Video game practice optimizes executive control skills in dual-task and task switching situations

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ABSTRACT

We examined the relation of action video game practice and the optimization of executive control skills that are needed to coordinate two different tasks. As action video games are similar to real life situations and complex in nature, and include numerous concurrent actions, they may generate an ideal environment for practicing these skills (Green & Bavelier, 2008). For two types of experimental paradigms, dual-task and task switching respectively; we obtained performance advantages for experienced video gamers compared to non-gamers in situations in which two different tasks were processed simultaneously or sequentially. This advantage was absent in single-task situations. These findings indicate optimized executive control skills in video gamers. Similar findings in non-gamers after 15 h of action video game practice when compared to non-gamers with practice on a puzzle game clarified the causal relation between video game practice and the optimization of executive control skills.

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1. Introduction

Recent studies suggest that extensive practice of video games can improve a number of cognitive functions and skills for instance, basic visual attention (Castel, Pratt, & Drummond, 2005; Feng, Spence, & Pratt, 2007; Green & Bavelier, 2003, 2006a, 2006b, 2007; Riesenhuber, 2004), in younger and older adults (Colzato, van Muijden, Band, & Hommel, 2011). For example, Green and Bavelier (2003, 2006b) demonstrated that video gamers show improved spatial and temporal visual attention as well as an increased visual attentional capacity when compared to non-gamers. Moreover, the authors showed that having participants play action video games for 10 or more hours improves their performance on a number of basic laboratory tasks testing attentional abilities; the latter finding is an indicator for the causal role of action video game playing in the observed improvements. Since not all studies are successful in providing evidence for "transfer effects" between action video game playing and basic cognitive functions and skills (e.g., spatial abilities, Sims & Mayer, 2002; working memory functions, Boot, Kramer, Simons, Fabiani, & Gratton, 2008), the underlying cognitive mechanisms of "successful transfers" remain a matter for debate. While observed advantages

due to action video game playing may result from changes in visual "lower-level" attentional skill (Green & Bavelier, 2003), "higher-level" attentional control (Chisholm, Hickey, Theeuwes, & Kingstone, 2010; Hubert-Wallander, Green, & Bavelier, 2010) top-down strategy use (Clark, Fleck, & Mitroff, 2011), and/or the speed of stimulus–response mapping (Castel et al., 2005; Dye, Green, & Bavelier, 2009), an issue of high importance for psychological research and practice is whether action video game playing also affects executive control skills.

1.1. Why investigate executive control skills in action video games?

Executive control skills control and manage other cognitive processes. They are particularly involved in the processing of complex task situations such as those requiring participants to execute different tasks simultaneously or sequentially with rapid switches between them (e.g., Logan & Gordon, 2001; Norman & Shallice, 1986). By far, most of the existing research has been concerned with assessing the impact of action video games on subjects' performances in single-task situations; the question of whether or not action video game practice might results in optimizations and transfers of executive control skills that are used to coordinate several different tasks in complex task situations has rarely been addressed (see Green & Bavelier, 2006b, for an example of single-task performance with additional conflicting task information; see Maclin et al., 2011, for simultaneous task performance within the practiced game context). This is surprising given that the particular situation of action video

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game playing seems highly adequate for training executive control skills, as gaming typically requires the fast performance of several actions such as fight enemies, locate supplies, or navigate (Boot et al., 2008). These actions are performed at the same time or within close temporal proximity during the games and participants are required to continuously vary their priorities for different actions to achieve the goals of the game (e.g., survival of a fight situation). Moreover, the various actions are performed under strong time constraints. Typically, any relaxation in the players' action regime is punished by feedback through competition measures or by game termination. In cognitive research, these characteristics have been shown to be of high importance for developing and transferring optimized executive control skills (Karbach & Kray, 2009; Kramer, Larish, & Strayer, 1995; Liepelt, Strobach, Frensch, & Schubert, 2011; Meyer & Kieras, 1997).

Based on the observations about characteristics of action video games (e.g., several action goals, varying task priorities) and on findings in cognitive research, it is plausible to investigate whether action video game practice affects executive control skills associated with the coordination of two different tasks. That is, are these skills improved during game practice and can these skills then be transferred to test paradigms outside the game context? Dual-task and task switching paradigms are two types of laboratory tests for executive control skills in situations with simultaneously or sequentially presented tasks, respectively. In the present study, we applied both paradigms to investigate skill transfer from video game practice to test situations requiring dual-task processing and task switching.

1.2. Executive control skills in dual tasks and task switching

For the dual-task test, we applied the paradigm of the Psychological Refractory Period (PRP) type. In the PRP paradigm, two different choice reaction-time (RT) tasks are presented in short succession separated by a variable stimulus onset asynchrony (SOA) between the first task (Task 1) and the second task (Task 2). Typically, RTs of Task 2 increase, the shorter the SOA between both tasks are, while the SOA has no effect on RTs of Task 1 (e.g., Pashler, 1994; Pashler & Johnston, 1989; Schubert, 2008). This increase of Task 2 RTs is explained by a processing bottleneck within the component tasks, due to which certain processes in Task 1 and 2 are not processed simultaneously, but sequentially. The sequential processing leads to increased postponement of certain processing stages in Task 2, particularly with decreasing SOAs. The prominent central bottleneck model locates the sequential processing bottleneck at a central response selection stage (McCann & Johnston, 1992; Pashler, 1994; Schubert, 1999; but see Meyer & Kieras, 1997); in contrast, this model assumes no such bottleneck processing at initial perception and final motor execution stages within these tasks. In the present dual-task test, we presented Task 1 and Task 2 separately in a single-task situation in addition to the combined presentation of both tasks in the PRP dual-task type; single-task situations provide RT performance measures for both tasks in isolation.

The PRP paradigm is a valuable tool to investigate processing bottlenecks within component tasks (Pashler, 1994). In addition, recent studies applied the PRP paradigm in combination with single-task presentations of its component tasks for analyses of executive control processes in situations with simultaneously presented tasks (Jiang, Saxe, & Kanwisher, 2004; Kamienkowski, Pashler, Sigman, & Dehaene, 2011; Liepelt et al., 2011). Several authors (e.g., Luria & Meiran, 2003; Schubert & Szameitat, 2003; Sigman & Dehaene, 2005, 2006; Szameitat, Lepsien, von Cramon, Sterr, & Schubert, 2006) have assumed that such executive processes are involved in the coordination of the two task streams of a PRP dual task. For example, the need to coordinate two tasks instead of only one task may cause additional executive processes in dual-task situations, when participants are faced with a dual-task trial compared to a single-task trial. In line with this assumption, one can observe a general increase of RTs for Task 1 in

PRP dual tasks compared to a situation when this task is performed in isolation, which points to the action of time-consuming control processes at the beginning of the dual-task trial. A potential improvement of executive control skills during action video game practice, including their required coordination of and rapid switching between multiple game-related actions, might speed up these processes. A comparison of dual-task and single-task RTs should therefore provide an opportunity to test for such a speed-up and to test for a video-game based improvement of executive control skills in dual tasks.

In contrast to dual-task tests, participants perform two different choice RT tasks in sequential trials in task switching tests. Therefore, mixing these tasks results in switches between tasks or repetitions of one task; in single-task situations, tasks are presented in isolation. Switching from one task to another requires executive control for a reconfiguration of the cognitive task set, a process that has often been found to increase RTs on task-switch trials compared to task-repetition trials (e.g., Allport, Styles, & Hsieh, 1994; Rogers & Monsell, 1995). Alternatively, RTs on task-repetition trials typically increase single-task RTs (e.g., Koch, Prinz, & Allport, 2005). This increase indicates executive control for resolving stimulus conflicts between tasks when intermixed within one block, in contrast to isolated task performance within single-task situations (Rubin & Meiran, 2005); note that the same set of stimuli is typically used in both tasks resulting in ambiguous bottom-up activation of competing task sets. A potential improvement of executive control skills may speed-up these processes while practicing action video games that require the coordination of and switching between multiple game-related actions. A comparison of switch, repetition, and single-task RTs provides an opportunity to analyze this speed-up and, therefore, to test the practice-related improvement of executive control skills in the task switching test.

While the effect of video game practice on dual-task performance has not been studied so far, there are preliminary findings pointing to a relation between action video game playing and executive control skills in task switching. For example, Karle, Watter, and Shedden (2010) found reduced RTs in task-switch trials in video gamers reporting much experience of action video game playing compared to non-gamers (see also Boot et al., 2008; Colzato, van Leeuwen, van den Wildenberg, & Hommel, 2010). However, these studies included no single-task situation to assess the effects of stimulus conflict resolution, i.e. the difference between repetition and single-task trials. Furthermore, these studies do not allow us to deduce a possible causal role of action video game playing for the improvement of executive control, as it remains open whether practice per se or differences in perceptual, cognitive, or motivational variables between video gamers and non-gamers are responsible for the observed differences (Green & Bavelier, 2003). While we test for executive control skills in situations with two tasks in experienced video gamers compared to non-gamers in Experiment 1, we focus on the causal role of video game playing in Experiment 2.

In both experiments, we comprehensively test for improved executive control skills in contrast to an alternative hypothesis about the possible origin for the improved dual-task and task switching performance in video gamers/video game trainees. According to this hypothesis, not an improvement of executive control skills causes improved performance but an exclusive speed-up of processing stimulus–response mappings within the single component tasks, as suggest by Castel et al. (2005).

2. Experiment 1

Experiment 1 examined the performance of video gamers and non-gamers in a dual-task and a task switching test to assess executive control skills in persons with action video game expertise. The specific hypotheses are the following: if video gamers have enhanced executive control skill then they, in comparison with non-gamers,

should demonstrate a performance advantage (i.e., lower RTs and/or error rates) (1) in situations with simultaneously presented tasks compared with separately presented single tasks (dual-task test) and (2) in task switches compared with task repetitions and in task repetitions compared with single tasks (task switching test). Alternatively, if video games results in enhanced and transferable executive control skills then these gamers, in comparison with non-gamers, should not demonstrate an exclusive performance advantage (i.e., lower RTs and/or error rates) (1) in dual task compared with single tasks (dual-task test) and (2) in task switches compared with task repetitions and in task repetitions compared with single tasks (task switching test).

2.1. Methods

2.1.1. Participants

Twenty students and non-students were recruited from the Berlin community through two types of information flyers. While one type of flyer promoted a series of experiments for males highly experienced in action video gaming (video gamers) the other type of flyer promoted this series for males inexperienced in video gaming (non-gamers); so, both types of flyers were addressed to particular subgroups which potentially equalizes the general level of motivation to conduct the experimental series (Boot, Blakely, & Simons, 2011). Only males underwent testing because of the relative scarcity of females with sufficient experience in video game playing. The separation of the group of males into two groups, video gamers (mean age = 25.9 years, $SD = 5.6$) or non-gamers (mean age = 24.3 years, $SD = 7.0$), was validated with an interview about the amount of their video game experience in action games in the last 6 months prior to testing (Green & Bavelier, 2007). To be considered a video gamer, a participant needed to report 6 or more hours a week of action game playing. The criterion to be considered a non-gamer was a report of less than 1 h per week of action game play. All participants had normal or corrected-to-normal vision and were naïve about the purpose of the experiment. A handedness test (Oldfield, 1971) indicated that participants in both groups were right-handed. Subjects were paid 16 € for participation in this experiment. All participants consented to act as a research subject for the Humboldt University Berlin.

In order to further characterize the participants, we conducted paper-and-pencil tests on attention and concentration performance (d2 Test; Brickenkamp & Zillmer, 1998), a vocabulary test (Wortschatztest [WST]; Anger et al., 1968) and a non-verbal intelligence test (Cultural Fair Intelligence Test [CFT 20-R]; Weiss, 2006). Participants were asked to rate their current general health status relative to their age group on a scale of 1 (poor) to 5 (excellent) and to indicate the number of years of formal education they had received (Table 1). Overall, we found no significant difference between both groups in these measures.

2.1.2. Apparatus

Visual stimuli in the following experiments were presented on a 17-inch color monitor and auditory stimuli were presented via headphones which were connected to a Pentium I IBM-compatible PC. The experiment was controlled by the software package ERTS (*Experimental Runtime System*; Beringer, 2000).

2.1.3. Experimental tests

2.1.3.1. Dual-task test

2.1.3.1.1. Stimuli. Participants performed a visual and an auditory RT task in the present dual-task test. We selected tasks with different input modalities to minimize the impact of processes coordinating simultaneous (visual) stimuli; in this way, differences in dual-task performance would reflect sheer differences in processes of executive control on selecting and executing multiple responses (e.g., Meyer & Kieras, 1997). Perceptual control processes in video gamers were already extensively investigated in previous studies (e.g., Castel et al., 2005; Clark et al., 2011) and would not represent a novel research focus. As illustrated in Fig. 1A, Task 1 included the presentation of sine-wave tones with pitches of either 350, 900, or 1650 Hz via headphones. Participants responded with the index, middle, and ring finger of the right hand, respectively. Task 2 included the presentation of small, middle and large visually presented triangles and responses with the ring, the middle and the ring finger of the left hand, respectively.

2.1.3.1.2. Procedure and design. Participants performed single-task blocks in which only one of the two tasks were presented. They also performed dual-task blocks that included the presentation of both tasks. Trials of single-task blocks started with the presentation of three dashes next to each other of which the middle dash was located at the center of the screen. The dashes remained on the screen until the end of each trial. After 500 ms, an auditory stimulus (i.e., sine-wave tone) appeared for 40 ms in auditory single-task block trials, or a visual stimulus (i.e., triangle) appeared centrally in the visual single-task block trials. Similar to single-task trials, dual-task block trials also started with the presentation of three white dashes. After 500 ms, an auditory stimulus was presented, followed by the presentation of a visual stimulus. The interval between the onsets of both stimuli (i.e., SOA) was 50, 100 or 400 ms (Fig. 1A).

Single-task blocks consisted of 45 single-task trials and stimuli were presented with equal frequency in a random order. In all 54 trials of the dual-task blocks, auditory and visual stimuli were presented with equal frequency and stimuli were selected randomly. The number of trials with SOAs of 50, 100, and 400 ms was counterbalanced. Participants were instructed to respond as quickly and as accurately as possible in single-task blocks as well as in the dual-task blocks. In dual-task block trials, priority was given for Task 1 (i.e., the auditory task).

Table 1

Age, attention and concentration performance, non-verbal intelligence, and vocabulary knowledge, formal education, and general health status for video gamers and non-gamers (Experiment 1) as well as for the MoH group, Tetris group, and no-practice group (Experiment 2). Standard deviation in parentheses.

	Experiment 1		Experiment 2		
	Video gamers	Non-gamers	MoH	Tetris	No practice
N	10	10	10 (5 females)	10 (5 females)	12 (6 females)
Age(inyears)	25.9 (5.6)	24.3 (7.0)	24.8 (3.4)	24.0 (4.2)	24.9 (4.0)
Attention and concentration performance (D2)					
Overall performance	482.3 (65.0)	475.8 (54.6)	549.3 (92.8)	543.7 (84.4)	543.9 (94.2)
Concentration peiformnance	183.4 (39.1)	177.9 (26.7)	205.2 (65.4)	224.5 (110.8)	230.2 (93.83)
Intelligence test (CFT 20-R)					
IQ	102.8 (14.7)	99.3 (14.0)	106.4 (21.2)	101.1 (19.4)	108.7 (12.7)
Vocabulary test (WST)					
IQ	102.3 (12.7)	106.8 (11.8)	113.5 (10.2)	110.5 (9.3)	112.7 (10.4)
Education(in years)	14.0 (2.6)	13.5 (2.2)	16.9(2.9)	16.2 (2.8)	16.2(3.0)
Health status (1–5)	4.2 (0.8)	4.1 (0.6)	4.0 (1.3)	3.9 (0.8)	4.0 (0.6)
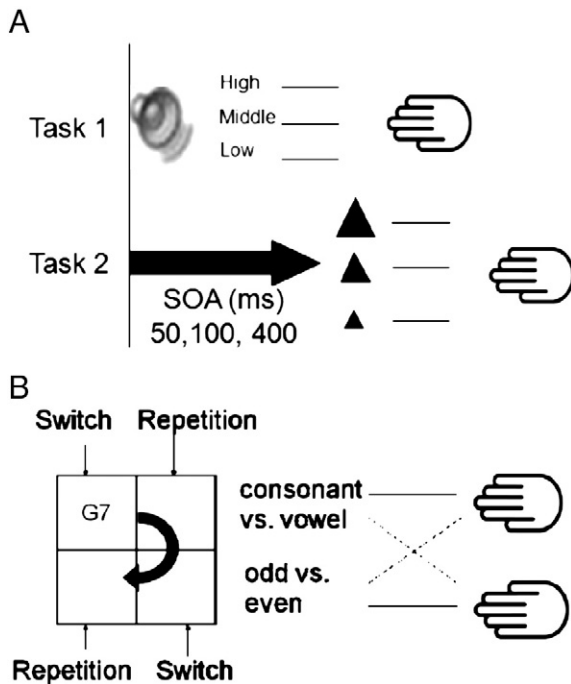
Fig. 1. Illustration of (A) a dual-task situation (including Tasks 1 and 2) of the dual-task test and (B) a mixed block (including the letter and digit task and an exemplary letter-digit stimulus pair) of the task switching test.

At the beginning of the present dual-task test, one single-task block of Task 1 and one single-task block of Task 2 was conducted. Whereas half of the participants started with a block of Task 1 followed by a block of Task 2, the remaining participants performed the blocks in the opposite order. Following the 2 single-task blocks, 5 blocks of dual tasks were conducted.

2.1.3.2. Task-switching test. The present task switching test was adapted from Rogers and Monsell (1995, Experiment 1).

2.1.3.2.1. Stimuli. In the current task switching test, visual stimulus pairs consisting of a letter and a digit were presented, as illustrated in Fig. 1B. The letter was either a consonant (sampled randomly from the set G, K, M, and R) or a vowel (sampled randomly from the set A, E, I, and U). The digit was either even (sampled randomly from the set 2, 4, 6, and 8) or odd (sampled randomly from the set 3, 5, 7, and 9) in the stimulus pairs. The letter and the digit, as well as the order of both in the stimulus pair were randomly selected. Stimulus pairs were displayed in Helvetia font, which subtended at a visual angle of 1.0° horizontally and 0.9° vertically when screen-participant distance was 60 cm (approx. 24 in.). The pairs were presented in the center of 4 boxes that defined the corners of a square subtending 6.7° horizontally and vertically.

In the letter task, participants pressed a left key with the left index finger when a consonant was presented and a right key with the right index finger when a vowel was presented in the stimulus pairs. In the digit task, participants pressed a left key with the left index finger when an even digit was presented and a right key with the right index finger when an odd digit was presented.

2.1.3.2.2. Procedure and design. In each trial, a stimulus pair remained on the screen until the participant pressed a key or 5000 ms had elapsed. Then a blank interval of 150 ms followed before a new trial started when the participant made a correct response. When the participant made an incorrect response, a beep sounded for 30 ms and the following inter-trial interval was extended to 1500 ms.

Presentation of the first stimulus pair in each block started in the upper left box and the trial-to-trial presentation moved clockwise to the subsequent box. Two types of blocks were presented that consisted of 48 trials each. In single-task blocks either the letter task or the digit task was instructed exclusively (i.e., single-task trials). In mixed blocks, however, participants conducted the letter task when the stimulus pairs were presented in the upper left and upper right boxes of the framework on the monitor and they conducted the digit task when the stimulus pairs were presented in lower right and lower left boxes (Fig. 1B). So, trials with task switches (i.e., task-switch trials) alternated with trials of task repetitions (i.e., repeat trials). This type of fixed sequencing of task-switch trials and repeat trials resulted in a task switching situation with predictive switches (Rogers & Monsell, 1995).

The task switching test started with two single-task blocks including one block of the letter task and one block of the digit task. Whereas half of the participants conducted the letter task first and the digit task second, the remaining participants conducted a reverse block order. Four mixed blocks were subsequently presented. Participants were instructed for speed and accuracy in each block. Note that due to the moderate number of trials in mixed blocks we exclusively analyzed performance for task-switch and repetition trials. However, we performed no additional analyses on congruent trials (i.e., letter and digit of a stimulus pair map on the identical response) and incongruent trials (i.e., letter and digit of a stimulus pair map on different responses; Rogers & Monsell, 1995).

2.2. Results

2.2.1. Dual-task test

We included the error rate and RT dual-task data of the 50, 100, and 400 ms SOA conditions as well as the single-task data into the same analyses. Task 1 and Task 2 performance was separately analyzed in mixed measures ANOVAs including the within-subject factor TRIALTYPE (50 ms, 100 ms, 400 ms, and single tasks) and the between-subject factor GROUP (video gamers vs. non-gamers). In the RT analyses we excluded trials with incorrect responses.

The error rates of Task 1 were numerically reduced in video gamers when compared with non-gamers, $F(1,18) = 4.189$, $p < .06$, $\eta p^2 = .19$, and in the 400 ms SOA condition compared with the other conditions, $F(1,18) = 3.270$, $p < .05$, $\eta p^2 = .15$. There was no interaction in the error analysis, see Table 2 (note that the numerically larger error rates in single tasks compared with the dual tasks might result from the scheduling of single-task blocks before dual-task blocks in the dual-task test).

The RT analysis of Task 1 revealed generally faster RTs in video gamers than in non-gamers, $F(1, 18) = 12.981$, $p < .01$, $\eta p^2 = .42$, and faster RTs in single-task than in dual-task situations, $F(3, 54) = 77.053$, $p < .001$, $\eta p^2 = .81$. Both factors were qualified by an interaction of TRIALTYPE × GROUP, $F(3, 54) = 9.553$, $p < .001$, $\eta p^2 = .35$. As illustrated in Fig. 2A, video gamers specifically outperformed non-gamers in the dual-task situation (i.e., SOA = 50, 100, and 400 ms), $ts(18) > 3.205$, $ps < .01$, while performance was similar for both groups in single tasks, $t(18) < 1$.

In the Task 2 error analysis, no effects or interactions were significant (Table 2). In a similar analysis, RTs differed between the different trial types, $F(1,18) = 246.340$, $p < .01$, $\eta p^2 = .93$. That is, first, dual-task RTs increased with decreasing SOA and, second, dual-task RTs generally increased single-task RTs. TRIALTYPE was qualified by an interaction with GROUP, $F(3, 54) = 3.173$, $p < .05$, $\eta p^2 = .15$. This interaction reflects the fact that dual-task RTs were particularly faster in video gamers than in non-gamers, $ts(18) > 2.534$, $ps < .05$, while the two groups showed similar RTs in single tasks, $t(18) < 1$ (see Fig. 2A).

2.2.2. Task-switching test

Error data and RTs were collapsed over the letter and the digit tasks and analyzed with separate mixed measures ANOVAs with TRIALTYPE (switch trials, repetition trials, and single-task trials) as within-subject factor and GROUP (video gamers vs. non-gamers) as

Table 2
Mean error rates (in percent) for the dual-task test in single-task and dual-task trials (SOA = 50, 100, and 400 ms) for video gamers and non-gamers in Experiment 1 as well as for the MoH group, Tetris group, and no-practice group in Experiment 2.

	Experiment 1		Experiment 2					
	Video gamers	Non-gamers	Pre-test			post-test		
			MoH	Tetris	No practice	MoH	Tetris	No practice
Task 1								
SOA 50 ms	4.0 (1.1)	8.9 (1.7)	6.0 (1.2)	10.3 (3.6)	8.3 (1.0)	5.0 (1.5)	8.1 (1.8)	4.5 (1.1)
SOA l00 ms	4.8 (1.0)	8.0 (1.5)	4.1 (1.0)	7.3 (3.5)	11.4 (2.3)	4.3 (1.0)	8.2 (1.4)	4.2 (1.3)
SOA 400 ms	3.6 (1.0)	5.2 (1.2)	4.4 (1.4)	6.8 (2.5)	4.6 (0.9)	2.8 (1.1)	8.0 (2.7)	4.3 (1.5)
Single-task trials	6.0 (1.4)	9.0 (1.6)	8.0 (2.2)	9.7 (2.4)	9.4 (3.9)	3.3 (1.5)	8.7 (2.6)	6.7 (1.6)
Task 2								
SOA 50 ms	7.2 (1.1)	9.8 (1.8)	2.6 (1.1)	7.5 (2.0)	4.7 (1.1)	2.6 (1.1)	7.5 (1.6)	4.7 (1.0)
SOA l00 ms	7.2 (1.1)	9.9 (2.4)	4.1 (1.1)	4.2 (2.3)	8.8 (1.5)	4.1 (1.3)	4.2 (3.4)	8.8 (1.2)
SOA 400 ms	7.0 (1.3)	7.9 (1.9)	1.9 (1.3)	7.9 (2.6)	3.1 (0.8)	1.9 (1.7)	7.9 (3.1)	3.1 (0.3)
Single-task trials	8.7 (1.7)	11.6 (2.0)	7.3 (2.3)	10.7 (4.2)	7.8 (1.8)	6.0 (1.5)	8.0 (2.6)	5.0 (2.0)

between-subject factor. The error rate analysis revealed a main effect of TRIALTYPE, $F(2, 36) = 13.593$, $p < .001$, $\eta p^2 = .43$, indicating higher error rates in switch trials than in repetition and single-task trials. There was no main effect of or interaction with GROUP (Table 3). The identical analysis on RTs revealed a main effect of TRIALTYPE, $F(2, 36) = 92.789$, $p < .001$, $\eta p^2 = .84$, with slowest RTs in switch trials, followed by repetition and single-task trials. Importantly, the interaction of TRIALTYPE × GROUP, $F(2, 36) = 6.179$, $p < .01$, $\eta p^2 = .26$, was significant. While switch-trial RTs were larger in non-gamers than in video gamers, $t(18) = 2.425$, $p < .05$, RTs did not differ in repetition and single-task trials, $ts(18) < 1$, as illustrated in Fig. 3A. GROUP showed no main effect.

2.2.3. Integrated analysis of dual tasks and task switching

In the following paragraph, we examine whether the hypothesis of speed-up processing of stimulus–response mappings may explain our findings in the dual-task test and the task switching test. Therefore, we assessed the performance in these tests within a single graphical analysis. We drew a scatter plot of the Brinley-plot type as a tool for these assessments (Dye et al., 2009). Brinley plots have the advantages that (1) the performance of two different groups in the same experimental condition is reflected within a single data point, and (2) data of multiple conditions and tests are represented within a single plot. The latter is of enormous importance because results of the dual-task and the task switching tests can be combined within a single graph. Due to this combination, Brinley plots represent an analytic tool including novel information when compared to the separate illustration of test data in Figs. 2 and 3.

In detail, for the dual-task test we displayed the single-task and dual-task data in the 50 ms SOA condition of Tasks 1 and 2. We selected the 50 ms SOA condition because that condition provides the largest amount of temporal overlap when processing two tasks (Pashler & Johnston, 1989). Therefore, this condition represents the most demanding dual-task condition and was regarded to be the most solid test of the executive control skills of participants in the present dual-task situation. For the task switching test, we displayed the repetition and switching data. In Fig. 4, the RT performance of the video gamers is plotted on the x-axis and that of the non-gamers is plotted on the y-axis.

Let's consider the possibility that the differences in the performance levels of video gamers and non-gamers in complex task situations (i.e., dual-task and task switching situations) arise from a difference in the processing speed for stimulus–response mappings (Castel et al., 2005). In this case, group differences in complex and simple situations (e.g., single tasks or task repetitions) are explained by a single underlying factor with a group difference in complex situations being identical to the group difference in simple situations. In more detail, a group difference of 100 ms in complex situations would then relate to a difference of 100 ms in the simple situation.

Consequently, data points of simple and complex situations of the dual-task test (i.e., single and dual tasks) and of the task switching test (i.e., repetition and switch) should then be located along lines with slopes of +1 in the Brinley plots. However, if the difference between the performance levels in complex situations does not arise from the exclusive impact of one single factor, e.g. processing speed of stimulus–response mappings, but is caused by the additional impact of a further factor, e.g. executive control skills, then we should expect a different pattern: lines connecting data points of simple and complex situations in the two tests should deviate from the +1 slope function. This is because group differences in complex situations differ from those in simple situations. In the Brinley Plot, there should be a pattern reflecting a steeper increase in the non-gamers' processing time in complex but not in simple situations compared to the video gamers.

As illustrated in Fig. 4, lines connecting single and dual-tasks in the dual-task test as well as repetition and switch situations in the task switching test were shifted towards the corresponding axis of the Brinley plot (y-axis) and diverged from a slope of +1. These results demonstrate that the advantages of video gamers in dual-task and switching situations do not result exclusively from differences in processing speed of stimulus–response mappings in the single-task situations; they suggest that a further factor such as improved executive control skills contributes an additional processing advantage in complex situations for gamers compared to non-gamers.

2.3. Discussion

The data of the dual-task test showed decreased RTs for Task 1 and Task 2 in video gamers compared with non-gamers; this advantage was specifically observed in dual-task and there was no such advantage in single-task situations. These data are consistent with the hypothesis of enhanced executive control skills in experienced video gamers in comparison with non-gamers. While former studies provided evidence for superior executive control of video gamers in single-task situations with additional conflicting task information (e.g., Green & Bavelier, 2003, 2006b), these results represent one of the first demonstrations of superior executive control skills of video gamers in transfer situations with two tasks presented simultaneously.

The task switching test demonstrated a performance advantage for video gamers, compared to non-gamers in the switching situation and no advantage in repetition and single-task situations. Similar to the dual-task test, the task switching test produces data that are consistent with the hypothesis of enhanced executive control in switching situations in experienced video gamers when compared with non-gamers. These findings extend the observations in previous studies on video game practice effects (Boot et al., 2008; Colzato et al., 2010; Karle et al., 2010) because they indicate optimized executive control skills for an enhanced switching between two different tasks
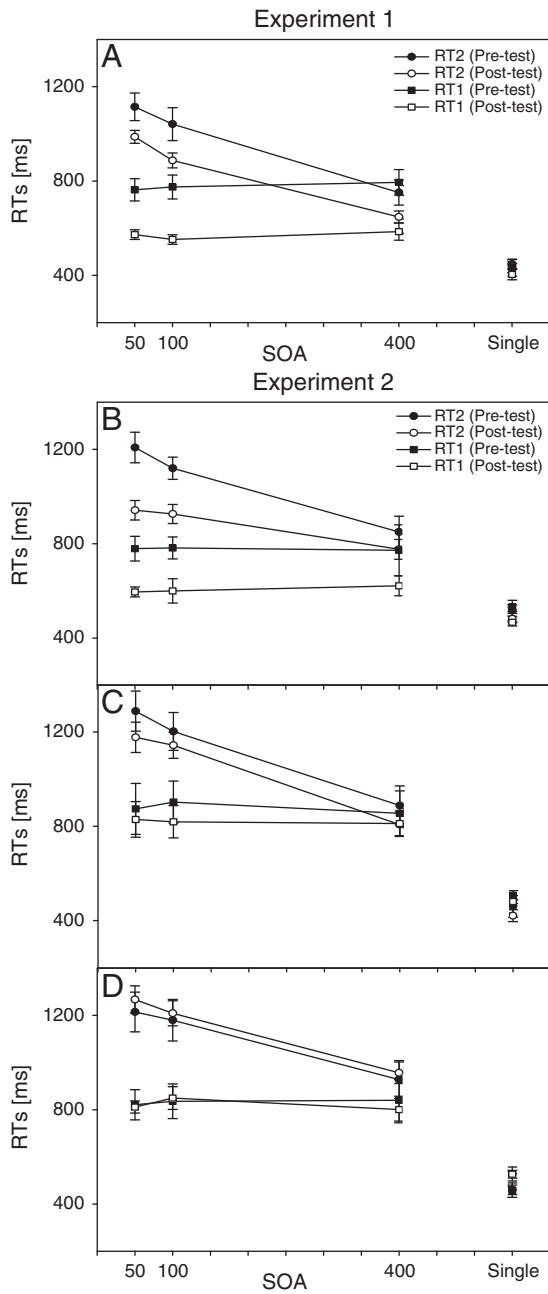
Fig. 2. Reaction times (RTs) in ms in single-task trials (ST) and dual-task trials (DT) for Task 1 and 2 of the dual-task test in Experiments 1 and 2. Panel (A): In Experiment 1, RTs for the video gamers and non-gamers were compared. Panel (B, C, D): in Experiment 2, groups of non-gamers were trained on the action video game Medal of Honor (MoH; Panel A), on the puzzle game Tetris (Panel C) or had no practice (Panel D) and their RTs were measured in a pre-test session (pre-test) and in a post-test session (post-test). Significant differences between RTs are indicated by asterisks (*).

while there are no such skills for a better performance when two tasks are intermixed.

In sum, the findings of Experiment 1 provided evidence for optimized executive control skills in video gamers. However, the issue whether there is a causal role of video game playing for improving these executive skills remains open. The enhanced executive control skills observed in video gamers could either be the result of video game playing per se, or it could be the case that video gamers have inherently optimized executive control skills (Green & Bavelier, 2003, 2006a). According to the latter alternative, greater success at video games due to higher inherent skills might provide a motivating factor to play these games more often, whereas the lower inherent skills of non-gamers possibly limit their success and, as a result, cause them to refrain from playing. An investigation of this potential causal role of video game playing and optimized executive control skills is the objective of Experiment 2.

3. Experiment 2

To focus on the causal role of playing video games, we trained two groups of non-gamers in two games with different demands on executive control processes for 15 h, and tested their performance in the dual-task and task switching tests in a post-test session after practice. We selected the fast-paced ego-shooter action game *Medal of Honor* (MoH) which simulates World War II combat situations with the aim of killing enemies while avoiding being killed. We selected this game for different reasons. First, this game is similar to those played by the video gamers of Experiment 1 and of other studies investigating video gamers and transfer effect after action video game playing (e.g., Boot et al., 2008; Feng et al., 2007; Green & Bavelier, 2003, 2006a). Second, this game includes the simultaneous coordination of multiple game-related actions and requires rapid switching between them under strong time constraints (Boot et al., 2008; Feng et al., 2007; Green & Bavelier, 2003); according to Kramer et al. (1995), the repeated practice in such task settings may lead to the optimization of executive control skills in multiple task situations. Third, such an optimization is supported by the fact that MoH includes situations with variable priority (Boot et al., 2008; e.g., priority on taking aim at objects while navigating through space in Situation A and priority on navigating through space while taking aim at objects in Situation B). A second group of non-gamers was trained in the puzzle game *Tetris*. In Tetris, players rotate and move blocks descending from the top of the screen so that these blocks form lines at the bottom of the screen. This game contains a challenging visuospatial component involving mental rotation processes in working memory (Okagaki & Frensch, 1994; Sims & Mayer, 2002); however, it requires focusing on only one task and one object at a time. Tetris, therefore, was not expected to improve executive control skills and thus represents an excellent control condition for cognitive and also motivational effects. The specific hypotheses are the following: if MoH practice causes an optimization of executive control skills it should lead to selective performance advantages (i.e., lower RTs and/or error rates) in (1) the dual-task situation and (2) the task switching situation during post-test when compared with performance after practicing Tetris; potential advantages in single-task as well as

Table 3
Mean error rates (in percent) for the task switching test in single-task trials, repetition trials and switch trials for video gamers and non-gamers in Experiment 1 as well as for the MoH group, Tetris group, and no-practice group in Experiment 2.

	Experiment 1		Experiment 2					
	Video Gamers	Non-gamers	Pre-test			Post-test		
			MoH	Tetris	No practice	MoH	Tetris	No practice
Switch trials	17.9 (4.0)	19.8 (4.0)	7.6 (1.4)	8.9 (2.7)	10.6 (2.6)	6.9 (0.8)	9.3 (1.7)	5.1 (1.1)
Repetition trials	7.7 (3.4)	10.7 (2.6)	1.3 (0.5)	7.2 (5.0)	2.8 (1.1)	2.8 (0.9)	3.3 (1.6)	1.9 (0.9)
Single-task trials	5.7 (0.6)	6.4 (0.9)	3.8 (0.9)	13.5 (5.9)	10.3 (4.5)	3.3 (0.8)	3.0 (1.0)	1.5 (0.3)
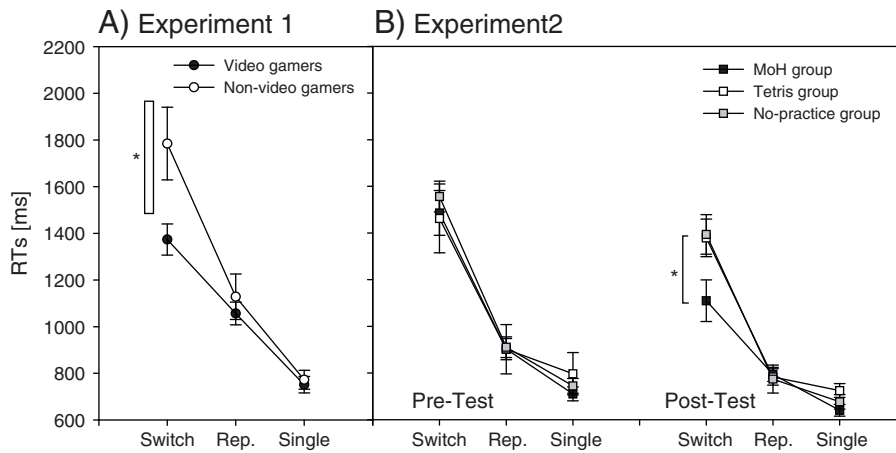
Fig. 3. Reaction times (RTs) in ms in switch trials (Switch), repetition trials (Rep.) and single-task trials (Single) of the task switching test in Experiments 1 and 2. Panel (A): In Experiment 1, RTs for the video gamers and non-gamers were compared. Panel (B): In Experiment 2, groups of non-gamers were trained on the action video game Medal of Honor (MoH), on the puzzle game Tetris or had no practice and their RTs were measured in a pretest session (pre-test) and in a post-test session (post-test). Significant differences between RTs are indicated by asterisks (*).

repetition situations (for the task switching test only) should be reduced or non-existent. Alternatively, if MoH practice causes no optimization of executive control skills it should not lead to selective performance advantages (i.e., lower RTs and/or error rates) in (1) the dual-task situation and (2) the task switching situation during post-test when compared with the performance after practicing Tetris.

In a pre-test session, we assessed for similar dual-task and task switching performance levels prior to practice in the MoH and Tetris trainees. To control for test–retest improvements in the two groups of trainees, a third group of non-gamers received no practice between the pre- and post-tests.

3.1. Methods

3.1.1. Participants

Thirty-two students of psychology and educational sciences from the LMU Munich were randomly placed into 3 practice groups

Fig. 4. Brinley plot illustrating RT performance in the dual-task and task switching test for video gamers (x-axis) and non-gamers (y-axis) in Experiment 1. Single-task and dual-task (i.e., 50 ms SOA condition) data points for Task 1 (RT1) and Task 2 (RT2) in the dual-task test are connected with dashed lines, so are data points of switch and repetition trials of the task switching test (TS).

(Table 1). These students were naïve to the objective of the study as they were recruited via e-mails that included no details about the practice and test sessions. Ten participants practiced either MoH (mean age = 25.2, years, $SD = 3.8$) or Tetris (mean age = 24.4 years, $SD = 4.0$) while 12 participants had no practice at all (mean age = 24.5 years, $SD = 3.5$). Although systematic investigations of gender effects were not the primary focus of the present study, we equally included males and females into each participant group in order (1) to produce practice results generalizable to gender-mixed groups and (2) to control for practice/no-practice effects across gender (Green & Bavelier, 2006b); in fact, potential gender differences within experimental groups can be reduced due to practice (Feng et al., 2007). All participants were right-handed as measured by the Edinburgh Handedness Inventory (Oldfield, 1971). In an interview, the participants reported no video-game practice in the last 6 months prior to testing. Table 1 presents the participants' performance on the paper-and-pencil tests, the data of their health status, and formal education, which did not differ between the three groups. For participating in this experiment, we paid 8 € per practice session and 12 € per pre-test/post-test. All participants consented to act as a research subject for the Ludwig-Maximilians-University Munich.
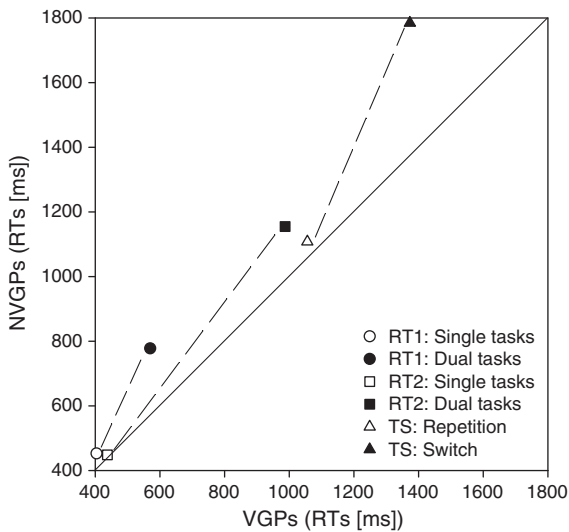
3.1.2. Experimental tests

Experimental tests were identical to Experiment 1.

3.1.3. Testing schedule

All participants conducted the dual-task and the task switching test in a pre-test session. Participants (of the training groups) then practiced MoH or Tetris for 15 subsequent one-hour sessions that were distributed across 4 weeks while the no-practice group had no contact with the laboratory practice situation during that time; game performance of the training groups was assessed at the beginning as well as at the end of practice. Subsequently, all participants participated in a post-test session comprising tests identical to the pre-test session.

3.2. Results

We first present data of game performance followed by transfer data in the dual-task and task-switching test before and after game practice. In no analysis did we include gender as a factor, as a preliminary data observation indicated neither effects of nor interactions

with gender (Green & Bavelier, 2006a). A systematic analysis of gender effects on game and transfer performance is, however, a promising question for future studies.

3.2.1. Game performance gains

Performance in MoH increased by 19.8% and 32.7% as regards accuracy and number of hits during practice, respectively. Participants in the Tetris group showed an increase of 256% in the number of completed rows and an increase of 214% in mean scores from the first to the last practice session. These measures showed that practice of MoH as well as Tetris leads to game-related improvements. A post-test interview indicated that the application of Tetris was successful to control for motivational effects during practicing MoH (Boot et al., 2011); trainees showed similar self-rated values of motivation during practice as well as demand and difficulty of playing either MoH or Tetris, $ts(18) < 1.457$, $ps > .20$.

3.2.2. Dual-task test

Task 1 and Task 2 performance was analyzed with mixed measures ANOVAs including the within-subject factors SESSION (pre-test vs. post-test), and TRIALTYPE (50 ms, 100 ms, 400 ms, and single tasks) as well as the between-subject factor GROUP (MoH, Tetris, and no-practice). Only correct trials were included into the RT analyses.

The error analysis of Task 1 showed reduced error rates during post-test compared to pre-test, $F(1, 29) = 12.819$, $p < .001$, $\eta p^2 = .31$, reduced error rates in the MoH when compared to the Tetris group, $F(2, 29) = 3.656$, $p < .05$, $\eta p^2 = .20$, as well as reduced error rates in the 400 ms SOA condition compared with the remaining single-task and dual-task conditions, $F(3, 87) = 2.964$, $p < .05$, $\eta p^2 = .10$. The interactions were not significant (Table 2).

The identical analysis on RTs showed faster RTs in single tasks than in dual tasks, $F(1, 29) = 986.731$, $p < .001$, $\eta p^2 = .75$, and faster RTs during post-test compared to pre-test, $F(1, 29) = 8.863$, $p < .01$, $\eta p^2 = .23$. The latter effect on SESSION was moderated by the factor GROUP, $F(2, 29) = 3.736$, $p < .05$, $\eta p^2 = .21$. Most importantly, we found an interaction of SESSION × TRIALTYPE × GROUP, $F(6, 87) = 3.545$, $p < .01$, $\eta p^2 = .20$, indicating that dual-task RTs and single-task RTs varied differently from pre- to post-test across the 3 groups of participants. In detail, all groups showed similar single-task RTs during pre- and post-test, $ts(18) < 1$. However, dual-task RTs in Task 1 significantly decreased in the MoH group from pre-test to post-test at the 50 and 100 ms SOA level, $ts(9) > 2.774$, $ps < .05$, and decreased marginally significant at the 400 ms SOA level, $t(9) = 1.968$, $p < .07$. In contrast, these RTs in the Tetris and the no-practice groups remained unaffected, $ts(9) < 1$; this is illustrated in Fig. 2B, C, and D. The main effect of GROUP and the remaining interactions were non-significant.

The Task 2 error analysis showed a main effect of TRIALTYPE, $F(3, 87) = 3.400$, $p < .05$, $\eta p^2 = .11$, reflecting higher error rates in single tasks compared with the 400 ms SOA condition, $p < .05$ (potentially because of the scheduling of single-task blocks before the dual-task blocks). There were no further main effects or interactions.

The identical analysis on RTs revealed faster RTs during post-test than during pre-test, $F(1, 29) = 13.411$, $p < .001$, $\eta p^2 = .32$, and faster RTs in single tasks followed by the 400, 100, and 50 ms SOA condition, $F(3, 87) = 284.614$, $p < .001$, $\eta p^2 = .91$. Both results were qualified by an interaction of SESSION × TRIALTYPE, $F(3, 87) = 3.122$, $p < .05$, $\eta p^2 = .10$, indicating that the RT decrease from pre- to post-test was present in dual tasks, $Fs(1, 29) > 4.674$, $ps < .05$, but not in single tasks, $Fs(1, 29) = 1.538$, $p > .15$. Most importantly, we found an interaction of SESSION × TRIALTYPE × GROUP, $F(6, 87) = 2.476$, $p < .05$, $\eta p^2 = .15$: There was a reduction of dual-task RTs at the 50 and 100 ms SOA conditions in the MoH group from pre-test to post-test, $ts(9) > 3.845$, $ps < .01$, while there was no such difference at the 400 ms SOA condition and in the single-task condition in that group, $ts(9) < 1.406$, $ps > .19$; importantly, the Tetris and the no-practice

groups showed similar RTs at all SOA and single-task conditions during pre-test and post-test, $ts(9) < 1.838$, $ps > .10$, as illustrated in Fig. 2B, C, and D.

3.2.3. Task-switching test

Error data and RT data of correct trials were submitted to mixed measures ANOVAs with SESSION (pre-test vs. post-test) and TRIALTYPE (switch trials, repetition trials, and single-task trials) as within-subject factors and GROUP (MoH, Tetris, and no-practice) as a between-subject factor. The error rate analysis showed that participants made less errors in repetition trials than in single-task and switch trials, $F(2, 58) = 7.904$, $p < .01$, $\eta p^2 = .21$; the lower error rates in repetition compared to single-task trials may arise from the scheduling of single-task blocks before the mixed blocks during the task switching test. This type of trials showed, however, the largest practice related benefit as indicated by an interaction of TRIALTYPE and SESSION, $F(2, 58) = 3.215$, $p < .05$, $\eta p^2 = .10$. The remaining main effects and interactions were not significant (Table 3).

An identical analysis on RTs showed faster RTs during post-test than during pre-test, $F(1, 29) = 12.830$, $p < .001$, $\eta p^2 = .30$, as well as faster RTs in single tasks, followed by repetition and switch trials, $F(2, 58) = 250.742$, $p < .001$, $\eta p^2 = .90$. The significant interaction of SESSION and TRIALTYPE, $F(2, 58) = 5.648$, $p < .01$, $\eta p^2 = .16$, reflects the fact that practice-related RT benefits were larger in switch trials followed by repetition trials and single-task trials. Most importantly, we found an interaction of SESSION × TRIALTYPE × GROUP, $F(4, 58) = 3.071$, $p < .05$, $\eta p^2 = .18$. This interaction indicated that switch RTs decreased from pre- to post-test in the MoH group, $F(1, 29) = 14.894$, $p < .001$, $\eta p^2 = .34$, but this was not the case in the Tetris and no-practice groups, $Fs(1, 29) < 3.326$, $ps > .08$, $\eta p^2 = .10$ (Fig. 3B). During pre-test, RTs in switch, repetition, and single-task trials were similar between all groups, all $ps > .30$, while they were exclusively similar in repetition and single-task trials during post-test, all $ps > .07$. The effect of GROUP and the remaining interactions were not significant.

3.2.4. Integrated analysis of dual tasks and task switching

Similar to Experiment 1, we investigate whether the possible origin for the improved dual-task and task switching performance in MoH trainees are improved executive control skills or exclusively improved speed-up of processing stimulus–response mappings within the single component tasks within a single graph of the Brinley Plot-type. In the present experiment, this Brinley Plot displays the performance gains (i.e., RT decreases) from pre- to post-test of MoH (y-axis) and Tetris trainees (x-axis). To support the assumption of improved executive control skills, there should be a pattern reflecting a steeper increase of training gains in complex but not in simple situations in MoH trainees compared to Tetris trainees in this plot, i.e. slopes between single and dual tasks/task switches and task repetition should diverge from $+1$.

As illustrated in Fig. 5, lines connecting data points of single and dual tasks in the dual-task test as well as repetition and switch situations in the task switching test were shifted towards the corresponding axis of the Brinley Plot (y-axis) and diverged from a slope of $+1$. These results demonstrate that the advantages of MoH trainees in dual-task and switching situations do not exclusively result from differences in processing speed of stimulus–response mappings in the single-task situations. In fact, a further factor such as improved executive control skills contributes an additional processing advantage in complex situations for MoH trainees compared to Tetris trainees.

3.3. Discussion

In the MoH group, dual-task performance improved from pre- to post-test while single-task performance remained constant. There was neither single nor dual-task improvement in the Tetris and the no-practice groups. We interpret these findings as consistent with
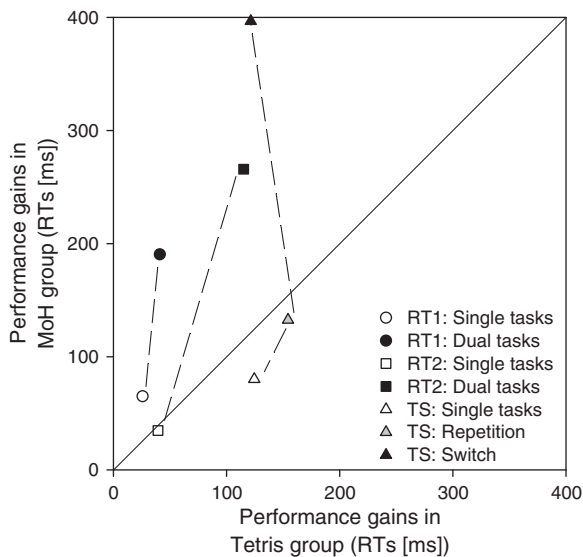
Fig. 5. Brinley plot illustrating RT performance gains (i.e., RT decreases) from pre- to post-test in the dual-task and task switching tests compared for the MoH and Tetris trainees in Experiment 2. Single-task and dual-task (i.e., 50 ms SOA condition) data points for Task 1 (RT1) and Task 2 (RT2) in the dual-task test are connected with dashed lines, so are data points of switch and repetition trials of the task switching test (TS).

the hypothesis of optimized executive control skills resulting from action video game practice; they are not consistent with the hypothesis of an exclusive speed-up in stimulus–response mapping processes. The present data, therefore, provide evidence for a causal role of this type of practice for the optimization of executive control skills (Green & Bavelier, 2003). This assumption is not confounded by different initial performance levels before practice.

As for dual tasks, we also found evidence for a causal relationship between action video game practice and improved executive control processes in the present task switching test. That is, the group of participants practicing MoH selectively showed improved performance in the task switching situation when compared to the Tetris and no-practice groups. Similar to the dual-task test, we interpret these findings as consistent with the hypothesis of optimized executive control skills resulting from action video game practice, while they are not consistent with the hypothesis of an exclusive speed-up in stimulus–response mapping processes. This is one of the first demonstrations of a causal role of video game practice to improve executive control skills regulating the switch between two tasks in a task switching situation; earlier practice studies provided no such evidence (e.g., Boot et al., 2008).

This assumption on the causal role of video game practice and the improvement of executive control skills is not confounded by different initial performance levels before practice and different performance levels in repetition and single-task trials. In detail, all three experimental groups showed similar performance during the task-switch pre-test. Furthermore, performance in repetition and single-task trials of the post-test was also similar between all three groups; thus, the switching advantage after action video game practice is not affected by differences in alternative skills required for the performance of two intermixed tasks. Data in repetition and single-task trails during post-test provide no evidence for an optimization of these skills after action video gaming.

4. General discussion

Green and Bavelier (2003, 2006a, 2006b, 2007) and others (e.g., Castel et al., 2005; Feng et al., 2007; Riesenhuber, 2004) showed that extensive practice of video games leads to processing advantages

in cognitive skills such as basic visual attention. Our study extends these findings by demonstrating that practicing video games selectively optimizes executive control skills that are associated with the coordination of two different tasks. Specifically, video gamers, compared to non-gamers, showed an improved performance in dual-task and task switching situations when two different tasks were presented simultaneously or sequentially, respectively; there was no difference in the single-task and task-repetition performance between video gamers and non-gamers. Non-gamers trained in an action video game for 15 h showed selective performance gains in dual-task and task switching situations when compared to non-gamers practicing a puzzle game or having no game practice. This finding establishes a causal relationship between video game experience and the improvement of executive control skills in dual-task and task switching situations. So, this study provides one of the first conclusive evidences of causative effects of action video gaming on executive control skills in dual-task and task switching situations. Further, Brinley–Plot analyses provide no evidence for the hypothesis that improved dual-task and task switching performance simply arise from faster stimulus–response mappings within the single component tasks.

4.1. Characterization of enhanced executive control skills after video game practice

What specific skills are enhanced in the present dual-task and task switching situations after action video game training? For the dual-task test, the reduced dual-task RTs for Task 1 and Task 2 after action video game practice, compared to no practice of action video games, indicate optimized and speeded executive control processes. According to several authors (e.g., Luria & Meiran, 2003; Schubert & Szameitat, 2003; Sigman & Dehaene, 2006) such executive processes are necessary in order to activate two task sets at the beginning of a dual-task trial as well as to coordinate and to schedule their processing order at or before the bottleneck. As already mentioned in the Introduction section, the observation of increased RTs in Task 1 compared to the same task in isolation is usually interpreted as pointing to additional control processes involved in the activation of two task sets at the beginning of a dual-task trial. The present findings are consistent with the assumption that action video game practice leads to an improvement of these processes, which would explain the observed speeded RTs on Task 1 after action video game playing. The assumption of speeded executive control processes at the beginning of the dual-task trial is also consistent with the observation of the faster RT2 after playing these games. This is so, because Task 2-processing is not independent of Task 1 processing in PRP dual tasks. Due to a bottleneck of the cognitive system, the response selection stage in Task 2 cannot start before the end of this stage in Task 1 (e.g., McCann & Johnston, 1992; Pashler, 1994; Schubert, 1999). Therefore, when processing of the response selection stage in Task 1 finishes earlier because of speed-up task scheduling and/or task initiation at the beginning of Task 1 processing, then there is also an earlier start of the response selection stage in Task 2; this leads to decreased RTs in this latter task. Additional support for the assumption of Task 1-Task 2 dependencies comes from the RT data in the different SOA conditions in the present Experiment 2. Here, in the 400 ms SOA condition, there is no dual-task performance advantage in Task 2 for the MoH group compared with the Tetris and no-practice groups, while there is such an advantage in the remaining SOA conditions and also in Task 1. In the 400 ms SOA condition, it may be the case that the response selection stage in Task 1 finishes before the response selection stage in Task 2 is ready to start. If this is the case, then performance advantages in Task 1 due to optimized executive control processes in the MoH group, do not propagate into Task 2; rather Task 2 processing is then independent from variations in the processing latencies in Task 1.

For the task switching test, we found selectively reduced RTs in the switching situation while there is no evidence for a performance advantage after video game practice in the repetition situation. The

reduction of switch RTs may be associated with executive control skills that allow a speeded switch between tasks. The speeded switch may reflect optimized implementation processes to activate the task set of an upcoming task (e.g., Rogers & Monsell, 1995; Rubinstein, Meyer, & Evans, 2001) and/or a reduced inhibition of this task through the task set of a previous task (e.g., Allport et al., 1994; Mayr & Keele, 2000; for a combined approach see Monsell, 2003; Strobach et al., 2012). On the other hand, the lacking performance advantage after video game practice in the repetition situation indicates that this type of practice does not enhance skills associated with the control of stimulus conflicts in intermixed task settings (Rubin & Meiran, 2005). It also shows that advantages in task switching follow from skills for speeded task switches but not from other optimized skills e.g., improved stimulus conflict resolution.

4.2. Relation to other studies on action video game practice and executive control

Interestingly, Boot et al. (2008) provided evidence for improved task switching performance in expert video gamers but showed no such improvement in non-gamers that practiced an action video game when compared with non-gamers who practiced Tetris. The current demonstration of a task switching advantage in non-gamers after action video game practice indicates that important boundary conditions may exist for the effectiveness of video game practice to improve performance in transfer tests, e.g. the task switching test (Boot et al., 2008). One reason for the discrepancy in findings between our study and that of Boot et al. may be that the number of administered transfer tests affects the occurrence of possible transfer effects. Boot et al. assessed transfer effects in 12 different tests on executive control, visual attention, and spatial memory during pre- and post-test sessions. This amplified number of tests in the Boot et al. study could have prevented transfer effects after video game practice. This is so, because mental effort in one transfer test may undermine the efforts in later tests; such aftereffects were particularly found between tests on exercising executive control (Schmeichel, 2007). Correspondingly, aftereffects may have harmed the occurrence of possible performance differences between a group of action video gamers and the group of Tetris gamers in the Boot et al. study. In the present study, we conducted only two transfer tests, so the possible aftereffects on the performance in transfer tests were small and transfer effects were expressed. Consistent with this assumption of an impact of aftereffects on transfer effects are the findings of Green and Bavelier (2003) as these authors only included three transfer tests on visual attention in their study. In contrast to Boot et al., Green and Bavelier were able to find transfer effects on visual attention which is consistent with the current proposal about the possible impact of the number of tests on transfer efficiency.

An alternative reason for the discrepancy between the task switching results in the present study and the study by Boot et al. (2008) could originate in the administered task switching paradigms. While Boot et al. indicate upcoming tasks in mixed block via color cues in the beginning of each trial, participants were required to maintain a pre-instructed task sequence in the present study (e.g., AABBAABB). Such maintenance increases the demand on working memory capacity in the latter compared to the former type of mixing blocks (e.g., Gajewski et al., 2010; Reuter-Lorenz & Sylvester, 2005). It could be that predominantly the impact of this increased demand, due to the pre-instructed task sequence, explains the different outcome in task-switch trials between the Boot et al. and the present study: MoH trainees optimize working memory capacity within 15 h of practice which allows for improved performance in switching situations. In contrast, there may be no practice-related enhancement of processes required for optimization of task switching including task cueing as in the Boot et al. study.

The present findings, suggesting effects of action video gaming on executive control skills in dual tasks and task switching, are interesting from the perspective of video game practice research, but they are also interesting from a broader theoretical perspective on executive control mechanisms. A number of theories on executive control mechanisms, e.g. the central executive system in the working model of Baddeley (2003) or the Supervisory Attentional System (Norman & Shallice, 1986), suppose that these mechanisms are functionally distinct from the processes they organize (e.g., processes of single-component tasks). Recent practice studies have demonstrated that executive control skills involved in the coordination of two different tasks in dual-task and task switching situations are to some degree distinct from processes involved in single-task situations (Karbach & Kray, 2009; Liepelt et al., 2011). These studies showed that dual-task practice and task switching practice may result in selective optimizations of executive control skills in the practiced situation and that these skills are transferable to alternative task switching and dual-task situations, respectively. As in these studies, we demonstrate that practice can selectively alter executive control skills; the selective alteration of these skills implies their distinctiveness from single-task processing. Thus, the present data underline the theoretical assumption of a distinctiveness of executive control skills and processes of single component tasks.

However, it remains an open issue why there are no group differences in simple task situations (i.e., single tasks and task repetitions). Our findings of similar single-task performance in different groups (i.e., video gamers vs. non-gamers) and after different types of practice (i.e., MoH, Tetris, and no-practice) are consistent with numerous other findings in the field of transfer effects on executive control skills after practice. In particular, our lab provided evidence for non-existent transfer effects to single-task situations but transfer effects to dual-task situations with novel component tasks (including novel stimuli and/or stimulus–response mappings; Liepelt et al., 2011; see also Bherer et al., 2005, 2008; Erickson et al., 2007; Kramer et al., 1995) after dual-task practice (with simultaneously presented tasks) compared to single-task practice (with separately presented tasks). Further, dual-task practice, single-task practice, and no-practice resulted in similar performance in single tasks but different performance in switching conditions of a task switching test very similar to the present test situation (Strobach et al., in press). Thus, findings of a lacking single-task performance difference after different types of practice are somehow established in the literature on executive control skills. Kramer et al. (1995) explained such a lacking effect with different levels of generalizability of different types of processes. While processes of stimulus–response mapping (a potential source of performance differences in single tasks) are specific for particular tasks, executive control skills can be general and transferable to other task situations. Since the specific component tasks in the present dual-task and the task switching tests were not presented during practice, there is no reason to assume performance differences in the processing level of stimulus–response mappings and, thus, in simple task situations.

Besides the theoretical impact of the present findings, the study suggests implications for practical applications. Practice regimes that efficiently optimize executive control skills and that are applied in action video games requiring the execution of different simultaneous activities may be of great interest for a wide community; in particular, because the related executive control skills are responsible for many changes in cognitive functioning, e.g. across the life-span (Green & Bavelier, 2008; Salthouse, Atkinson, & Berish, 2003) or due to disease-related impairments (Reichenberg & Harvey, 2007). Impaired control skills have been shown to be associated with declined planning abilities, e.g. in elderly subjects (West, 1996), patients with schizophrenia (Morris, Rushe, Woodruffe, & Murray, 1995), or with frontal lesions (Shallice & Burgess, 1991). Video game practice may therefore prove to provide a marked optimization of executive

control skills in individuals with a decline in these skills. Based on the present study (particularly Experiment 2), it remains unclear whether other action video games exist that may provide a marked optimization of MoH since we included only this training game. However, one may speculate that other games of this genre (i.e., action video games) including similar general characteristics like those of MoH may do so. Among others, these games should be fast-paced and should include the coordination of multiple game-related actions in situations with varying priority.

4.3. Summary

In sum, we provided evidence that action video game practice improves executive control skills in situations with two different choice RT tasks presented simultaneously or sequentially. We showed thus transfer effects of this type of practice to dual tasks and task switching tests. Additionally, we demonstrated the causal role of action video game practice and the improvement of executive control skills in these tests.

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