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The effect of action video game experience on task-switching

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ABSTRACT

There is now a substantial body of work demonstrating that action video game experience results in enhancements in a wide variety of perceptual skills. More recently, several groups have also demonstrated improvements in abilities that are more cognitive in nature, in particular, the ability to efficiently switch between tasks. We add to this body of work by demonstrating that the action video game player switch cost advantage generalizes to (1) vocal responses in addition to traditional manual responses, (2) tasks that are more cognitive rather than perceptual in nature, and (3) goal switches as well as motor switches. Finally, a training study establishes that the relationship between the reduction in switch cost and action game playing is causal.

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1. Introduction

Switching between tasks occurs regularly in day-to-day living, perhaps today more than ever, as improvements in technology allow increasingly more distinct tasks to be available on a single device. For instance, at any given time a computer user may be repeatedly switching between an email client, a web browser (with itself having many open tabs), a chat program, a calendar, a music player, and potentially many more programs that are all running and available simultaneously.

Carefully controlled laboratory studies have repeatedly demonstrated that such switching results in a direct decrement in behavioral performance (for reviews see: Allport & Wylie, 1999; Kiesel et al., 2010; Koch, Gade, Schuch, & Philipp, 2010; Monsell, 2003; Vandierendonck, Liefooghe, & Verbruggen, 2010). As an example, imagine an experiment where on every trial a digit (from 1 to 9) is presented alongside a letter (five vowels and five consonants). If, on a given trial, the stimulus background is blue, the subject is to indicate whether the digit is even or odd. Conversely, if the stimulus background is yellow, the subject is to indicate whether the letter is a vowel or a consonant. Reaction times are typically faster on a given task if the previous trial was the same task than if the previous trial was a different task, with the difference in reaction time between these two situations being referred to as the "switch

cost." Although the basic switch cost result (Jersild, 1927) has been replicated in tens, if not hundreds, of experiments, there has been, and continues to be, substantial debate regarding the mechanistic root of the cost, with some papers arguing that the costs reflect the time necessary for task-set reconfiguration (Logan & Gordon, 2001; Rogers & Monsell, 1995), others arguing the effects can be accounted for by proactive interference/task-set inertia (Allport, Styes, & Hsieh, 1994; Allport & Wylie, 1999), and others still arguing that neither alone best explains the data (Ruthruff, Remington, & Johnston, 2001; Sohn & Carlson, 2000). The purpose of the current paper is not to expound upon or clarify these issues, but is instead to contribute to a burgeoning literature examining the effects of playing a specific genre of video games, so-called "action" video games, on perceptuo-motor skills (for reviews see: Green, Li, & Bavelier, 2010; Hubert-Wallander, Green, & Bavelier, 2011; Spence & Feng, 2010). More specifically, the current paper examines the extent to which the ability to rapidly switch between tasks is modified by action gaming, an issue that has been the topic of several recent studies (Andrews & Murphy, 2006; Boot, Kramer, Simons, Fabiani, & Gratton, 2008; Colzato, van Leeuwen, van den Wildenberg, & Hommel, 2010; Karle, Watter, & Shedden, 2010).

In Experiment 1, the effect of output type (keyboard button press or vocal response) was assessed to test whether the task switch benefit in expert action video game players (AVGPs) is related to an enhanced ability to map/re-map response sets that utilize button presses, a common occurrence in action video games, or generalizes to other, unfamiliar responses such as vocal response. In Experiment 2, performance was compared in a paradigm in which the relevant

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stimuli are either more perceptual in nature (colors/shapes) or more cognitive in nature (digits odd/even; letters vowel/consonant) as recent work has demonstrated a reduced benefit in AVGPs in tasks that require retrieval and manipulation of internal representations (Anderson, Green, & Bavelier, submitted for publication). In Experiment 3, the effect of switching stimulus–response mappings, rather than task goal or task-relevant stimuli, was evaluated. Finally, in Experiment 4, the extent to which the reductions in switch cost are causally related to action video game experience was evaluated in a training study.

2. Literature review

There is now a substantial body of work demonstrating that action video game experience, but not necessarily experience with other game genres, results in enhancements in a wide variety of perceptual, visuo-spatial and perceptuo-motor skills (Donohue, Woldorff, & Mitroff, 2010; Green & Bavelier, 2003, 2007; Green, Pouget, & Bavelier, 2010; Spence, Yu, Feng, & Marshman, 2009; West, Stevens, Pun, & Pratt, 2008). Games in the action genre differ from those in alternative genres along several dimensions including the high velocity with which objects move, the presence of many objects that are only transiently visible (items that pop in and out of view), the degree of perceptual, cognitive, and motor load (the number of enemies to monitor at once, the number of possible actions, etc.), the amount of peripheral processing (items often first appear at the edges of the screen), and the level of spatial and temporal uncertainty (subjects cannot know exactly when or where objects will appear, thus requiring constant prediction and updating). The types of perceptual improvements noted as a result of playing this type of game range from low-level visual skills (e.g. contrast sensitivity – Li, Polat, Makous, & Bavelier, 2009), to aspects of spatial (Green & Bavelier, 2006a) and temporal visual attention (Li, Polat, Scalzo, & Bavelier, 2010), to "higher" functions such as mental rotation and multiple-object tracking (Feng, Spence, & Pratt, 2007; Green & Bavelier, 2006b)). Another commonly reported advantage conveyed by action video game experience is a speeding of reaction time (Bialystok, 2006; Castel, Pratt, & Drummond, 2005; Dye, Green, & Bavelier, 2009a; Hubert-Wallander, Green, Sugarman, & Bavelier, 2011). Dye and colleagues recently performed a meta-analysis of the action video game and reaction time literature (Dye, Green, & Bavelier, 2009b). Interestingly, not only was action game experience associated with faster reaction times, a clear linear relationship between the reaction time of AVGPs and non-action video game players (nAVGPs) across tasks and task conditions was observed, with AVGPs being around 10–12% faster than non-action gamers. This relationship held despite the fact that the tasks are seemingly quite disparate (e.g. visual search, N-back working memory, Go/Nogo, proactive interference, Posner cueing) and that the overall reaction times differed by nearly an order of magnitude (i.e. from tasks where mean RTs were very fast – around 200 ms – all the way to tasks where mean RTs were quite slow – around 2000 ms). Furthermore, well-controlled training studies have established a causal link between video game experience and the enhanced abilities, demonstrating that the results are not simply due to the possibility that people who play games have better perceptual skills than those who do not. This body of work has prompted the evaluation of action game training for practical applications such as the rehabilitation of adults with amblyopia (Li, Ngo, Nguyen, & Levi, 2011) or the training of surgeons (Schlickum, Hedman, Enochsson, Kjellin, & Fellander-Tsai, 2009).

Although the bulk of the action video game literature has focused on visual skills, several groups have examined what are thought of as more cognitive or executive functions and more specifically whether AVGPs have reductions in task switch cost as compared to nAVGPs. For example, Colzato and colleagues (Colzato et al., 2010) documented lower switch cost in AVGPs than nAVGPs on a predictable task switch paradigm in which subjects switched every four trials between local and global perceptual judgments of Navon-type hierarchical shapes. Boot et al. (2008) also observed a smaller switch cost in AVGPS in a task in which subjects had to classify a digit as either greater/less than 5 or odd/even, with the current task being indicated by the background color of the digit. Andrews and Murphy (2006) observed a smaller switch cost in AVGPs than nAVGPs on a predictable switching paradigm. However, the effect was only significant when the response–stimulus interval (the duration between the participant's response and the onset of the following trial) was very short (150 ms); at longer response–stimulus intervals (600 and 1200 ms), differences in switch costs between groups fell shy of significance. Finally, Karle and colleagues (2010) tested task-switching abilities in AVGPs using two different paradigms. In the first paradigm the tasks were simple. Subjects viewed a single stimulus (A, B, C, 1, 2, or 3) and had a single response key for each stimulus. Each hand was paired with either letter or number stimuli. Each trial began with a cue that preceded the stimulus by 100 or 1000 ms. The cue could be informative as to the task set for the next trial or uninformative. Overall, they found a marginally lower switch cost in AVGPs. The AVGP group had a smaller switch cost than nAVGPs only for trials with informative cues and longer cue-to-stimulus intervals. In a second experiment, the paradigm required far more complex cognitive control processes for task switching. Subjects viewed a single digit (2, 3, 4, 6, 7, or 9) and had to perform one of three tasks as determined by a visually presented verbal cue – odd/even, prime/multiple, or less/more than 5. Additionally, stimulus–response mappings included a finger on each hand for every task, therefore preventing subjects from being able to associate a given task with a single hand. With these added complexities, no differences in switch cost between groups were observed, although shorter RTs overall were observed in AVGPs.

3. Experiment 1

The goal of Experiment 1 was to determine whether the reductions in switch-cost noted in AVGPs are dependent on a keyboard button press method of response. Indeed, one key part of the "task-set" is the mapping from stimulus to response and thus, if it is this ability that is the root of the benefit in AVGPs, one would predict that in an otherwise exactly equivalent task utilizing a vocal method of response (which does not require such a remapping and is also not part of standard action gaming activity), no such enhancements should be noted.

3.1. Participants

Eighteen males with normal or corrected-to-normal vision were placed into one of two groups, AVGP or nAVGP, based on their responses to a questionnaire administered prior to the experiment. Only males were tested due to the scarcity of females with sufficient action video game experience.

The criterion to be considered an AVGP was a minimum of 5 h per week of action video game usage over the previous 6 months. Eight males with a mean age of 18.7 years fell into this category. An abridged list of the games reported as played includes Halo 2 (Microsoft Game Studios, Redmond, WA), Unreal Tournament 2004 (Atari, New York, NY), and Grand Theft Auto III (Rockstar North, Edinburgh, Scotland, UK).

The criteria to be considered a nAVGP were little, and preferably no, action video game usage over the previous 6 months and minimal usage of sports or fighting games was preferable. Usage of

strategy games such as The Sims (Electronic Arts, Inc, Redwood City, CA) or World of Warcraft (Blizzard Entertainment, Irvine, CA) did not disqualify a subject from being considered a nAVGP. Ten males with a mean age of 19.9 years fell into this category. All 10 reported no action video game usage in the past 6 months and little to no video game experience of any type.

Written informed consent was obtained, and each participant was paid $8 for each hour of participation.

3.2. Procedure

Subjects viewed a display on a 51 cm monitor. The procedure was qualitatively similar to Experiment 1 in Monsell, Sumner, and Waters (2003) and is illustrated in Fig. 1. Eight evenly spaced radii of a circle were continuously displayed on the monitor. The horizontal line was thicker than the vertical and diagonal lines. At the onset of each trial, a colored object appeared between two of the radii (i.e., in a "piece of the pie"). The object could be a circle or a square, and the color could be blue or red. If the object appeared below the horizontal line, the subject was instructed to indicate the color. If the object appeared above the horizontal line, the subject was instructed to indicate the shape. The object remained on the screen until the subject made a response. The subject was instructed to respond as quickly and accurately as possible. One second after the response, another colored object would appear, always in the next location counterclockwise from the previous object (note: this somewhat long response stimulus interval – RSI – was required to ensure that all vocal responses could be captured, processed, and a consistent RSI applied). Therefore, the subject was always aware of the location of the shape on the next trial, and whether that trial would be a "shape" or a "color" trial. The task changed predictably every four trials (and the spatial layout ensured that subjects did not need to mentally keep track of where they were in a sequence to know when a switch was occurring – an ability that may differ between AVGPs and nAVGPs); these trials will henceforth be called "switch trials." The three trials following these trials will be referred to as "non-switch trials."

Two types of response methods were employed in separate blocks. The first was a standard keyboard response. On color trials, subjects used the middle and index fingers of their left hand to indicate red and blue, respectively. On shape trials, they used the index and middle fingers of their right hands to indicate circle and square, respectively. Each possible response was therefore mapped to a separate motor response, and each task set was linked to a single hand. The second response method was vocal. Subjects were instructed to speak the answer clearly into a microphone placed in front of them. In both cases, subjects were asked to respond as quickly and accurately as possible. All subjects completed two blocks of keyboard response trials and two blocks of vocal responses in an interleaved fashion. The order was counterbalanced so that half of the subjects in each group completed the keyboard responses first and the other half completed the vocal responses first (i.e. either Keyboard/Vocal/Keyboard/Vocal or Vocal/Keyboard/Vocal/Keyboard). Each block consisted of 320 trials for a total of 1280 trials.

3.3. Results

Accuracy data for all trials were entered into a 2 (group: AVGP/nAVGP) $\times$ 2 (response type: manual/vocal) $\times$ 2 (trial type: switch/non-switch) ANOVA. A strong main effect of trial type was observed ($F(1,16) = 46.28$, $p < .001$, $\eta_p^2 = .743$), with lower accuracy on switch trials (Mean ± SEM: switch: .91 ± .010; non-switch: .96 ± .005). No main effect of response type was observed (manual: .94 ± .008; vocal: .93 ± .009; $p > .261$). However, a significant interaction between response type and trial type ($F(1,16) = 8.72$, $p = .009$, $\eta_p^2 = .353$) indicated a greater reduction in accuracy on switch trials in the vocal than the manual response condition (manual: switch: .93 ± .010, non-switch: .96 ± .006; vocal: switch: .89 ± .015, non-switch: .97 ± .005).

No main effect of group was observed (AVGP: .93 ± .015; nAVGP: .94 ± .007; $p > .8$), however, the interaction between group and response approached significance ($F(1,16) = 4.35$, $p = .053$, $\eta_p^2 = .214$). The AVGP group had similar accuracies across both response types (manual: .93 ± .016; vocal: .94 ± .015), but the nAVGP group was more accurate for manual than vocal responses (manual: .95 ± .007; vocal: .92 ± .011). The three-way interaction between group, response, and trial type was not significant ($p > .25$).

Reaction time analyses were conducted on median RTs in each condition in a similar manner to Experiment 1 in Monsell et al. (2003). Before analysis, both error trials and trials immediately following an error were removed. Trials with unclear or multiple vocal responses were also removed, as well as the trials that immediately followed them. Lastly, trials with response times less than 150 or greater than 2000 ms were removed. Overall, these trials represented 9.8% of all trials. RT distributions for each subject
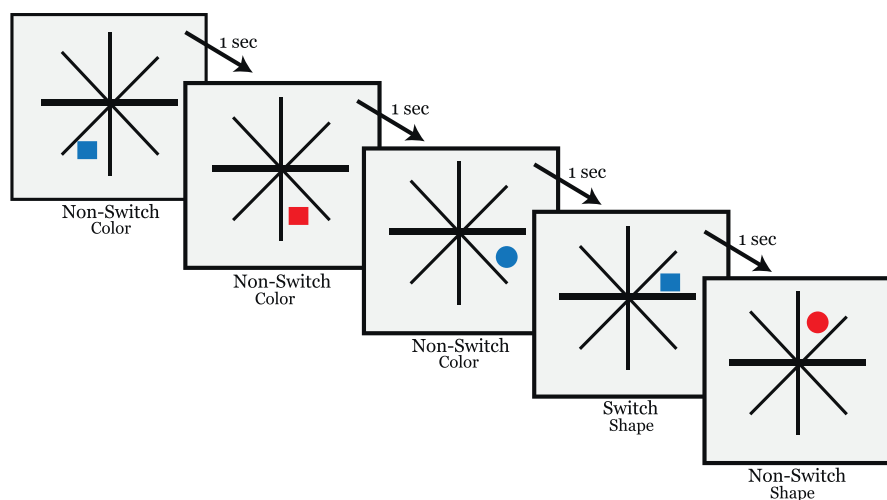

Fig. 1. Illustration of the paradigm used in Experiment 1. On each trial the stimulus would appear in the location counterclockwise from that on the previous trial. The task changed every time the stimulus crossed the horizontal line. The correct responses for the trials shown are "blue, red, blue, square, circle." (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

were examined and there were no outliers in this study (i.e., no subjects with RTs above or below 2 std from the mean of their group).

RT data were entered into a 2 (group) × 2 (response) × 2 (trial type) ANOVA. A strong main effect of trial type was observed ($F(1,16) = 59.33$, $p = .001$, $h_p^2 = .788$), with switch trials having much longer reaction times than non-switch trials (Mean ± SEM: switch: 496 ± 32 ms; non-switch: 381 ± 15 ms). A main effect of response was observed ($F(1,16) = 4.93$, $p = .041$, $\eta_p^2 = .235$), with longer RTs being observed for manual than vocal responses (Manual: 457 ± 24 ms, Vocal: 421 ± 24 ms). An interaction between response and trial type ($F(1,16) = 15.83$, $p = .001$, $\eta_p^2 = .497$) revealed a smaller switch cost for vocal trials (manual switch cost: 161 ± 31 ms; vocal switch cost: 68 ± 13 ms).

As predicted, a main effect of group was observed ($F(1,16) = 33.22$, $p < .001$, $\eta_p^2 = .675$) with AVGPs having shorter reaction times than nAVGPs (AVGP: 353 ± 15 ms; nAVGP: 507 ± 21 ms). Importantly, a significant interaction between group and trial type was observed ($F(1,16) = 18.43$, $p = .001$, $\eta_p^2 = .535$), indicating a smaller switch cost for AVGPs (Fig. 2). No interaction was observed between group and response ($F(1,16) = 0.17$, $p = .685$, $\eta_p^2 = .011$), however, the three-way interaction between group, response, and trial type was significant ($F(1,16) = 7.78$, $p = .013$, $\eta_p^2 = .327$), due to a larger switch cost for manual responses in the nAVGP group. Importantly, when each response method was analyzed separately, the AVGP group had a lower switch cost for both modalities (manual: $F(1,16) = 16.10$, $p = .001$, $\eta_p^2 = .502$; vocal: $F(1,16) = 7.61$, $p = .014$, $\eta_p^2 = .322$) confirming smaller switch-costs in AVGPs in each response mode.

Although the switch cost is lower in AVGPs than nAVGPs, both as demonstrated by the significant interaction term, as well as a *t*-test directly on switch-costs ($t(1,16) = 4.29$, $p < .001$, Cohen's $d = 2.16$), there is a potential confound in that differences in switch cost could be due to the overall increased speed of processing and shorter RTs that have been well-documented in AVGPs (Dye et al., 2009b) and are again present in this study. In other words, rather than reflecting differences in executive control and task-switch between the two populations, this difference may be the result of equivalent switch costs riding over different baseline RTs. Indeed, an RT difference of 200 ms derived from subtracting RTs from two different conditions that are respectively 1,000 ms and 800 ms is unlikely to have the same significance as the same RT difference derived from comparing baseline RTs of 500 ms and 300 ms. Because the switch cost is computed as the difference between switch and non-switch trials, we would always expect smaller switch costs in populations that have shorter RTs, as is the case in AVGPs. To address this issue, the switch cost was also analyzed as the percent increase in RT from non-switch to switch trials. This
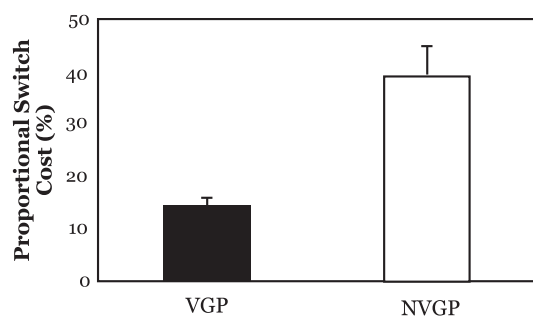

Fig. 3. Proportional switch cost: After correcting for baseline differences in speed of response, AVGPs still demonstrated an enhancement in switching ability. *Error bars represent the standard error of the mean.

"proportional switch cost" is shown in Fig. 3. Although this measure reduces the differences between groups, the cost is still lower in the AVGP group ($t(1,16) = 3.85$, $p < .001$ Cohen's $d = 1.94$).

3.4. Discussion

Consistent with previous research (Andrews & Murphy, 2006; Boot et al., 2008; Colzato et al., 2010; Karle et al., 2010), a smaller switch cost was noted in AVGPs. Furthermore, beyond this basic fact, the results demonstrate that the increased ability to switch was not restricted to the manual response mode that is likely highly over-trained in AVGPs, but also generalized to vocal responses, which are not part of the typical game activities. The strong positive correlation across all subjects between manual and vocal response switch costs ($r = .59$) is also consistent with the idea that these tasks are tapping a similar underlying mechanism. Finally, by examining the proportional switch cost, we demonstrated that the reduced switch cost in AVGPs cannot be attributed solely to an overall speeding of RTs. Also consistent with the larger body of research on reaction times in AVGPs is the finding of equivalent accuracy in the two groups, which indicates that the shorter RTs observed in AVGPs cannot be attributed to a "speed-accuracy trade-off."

In Experiment 2 we ask whether the advantage noted in the perceptual task in Experiment 1 is similar in magnitude to that in a more cognitive task. Furthermore, although in Experiment 1 the groups had statistically indistinguishable accuracies, it may nevertheless be the case that an emphasis on speed may place the groups in a regime that unduly favors the AVGPs (who are likely to be more accustomed to operating under severe time pressure). Thus, in Experiment 2 the instructions were altered slightly to emphasize accuracy over speed of response.
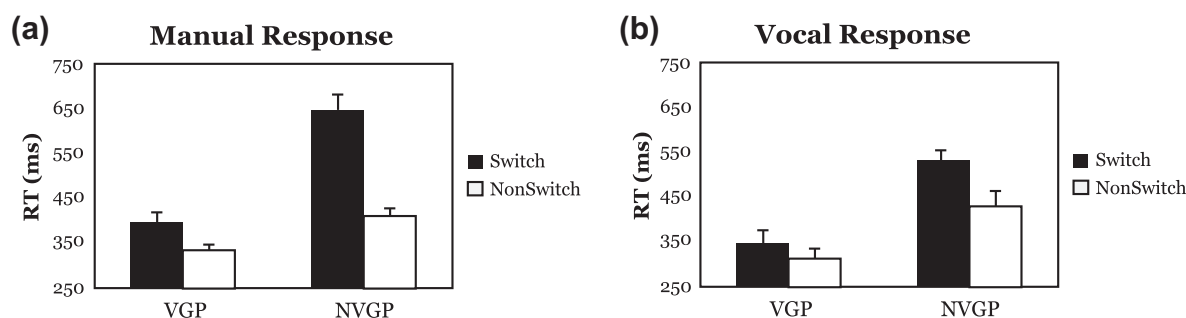

Fig. 2. Reaction times as a function of switch status plotted by gamer status. (a) Manual responses, (b) vocal responses. AVGPs show a clear speed advantage over nAVGPs in all conditions. Critically, the difference between switch and non-switch trials is also reduced in AVGPs, indicating an enhancement in switching ability. *Error bars represent the standard error of the mean.

4. Experiment 2

Experiment 2 was closely modeled after Experiment 1, repeating the manual response mode with colored objects, and extending the basic setup to a cognitive task using digits between 1 and 9 (with the exclusion of 5). On these cognitive blocks, participants were instructed to indicate whether the digit was less than or greater than 5 when presented in the lower visual field, and whether it was odd or even when presented in the upper visual field. We asked whether the previously established smaller switch cost displayed by AVGP in a perceptual task would be of a similar magnitude in a cognitive task. Recent research (Anderson et al., submitted for publication) has suggested that the enhancements noted in AVGPs in tasks that primarily demand reacting to external features of objects may be reduced, or eliminated altogether, in tasks that require accessing and manipulating internal representations.

4.1. Participants

Twenty-eight males with normal or corrected-to-normal vision, none of whom participated in Experiment 1, were classified as AVGPs or nAVGPs based on criteria similar to that used above, with two pertinent alterations. First, the timeframe of previous play on the main questionnaire was extended to the past year, rather than the previous 6 months. Second, an additional questionnaire was administered asking about all game usage further back than the previous 1 year. Again, no females were tested due to the scarcity of females qualifying as part of the AVGP group.

All participants classified as AVGPs reported a minimum of 5 h of first person shooter playing time per week during the previous year, except for one subject who reported three to 5 h in the past 9 months, but was included due to extensive play (ten or more hours a week) reported over the previous 3 years. Fourteen males with a mean age of 20.6 years old qualified as AVGPs. A truncated list of the games reported includes Halo 2 (Microsoft Game Studios, Redmond, WA), Unreal Tournament 2004 (Atari, New York, NY), Call of Duty (Activision Publishing, Santa Monica, CA) and Grand Theft Auto III (Rockstar North, Edinburgh, Scotland, UK).

To be considered as a nAVGP, participants had to report minimal to no action video game usage over the previous year and little use of sports or fighting games. In addition, they had to report minimal action video game play prior to the previous 1 year. All participants reported not playing action games within the past 12 months, with the exception of one subject who reported less than 1 h per week of first-person shooting.

4.2. Procedure

Subjects viewed a display on a 51 cm monitor. The perceptual task was run under the same procedure as Experiment 1, while the cognitive task was qualitatively similar and is illustrated in Fig. 4. For the cognitive task, at the onset of each trial, a number between 1 and 9 (with the exclusion of 5) appeared between two of the radii. When the number appeared below the horizontal line, the subject was instructed to indicate if the number was less than or greater than 5. When the number appeared above the horizontal, the subject was directed to indicate if the number was odd or even. All subjects were directed to give accurate responses, and then to do so as quickly as possible. It was predicted that this slight change in instruction would lead to increased accuracy, particularly for switch trials. The number remained on the screen until a subject made a response, which was followed by a one second pause before the next number appeared in the next location counterclockwise from the previous number. In the perceptual task, as in Experiment 1, subjects indicated the color (red or blue) of the

object in the lower visual field, and in the upper visual field indicated the shape (square or circle). The order was counterbalanced so that half of the subjects in each group completed the cognitive task first and the other half completed the perceptual task first.

A standard keyboard response method was used for both the perceptual and cognitive task. Participants responded to stimuli in the lower visual field with their middle and index fingers on their left hand, and for stimuli in the upper visual field, they used the middle and index fingers on their right hand.

Before the experimental blocks began, participants were run on a practice block that consisted of 128 trials. There was no auditory feedback to indicate if the response was correct in either the practice or experimental block, but the experimenter watched the practice trials to ensure subjects understood the directions and were performing the task accurately. The experimental blocks consisted of 320 trials for each of the task types, cognitive and perceptual. Subjects were run on both tasks, with a distracting task in between that lasted approximately 30 min to prevent any effects due to carry-over between tasks. The order of the tasks was randomized between subjects and was comparable across groups (AVGPs, nAVGPs).

4.3. Results

Reaction time analysis followed the same exclusion criteria as in Experiment 1. Overall, these trials represented 9.4% of all perceptual trials and 10.3% of all cognitive trials. Median RT values were computed for each condition within each subject. Four subjects, two from both the nAVGP and AVGP group, fell far outside of two standard deviations of the group mean for either accuracy or RT and were removed from both tasks, leaving 12 subjects in each group for the analyses.

Accuracy data for all trials were entered into a 2 (group: AVGP/nAVGP) $\times$ 2 (condition: cognitive, perceptual) $\times$ 2 (trial type: switch, non-switch) ANOVA. There was a significant main effect of trial type ($F(1,22) = 15.81$, $p = 0.001$, $\eta_p^2 = 0.418$) with lower accuracy on switch trials (Mean ± SEM: switch: 0.94 ± 0.005, non-switch: 0.96 ± 0.002). There was neither a main effect of accuracy between groups (AVGP: 0.95 ± 0.006, nAVGP: 0.96 ± 0.005) nor an interaction between group and trial type (AVGP: switch: 0.94 ± 0.008, non-switch: 0.96 ± 0.004, nAVGP: switch: 0.95 ± 0.007, non-switch: 0.96 ± 0.003). Importantly, accuracy was higher in Experiment 2 than Experiment 1, particularly for the switch trials (91% in Experiment 1 versus 94% in Experiment 2), suggesting that the slight change in instruction did indeed bias subjects toward accuracy. No main effect of condition was observed (perceptual: 0.95 ± 0.005, cognitive: 0.952 ± 0.004), nor was a condition $\times$ group interaction. There was no significant interaction between group, condition, and trial type (all $ps > .1$).

Reaction time data were entered into a 2 (group) $\times$ 2 (condition) $\times$ 2 (trial type) ANOVA. There was an overall main effect of group on reaction time ($F(1,22) = 9.75$, $p = 0.005$, $\eta^2 = 0.307$), with AVGPs having faster reaction times than nAVGPs (Fig. 5). No significant effects were observed for condition or for the two-way interactions between condition and group or condition and trial type. There was a sizeable main effect of trial type ($F(1,22) = 88.44$, $p < 0.001$, $\eta_p^2 = 0.801$) with switch trials having notably slower reaction times than non-switch trials (Mean ± SEM: switch: 760 ± 28 ms, non-switch: 559 ± 14 ms). Importantly, there was a significant effect between trial type and group ($F(1,22) = 7.67$, $p = 0.011$, $\eta_p^2 = 0.258$), indicating smaller switch costs in AVGPs than nAVGPs (AVGP: 161 ± 28 ms, nAVGP: 294 ± 29 ms). As in Experiment 1, this finding was confirmed by a post hoc t-test on switch costs ($t(1,22) = 2.771$, $p = 0.011$, Cohen's $d = 1.182$) and again the sizes of the switch costs in individual subjects were strongly positively correlated between the two tasks ($r = 0.61$).
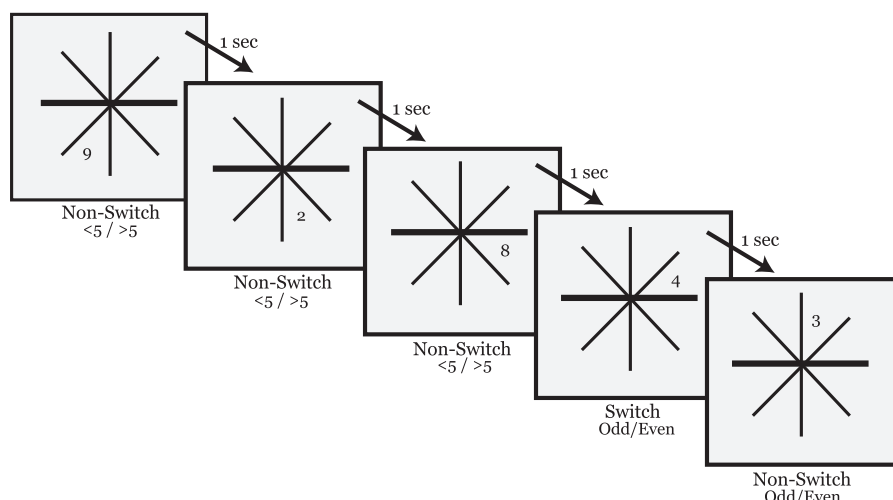
Fig. 4. Illustration of the cognitive paradigm used in Experiment 2. Each stimulus appears 1 s after response, in a counterclockwise location from the previous trial. The task changed every time the stimulus crossed the horizontal line. The correct responses for the trials shown are "greater than 5, less than 5, greater than 5, even, odd."
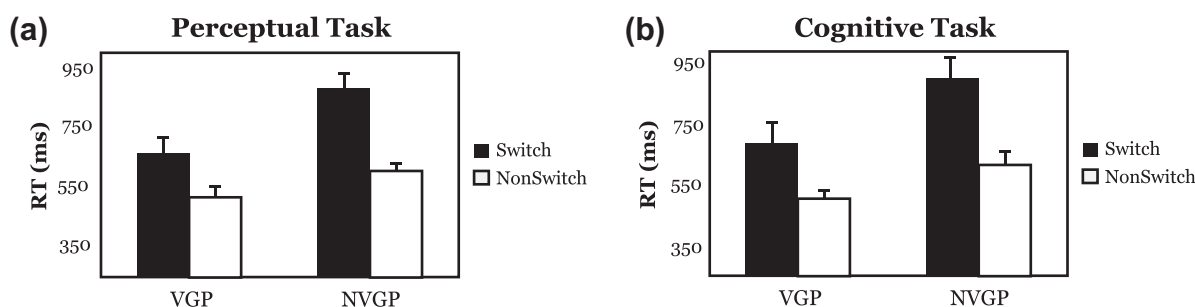

Fig. 5. Reaction times for each trial type plotted by AVGPs and nAVGPs. (a) RT values in perceptual task. (b) RT values in cognitive task. AVGPs show a clear speed advantage over nAVGPs in all conditions. Critically, the difference between switch and non-switch trials is also reduced in AVGPs, indicating an enhancement in switching ability. *Error bars represent the standard error of the mean.

There was no significant three-way interaction between group, condition, and trial type ($p = 0.79$).

As in Experiment 1, proportional switch costs were computed and analyzed to determine if the switch cost reduction can be accounted for by baseline RT differences between AVGPs and nAVGPs. Again, this "proportional switch cost," was significantly smaller in the AVGP group ($t(1, 22) = 2.350$, $p = 0.028$, Cohen's $d = 1.002$).

4.4. Discussion

Experiment 2 asked whether the size of the switch cost reduction seen in AVGPs was dependent on the nature of the task – perceptual or cognitive. Although there is recent work suggesting that the advantage seen in AVGPs in many tasks requiring a response based on an external stimulus is reduced in tasks that require access to internal representations (Anderson et al., submitted for publication), in Experiment 2 the size of the switch cost reduction was equivalent in both tasks.

As in Experiment 1, the magnitudes of the switch costs were correlated across subjects, which is consistent with the expected findings given a common bottleneck in both paradigms that is partially reduced in AVGPs. In addition, not only did the two groups perform the task at equivalent levels of accuracy, they did so with greater accuracy than in Experiment 1, suggesting that the switch-cost advantage seen in Experiment 1 was not due exclusively to performing a task in a speed-emphasis context.

In Experiment 3 we revisit the role of response mappings. Although Experiment 1 demonstrated that the AVGP switch-cost advantage is not solely a function of an ability to map responses onto arbitrary key presses, this finding does necessarily imply that this ability is not enhanced in AVGPs. Thus, in Experiment 3, we asked whether the AVGP advantage would be magnified in a condition in which the only switch was in stimulus–response mapping, rather than task goal or task-relevant stimuli.

5. Experiment 3

The "task-set" is commonly thought to encompass at least four components: the overall goal (e.g. attend to color or shape), the relevant dimensions (e.g. blue and red), the possible responses (e.g. the relevant keys), and the mapping from a conceptual "answer" to a physical response (e.g. the "m" key = blue, the "n" key = red). While task-switching studies typically call for a change in the overall goal, it is possible to keep goals, relevant dimensions, and possible responses fixed and only vary the mapping between the conceptual answer and the physical response – termed hereafter 'motor switch'. If AVGPs benefit exclusively from swifter motor switches, we should find greater group differences in a task that manipulates only motor switches than in a task that varies the overall goal but keeps the mapping from conceptual answer to physical responses fixed throughout the experiment.

5.1. Participants

Thirty-two males with normal or corrected-to-normal vision were classified as either AVGPs or nAVGPs based on criteria similar to that used in Experiment 2. Those who did not meet either cate-

gory's game play requirements (four subjects) were excluded. Two additional subjects (one from each group) were also removed as being clear outliers (RTs far greater than 2 SD beyond the group means). As before, the scarcity of females qualifying as part of the AVGP group prevented females from being tested in this experiment.

All participants classified as AVGPs reported a minimum of 5 h per week of action video game playing time throughout the previous year, except for three subjects who reported three to 5 h in the past 12 months, but were included due to extensive habitual play (ten or more hours a week) reported for the previous few years. Twelve males qualified as AVGPs, with a mean age of 20.4 years old. A list of common games reported includes, but is not limited to, Halo 2 (Microsoft Game Studios, Redmond, WA), Unreal Tournament 2004 (Atari, New York, NY), Call of Duty (Activision Publishing, Santa Monica, CA) and Grand Theft Auto III (Rockstar North, Edinburgh, Scotland, UK).

Fourteen males with a mean age of 19.93 years old qualified as part of the nAVGP group. All participants reported not playing any action game within the past 12 months, and all reported minimal experience with action games in previous years.

5.2. Procedure

Subjects viewed stimuli at a distance of 60 cm from the screen. Both the cognitive and motor remapping paradigms had identical stimuli, with the differences arising from task and response methods (see Fig. 6). In both conditions, a number between 1 and 9 (with the exclusion of 5; Courier New Bold, font size 96) was displayed within a gray circle against a colored background at the onset of each trial. The color of the area surrounding the circle was either blue or yellow, and indicated which task the subject was to perform.

For the cognitive task, the subject was to answer if the number was odd or even for one of the background colors, and whether it was less than five or greater than five for the other background color. The association between background color and task was counterbalanced between subjects. Subjects used one of two keys to respond, one for their left index finger and one for their right index finger. The significance of the key response changed with the background color. For example, the left index finger meant "less than 5" when the background was blue, but was the response for "odd" when the background was yellow. In this version, the switch in color background indicates a switch in cognitive task between less/greater than to odd/even, and vice versa. The mapping of a given response to a key was kept constant throughout.

For the motor stimulus–response switch task, subjects always answered whether the number was odd or even. However, they were instructed to use different hands depending on the background color of the screen. For instance, their middle and index fingers on their left hand were used to respond when the color was blue, and the right middle and index fingers when the background color was yellow. In this version, the switch in color background indicates a switch in motor mapping uniquely, but no change in the task goal or relevant stimuli.

All subjects were directed to respond as quickly and as accurately as possible. The number remained on the screen until the subject made a response. The stimuli were pseudorandomized so that subjects were not able to predict upcoming changes. Each stimulus display was immediately followed by the next display upon the subject's response. All key-response mappings were counterbalanced for color coding and hand mapping. In the cognitive task, half of the subjects in each group were tested with "odd/even" being associated with blue, and the other half were tested with it being cued by yellow to account for any color preference influence on response times. Likewise, in the motor task, half of the AVGPs and nAVGPs were tested with the left hand responses being cued by a blue background, and the other half had their left hands cued by yellow. Also, the order of task, cognitive or motor, was counterbalanced in a similar fashion so that half of the subjects in each group completed the cognitive task first, and half performed the motor task.

Before beginning the experimental blocks, participants completed a practice block of 40 trials. There was no auditory feedback to indicate if the response was correct in either the practice or experimental block, but the experimenter watched the practice trials to ensure subjects understood the directions and were performing the task accurately. There were two experimental blocks per task type, cognitive and motor, each consisted of 170 trials. Subjects completed both tasks, with an irrelevant task in between that lasted approximately 30 min to prevent any effects due to carryover between tasks.

5.3. Results

Accuracy data for all trials were entered into a 2 (group: AVGP/nAVGP) × 2 (switch status: switch/non-switch) × 2 (condition: cognitive/motor) ANOVA. A strong main effect of switch status was observed ($F(1,24) = 38.15$, $p < .001$, $\eta^2 = .614$), with lower accuracy on switch trials (Mean ± SEM: switch: $.94 \pm .012$; non-switch: $.97 \pm .008$). A main effect of condition was observed indicating lesser accuracy on the motor switch task (cognitive: $.96 \pm .007$; motor: $.95 \pm .007$; $F(1,24) = 5.173$, $p = .032$, $\eta^2 = .177$). Likewise, there was a significant interaction between switch status and condition ($F(1,24 = 8.384$, $p = .008$, $\eta^2 = .259$), indicating a greater switch cost for motor than cognitive responses (cognitive: switch: $.95 \pm .012$, non-switch: $.96 \pm .008$; motor: switch: $.92 \pm .017$, non-switch: $.96 \pm .010$).

No main effect of group was observed (AVGP: $.946 \pm .011$; nAVGP: $.955 \pm .009$; $F(1,24) = .891$, $p = .355$, $\eta^2 = .036$). Interactions between group and switch status, condition and group and the three-
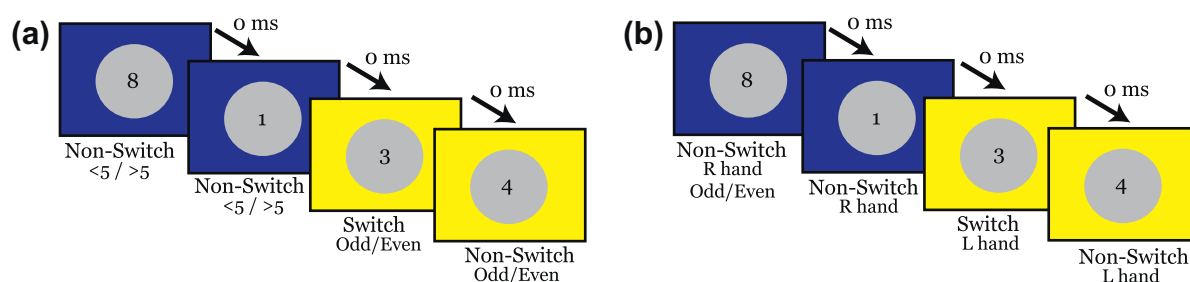

Fig. 6. Illustration of both paradigms used in Experiment 3. (a) Cognitive task: correct responses for the trials shown are - greater than 5, less than 5, odd, even." (b) Stimulus–response motor remapping task: correct responses for the trials shown are - right hand, even; right hand – odd; left hand – odd; left hand – even.

way interaction between group, switch status, and condition were all non-significant (all *p* values were greater than 0.05).

Reaction times were analyzed in a manner analogous to Experiments 1 and 2 (13.5% of trials removed).

Median RT data were entered into a 2 (group) × 2 (switch status) × 2 (condition) ANOVA. A strong main effect of switch status was observed ($F(1,24) = 188.1$, $p < .001$, $\eta^2 = .887$) with longer reaction times in switch trials than non-switch trials (Mean ± SEM: switch: $1073 ± 57$ ms; non-switch: $658 ± 24$ ms). Also, a strong main effect of condition was observed ($F(1,24) = 20.662$, $p < .001$, $\eta^2 = .463$), with longer RTs for cognitive than motor switches (cognitive: $897 ± 36$ ms, motor: $834 ± 32$ ms).

A main effect of group was observed ($F(1,24) = 11.73$, $p = .002$, $\eta^2 = .328$) with AVGPs having significantly faster RTs than nAVGPs (AVGP: $776 ± 34$ ms; nAVGP: $955 ± 47$ ms). Importantly, an interaction between group and switch status was observed ($F(1,24) = 8.089$, $p = .009$, $\eta^2 = .252$), indicating a smaller switch cost for AVGPs (Fig. 7), which was confirmed by subsequent *t*-tests (cognitive task: $t(1,24) = 3.026$, $p = .006$); motor task: $t(1,24) = .2.407$, $p = .024$). As in Experiments 1 and 2, the size of the switch cost was well correlated between tasks ($r = .7$). No interaction effect was observed between group and condition ($F(1,24) = 1.085$, $p = .308$, $\eta^2 = .043$).

As in Experiments 1 and 2, proportional switch costs were computed and analyzed to determine if the switch cost reduction can be accounted for by baseline RT differences between AVGPs and nAVGPs. As in Experiment 1, this "proportional switch cost," was significantly smaller in the AVGP group ($F(1,24) = 4.2$, $p = 0.05$).

5.4. Discussion

The results are consistent with those of Experiments 1 and 2, with smaller switch costs being observed in AVGPs than nAVGPs. The fact that the size of the advantage was similar in both the cognitive and motor remapping versions suggests that there is no disproportionate AVGP advantage in the ability to swiftly remap stimuli to associated responses. Furthermore, unlike in Experiments 1 and 2, the switches in Experiment 3 were unpredictable. The finding of an AVGP advantage in such an unpredictable task switch task is consistent with the results of Boot et al. (2008). Finally, unlike Experiments 1 and 2, Experiment 3 used an extremely short RSI (0 ms), demonstrating that switch cost benefits in AVGP are not restricted to either long or short RSIs.

While Experiments 1, 2, and 3 establish the generality of a smaller switch-cost in switch paradigms in avid action video game players, the relationship between gaming and improved switch cost is only correlational. There is no direct evidence in the literature that regular action video game usage causes the observed differences in switch cost. To address this issue, we conducted a training study attempting to reduce the switch cost through the usage of action video games.

6. Experiment 4

Experiments 1, 2, and 3 revealed significant differences in switch cost between AVGPs and nAVGPs. If better task switching in AVGPs is truly the result of playing action video games, one should be able to reduce the switch cost by asking nAVGPs to play action video games. In a previous training study, Boot et al. (2008) pre-tested nAVGPs on their version of the task-switch paradigm, trained the subjects for 10 h on either an action game or a control game, did an intermediate second test, trained for another 10 h, and finally did a post-test. In this design, they failed to find a significant effect of game training (i.e., the action-trained subjects did not improve more than the subjects trained on a control game). In an attempt to maximize the potential to find a significant effect, we performed a slightly modified version of this training. First, we trained for a significantly longer duration (50 h), as the 20 h utilized by Boot et al. (2008) represents less than an average month of playing time for an AVGP. Second, we limited our testing to pre-and post-tests, as repeatedly testing individuals on the same task greatly increases the probability of task-specific learning. In other words, there is no better way to improve on a task than directly training on that very task. When the focus is on whether an alternative training task can improve performance, it is thus preferable to keep testing sessions both short and to a minimum. In Experiment 4, subjects were pre-tested on a similar version of the task as in Experiment 1 (keyboard response condition only). The subjects were then randomly assigned to one of two groups. The "Action" group was asked to play fast-paced action video games similar to those played by our AVGPs. The "Control" group was asked to play slower paced, commercially available games with less demand on distributed attention and the dynamic reallocation of resources. Participants came to the laboratory to play their assigned video games. A few days after the end of their training, both groups came back to the laboratory for a post-test on the same task-switching task that they had experienced in the pre-test. If the effect of action video game playing on task switching is truly causal, those individuals trained on action games should show a greater reduction in switch cost than those trained on the control game. Such an outcome would unambiguously establish that action game play reduces switch cost and therefore enhances executive control.

6.1. Participants

Thirty-six subjects were randomly assigned to one of two groups, Action ($N = 19$) or Control ($N = 17$). One subject was removed as an outlier, as his reaction times fell more than two standard deviations from the mean on a battery of pre-tests including the task switch experiment described here. This left us with eighteen individuals (seven males, mean age: $25.7 ± 0.9$ years) assigned to the Action group and seventeen individuals (four males, mean
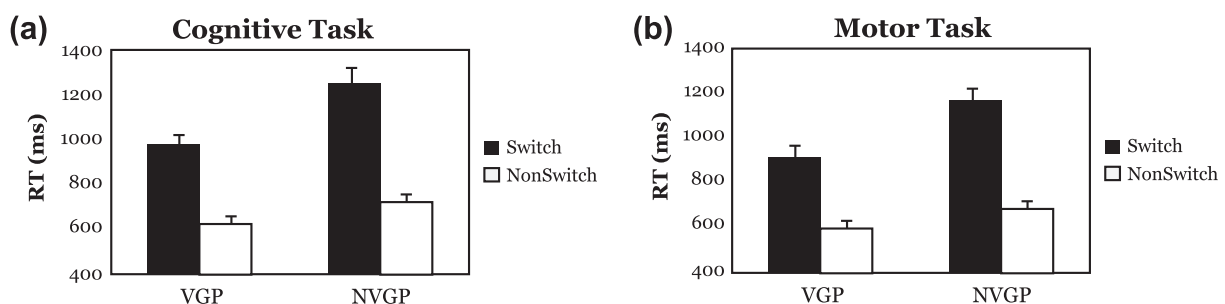

Fig. 7. RT values in Experiment 3 for switch status, plotted by group (gamer status). (a) Cognitive task, (b) motor task. AVGPs show a clear speed advantage over nAVGPs in all conditions. Critically, the difference between switch and non-switch trials is also reduced in AVGPs, indicating an enhancement in switching ability. *Error bars represent the standard error of the mean.

age: 24.7 ± 0.6 years) assigned to the Control group. All subjects had reported no prior experience with video games of any type.

6.2. Procedure

The experimental procedure was almost identical to that of Experiment 1, with the exception that only manual responses were utilized in this experiment.

Subjects completed two experimental blocks of 320 trials for a total of 640 trials for a baseline measurement (the "pre-training" test) as well as several other tasks unrelated to the current paper (e.g. motion discrimination, visual search, contrast detection -however note: the data presented here was acquired over the course of 3 separate training studies – and thus the unrelated tasks are not identical in all subjects). All subjects then played 50 h of video games over the course of the next several weeks (average length: 8.5 weeks, range 6–14 weeks). This period was the "Training" phase of the experiment. Subjects in the Action group played exclusively action games (Unreal Tournament 2004 and Call of Duty 2, Activision, Santa Monica, CA), and subjects in the Control group played exclusively strategy games (The Sims 2 and The Sims 2: Open for Business, both Electronic Arts, Redwood City, CA). A few days after completing their training, subjects completed two more experimental blocks of 320 trials each (the "Post-Training" test).

6.3. Results

Reaction time and accuracy data were treated in the same way as in Experiment 1 (7.61% of all trials were removed prior to RT analyses).

Accuracy data for all trials were entered into a 2 (group: action/control) $\times$ 2 (test: pre/post) $\times$ 2 (trial type: switch/non-switch) ANOVA. The only significant effect was that of trial type ($F(1,33) = 7.18$, $p = .011$, $\eta_p^2 = .179$) with switch trials having lower accuracy than non-switch trials (switch: .96 ± .004, non-switch: .97 ± .002). There were no main effects of group (action: .96 ± .003, control: .97 ± .003; $p > .7$,) or test (pre: .97 ± .003, post: .96 ± .003; $p > .29$).

Median RT data were entered into a 2 (group) $\times$ 2 (test) $\times$ 2 (trial type) ANOVA. A main effect of trial type was observed ($F(1,33) = 98.98$, $p < .001$, $\eta_p^2 = .750$), with longer RTs for switch trials than for non-switch trials (switch: 599 ± 21 ms, non-switch: 417 ± 10 ms). A main effect of test was observed ($F(1,33) = 20.97$, $p < .001$, $\eta_p^2 = .389$), with subjects responding faster after training (pre: 537 ± 20 ms; post: 479 ± 19 ms). An interaction between test and trial type ($F(1,33) = 47.38$, $p < .001$, $\eta_p^2 = .589$) indicated an overall reduction in switch cost at post-test (pre switch cost: 213 ± 18 ms; post switch cost: 152 ± 20 ms).

There was no main effect of group ($F(1,33) = 1.112$, $p = .299$, $\eta_p^2 = .033$). However, a significant interaction between test and group ($F(1,33) = 7.59$, $p = .009$, $\eta_p^2 = .187$) indicated that the action-trained group decreased their RT more between pre-and post-tests than the control-trained group (pre: action: 534 ± 26 ms, control: 540 ± 16 ms; post: action: 443 ± 23 ms, control: 517 ± 29 ms). More importantly, an interaction between group, test, and trial type ($F(1,33) = 5.72$, $p = .023$, $\eta_p^2 = .148$) indicated a greater switch cost reduction between pre-and post-tests in the action-trained group as compared to the control-trained group (Fig. 8). To further confirm that action game trainees significantly reduced their switch cost from pre- to post-training, we analyzed each group separately. Action-trainees showed a main effect of test ($F(1,17) = 36.95$, $p < .001$, $\eta_p^2 = .685$) confirming faster RTs after than before training. A main effect of trial type was also present, with switch trials being slower than non-switch trials ($F(1,17) = 37.48$, $p < .001$, $\eta_p^2 = .688$). These two factors interacted,

indicating significant reduction in switch cost between pre-and post-training in action-game trainees ($F(1,17) = 61.98$, $p = .001$, $\eta_p^2 = .785$). Control-trainees displayed a main effect of trial type ($F(1,16) = 68.0$, $p = .0001$, $\eta_p^2 = .81$), no effect of test and a small decrease in switch cost ($F(1,16) = 7.52$, $p = .014$, $\eta_p^2 = .32$). The difference in switch cost improvement between groups was confirmed by a paired sample t-test ($t(1,33) = 2.39$, $p = .02$, Cohen's $d = 0.83$).

To account for the fact that the Action group had shorter RTs for both switch and non-switch trials at post-test, the reduction in the proportional switch cost is shown in Fig. 9. Unlike in Experiments 1–3, where the AVGP benefit was robust to this correction, the difference between groups in proportional switch cost was only marginally significant given a one-tailed test ($t(1,33) = 1.67$, $p = .052$ one-tailed, Cohen's $d = 0.58$). This suggests that a large portion of the benefit conveyed by training was in overall RT reduction, rather than task-switching per se.

6.4. Discussion

As expected from simple test–retest effects, both groups decreased their RTs from pre-test to post-test, and displayed reduced switch cost. Importantly, however, the action-trained video game group showed a greater decrease in switch cost than the control-trained group. The impact of training on the interpretation of the change in task-switch cost is worth considering carefully. When switch costs were corrected for baseline reaction time (Fig. 9), the change in task switch cost between action-trained and control-trained groups was only marginally significant given a one-tailed test. The fact that the group difference was in the very direction predicted and nearing significance is consistent with the claim that action game play reduces task-switch cost. Yet, it makes clear that part of the reduction in switch cost is directly related to faster overall RTs. When the RT contribution is accounted for, an effect likely remains but it is certainly weaker. Thus, to the extent that action video games can indeed reduce task-switch cost, the effect seems less robust than the previously seen effects of action video games on various aspects of visual attention and low-level vision (Green & Bavelier, 2003; Li et al., 2009).

A combination of factors may have conspired to diminish possible effects of training in the present study, including (i) the possibility that specific test–retest improvements overwhelmed the more general influence of training, (ii) that the control games also enhanced task-switching abilities, or (iii) the length of the training was insufficient to definitively alter task-switching. First, there is indeed a large literature, as discussed above, documenting that the best way to improve performance on a task-switch paradigm is to practice on that very paradigm. In our case, participants were all pre- and post-tested on the same task-switch paradigm allowing for such task-specific learning to occur. This may explain in part why even the group trained on control games in Experiment 3 exhibited significant reductions in task-switch cost. A better design to establish that task-switching is trainable may be to use different task-switch paradigms at pre-and post-tests since only minimal transfer may be observed when using conceptually similar, but not exactly identical task-switch paradigms. Second, the control-trained group was required to play games that at their core require one to maintain multiple goals in mind and alternate between them to better develop the life of the character. This may have led to the slight increase in task-switching ability noted in control-trainees, reducing the difference between the action-and control-trained groups. Third, while 50 h of action video game training is obviously sufficient to greatly speed reaction times, it may not be quite sufficient to increase task-switching ability to the same level as in expert game players. Longer training studies may be in order. Similar considerations may account for the failure to find a training effect in Boot et al. (2008)). They too observed a
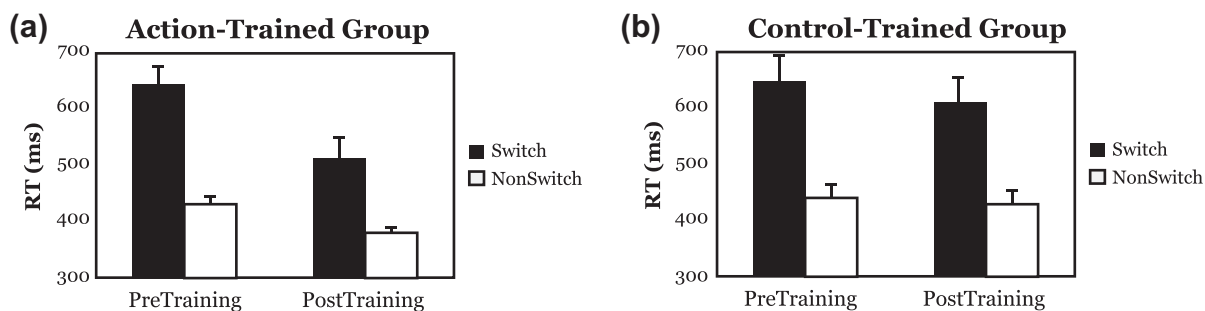
Fig. 8. Reaction times for the (a) action and (b) control-trained groups. Error bars represent the standard error of the mean. Note the similarities between groups before training, and the substantial reduction in RT and switch cost in the action group after training.
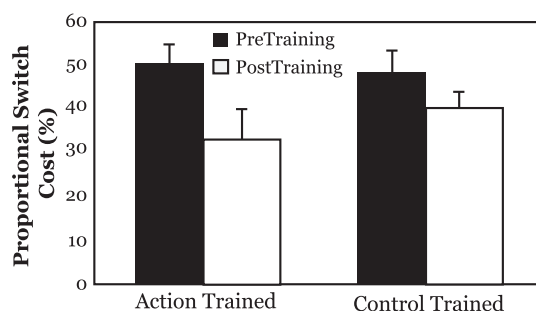

Fig. 9. Proportional switch cost before and after training in both groups.

clear reduction in switch cost in expert game players, but they failed to find an effect of action game training. It will be for future study to clarify how the nature of the switch paradigm may interact with training.

7. General discussion

Several studies have now noted reductions in switch costs in AVGPs as compared to nAVGPs (Andrews & Murphy, 2006; Boot et al., 2008; Colzato et al., 2010; Karle et al., 2010). The results of the four experiments here expand this literature in several key ways. First, as shown in Experiment 1, the AVGP advantage in switch-cost cannot be attributed to the ability to make responses via button presses on a keyboard, or more specifically, the ability to map and re-map decisions onto arbitrary button arrangements (i.e. there is no particular reason why the "M" key should equal "red", and "N" equal "blue"). AVGPs do show an advantage where such mappings are required, but show the exact same advantage when using a vocal method of response (which should be roughly equivalently familiar in AVGPs and nAVGPs). Experiment 2 showed that the switch-cost advantage was not disproportionately strong in a task that was more perceptual in nature (color/shape of stimulus), versus a condition that was more cognitive in nature (odd/even, high/low – which requires access to, and to some extent, manipulation of, internal representations). Experiment 3 demonstrated that the AVGP advantage was also roughly equivalent in a condition wherein the switch required a goal shift and in a condition where the switch involved only a change in motor response set. Furthermore, in this experiment, unlike Experiments 1 and 2, the switches were unpredictable, thus replicating the findings of Boot et al. (2008) that the AVGP advantage is not limited to predictable switches. Finally, Experiment 4 examined the question of causation. Training on an action game did indeed result in reductions in switch-cost that were greater than training on a control game. However, when controlling for the fact that action game playing resulted in overall faster RTs (i.e. on both switch and non-

switch trials), the advantage was only marginally significant. We would note that of the studies examining the effect of AVGPs on task-switching, only Karle et al. (2010) performed this type of correction. Given that such training does indeed reduce all RTs, this should be an important standard going forward.

In sum, action video game play appears to be a promising intervention to both lower RTs and additionally diminish the cost of switching between tasks. This result is worth considering in the larger context of technology use and its effect on task-switching. Indeed, as discussed initially, we are constantly asked to switch between multiple applications on the various digital devices that have invaded our lives. Recent work by Ophir, Nass, and Wagner (2009) demonstrated that undergraduates that acknowledge being high multi-media taskers (i.e., constantly switching between different types media) have poor task-switching abilities. This poor performance is witnessed despite these participants holding the belief they excel at task-switching. Thus, clearly task switching can be altered via some types of experience, either for the better or for the worse. Further understanding the conditions that shape task switching abilities should be an important avenue of research for future works.

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