Switch rates and switch costs should vary as a function of RTS experience.
H3: Psychological refractory period paradigm. Both RTS and FPS players should show a PRP effect in terms of faster responses in the second task for the long SOA compared to the short SOA.
H3a. RTS players should exhibit a smaller PRP effect than FPS players.
H3b. The PRP effect should decrease as a function of RTS gaming practice.

Data Availability

Raw data and analysis scripts are available on the Open Science Framework (https://osf.io/c3qad/).

Results

Main Analysis: RTS Vs. FPS Players

In the following sections, we report the results of the reaction time (RT) analysis for the critical measures of each task. Specifically, we first tested for task-switching effects in the player groups separately and then compared the resulting performance costs between groups. We additionally qualified nonsignificant results via Bayes factor analyses. All reported Bayes factors (*BF*s) are therefore calculated as the ratio of the probability of the data given the null hypothesis relative to the alternative hypothesis (BF_{01}). JZS-*BF*s were calculated using the BayesFactor package version 0.9.12-2 for R3.3.2, and we interpret values of BF_{01}s > 3 as substantial evidence and BF_{01}s > 10 as strong evidence for the null hypothesis of no difference between RTS and FPS players (for typical conventions regarding the interpretation of *BF*s, see Jeffreys 1961).

All statistics were computed on the mean RTs of each participant in each experimental condition after excluding error trials, response omissions, and trials following these errors. Corresponding analyses of error percentages (PEs) can be found in Appendix 2 and we only mention these analyses when their results qualify the RT data. Detailed analyses of the DotA 2 subsample can be found in Appendix 3.

Cued Task-Switching

Mean mixing costs, switch costs, and overall RTs for both groups are plotted in Fig. 2a (see Table 1 for descriptive statistics). Significant mixing costs emerged for both the RTS group, $t(709) = 22.36$, $p < .001$, $d = 0.84$, and the FPS group, $t(110) = 8.44$, $p < .001$, $d = 0.80$ (effect sizes for

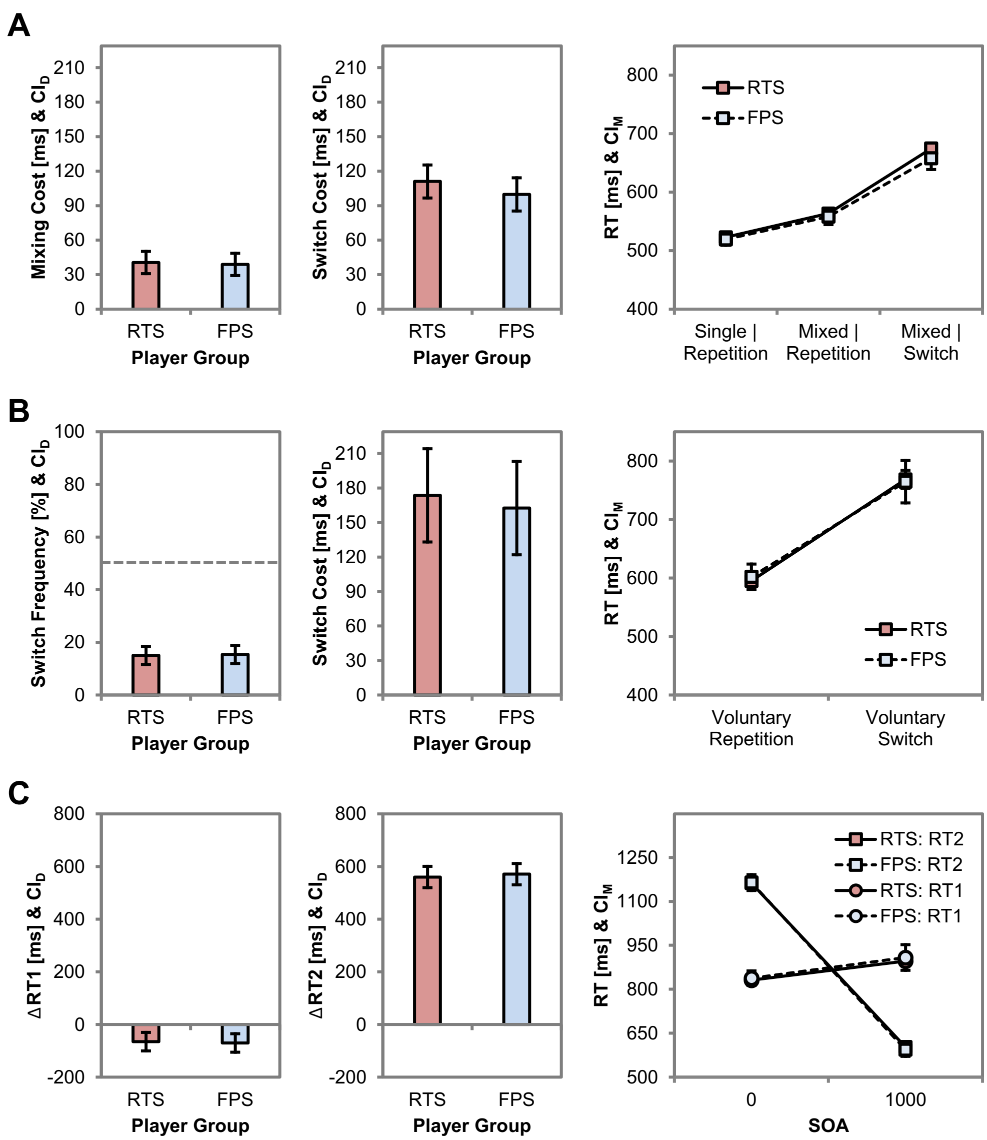

Fig. 2 Results of the reaction time (RT) analysis for real-time strategy (RTS) and first-person shooter (FPS) players. CI_D denotes 95% confidence intervals for the between-group difference (Pfister and Janczyk 2013), and CI_M denotes 95% confidence intervals for individual means. **a** Mixing costs and switch costs as measured in the cued task-switching paradigm, accompanied by the corresponding raw RTs. **b** Switch frequencies and switch costs as measured in the voluntary task-switching paradigm, and corresponding raw RTs. **c** Effects of stimulus-onset asynchrony (SOA) on RT for the first task (ΔRT1) and for second task (ΔRT2) of the psychological refractory period paradigm, accompanied by the raw RT for both tasks

within-group tests were computed as $d = d_z = {}^{t}/_{\sqrt{n}}$). Mixing costs did not differ between groups, $t(819) = 0.36$, $p = .723$, $d = 0.04$ (effect sizes for between-group tests were computed as $d = d_z = t \cdot \sqrt{{}^{1}/_{n_{\mathrm{RTS}}} + {}^{1}/_{n_{\mathrm{FPS}}}}$), and a follow-up Bayesian analyses suggested evidence in favor of the null hypothesis of no between-group difference, $BF_{01} = 8.33$.

A similar picture emerged for switch costs that were present in the RTS group, $t(709) = 41.10$, $p < .001$, $d = 1.54$, and the FPS group alike, $t(110) = 14.59$, $p < .001$, $d = 1.39$. The between-group comparison again returned nonsignificant results, $t(819) = 1.52$, $p = .128$, $d = 0.16$, that were tentatively supported by a Bayes factor of $BF_{01} = 2.89$ in favor of the null hypothesis of no between-group difference (with descriptively larger switch costs for the RTS group).

Finally, a full 2 × 3 analysis of variance (ANOVA) with the between-subjects factor group (RTS vs. FPS) and the within-subjects factor task sequence (single-task block: task repetition, mixed block: task repetition, mixed block: task-switch) showed a main effect of task sequence, $F(2, 818) = 629.15$, $p < .001$, $\eta_p^2 = 0.61$, but neither a main effect of group, $F(1, 819) = 1.38$, $p = .241$, $\eta_p^2 < 0.01$, nor an interaction of both factors, $F(2, 818) = 1.34$, $p = .261$, $\eta_p^2 < 0.01$.[2]

Voluntary Task-Switching

Mean switch frequencies, switch costs, and overall RTs for both groups are plotted in Fig. 2b (see Table 1 for descriptive statistics). Participants in the RTS group showed a mean switch frequency of 15.0% and this frequency clearly differed from 50% as would be expected by chance, $t(851) = 54.31$, $p < .001$, $d = 1.86$. The same held true for the FPS group with a mean switch frequency of 15.4%, $t(132) = 21.63$, $p < .001$, $d = 1.88$. A between-group comparison returned nonsignificant results, $t(983) = 0.19$, $p = .848$, $d = 0.02$, and a Bayes factor of $BF_{01} = 9.47$ indicated evidence in favor of the null hypothesis of similar switch frequencies across groups.

The rather low switch rates were further driven by several participants opting to perform task repetitions throughout, and the analyses of switch costs are therefore only based on the subsample of participants who opted to switch at least once ($n = 622$). These participants showed reliable switch costs both, for the RTS group, $t(534) = 22.58$, $p < .001$, $d = 0.98$, and for the FPS group, $t(86) = 8.21$, $p < .001$, $d = 0.88$. Mirroring the results of the cued task-switching paradigm, switch costs did not differ between groups, $t(620) = 0.53$, $p = .594$, $d = 0.06$, and this finding was backed up by the results of the Bayesian analysis, $BF_{01} = 6.86$.

A 2 × 2 ANOVA with the between-subjects factor group (RTS vs. FPS) and the within-subjects factor task sequence (task repetition vs. task-switch) showed a main effect of task sequence, $F(1, 620) = 264.49$, $p < .001$, $\eta_p^2 = 0.30$, but neither a main effect of group, $F(1, 620) = 0.01$, $p = .910$, $\eta_p^2 < 0.01$, nor an interaction of both factors, $F(1, 620) = 0.28$, $p = .594$, $\eta_p^2 < 0.01$. Analyses of the error data replicated these findings except for a marginally significant main effect of group with overall more errors for the FPS group than for the RTS group (see Appendix 2).

Psychological Refractory Period Paradigm

Mean effects of SOA on RTs in the first task (ΔRT1) and the second task (ΔRT2) as well as overall RTs for both groups are plotted in Fig. 2c (see Table 1 for descriptive statistics). The effect on the first task was small but significant for the RTS group, $t(743) = 9.99$, $p < .001$, $d = 0.37$, and the FPS group alike, $t(114) = 4.01$, $p < .001$, $d = 0.37$, and there was no between-group difference, $t(857) = 0.30$, $p = .765$, $d = 0.03$, $BF_{01} = 8.64$.

Data of the second task showed a pronounced PRP effect for both RTS group, $t(743) = 131.69$, $p < .001$, $d = 4.83$, and the FPS group, $t(114) = 50.57$, $p < .001$, $d = 4.72$. The group comparison again indicated equal effects in both groups, $t(857) = 0.94$, $p = .347$, $d = 0.09$, $BF_{01} = 5.89$.

Separate 2 × 2 ANOVAs with the between-subjects factor group (RTS vs. FPS) and the within-subjects factor SOA (0 vs. 1000 ms) on the raw RTs of both tasks only showed main effects of SOA, $ps < .001$, but no main effect of group, $ps > .567$, nor an interaction of group and SOA, $ps > .347$. Corresponding analyses of the error data (see Appendix 2) qualified this pattern by showing overall higher error rates for the FPS group than for the RTS group.

Follow-Up Analysis: Non-FPS/RTS Controls

Prompted by the lack of performance differences between the RTS and the FPS group, we additionally made efforts to collect data of participants without gaming experience in either genre as a control group.[3] To match this sample to the formerly collected experimental groups (RTS and FPS), we placed similar advertisements to those that had been used to recruit gamers in "subreddits" for Chess and Go. We assumed that neither of these games comes with positive effects on task-switching performance, as they do not involve rapid switching between different tasks. The subreddit posts resulted in 169 page visits and about 50 usable data sets for each paradigm. In the initial survey,

[2] We report multivariate tests of all within-subjects effects in the ANOVA to counter possible violations of sphericity.

[3] We thank an anonymous reviewer and the editor of this paper for prompting the collection of this additional group.

Table 1 Mean reaction times (RTs) in milliseconds, corresponding standard deviations (SDs), and sample sizes (*n*) for the group of real-time strategy (RTS) and first-person shooter (FPS) players

Paradigm	Condition	RTS group			FPS group		
		RT	SD	*n*	RT	SD	*n*
Cued task-switching	Single | repetition	523	57	710	519	55	111
	Mixed | repetition	563	75	710	558	72	111
	Mixed | switch	674	105	710	658	102	111
Voluntary task-switching*	Voluntary repetition	595	94	535	602	102	87
	Voluntary switch	769	181	535	765	170	87
PRP: R1	SOA = 0 ms	831	122	744	838	135	115
	SOA = 1000 ms	896	234	744	908	237	115
PRP: R2	SOA = 0 ms	1163	149	744	1164	147	115
	SOA = 1000 ms	603	129	744	593	122	115

PRP psychological refractory period, *SOA* stimulus-onset asynchrony, *R1/R2* responses to the first and second task

*Switch frequency (in %): RTS group ($n = 852$): $M = 15.05$, SD = 18.79; FPS group ($n = 133$): $M = 15.38$, SD = 18.46

participants now reported their current overall gaming experience as well as their gaming habits at the zenith of their video game involvement. Note that the experimental groups involved players with as low as 5 h gaming per week. Therefore, we only included participants in the control group who stated no video game involvement at all (0 h per week in both questions), resulting in a total of $n = 33$ usable data sets. All of those participants stated to be male with a mean age of 25.91 years. Descriptive statistics for all relevant RT effects are summarized in Table 2; descriptive statistics and corresponding analyses for the PE data can be found in Table 5 in Appendix 4.

Cued Task-Switching

The control group showed significant mixing costs, $t(23) = 5.92$, $p < .001$, $d = 1.21$, and switch costs, $t(23) = 9.11$, $p < .001$, $d = 1.86$. To compare the experimental and the control group, we performed one-way ANOVAs with the between factor group (RTS vs. FPS vs. control) for all relevant effects individually. None of these ANOVAs returned a significant between-group difference (all *p*s > .220). We additionally contrasted the control group against the two experimental groups for all ANOVAs, again with no comparison reaching significance (all *p*s > .272; see Table 6 in Appendix 4 for contrast estimates).

Table 2 Mean reaction times (RTs) in milliseconds as well as corresponding standard deviations (SDs) and sample sizes (*n*) for the control group

Paradigm	Condition	RT	SD	*n*
Cued task-switching	Single | repetition	526	114	24
	Mixed | repetition	577	118	24
	Mixed | switch	675	128	24
Voluntary task-switching*	Voluntary repetition	594	88	14
	Voluntary switch	758	167	14
PRP: R1	SOA = 0 ms	852	136	23
	SOA = 1000 ms	854	223	23
PRP: R2	SOA = 0 ms	1210	160	23
	SOA = 1000 ms	615	161	23

PRP psychological refractory period, *SOA* stimulus-onset asynchrony, *R1/R2* responses to the first and second task

*Switch frequency (in %; $n = 23$): $M = 14.48$, SD = 16.66

Voluntary Task-Switching

Voluntary switch rates of the control group (14.48%) were significantly lower than would have been expected by chance (50%), $t(22) = 10.22$, $p < .001$, $d = 2.13$. This effect did not differ between all three groups $F(2, 1005) = 0.03$, $p = .970$, $\eta_p^2 < 0.01$, or when contrasting the control and the experimental groups (see Table 6 in Appendix 4). Those participants of the control sample that opted to switch at least once showed significant switch costs, $t(13) = 3.89$, $p = .002$, $d = 1.04$, but switch costs did not differ between groups $F(2, 633) = 0.16$, $p = .856$, $\eta_p^2 < 0.01$. The contrast between control and the experimental groups was far from significant ($p = .942$).

Psychological Refractory Period Paradigm

The control group showed a significant PRP effect $t(22) = 22.24$, $p < .001$, $d = 4.64$, while there was no effect of the SOA manipulation on the first response in each trial, $t(22) = 0.05$, $p = .957$, $d = 0.01$. Both effects were independent of group (*p*s > .221). The contrasts between the control group and experimental groups were nonsignificant as well, but note that participants of the control group showed a trend toward a smaller effect of SOA on the first response when contrasted against the experimental groups ($p = .083$). The same contrast on SOA manipulation of the second response revealed no significant effect either ($p = .235$). Significant differences in favor of the control group emerged in the error data (see Appendix 4).

Discussion

The present study compared the task-switching performance of a large sample of RTS players to a control group of FPS players. Measures of task-switching performance were taken from basic studies to characterize the according capacity as precisely as possible. We thus assessed switch costs to capture difficulties associated with switching from one task to another, mixing costs to capture difficulties associated with the simultaneous representation of competing task sets, voluntary switch frequencies to capture voluntary preferences for task-switches and repetitions, as well as the PRP effect to capture difficulties associated with capacity limitations during response selection (Kiesel et al. 2010; Monsell 2003; Pashler 1994). We expected RTS players to outperform FPS players on at least some of these measures, because RTS games seem to draw heavily on flexible task-switching behavior whereas FPS games emphasize fast-paced responding.

The results yielded reliable costs on all relevant measures: Participants were slower in task-switch trials than in task-repetition trials, they were slower when having to keep two task sets active as compared to having only a single task set in mind, they consistently preferred task repetitions over task-switches, and they showed a reliable PRP effect. Crucially, these results were present for both groups and a direct between-group comparison yielded strong evidence in favor of equal performance. In other words, RTS players did not outperform FPS players on any measure related to task-switching, and they showed only negligible advantages in overall accuracy.

The comparison of both video game player groups to a control group of Chess and Go players further suggested no benefits of video gamers relative to the control group. If anything, the control group showed better performance in the error data by responding slightly more accurately in the PRP paradigm. These data may be taken to suggest that the present control group of Chess and Go players may be a more conservative benchmark than control groups without any (documented) specific expertise as they are typically recruited in the field (Dale and Green 2017). It should also be noted that the control group came with a considerable exclusion rate due to self-reported gaming experience. Even though we employed a rather strict criterion of no reported gaming experience at all, this exclusion rate is still surprising, as we specifically requested participants with no video gaming experience in the advertisements. This can be seen as evidence that an adequate control group is difficult to assess in quasi-experimental designs such as the present one (see Boot et al. 2011, for related comments). On this note, many comments on the posts led us to believe that participants caught onto their role as control group quite quickly. Hence, the following results should be treated with additional caution (see Schwarz et al. 2017, for a possible impact of such expectancies).

Under the present conditions, video game players thus did not show any superior task-switching performance as compared to control participants without extensive experience with video games. These results seem to be at odds with several recent quasi-experimental comparisons of video gamers and nongamer control groups as described in the introduction (Andrews and Murphy 2006; Boot et al. 2008; Cain et al. 2012; Dale and Green 2017). This is all the more surprising since many previous studies at first glance seem to have employed similar experimental protocols by also measuring switch costs for simple odd/even and smaller/larger categorizations via keypress responses. A careful analysis of the experimental designs, however, reveals that reliable advantages for video game players can especially be observed when using predictable task sequences, such as in AABB designs (Andrews and Murphy 2006; Dale and Green 2017). Because participants have ample time to prepare upcoming switch trials in such designs, the advantage of video game players has been explained in terms of stronger attentional capacities in this group rather than superior switching performance (Karle et al. 2010). The picture becomes less clear when considering studies that employed unpredictable task sequences, such as the present one, with some studies reporting advantages for video game players (Boot et al. 2008; Cain et al. 2012; Green et al. 2012) while others reported no differences between groups (Karle et al. 2010). From the mentioned studies with positive findings, one was based on a rather limited sample size ($n < 10$ per group in Boot et al. 2008), whereas another study examined task-switching in a context in which it was combined with other demanding processing requirements in terms of a flanker task (Cain et al. 2012). The study by Green et al. (2012), however, included unpredictable task sequences and did indeed find advantages for action video game players (in this case: Halo 2, Unreal Tournament, Grand Theft Auto III) as compared to non-action video game players (including players of The Sims and World of Warcraft) and therefore represents the most conclusive case for such advantages. Thus, even though previous findings agree that video gaming might be associated with superior attentional performance and executive functions, the evidence in support of genuine task-switching advantages for either RTS or FPS players is presently mixed. The current results are fully consistent with the available evidence regarding a comparable performance of RTS and FPS players in task-switching settings though (cf. Dale and Green 2017). In conjunction, these studies further support recent suggestions that called for "replacing the genre-based approach to studying video game effects (e.g. action, real time strategy, among others) with an approach that focuses on the structural characteristics that drive behavioral enhancements" (Green and Bavelier 2015, p. 106). Pursuing this approach would also require a detailed content analysis of individual games and the behavior they trigger. This analysis could then be used to develop experimental designs that isolate the specific processes in externally valid settings. At the same time, such "elementist" approaches have recently come under criticism (Gozli 2017; Gozli and Deng 2017), as isolated perspectives (such as the present focus on task-switching as one particular component of multitasking) may have difficulty explaining externally valid situations. Indeed, media-multitasking in the field can be presumed to draw on a broad spectrum of cognitive processes, and agents likely strive to accomplish a variety of subgoals that are structured in a hierarchical fashion. Monitoring attainment of such diverging goal states clearly requires additional processes than are captured in measures of task-switching alone.

Finally, it should be noted that in the present study participants were matched to their player group solely according to the genre they dedicated most hours per week to. Besides this comparison of magnitude, the applied categorization disregarded the hours played in the other genre. In fact, many participants that were entered into the analysis reported experience in both FPS and RTS games (see Table 4 in Appendix 1). Even though this pattern diminishes possible differences between the two groups, many gamers do indeed choose to play multiple genres or games that incorporate mechanics from different game styles (see Dale and Green 2017). Confirming this notion, about 40% of our participants stated to play both RTS and FPS games regularly. Additionally, most participants disclosed one or more favorite games that did not belong to their associated group. More fine-grained analyses could therefore limit the data set to genre-pure players or explicitly model experience with both types of games separately (but see Green et al. 2017 for several possible pitfalls). We therefore opted to perform a follow-up analysis on a subsample of the data to arrive at a purer composition of groups. For this follow-up analysis, we considered only participants who played their preferred genre with a frequency of at least 90% of their total playing time, and spent only 5 h or less in the nonpreferred genre. RTS players still did not outperform FPS players in any measure (see Appendix 5 for descriptives and corresponding test statistics). As another consequence of the applied categorization, our group comparisons of RTS and FPS comprised players with rather heterogeneous experience (ranging from 5 h per week to more than 50 h). Despite the clear results of the overall group comparisons, our main results therefore do not inform whether stronger between-group effects might be achieved by using more extreme groups in terms of the total amount played. This alternative view, however, is not consistent with many FPS training studies that found significant improvements in domains other than task-switching after only 10 to 15 h of gaming in total (e.g., Green and Bavelier 2003; Strobach et al. 2012a). The exploratory analyses of the DotA 2 (i.e., RTS) players (Appendix 3) further indicate that the observed pattern of results does not depend on gaming experience so that more gaming experience cannot be seen as a promising way to improve task-switching performance (see Gnambs and Appel 2017, for similar conclusions). This is especially true for estimates of experience that are solely based on time spent playing the game such as in the present study. It is, however, debatable whether these experience-based estimates necessarily translate to individual skill levels. An alternative determination of "expertness" might be provided by game-specific ELO rating systems (Elo 1978). Such rating systems were first proposed in the context of Chess and they express a player's skill and win-ratio relative to all active players to determine their rank within the game (for uses outside chess, see, e.g., Hvattum and Arntzen 2010; Neumann et al. 2011). Even though this approach might provide a considerably more accurate classification system than hours played per week, it also comes with several drawbacks. Firstly, many games employ different rating systems for different servers or matchmaking platforms and for different game modes within individual platforms. ELO ratings for these sources are not necessarily commensurate which renders comparisons between different gamers rather difficult. Games may further only use ELO to rate specific "ranked" games, blurring the skill levels of more causal players. Secondly, many games do not openly provide a player's ELO but only very crude league/division systems. Even though there are many applications that provide the service of calculating an ELO-like statistic for a game, the exact value is prone to differ. Determining a reliable ELO-value to rank or compare individual players in a given study may thus not always be possible.

Taken together, our findings suggest that RTS games do not yield more promise than FPS games when it comes to designing cognitive training interventions to improve task-switching performance.

Appendix 1: Sample Characteristics

Table 3 Distribution of played games over all participants and within the group of real-time strategy (RTS) and first-person shooter (FPS) players in absolute (n) and relative (%) sample size (rounded). The data of 11 participants was recorded according to their open-ended answers in the initial survey due to data entry errors

Genre	Game	Overall		RTS group		FPS group	
		n	%	*n*	%	*n*	%
RTS games	DotA 2	965	83.55	904	90.13	61	40.13
	Age of Empires	14	1.21	14	1.40	0	0.00
	League of Legends	13	1.13	13	1.30	0	0.00
	Starcraft 2	8	0.69	3	0.30	5	3.29
	Multiple	29	2.51	28	2.79	1	0.66
	Other	71	6.15	41	4.09	30	19.74
	None	55	4.76	0	0.00	55	36.18
Σ		1155	100.00	1003	100.00	152	100.00
FPS games	Counter Strike / CS:GO	229	19.83	165	16.45	64	42.11
	Battlefield (all)	39	3.38	22	2.19	17	11.18
	Call of Duty (all)	3	0.26	2	0.20	1	0.66
	Multiple	22	1.90	11	1.10	11	7.24
	Other	191	16.54	132	13.16	59	38.82
	None	671	58.10	671	66.90	0	0.00
Σ		1155	100.00	1003	100.00	152	100.00

Fig. 3 Distribution of players across continents

Table 4 Sample characteristics separated by player group. Gender in absolute (n) and relative (%) sample size (rounded), mean age (M) in years as well as mean hours played overall and in both genres per week and corresponding standard deviations (SD)

		Overall		RTS group		FPS group	
		n	%	*n*	%	*n*	%
Gender	Male	1112	96.28	964	96.11	148	97.37
	Female	31	2.68	28	2.79	3	1.97
	Not specified	12	1.04	11	1.1	1	0.66
		M	SD	*M*	SD	*M*	SD
Age		22.23	4.18	22.25	4.11	22.12	4.62
Gaming hours per week		26.75	13.00	26.59	13.00	27.83	12.95
RTS hours per week		19.61	12.99	21.83	12.35	4.93	5.30
FPS hours per week		4.68	7.63	2.57	4.31	18.56	9.92

RTS real-time strategy, *FPS* first-person shooter

Appendix 2: Error Analyses

The analysis of the error data followed the same strategy as the RT analysis. Trials with response omissions and trials following either errors or response omissions were excluded from the analysis and PEs were computed by dividing the frequency of error trials by the frequency of error trials plus the frequency of correct trials. Resulting effects are plotted in Fig. 4 and descriptive statistics can be found in Table 4.

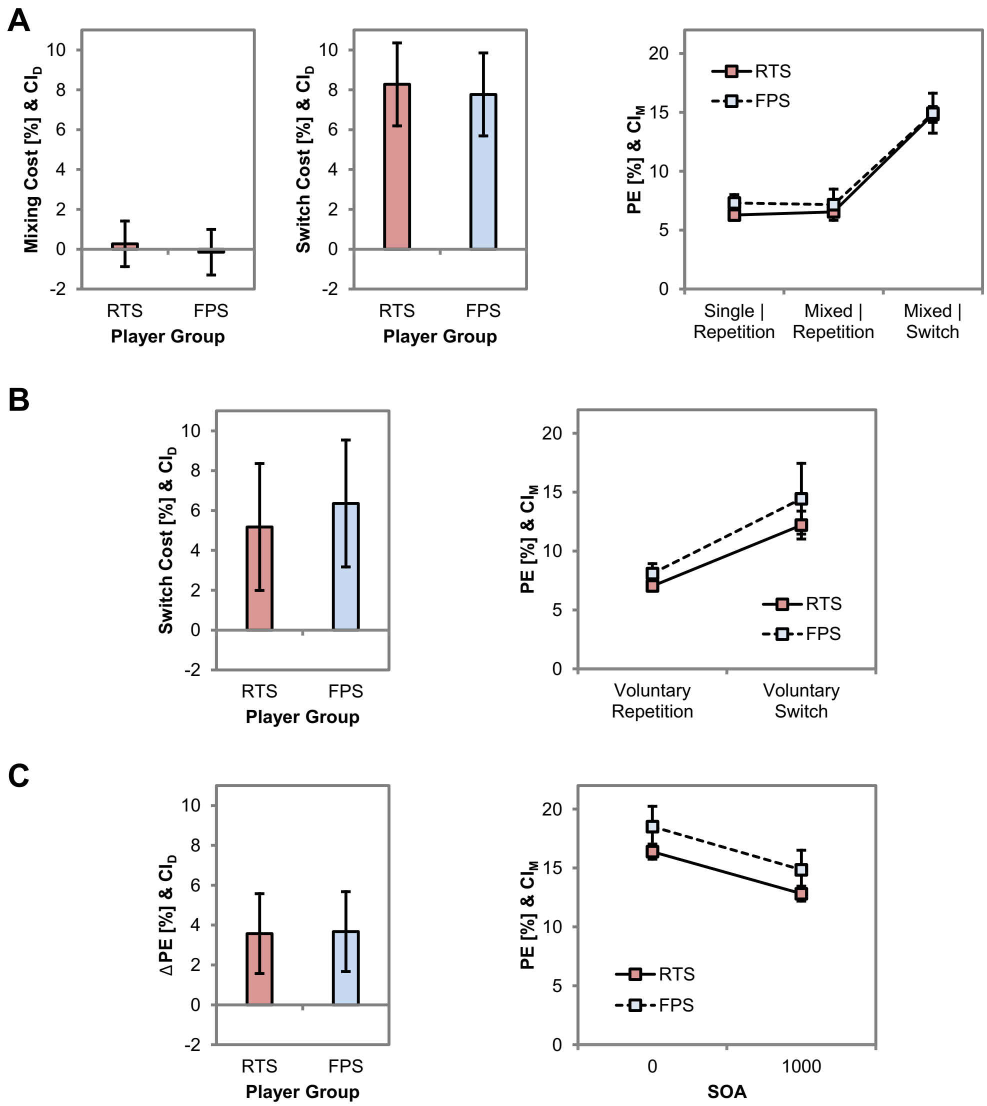

Fig. 4 Results of the analysis of error percentages (PEs) for real-time strategy (RTS) and first-person shooter (FPS) players. CI_D denotes 95% confidence intervals for the between-group difference (Pfister and Janczyk 2013), and CI_M denotes 95% confidence intervals for individual means. **a** Mixing costs and switch costs as measured in the cued task-switching paradigm, accompanied by the corresponding raw PEs. **b** Switch frequency and switch costs as measured in the voluntary task-switching paradigm, and corresponding raw PEs. **c** Effects of stimulus-onset asynchrony (SOA) on PE in the psychological refractory period paradigm, and corresponding raw PEs

Table 5 Mean error percentages (PEs), corresponding standard deviations (SDs), and sample sizes (n) for the group of real-time strategy (RTS) and first-person shooter (FPS) players

Paradigm	Condition	RTS group			FPS group		
		PE	SD	*n*	PE	SD	*n*
Cued task-switching	Single | repetition	6.28	3.31	710	7.31	3.80	111
	Mixed | repetition	6.55	5.80	710	7.16	7.03	111
	Mixed | switch	14.82	9.51	710	14.93	9.01	111
Voluntary task-switching	Voluntary repetition	7.04	4.23	535	8.09	3.95	87
	Voluntary switch	12.21	13.99	535	14.45	14.10	87
PRP	SOA = 0	16.39	8.88	744	18.52	9.30	115
	SOA = 1000	12.82	8.82	744	14.85	8.98	115

PRP psychological refractory period, *SOA* stimulus-onset asynchrony

Cued Task-Switching

PEs did not show any signs of mixing costs, neither for the RTS group, $t(709) = 1.29$, $p = .197$, $d = 0.05$, nor for the FPS group, $t(110) = 0.25$, $p = .803$, $d = 0.02$. The difference between both groups was not significant either, $t(819) = 0.73$, $p = .469$, $d = 0.07$, $BF_{01} = 6.88$. However, there were significant switch costs for both the RTS group, $t(709) = 21.41$, $p < .001$, $d = 0.80$, and the FPS group, $t(110) = 7.43$, $p < .001$, $d = 0.71$, but no between-group difference, $t(819) = 0.47$, $p = .635$, $d = 0.05$, $BF_{01} = 7.95$.

A 2 × 3 ANOVA with the between-subjects factor group (RTS vs. FPS) and the within-subjects factor task sequence (single-task block: task repetition, mixed block: task repetition, mixed block: task-switch) showed a main effect of task sequence, $F(2, 818) = 156.83$, $p < .001$, $\eta_p^2 = 0.28$, but neither a main effect of group, $F(1, 819) = 1.56$, $p = .212$, $\eta_p^2 < 0.01$, nor an interaction of both factors, $F(2, 818) = 0.75$, $p = .475$, $\eta_p^2 < 0.01$.

Voluntary Task-Switching

Significant switch costs were present for both the RTS group, $t(534) = 8.45$, $p < .001$, $d = 0.37$, and the FPS group, $t(86) = 4.50$, $p < .001$, $d = 0.48$. Mirroring the results of the cued task-switching paradigm, switch costs did not differ between groups, $t(620) = 0.73$, $p = .467$, $d = 0.08$, $BF_{01} = 6.10$.

A 2 × 2 ANOVA with the between-subjects factor group (RTS vs. FPS) and the within-subjects factor task sequence (task repetition vs. task-switch) showed a main effect of task sequence, $F(1, 620) = 50.57$, $p < .001$, $\eta_p^2 = 0.08$, and a descriptive trend toward higher error rates for the FPS group, $F(1, 620) = 3.52$, $p = .061$, $\eta_p^2 = 0.01$. The interaction of both factors was not significant, $F(1, 620) = 0.53$, $p = .467$, $\eta_p^2 < 0.01$.

Psychological Refractory Period (PRP) Paradigm

A trial was coded as erroneous if participants committed an error in at least one of the tasks. More errors occurred for the short SOA as compared to the long SOA and this was true for both the RTS group, $t(743) = 9.84$, $p < .001$, $d = 0.36$, and the FPS group, $t(114) = 3.29$, $p = .001$, $d = 0.31$. The between-groups comparison of this difference was not significant, $t(857) = 0.08$, $p = .933$, $d = 0.01$, $BF_{01} = 8.98$ (corrected for unequal variances due to a significant Levene test: $p = .013$; uncorrected values: $t = 0.10$, $p = .923$).

A 2 × 2 ANOVA with the between-subjects factor group (RTS vs. FPS) and the within-subjects factor SOA (0 vs. 1000 ms) on the raw PEs showed a main effect of SOA, $F(1, 857) = 50.24$, $p < .001$, $\eta_p^2 = 0.06$, and also a main effect of group, $F(1, 857) = 8.14$, $p = .004$, $\eta_p^2 = 0.01$, with overall more errors in the FPS group. The interaction was not significant, $F(1, 857) = 0.01$, $p = .923$, $\eta_p^2 < 0.01$.

Appendix 3: Exploratory Analyses of the DotA 2 Subsample

To assess how task-switching performance is influence by gaming experience (in terms of the self-reported number of hours played per week), we split the large sample of DotA 2 players into 11 subgroups of 5, 10, 15, … 50, and more than 50 (51+) hours per week. Mixing and switch costs of the cued task-switching paradigm were reliable across subgroups (Fig. 5). For the voluntary task-switching paradigm, there was a slight trend toward lower switch frequencies with more gaming experience, whereas switch costs were as robust as for the cued task-switching paradigm (Fig. 6). The effects in the PRP paradigm were also independent of subgroup (Fig. 7).

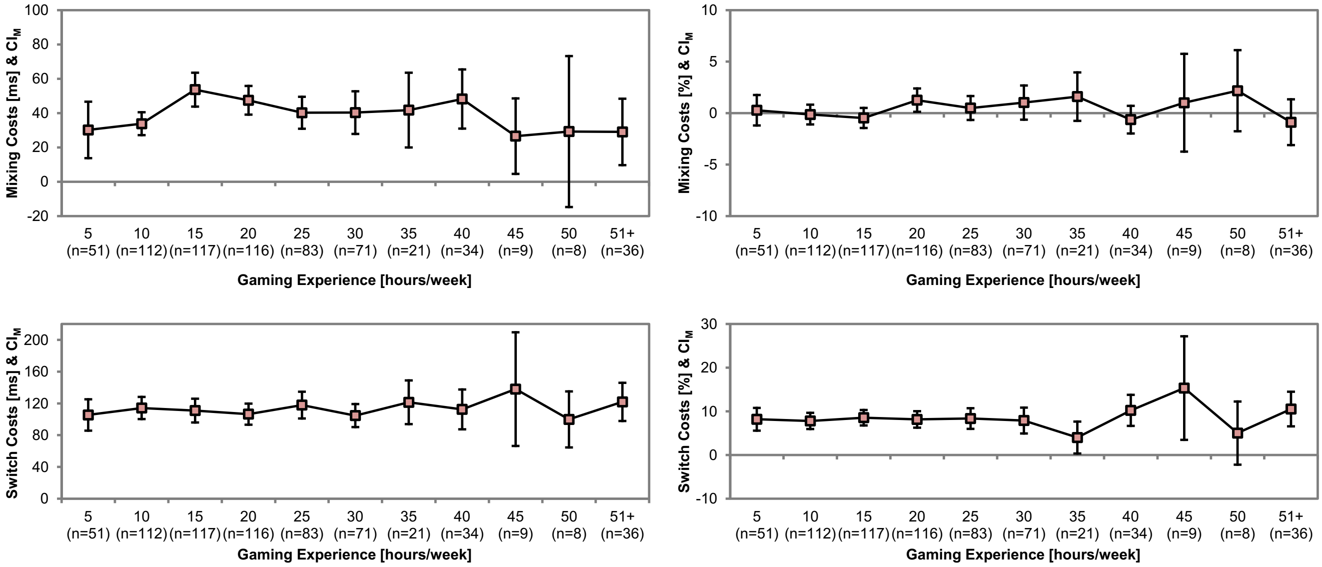

Fig. 5 Detailed analyses of the DotA 2 players for the cued task-switching paradigm. Mixing costs (upper panels) and switch costs (lower panels) for reaction times (RTs; left panels) and error percentages (PEs; right panels) are plotted for subgroups of varying self-reported gaming experience. Error bars represent 95% confidence intervals for the individual means, and sample sizes (*n*) are attached to the *x* axis

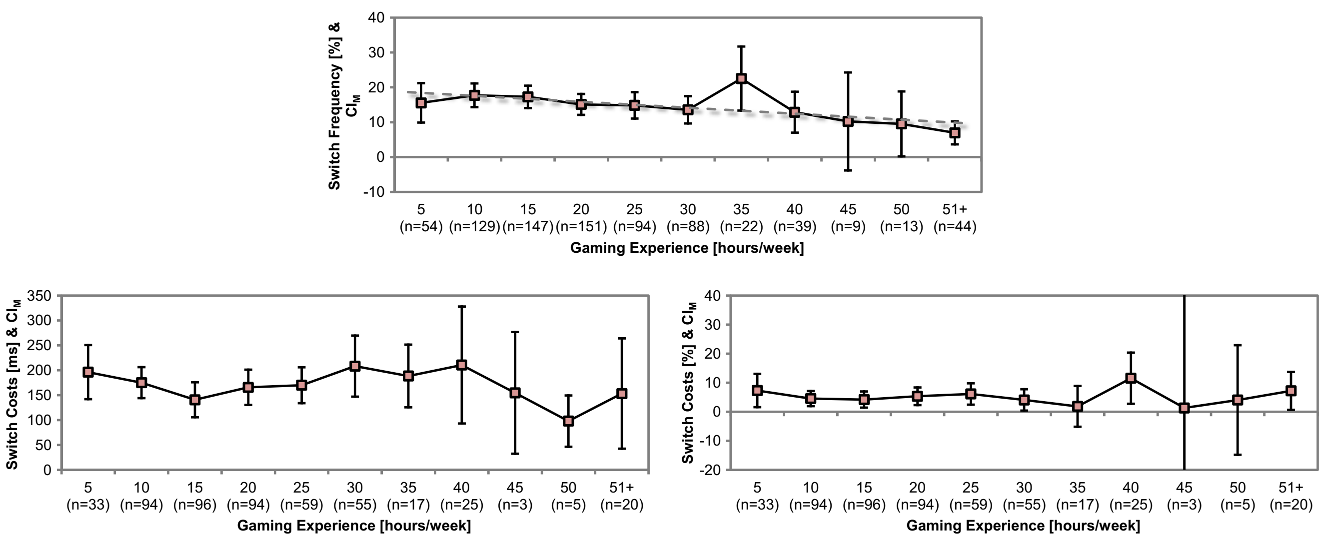

Fig. 6 Detailed analyses of the DotA 2 players for the voluntary task-switching paradigm. Switch frequencies are plotted in the upper-central panel, whereas switch costs are plotted in the lower panels (left for reaction times, RTs, right for error percentages, PEs). Error bars represent 95% confidence intervals for the individual means, and sample sizes (*n*) are attached to the *x* axis

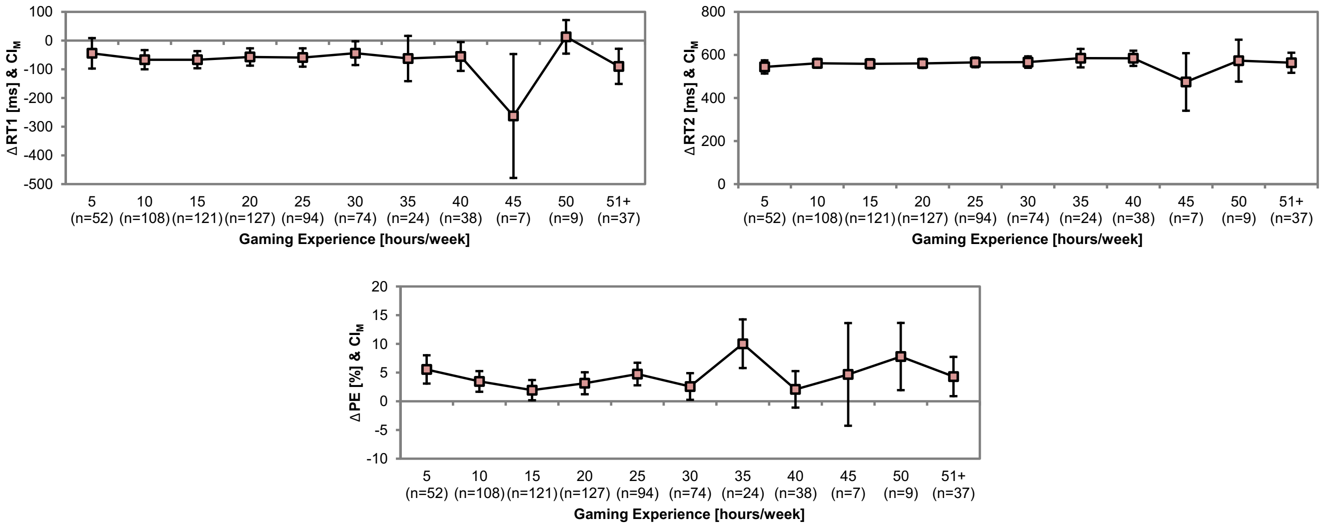

Fig. 7 Detailed analyses of the DotA 2 players for the psychological refractory period paradigm. The upper panels show the effect of stimulus-onset asynchrony (SOA) on reaction times (RTs) for the first task (ΔRT1) and the second task (ΔRT2), whereas the lower-central panel shows the effect of SOA on error percentages (ΔPE). Error bars represent 95% confidence intervals for the individual means, and sample sizes (*n*) are attached to the *x* axis

Appendix 4: Analysis of Control Group

Error Data

In the cued task-switching paradigm, the control group did not show significant mixing costs in PEs, $t(23) = 0.70$, $p = .490$, $d = 0.14$, but there were significant switch costs, $t(23) = 4.38$, $p < .001$, $d = 0.89$ (see Table 5). There were no significant differences between groups as measured by one-way ANOVAs (RTS vs. FPS vs. control) or contrasting the control against the two experimental groups (all $ps > .276$).

In the voluntary task-switching paradigm, switch rates of the control group (14.5%) were significantly lower than would have been expected by chance (50%), $t(22) = 10.22$, $p < .001$, $d = 2.13$. This effect did not differ between groups in the one-way ANOVA, $F(2, 1005) = 0.03$, $p = .970$, $\eta_p^2 < 0.01$, or when contrasting the control and the experimental groups (Table 6). There were no significant switch costs in errors for those control participants who opted to switch at least once, $t(13) = 1.06$, $p = .311$, $d = 0.28$, and switch costs did not differ between groups, neither in the one-way ANOVA, $F(2, 633) = 0.47$, $p = .628$, $\eta_p^2 < 0.01$, nor for the contrast analysis ($p = .463$).

In the PRP paradigm, the PEs of the control participants did not differ significantly between SOAs, $t(22) = 1.85$, $p = .078$, $d = 0.39$. However, the control participants showed a smaller effect of SOA on PEs, giving rise to a significant main effect of group, $F(2, 879) = 4.98$, $p = .007$, $\eta_p^2 = 0.01$, as well as a significant contrast control vs. experimental ($p = .002$). Finally, visual inspection of the raw PEs suggested overall fewer mistakes in the control group as compared to both experimental group. To qualify this impression, we computed a one-way ANOVA on the mean PEs across SOAs, and this analysis also yielded a significant main effect of group, $F(2, 879) = 5.52$, $p = .004$, $\eta_p^2 = 0.01$, and a significant contrast of the control group relative to both experimental groups ($p = .029$).

Table 6 Mean error percentages (PEs) in % as well as corresponding standard deviations (SDs) and sample sizes (*n*) broken down into separate conditions for the control group

Paradigm	Condition	PE	SD	*n*
Cued task-switching	Single | repetition	5.80	3.52	24
	Mixed | repetition	6.52	8.20	24
	Mixed | switch	12.17	7.43	24
Voluntary task-switching	Voluntary repetition	5.87	3.72	14
	Voluntary switch	8.83	10.35	14
PRP	SOA = 0 ms	10.63	7.43	23
	SOA = 1000 ms	13.81	11.13	23

PRP psychological refractory period, *SOA* stimulus-onset asynchrony

Table 7 Contrast estimates and corresponding 95% confidence intervals (CI) for every measured effect between the control group and the experimental groups

Paradigm	DV	Effect	Contrast estimate	95% CI
Cued task-switching	RT	Mixing costs	11.15	[− 8.76, 31.07]
		Switch costs	− 8.10	[− 37.64, 21.43]
	PE	Mixing costs	0.66	[− 1.69, 3.01]
		Switch costs	− 2.36	[− 6.62, 1.89]
Voluntary task-switching	Switch frequency	–	− 0.73	[− 8.57, 7.11]
	RT	Switch costs	− 3.57	[− 99.38, 92.25]
	PE	Switch costs	− 2.80	[− 10.29, 4.69]
PRP	RT1	–	66.33	[− 8.63, 141.29]
	RT2	PRP effect	29.80	[− 19.42, 79.03]
	PE	PRP effect	− 6.81	[− 11.08, − 2.53]

DV dependent variable, *RT* reaction time, *PE* error percentage, *PRP* psychological refractory period

Appendix 5: Extreme Groups

An analysis of more strictly separated experimental groups with at least 90% of overall gaming time spent on the assigned genre and less than 5 h per week spent on the other genre corroborated the findings of the main analysis (see Tables 8, 9, 10, and 11 below).

Table 8 Mean reaction times (RTs) in milliseconds, corresponding standard deviations (SDs), and sample sizes (*n*) for the extreme subgroups of real-time strategy (RTS) and first-person shooter (FPS) players

Paradigm	Condition	RTS group			FPS group		
		RT	SD	*n*	RT	SD	*n*
Cued task-switching	Single | repetition	526	59	361	531	45	19
	Mixed | repetition	567	76	361	557	79	19
	Mixed | switch	675	103	361	637	103	19
Voluntary task-switching*	Voluntary repetition	600	98	272	603	100	18
	Voluntary switch	759	184	272	789	184	18
PRP: R1	SOA = 0 ms	832	125	377	825	129	24
	SOA = 1000 ms	897	245	377	876	265	24
PRP: R2	SOA = 0 ms	1162	148	377	1154	138	24
	SOA = 1000 ms	605	133	377	590	147	24

PRP psychological refractory period, *SOA* stimulus-onset asynchrony

*Switch frequency (in %): RTS group ($n = 432$): $M = 14.87$, SD = 18.48; FPS group ($n = 29$): $M = 14.30$, SD = 18.42

Table 9 Mean error percentages (PEs) in % as well as corresponding standard deviations (SDs) and sample sizes (*n*) for the extreme subgroups of real-time strategy (RTS) and first-person shooter (FPS) players

Paradigm	Condition	RTS group			FPS group		
		PE	SD	*n*	PE	SD	*n*
Cued task-switching	Single | repetition	5.92	3.26	361	7.37	4.80	19
	Mixed | repetition	6.46	5.93	361	8.19	9.05	19
	Mixed | switch	13.80	9.29	361	17.46	12.71	19
Voluntary task-switching	Voluntary repetition	6.72	4.20	272	9.68	3.21	18
	Voluntary switch	12.21	14.44	272	15.45	14.19	18
PRP	SOA = 0 ms	15.75	8.71	377	20.15	7.51	24
	SOA = 1000 ms	12.59	8.72	377	17.05	10.19	24

PRP psychological refractory period, *SOA* stimulus-onset asynchrony

Table 10 Within-group tests for relevant task-switching effects separately for the extreme subgroups of real-time strategy (RTS) and first-person shooter (FPS) players

Paradigm	Condition	RTS group				FPS group			
		t	*df*	*p*	*d*	*t*	*df*	*p*	*d*
Cued task-switching	Mixing costs RT	16.76	360	<.001	0.88	2.18	18	.043	0.50
	Switch costs RT	29.59	360	<.001	1.56	7.65	18	<.001	1.76
	Mixing costs PE	1.81	360	.071	0.10	0.41	18	.686	0.09
	Switch costs PE	13.66	360	<.001	0.72	2.38	18	.028	0.55
Voluntary task-switching	Switch rate	39.52	431	<.001	1.90	10.44	28	<.001	1.94
	Switch costs RT	14.49	271	<.001	0.88	3.59	17	.002	0.85
	Switch costs PE	6.28	271	<.001	0.38	1.80	17	.089	0.43
PRP	ΔRT1	6.73	376	<.001	0.35	1.18	23	.252	0.24
	ΔRT2	89.10	376	<.001	4.59	26.04	23	<.001	5.32
	ΔPE	6.21	376	<.001	0.32	1.16	23	.256	0.24

RT reaction time, *PE* percentage of errors, *PRP* psychological refractory period, *ΔRT1* difference between reaction times of the first response (short stimulus-onset asynchrony (SOA = 0 ms) – long stimulus-onset asynchrony (SOA = 1000 ms)), *ΔRT2* difference between reaction times of the second response (SOA = 0 ms − SOA = 1000 ms), *ΔPE* difference of errors in either response (SOA = 0 ms − SOA = 1000 ms)

Table 11 Between-group comparisons of real-time strategy and first-person shooter players (RTS vs. FPS) of relevant task-switching effects of extreme subgroups

Paradigm	Condition	*t*	*df*	*p*	*d*
Cued task-switching	Mixing costs RT	1.36	378	.174	0.32
	Switch costs RT	1.71	378	.088	0.40
	Mixing costs PE*	0.13	378	.895	0.05
	Switch costs PE*	0.49	378	.628	0.18
Voluntary task-switching	Switch rate	0.16	459	.872	0.03
	Switch costs RT	0.60	288	.551	0.15
	Switch costs PE	0.08	288	.937	0.02
PRP	ΔRT1	0.36	399	.717	0.08
	ΔRT2	0.30	399	.761	0.06
	ΔPE	0.03	399	.977	0.01

RT reaction time, *PE* percentage of errors, *PRP* psychological refractory period, *ΔRT1* difference between reaction times of the first response (short stimulus-onset asynchrony (SOA = 0 ms) − long stimulus-onset asynchrony (SOA = 1000 ms)), *ΔRT2* difference between reaction times of the second response (SOA = 0 ms − SOA = 1000 ms), *ΔPE* difference of errors in either response (SOA = 0 ms − SOA = 1000 ms)

*Corrected test statistics due to unequal variances as indicated by significant Levene tests. (Mixing costs) Levene test: $p = .012$; uncorrected statistics: $t = 0.19$, $p = .846$. (Switch costs) Levene test: $p = .012$; uncorrected statistics: $t = 0.77$, $p = .440$

References

Allport, D. A., Styles, E. A., & Hsieh, S. (1994). Shifting intentional set: exploring the dynamic control of tasks. In C. Umiltà & M. Moscovitch (Eds.), *Attention and performance series. Attention and performance 15. Conscious and nonconscious information processing* (pp. 421–452). Cambridge: The MIT Press.

Andrews, G., & Murphy, K. (2006). Does video-game playing improve executive function? In M. A. Vanchevsky (Ed.), *Frontiers in cognitive psychology* (Ch. 8, pp. 145–161). New York: Nova Science.

Arrington, C. M., & Logan, G. D. (2004). The cost of a voluntary task switch. *Psychological Science, 15*(9), 610–615. https://doi.org/10.1111/j.0956-7976.2004.00728.x.

Basak, C., Boot, W. R., Voss, M. W., & Kramer, A. F. (2008). Can training in a real-time strategy videogame attenuate cognitive decline in older adults? *Psychology and Aging, 23*(4), 765–777. https://doi.org/10.1037/a0013494.

Becker, M. W., Alzahabi, R., & Hopwood, C. J. (2013). Media multitasking is associated with symptoms of depression and social anxiety. *Cyberpsychology, Behavior and Social Networking, 16*(2), 132–135. https://doi.org/10.1089/cyber.2012.0291.

Bediou, B., Adams, D. M., Mayer, R. E., Tipton, E., Green, C. S., & Bavelier, D. (2017). Meta-analysis of action video game impact on perceptual, attentional, and cognitive skills. Psychological Bulletin. Advance online publication. https://doi.org/10.1037/bul0000130.

Boot, W. R., Kramer, A. F., Simons, D. J., Fabiani, M., & Gratton, G. (2008). The effects of video game playing on attention, memory, and executive control. *Acta Psychologica, 129*(3), 387–398. https://doi.org/10.1016/j.actpsy.2008.09.005.

Boot, W. R., Blakely, D. P., & Simons, D. J. (2011). Do action video games improve perception and cognition? *Frontiers in Psychology, 2*. https://doi.org/10.3389/fpsyg.2011.00226.

Cain, M. S., Landau, A. N., & Shimamura, A. P. (2012). Action video game experience reduces the cost of switching tasks. *Attention, Perception, & Psychophysics, 74*(4), 641–647. https://doi.org/10.3758/s13414-012-0284-1.

Cohen, J. E., Green, C. S., & Bavelier, D. (2008). Training visual attention with video games: not all games are created equal. In H. F. O'Neil & R. S. Perez (Eds.), *Computer games and team and individual learning* (pp. 205–227). Oxford: Elsevier.

Colcombe, S., & Kramer, A. F. (2003). Fitness effects on the cognitive function of older adults: a meta-analytic study. *Psychological Science, 14*(2), 125–130. https://doi.org/10.1111/1467-9280.t01-1-01430.

Colzato, L. S., van Leeuwen, P. J. A., van den Wildenberg, W., & Hommel, B. (2010). DOOM'd to switch: superior cognitive flexibility in players of first person shooter games. *Frontiers in Psychology, 1*. https://doi.org/10.3389/fpsyg.2010.00008.

Colzato, L. S., van den Wildenberg, W. P. M., & Hommel, B. (2014). Cognitive control and the COMT Val^{158}Met polymorphism: genetic modulation of videogame training and transfer to task-switching efficiency. *Psychological Research, 78*(5), 670–678. https://doi.org/10.1007/s00426-013-0514-8.

Dale, G., & Green, C. S. (2016). Video games and cognitive performance. In R. Kowert & T. Quandt (Eds.), *The video game debate: Unravelling the physical, social, and psychological effects of digital games* (pp. 131–152). New York: Routledge.

Dale, G., & Green, C. S. (2017). Associations between avid action and real-time strategy game play and cognitive performance: a pilot study. *Journal of Cognitive Enhancement,* 1–23. https://doi.org/10.1007/s41465-017-0021-8.

de Leeuw, J. R. (2015). jsPsych: a JavaScript library for creating behavioral experiments in a web browser. *Behavior Research Methods, 47*(1), 1–12. https://doi.org/10.3758/s13428-014-0458-y.

Dehaene, S., Bossini, S., & Giraux, P. (1993). The mental representation of parity and number magnitude. *Journal of Experimental Psychology: General, 122*(3), 371. https://doi.org/10.1037/0096-3445.122.3.371.

Demanet, J., Verbruggen, F., Liefooghe, B., & Vandierendonck, A. (2010). Voluntary task switching under load: contribution of top-down and bottom-up factors in goal-directed behavior. *Psychonomic Bulletin and Review, 17*(3), 387–393. https://doi.org/10.3758/PBR.17.3.387.

Dobrowolski, P., Hanusz, K., Sobczyk, B., Skorko, M., & Wiatrow, A. (2015). Cognitive enhancement in video game players: the role of video game genre. *Computers in Human Behavior, 44*, 59–63. https://doi.org/10.1016/j.chb.2014.11.051.

Elo, A. E. (1978). *The rating of chess players, past and present*. New York: Arco.

Fröber, K., & Dreisbach, G. (2017). Keep flexible—keep switching! The influence of forced task switching on voluntary task switching. *Cognition, 162*, 48–53. https://doi.org/10.1016/j.cognition.2017.01.024.

Garner, K. G., Tombu, M. N., & Dux, P. E. (2014). The influence of training on the attentional blink and psychological refractory period. *Attention, Perception, & Psychophysics, 76*(4), 979–999. https://doi.org/10.3758/s13414-014-0638-y.

Glass, B. D., Maddox, W. T., & Love, B. C. (2013). Real-time strategy game training: emergence of a cognitive flexibility trait. *PLoS One, 8*(8), e70350. https://doi.org/10.1371/journal.pone.0070350.

Gnambs, T., & Appel, M. (2017). Is computer gaming associated with cognitive abilities? A population study among German adolescents. *Intelligence, 61*, 19–28. https://doi.org/10.1016/j.intell.2016.12.004.

Gozli, D. G. (2017). Behaviour versus performance: the veiled commitment of experimental psychology. *Theory & Psychology, 27*(6), 741–758. https://doi.org/10.1177/0959354317728130.

Gozli, D. G., & Deng, W. (2017). Building blocks of psychology: on remaking the unkept promises of early schools. *Integrative Psychological and Behavioral Science*, 1–24. https://doi.org/10.1007/s12124-017-9405-7.

Gozli, D. G., Bavelier, D., & Pratt, J. (2014). The effect of action video game playing on sensorimotor learning: evidence from a movement tracking task. *Human Movement Science, 38*, 152–162. https://doi.org/10.1016/j.humov.2014.09.004.

Green, C. S. (2014). The perceptual and cognitive effects of action video game experience. In F. C. Blumberg (Ed.), *Learning by playing: video gaming in education* (pp. 29–41). New York: Oxford University Press.

Green, C. S., & Bavelier, D. (2003). Action video game modifies visual selective attention. *Nature, 423*(6939), 534–537. https://doi.org/10.1038/nature01647.

Green, C. S., & Bavelier, D. (2012). Learning, attentional control, and action video games. *Current Biology, 22*(6), R197–R206. https://doi.org/10.1016/j.cub.2012.02.012.

Green, C. S., & Bavelier, D. (2015). Action video game training for cognitive enhancement. *Current Opinion in Behavioral Sciences, 4*, 103–108. https://doi.org/10.1016/j.cobeha.2015.04.012.

Green, C. S., Sugarman, M. A., Medford, K., Klobusicky, E., & Bavelier, D. (2012). The effect of action video game experience on task-switching. *Computers in Human Behavior, 28*(3), 984–994. https://doi.org/10.1016/j.chb.2011.12.020.

Green, C. S., Kattner, F., Eichenbaum, A., Bediou, B., Adams, D. M., Mayer, R. E., & Bavelier, D. (2017). Playing some video games but not others is related to cognitive abilities: a critique of Unsworth et al. (2015). *Psychological Science, 28*(5), 679–682. https://doi.org/10.1177/0956797616644837.

Hvattum, L. M., & Arntzen, H. (2010). Using ELO ratings for match result prediction in association football. *International Journal of Forecasting, 26*(3), 460–470. https://doi.org/10.1016/j.ijforecast.2009.10.002.

Jeffreys, H. (1961). *Theory of probability* (3rd ed.). Oxford: Clarendon.

Karle, J. W., Watter, S., & Shedden, J. M. (2010). Task switching in video game players: benefits of selective attention but not resistance to proactive interference. *Acta Psychologica, 134*(1), 70–78. https://doi.org/10.1016/j.actpsy.2009.12.007.

Kiesel, A., Steinhauser, M., Wendt, M., Falkenstein, M., Jost, K., Philipp, A. M., & Koch, I. (2010). Control and interference in task switching—a review. *Psychological Bulletin, 136*(5), 849–874. https://doi.org/10.1037/a0019842.

Kim, Y.-H., Kang, D.-W., Kim, D., Kim, H.-J., Sasaki, Y., & Watanabe, T. (2015). Real-time strategy video game experience and visual perceptual learning. *Journal of Neuroscience, 35*(29), 10485–10492. https://doi.org/10.1523/JNEUROSCI.3340-14.2015.

Kray, J., Karbach, J., Haenig, S., & Freitag, C. (2012). Can task-switching training enhance executive control functioning in children with attention deficit/-hyperactivity disorder? *Frontiers in Human Neuroscience, 5*(180). https://doi.org/10.3389/fnhum.2011.00180.

Latham, A. J., Patston, L. L. M., & Tippett, L. J. (2013). The virtual brain: 30 years of video-game play and cognitive abilities. *Frontiers in Psychology, 4*. https://doi.org/10.3389/fpsyg.2013.00629.

Linn, D. (2015). November 2015—Fallout 4 and Black Ops III arise while StarCraft II shines [Blog post]. Retrieved from http://caas.

raptr.com/most-played-games-november-2015-fallout-4-and-black-ops-iii-arise-while-starcraft-ii-shines/

Mayr, U., & Bell, T. (2006). On how to be unpredictable: evidence from the voluntary task-switching paradigm. *Psychological Science, 17*(9), 774–780. https://doi.org/10.1111/j.1467-9280.2006.01781.x.

Meiran, N. (1996). Reconfiguration of processing mode prior to task performance. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22*(6), 1423–1442. https://doi.org/10.1037/0278-7393.22.6.1423.

Monsell, S. (2003). Task switching. *Trends in Cognitive Sciences, 7*(3), 134–140. https://doi.org/10.1016/S1364-6613(03)00028-7.

Moradzadeh, L., Blumenthal, G., & Wiseheart, M. (2015). Musical training, bilingualism, and executive function: a closer look at task switching and dual-task performance. *Cognitive Science, 39*(5), 992–1020. https://doi.org/10.1111/cogs.12183.

Moreno, S., Bialystok, E., Barac, R., Schellenberg, E. G., Cepeda, N. J., & Chau, T. (2011). Short-term music training enhances verbal intelligence and executive function. *Psychological Science, 22*(11), 1425–1433. https://doi.org/10.1177/0956797611416999.

Neumann, C., Duboscq, J., Dubuc, C., Ginting, A., Irwan, A. M., Agil, M., et al. (2011). Assessing dominance hierarchies: validation and advantages of progressive evaluation with Elo-rating. *Animal Behaviour, 82*(4), 911–921. https://doi.org/10.1016/j.anbehav.2011.07.016.

Olfers, K. J. F., & Band, G. P. H. (2017). Game-based training of flexibility and attention improves task-switch performance: near and far transfer of cognitive training in an EEG study. *Psychological Research*. https://doi.org/10.1007/s00426-017-0933-z.

Ophir, E., Nass, C., & Wagner, A. D. (2009). Cognitive control in media multitaskers. *Proceedings of the National Academy of Sciences, 106*(37), 15583–15587. https://doi.org/10.1073/pnas.0903620106.

Pashler, H. (1994). Dual-task interference in simple tasks: data and theory. *Psychological Bulletin, 116*(2), 220–244. https://doi.org/10.1037/0033-2909.116.2.220.

Pashler, H., & Johnston, J. C. (1989). Chronometric evidence for central postponement in temporally overlapping tasks. *The Quarterly Journal of Experimental Psychology Section A, 41*(1), 19–45. https://doi.org/10.1080/14640748908402351.

Pfister, R., & Janczyk, M. (2013). Confidence intervals for two sample means: calculation, interpretation, and a few simple rules. *Advances in Cognitive Psychology, 9*(2), 74–80. https://doi.org/10.2478/v10053-008-0133-x.

Pohl, C., Kunde, W., Ganz, T., Conzelmann, A., Pauli, P., & Kiesel, A. (2014). Gaming to see: action video gaming is associated with enhanced processing of masked stimuli. *Frontiers in Psychology, 5.* https://doi.org/10.3389/fpsyg.2014.00070

Powers, K. L., Brooks, P. J., Aldrich, N. J., Palladino, M. A., & Alfieri, L. (2013). Effects of video-game play on information processing: a meta-analytic investigation. *Psychonomic Bulletin & Review, 20*(6), 1055–1079. https://doi.org/10.3758/s13423-013-0418-z.

Rogers, R. D., & Monsell, S. (1995). Costs of a predictable switch between simple cognitive tasks. *Journal of Experimental Psychology: General, 124*(2), 207–231. https://doi.org/10.1037/0096-3445.124.2.207.

Rubin, O., & Meiran, N. (2005). On the origins of the task mixing cost in the cuing task-switching paradigm. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *31*(6).

Salminen, T., Strobach, T., Schubert, T., & Karbach, J. (2012). On the impacts of working memory training on executive functioning. *Frontiers in Human Neuroscience*, *6*. https://doi.org/10.3389/fnhum.2012.00166.

Schwarz, K. A., Pfister, R., & Büchel, C. (2017). The being a patient effect: negative expectations based on group labeling and corresponding treatment affect patient performance. *Psychology, Health & Medicine*. https://doi.org/10.1080/13548506.2017.1332375.

Strobach, T., Frensch, P. A., & Schubert, T. (2012a). Video game practice optimizes executive control skills in dual-task and task switching situations. *Acta Psychologica, 140*(1), 13–24. https://doi.org/10.1016/j.actpsy.2012.02.001.

Strobach, T., Liepelt, R., Schubert, T., & Kiesel, A. (2012b). Task switching: effects of practice on switch and mixing costs. *Psychological Research, 76*(1), 74–83. https://doi.org/10.1007/s00426-011-0323-x.

Strobach, T., Salminen, T., Karbach, J., & Schubert, T. (2014). Practice-related optimization and transfer of executive functions: a general review and a specific realization of their mechanisms in dual tasks. *Psychological Research, 78*(6), 836–851. https://doi.org/10.1007/s00426-014-0563-7.

Vandierendonck, A., Demanet, J., Liefooghe, B., & Verbruggen, F. (2012). A chain-retrieval model for voluntary task switching. *Cognitive Psychology, 65*(2), 241–283. https://doi.org/10.1016/j.cogpsych.2012.04.003.