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Task switching in video game players: Benefits of selective attention but not resistance to proactive interference

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A B S T R A C T

Research into the perceptual and cognitive effects of playing video games is an area of increasing interest for many investigators. Over the past decade, expert video game players (VGPs) have been shown to display superior performance compared to non-video game players (nVGPs) on a range of visuospatial and attentional tasks. A benefit of video game expertise has recently been shown for task switching, suggesting that VGPs also have superior cognitive control abilities compared to nVGPs. In two experiments, we examined which aspects of task switching performance this VGP benefit may be localized to. With minimal trial-to-trial interference from minimally overlapping task set rules, VGPs demonstrated a task switching benefit compared to nVGPs. However, this benefit disappeared when proactive interference between tasks was increased, with substantial stimulus and response overlap in task set rules. We suggest that VGPs have no generalized benefit in task switching-related cognitive control processes compared to nVGPs, with switch cost reductions due instead to a specific benefit in controlling selective attention.

1. Introduction

As playing video games has become an increasingly popular and widespread activity over the past several decades, research into the potential perceptual and cognitive effects of video game play has similarly developed. Following initial video game-related research focusing on transfer of training (e.g., Fabiani et al., 1989; Gopher, Weil, & Bareket, 1994), an increasing number of authors have become interested in investigating how expert video game players (VGPs) may differ from non-video game players (nVGPs), in terms of specific underlying mental processes. Visual perception and attention have been particularly well represented in studies to date. Superior ability has been reported for VGPs compared to nVGPs in divided visual attention (Greenfield, deWinstanley, Kilpatrick, & Kaye, 1994) and spatial attention via the useful field of view task (Feng, Spence, & Pratt, 2007). Similar findings have been demonstrated in children, including benefits in selective attention (Blumberg, 1998), and attentional capacity via multiple object tracking (Trick, Jaspers-Fayer, & Sethi, 2005).

Support for these findings can be found in a series of studies conducted by Green and Bavelier (2003, 2006a, 2006b, 2007), who have consistently demonstrated that VGPs outperform nVGPs on a variety of tasks that tap visuospatial attentional processing, and that such benefits appear to be trainable to a non-game playing population. In their earlier work, Green and Bavelier (2003) demonstrated VGP performance benefits in an attentional blink task, with better T1 identification and T2 detection compared to nVGPs. From these data, they suggested that expert video game players may have greater control over task switching in addition to better temporal attentional processing. Through their subsequent work with multiple object tracking (2006a, 2006b), and visual crowding (2007), Green and Bavelier argued that their findings indicated that VGPs' superior performance on complex visual processing tasks was likely the result of changes in the fundamental characteristics of the visual system brought about by extensive gameplay experience, and that it remained to be determined if there were also improvements to higher-order processing and cognitive control mechanisms. Castel, Pratt, and Drummond (2005) also found performance benefits for VGPs versus nVGPs using cuing and visual search paradigms. While VGPs were faster overall, and showed some benefit for more efficient self-directed visual search, they showed very similar patterns of lower-level effects, such as cuing and inhibition of return. From these data, Castel

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et al. (2005) suggested that VGPs may instead have a benefit in higher-level executive control processes, allowing for more efficient control and allocation of selective attention, and the ability to more rapidly establish stimulus–response mappings.

Recently, several authors have more directly examined whether video gaming expertise may be related to differences in cognitive control, specifically processes involved in task switching. Task switching paradigms typically measure the effects of various factors on *task switching cost*, defined as the difference between performing a task for a second time in sequence (repeat trials) compared to performing a task for the first time in sequence following a previous different task (switch trials). Andrews and Murphy (2006) used an alternating-runs (AABB task sequence) task switching paradigm based on methods from Rogers and Monsell (1995), and demonstrated that VGPs showed smaller task switching costs than nVGPs when response-to-stimulus durations were relatively short (150 ms in their study). Boot, Kramer, Simons, Fabiani, and Gratton (2008) investigated a range of cognitive abilities in a training study comparing VGP and nVGP participants, with executive control assessments including task switching and working memory operation span. They found no difference in operation span between gaming groups or as a result of training novices on a range of video games for 20 or more hours. Expert gamers showed smaller switch costs compared to novices, but video game training did not affect switch costs.

Our present study sought to more carefully distinguish what aspects of task switching and related cognitive control processes might selectively differ between expert video game players and non-video game players. We conducted two experiments to more closely examine VGP versus nVGP differences with respect to factors known to influence task switching processes, including the amount of time and information available prior to stimulus onset during which endogenously driven task set reconfiguration can be performed, and the degree of stimulus and response overlap between tasks.

In Experiment 1 we manipulated a range of stimulus, response and cuing parameters, to parametrically vary the difficulty in preparing for and responding to a given trial, in addition to a basic task switching manipulation. Cuing and trial timing parameters were manipulated so that even when response mappings were difficult, substantial endogenous preparation for a particular trial was possible given an informative cue and a longer cue-to-stimulus interval in some conditions. Although Experiment 1 employed randomized shifts between two sets of semantically distinct stimuli (letters A, B, C, and digits 1, 2, 3), we reduced the degree of overlap of task set rules, and hence the likely extent of trial-to-trial interference, by having no stimulus or response overlap between tasks, and having a direct univalent 1-to-1 mapping of each individual stimulus to a separate manual response. In effect, this task could have been conceptualised as a single task requiring mapping of six distinct stimuli to six distinct responses, with no requirement for any real switch of task set rules. This design also allowed us to assess VGP versus nVGP differences in a range of other effortful, selective attention-demanding processes, independent of task switching behaviour.

For Experiment 2, we employed a different task switching paradigm based on Arbuthnott and Frank's (2000) method for demonstrating additional reaction time costs for task alternation as compared with simple task switching—for example, longer reaction times on the final Task C in a C–B–C task sequence compared with an A–B–C task sequence. These findings have generally been taken as evidence for active inhibition of recently abandoned task set representations, a phenomenon that has come to be termed Backward Inhibition (Arbuthnott, 2005; Arbuthnott & Woodward, 2002; Mayr & Keele, 2000). In this experiment, we employed tasks with extensively overlapping task set rules, where the same six stimuli were remapped to two alternative responses for each task. As such, this required endogenous reconfiguration of task set based only on a pre-stimulus cue, in the face of likely substantial task switching-related proactive interference (Wylie & Allport, 2000).

Throughout this study, we were interested to see what aspects of task switching performance might differentiate video game experts from non-video game players, and whether other aspects of performance close to but separate from task switching itself might be revealed as more distinguishing of VGP and nVGP groups. To anticipate our results somewhat, the results from Experiment 1 demonstrated selectively better performance for VGP participants in a small set of conditions, reflecting a superior ability to actively prepare for an upcoming task when time and information were available, including relatively greater reductions in task switching costs under these conditions. However, while Experiment 2 showed faster performance for VGP versus nVGP groups in general, video gamers showed no selective benefit at all with regard to task switching costs. We consider these results with respect to likely component processes involved in task switching performance, including effortful selective attention-dependent preparation for upcoming task performance, and processes involved with resolving proactive interference arising from successive performance of different but overlapping tasks.

2. Experiment 1

Experiment 1 asked participants to make speeded responses to one of six single-character stimuli, under a range of intermixed stimulus, response, cuing and timing conditions. We expected to find a range of typical effects on performance for all participants—for example, we expected all participants to be slower when stimuli were harder to perceive, when more complex response mappings were used, and when response-to-stimulus durations were particularly short. We assessed our data with a particular focus on how our participant group variable (video game players versus non-video game players) interacted with other effects in these data, to assess what particular aspects of selective attention-demanding performance might be influenced by video gaming expertise.

2.1. Method

2.1.1. Participants

Fifty-six individuals from McMaster University's undergraduate student population participated in the experiment in exchange for course credit. All participants were male, and reported normal or corrected to normal vision. Our recruitment notice requested participants with either very little video game experience (only infrequent casual play at most, preferably none) or substantial and recent video game experience with immersive, first-person games (at least 4 h per week, and at least 1 h per session, for 6 months or more), which we confirmed in a post-experiment questionnaire. Several self-identified non-gaming participants were excluded from initial analyses based on their reporting considerable video game experience on their debriefing questionnaire. We analysed data for 30 participants identified as action video game players (VGPs) and for 26 participants identified as non-video game players (nVGPs), with no difference in age between groups (19.2 years versus 18.3 years, $t(25) = 1.11$, p = n.s.).

2.1.2. Apparatus and stimuli

Stimuli were the letters A, B and C, and the digits 1, 2 and 3, in Arial font and coloured medium grey, sized to subtend a vertical visual angle of approximately 2°. These stimuli were presented against a 7° vertical by 9° horizontal rectangular background area that was either high-contrast (white background with light grey random noise) or low-contrast (white background with black random noise) with the stimuli, creating "easy" versus "hard" stimulus perceptual conditions. These composite character-plus-background stimuli were presented against a constant dark grey background. A task cue was also presented on every trial, as a thin white, green or red rectangular frame surrounding the whole character-plus-background stimulus, approximately 0.5° visual angle larger both horizontally and vertically. All stimulus elements were centered on the screen relative to each other and the display itself. On a single trial, a task cue was presented for 100 ms or 1000 ms, which was then joined on screen by a character-plus-background stimulus that persisted until a response was made. The next trial began with a task cue following a constant 100 ms inter-trial interval. Erroneous responses elicited an immediate auditory feedback signal (100 ms, 100 Hz square wave). Character-plus-background stimuli were created as bitmap images in Adobe Photoshop, and then presented on a 19 inch ViewSonic P95f CRT monitor (1024 × 768 pixels, 85 Hz), via a Pentium 4 computer running Presentation® (v.12.0, http://www.neurobs.com) experimental software under a Windows XP operating system.

2.1.3. Procedure

Our procedure had a simple notional task for our participants—to respond with the correct one of three keys with their left hand to indicate an A, B or C stimulus, or to respond with the correct one of three keys with their right hand to indicate a 1, 2 or 3 stimulus. Our experimental procedure manipulated five within-subjects independent variables, each with two levels. First, stimulus perceptual difficulty was manipulated with high-contrast (easy) versus low-contrast (hard) stimuli as described above. Second, response mapping difficulty was manipulated with typical left-to-right response mappings of stimuli A, B and C to ring, middle and index fingers of the left hand, respectively, and stimuli 1, 2 and 3 to index, middle and ring fingers of the right hand, respectively (easy response mapping), versus an atypical left-to-right response mapping of stimuli B, C and A to ring, middle and index fingers of the left hand, respectively, and stimuli 2, 3 and 1 to index, middle and ring fingers of the right hand, respectively (hard response mapping). Third, task switching status was calculated based on whether the current trial was of the same letter versus number category as the previous trial or not, giving repeat versus switch trials, respectively. Fourth, we manipulated the cue-to-target time interval to be either 100 ms (short) or 1000 ms (long). Fifth and finally, we manipulated the informativeness of the task cue to either indicate with 100% predictability whether the upcoming stimulus would be a letter (red cue) or a number (green cue), or to provide no predictive information (white cue).

Single-character stimuli were presented randomly on each trial, with the constraint that any particular letter or number could not repeat on a subsequent trial. Stimulus noise and task switching factors were presented randomly mixed within blocks. Cue-to-target interval, response mapping and cue informativeness were manipulated between blocks of trials, alternating every one, two and four blocks, respectively. Participants performed 48 blocks of 32 trials each, for a total of 1536 trials over an approximate 40–45 min experimental session. Self-paced breaks were given in between every second block, when instructions for changes in response mapping were presented on screen, along with information about their mean reaction time and error rate for the previous 64 trials. Participants did not receive block-by-block instructions regarding changes of cue-to-target interval or cue informativeness, but were informed at the beginning of the experiment as to the cue colour-task relationships that would sometimes be present. This design gave six complete iterations of each response mapping x cue-to-target interval x cue informativeness block type, with the starting level of each of these factors counterbalanced across participants.

2.2. Results

One participant from each gaming group was excluded from analysis based on excessively errorful performance (greater than 20% errors overall). Trials with responses faster than 250 ms or slower than 2000 ms were excluded from analysis, representing 0.4% of all correct trials, distributed equally between video gaming groups. Trials immediately following an error trial were also excluded from reaction time analyses. Mean reaction time data for correct trials are presented in Fig. 1. A repeated-measures analysis of variance (ANOVA) was conducted with within-subjects factors of stimulus perceptibility (easy, hard), response mapping (easy, hard), task switching (repeat, switch), cue informativeness (cued, uncued), and cue-to-target interval (100 ms, 1000 ms), with video gaming status (VGP, nVGP) as a single between-subjects factor. Our primary goal was to assess how video gaming status interacted with the set of effects and interactions amongst conditions in our dataset.

A number of effects were evident across our dataset for all participants. High-contrast (easy) stimuli showed faster reaction times than low-contrast (hard) stimuli, responses were faster under typical (easy) response mapping than atypical (hard) mapping, repeat tasks were faster than switch tasks, and cued trials were faster than uncued trials, all supported by main effects, Fs > 44.00, ps < 0.001. In addition, a substantial series of 2-way and 3-way interactions involving subsets of stimulus perceptibility, response mapping, task switching, cue-to-target timing and cue informativeness factors suggested systematic influences on all participants' ability to actively prepare for and perform speeded responses. For example, both groups of participants showed reduced task switching costs (the difference between repeat and switch trial reaction times) with long cue-to-target intervals, $F(1, 52) = 17.09$, $p < 0.001$, with this effect more pronounced when informative cues were available, $F(1, 52) = 8.36$, $p < 0.01$. Similarly, task switching costs were systematically reduced under simple versus difficult response mapping conditions, $F(1, 52) = 317.44$, $p < 0.001$, with this effect more pronounced at long cue-to-target intervals, $F(1, 52) = 22.28$, $p < 0.001$, and with informative cues, $F(1, 52) = 5.28$, $p < 0.05$.

While a range of effects were observed across all participants, a selective number of interactions were additionally observed with video gaming status. Expert video gamers appeared to be able to additionally reduce their reaction times under certain combinations of task conditions, beyond the performance of non-video game players. VGPs reduced their reaction times to a greater degree than nVGPs with long cue-to-target intervals, supported by the interaction of gaming group with cue-to-target interval, $F(1, 52) = 4.38$, $p < 0.05$, and when informative task cues were available, supported by the interaction of gaming group with cue informativeness, $F(1, 52) = 21.62$, $p < 0.001$. Gamers showed additional reductions in RTs compared to non-video game players when these informative task cues were available on trials with long cue-to-target intervals, reflected by the 3-way interaction of these factors, $F(1, 52) = 7.44$, $p < 0.01$. Under long cue-to-target conditions, VGPs also demonstrated additional reductions in switch costs compared to nVGPs when stimulus perceptibility was easy, $F(1, 52) = 4.64$, $p < 0.05$. These effects were observed to modify the marginal 2-way interaction of task switching and gaming group, $F(1, 52) = 3.33$, $p = 0.074$, and the marginal main between-subjects effect of gaming group, $F(1, 52) = 3.78$, $p = 0.057$.

Considering the generally faster reaction times of VGPs compared to nVGPs, it is possible that the observed smaller switch costs for VGPs could be due simply to the difference in baseline

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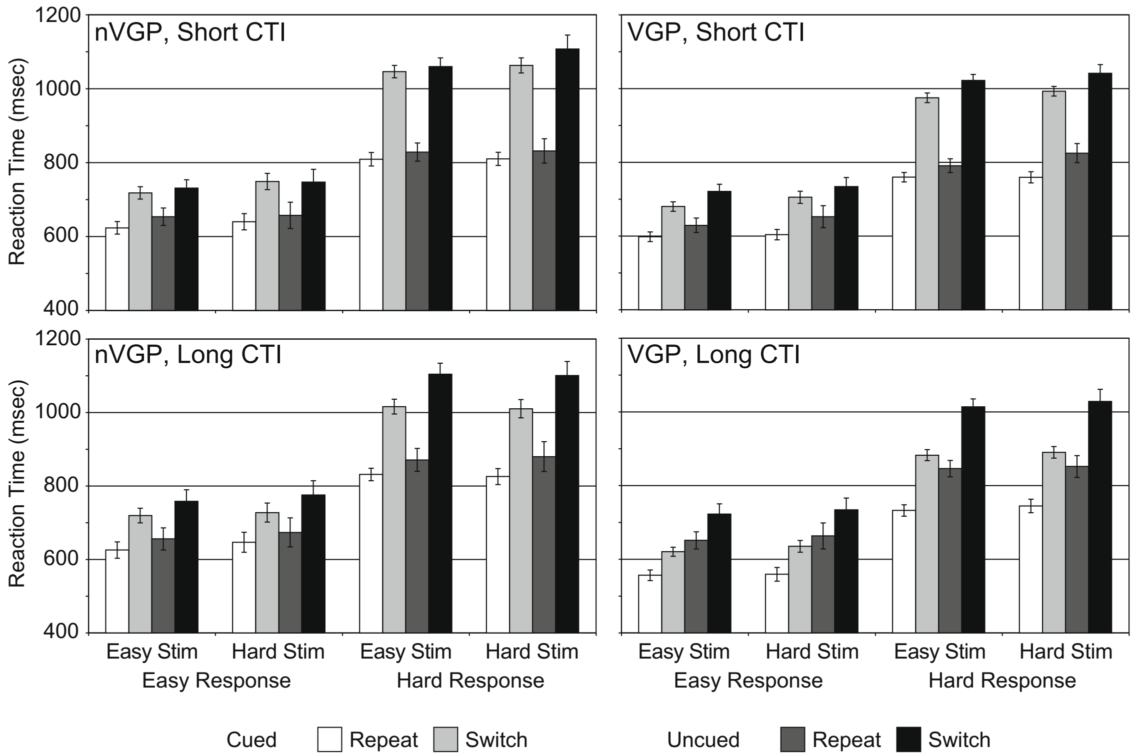

Fig. 1. Mean reaction time data for Experiment 1. Within a single panel, data are divided by task switching status (repeat or switch trial), and cue informativeness (cued or uncued), stimulus perceptual difficulty (Stim; easy or hard), and response mapping difficulty (easy or hard). These data are grouped by cue-to-target interval (CTI; short = 100 ms, long = 1000 ms), and video gaming participant group (VGP = video game players, nVGP = non-video game players). Error bars represent standard error of the mean. In addition to a main effect of faster responses for gamers, a number of interactions between overall task effects and gaming expertise group were observed.

RT between groups. To examine this possibility, we calculated switch costs as a proportion of mean repeat trial RT in each condition for each participant, and then reanalysed these normalized switch cost data as mentioned above (minus the repeat versus switch task factor). We observed a significant interaction of video gaming status with cue-to-target interval and stimulus perceptibility, $F(1, 52) = 4.18$, $p < 0.05$, matching the interaction of these factors with the repeat versus switch task factor in our mean RT analyses mentioned above. This suggests that reductions in switch costs for VGPs versus nVGPs are not simply due to baseline differences in RT between groups.

Error rate data were analysed via repeated-measures ANOVA with the same factors and levels as our mean reaction time data. Overall, errors displayed similar patterns of effects to reaction time data, although these error data were relatively more variable with fewer significant effects. For brevity, we omit a detailed presentation of these data here. Aside from a main effect of long cue-to-target interval trials producing more errors than short cue-to-target trials ($M = 7.12\%$ versus 5.90%, respectively) across all participants, $F(1, 52) = 13.57$, $p < 0.01$, there was little evidence of speed-accuracy tradeoff. A number of other main effects were observed across all participants, with fewer errors for cued versus uncued trials ($M = 6.19\%$ versus 6.83%), $F(1, 52) = 9.17$, $p < 0.01$, for repeat versus switch trials ($M = 5.46\%$ versus 7.56%), $F(1.52) = 41.65$, $p < 0.001$, and with easy versus hard response mappings ($M = 4.30\%$ versus 8.73%), $F(1, 52) = 73.29$, $p < 0.001$. A number of interactions mirrored a subset of those seen for reaction time data, including greater numbers of errors on switch tasks with difficult response mapping, $F(1, 52) = 6.45$, $p < 0.001$. This effect was slightly but significantly more pronounced in long cue-to-target trials, $F(1, 52) = 10.18$, $p < 0.01$, again reflecting some degree of speed-accuracy tradeoff under different trial timings. This interaction of cue-to-target interval, task switching and response mapping difficulty interacted further with gaming group, $F(1, 52) = 4.05$, $p < 0.05$, with VGPs showing a relatively smaller degree of speed-accuracy tradeoff than nVGPs, with systematically smaller error rates across this pattern of effects despite faster reaction times. While a number of other marginal effects were observed in interaction with video gaming group status, including a marginal main effect of numerically less errorful performance by video gamers compared to non-video game players, no other effects reached significance.

2.3. Discussion

Experiment 1 was designed to measure the extent to which participants could actively prepare for and respond to a basic choice response task under a range of stimulus, response, and cuing conditions, including a basic task switching manipulation. A large set of main effects and interactions were observed with these manipulations across all participants, as was expected. The observation of these effects suggests that our task manipulations were effective, and that we could reliably measure even small differences in performance (for example, the small but significant main effect of stimulus contrast across our data).

In addition to these findings, we observed a small but coherent set of interactions between our participant group variable and these within-subjects effects, suggesting a subset of conditions under which action video game experts showed selectively better task performance. While all participants were faster with informative cues and long cue-to-target intervals, video gamers appeared to be selectively and additionally better than non-video game players in being able to use informative cue information given enough time, to speed their overall performance. Further, with long preparation times and easily perceptible stimuli, VGPs reduced their task switching costs relative to nVGPs. This reduction in task switching cost persisted when we normalized participants' switch costs relative to their individual mean repeat trial RTs, suggesting that the apparent task switching benefit for VGPs is not simply due to differences in baseline RTs between groups.

In considering the particular set of conditions under which VGPs additionally outperformed nVGPs in this experiment, the selectively better ability to use cue information to prepare for upcoming task performance suggests a relative benefit in the ability to endogenously deploy selective attention to task-relevant stimulus processing for VGPs. Along these lines, one might wonder about the degree to which similar selective attention processes might have been the primary influence on our observed task switching differences in this experiment. Task set switching may be considered as a combination of processes, involving (at least in part) processes involved in the endogenously driven instantiation of a given task set, akin to Rogers and Monsell's (1995) description of *active reconfiguration*, and likely including cognitive control processes to deal with proactive interference from previous tasks and stimuli (e.g., Wylie & Allport, 2000). The present experiment afforded almost no trial-to-trial interference—each task was consistently mapped to a separate hand, with congruent stimulus–response mappings between tasks maintained for both easy and hard response mapping conditions (i.e., stimuli A and 1 were always mapped to the same left-to-right response in each hand, and so on), with no task overlap or stimulus-task cuing ambiguity. One could even conceptualise this experiment as having only a single task, mapping each of six distinct stimuli in a 1-to-1 fashion to six distinct responses.

Our observed switch costs do demonstrate that participants seemed to represent letter and digit stimuli as two separate tasks, with a cost of switching between them; this said, the processes involved in this switching may not fully represent the set of cognitive control processes typically implicated in many task switching situations. We conducted Experiment 2 to examine whether the observed performance advantage in task switching for video game experts versus non-video game players would persist under the conditions of more substantial proactive interference between tasks.

3. Experiment 2

Experiment 2 was based on the task switching procedure of Arbuthnott and Frank (2000), with three different tasks presented in a pseudorandom order to allow the comparison of repeat trials with simple switching from one trial to another, and the alternation from one trial to another and back again. This experiment was designed to have substantial task overlap, and hence cause substantial proactive interference from trial to trial, with six stimuli mapped to two alternative responses for each of three tasks, under three different sets of stimulus–response mapping rules. In contrast to typical response alternation paradigms, we again presented blocks of trials with both long (1000 ms) and short (100 ms) cue-to-target intervals, to explicitly assess whether participants could actively prepare for an upcoming trial given time to do so, and test whether VGPs would show a selective benefit under such conditions as they did in Experiment 1.

3.1. Method

3.1.1. Participants

Forty undergraduate students from McMaster University participated in exchange for course credit. All participants were male, and reported normal or corrected-to-normal vision. Participants were recruited as described in Experiment 1, with 20 participants identified in each video gamer (VGP) and non-gamer (nVGP) group. Mean age was not different between VGP and nVGP groups (19.0 years versus 18.6 years, $t(19) = 1.13$, p = n.s.).

3.1.2. Apparatus and stimuli

Stimuli were the digits 2, 3, 4, 6, 7 and 9, presented individually in the center of a computer display. One of three informative verbal task cues—"odd/even", "prime/multiple", or "less/more"—was also presented on screen directly above the current stimulus digit on every trial, indicating which of three speeded classification tasks participants should perform on the stimulus digit. Stimuli and task cues were presented in the same sized Arial font, with each element subtending approximately 1° vertical visual angle, with approximately 1.5° visual angle separating the near edges of stimulus and task cues vertically. On a single trial, a task cue was presented for either 100 ms or 1000 ms, and was then joined on screen by a single stimulus digit that persisted until response. The next trial began with a task cue following a constant 100 ms inter-trial interval. Erroneous responses elicited an immediate auditory feedback signal (100 ms, 100 Hz square wave). The same computer apparatus was used as in Experiment 1.

3.1.3. Procedure

Stimulus digits were presented randomly on each trial, with the constraint that a presented digit could not repeat on the subsequent trial. Participants performed one of three possible tasks on each trial, classifying the presented single digit as either odd or even, as a prime number or not, or whether that digit was larger or smaller than 5. Task order was systematically constrained to present ordered sequences of five tasks, in order to produce consistent numbers of four different trial types: *repeat* trials, where a task A followed another task A; *1-switch* trials, where a task A followed a different task B; *2-switch* trials, where a task A followed two successive different tasks B and C; and *alternate* trials, where a task A followed a previous task A from two trials ago, with an intervening task B. All four of these trial types were embodied in 5-trial sequences with an AABCB trial order structure, where trials two through five represented repeat (A), 1-switch (B), 2-switch (C) and alternate (B) trials, respectively. We computed all six possible iterations of these 5-trial sequences for combinations of our three tasks, plus all six combinations for another 5-trial sequence that similarly gave these four trial types in a different order, ABACC.

We presented these 12 sets of five tasks in a random order (preserving the 5-trial sequence structures), for a continuous block of 60 trials in an apparently random order. The initial trials in these 5-trial sequences could have represented a 2-switch (trial type A), repeat (B), or alternate trial (C) following a prior AABCB sequence, or a 1-switch (A or B) or repeat (C) trial following a prior ABACC sequence, depending on the identity of the initial trial in the current sequence and trials 4 and 5 in the previous sequence, and were analyzed as such. Within a 60-trial block, the random presentation order of these predefined 5-trial sequences gave a slightly greater expected proportion of repeat and 1-switch trials (26.6% each) compared to 2-switch and alternate trials (23.4% each), approximated as 12 trials per condition plus 33.3% (repeat and 1-switch) or 16.7% (2-switch and alternate) of the 11 initial-position trials, of a total 59 eligible trials (the first trial of a 60-trial block is undefined). These small differences in experienced condition probabilities were the same for all participants.

Participants responded to each digit stimulus based on the task rules indicated by the pre-stimulus cue on each trial. Participants responded with their left versus right index, middle and ring fingers for odd/even, prime/multiple and less/more (relative to the value 5) digit classifications, respectively. Task cues represented the consistent left/right mapping of the relevant category responses for each task, but did not indicate which pair of fingers was appropriate for a given task. Participants performed eight

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blocks of 60 trials, with a cue-to-target interval of 100 ms or 1000 ms alternated every block. Participants received self-paced breaks between every block, and were also given feedback on their mean reaction times and error rates for the previous block. Participants completed a single additional practice block prior to the main experiment, with 30 trials of each cue-to-target interval, which was not analysed. The order of cue-to-target interval alternation was counterbalanced across participants.

3.2. Results

In consideration of the overall longer reaction times in this experiment compared to Experiment 1, trials with responses faster than 300 ms or slower than 5000 ms were excluded from the analysis, representing 0.1% of all correct trials, distributed equally between video gaming groups. In addition to excluding error trials from reaction time analyses, we also excluded the two trials following an error trial, considering the dependence of our various task switching conditions on the preceding two trials. Mean reaction time data for trials from correct trial sequences are presented in Fig. 2. As in Experiment 1, we expected to observe a number of general effects on performance across all participants due to our various task manipulations. We were particularly interested to test how video gaming status interacted with this set of task manipulation effects. We conducted a repeated-measures ANOVA with within-subjects factors of switch type (repeat, 1-switch, 2-switch, alternate), task (odd/even, prime/multiple, less/more), and cue-to-target interval (100 ms, 1000 ms), with video gaming status (VGP, nVGP) as a single between-subjects factor.

From Fig. 2, a number of effects were again evident across our dataset. A main effect of switch type was observed, $F(3, 114) = 167.47$, $p < 0.001$, reflecting at minimum a substantially faster performance for repeat versus other trials, with alternate trials appearing consistently slower than 1-switch or 2-switch trials across most conditions. A main effect of task type was observed, $F(2, 76) = 35.84$, $p < 0.001$, with faster responses for the less/more task compared with odd/even or prime/multiple tasks. A main effect of cue-to-target interval was also observed, $F(1, 38) = 151.92$, $p < 0.001$, with overall faster responses on trials with a long (1000 ms) cue-to-target interval. These main effects were modified by the interaction of switch type and cue-to-target interval, most readily observed as a relative reduction in switching costs (the difference between repeat and switch trials) with long cue-to-target preparation times, $F(3, 114) = 6.91$, $p < 0.001$. Switch type also interacted with task type, with relatively smaller switching costs observed for the less/more task, $F(6, 228) = 6.78$, $p < 0.001$. The interaction of cue-to-target interval with task type and the 3-way interaction between these factors and switch type were not significant, $Fs < 1.2$.

As in Experiment 1, we were interested to examine the potential interaction of these task effects with video gaming experience. A main effect of video gaming group was observed, $F(1, 38) = 7.12$, $p < 0.05$, reflecting overall faster reaction times for video gamers compared with non-video game players. However, no interactions whatsoever were observed between our gaming group variable and any of our task factors, all $Fs < 1.1$.

To better assess switching condition differences between alternation trials and 1-switch and 2-switch trials, typically described as Backward Inhibition effects (Arbuthnott & Frank, 2000; Mayr & Keele, 2000), we repeated our ANOVA for reaction time data with a 3-level factor of switch type, excluding repeat trial data. A significant main effect was observed for switch type, $F(2, 76) = 16.68$, $p < 0.001$, supporting the observation of greater reaction time costs for alternation trials as compared to 1-switch and 2-switch trials. The interaction of switch type with task type supported the observation that reaction time costs for alternation trials versus 1-switch

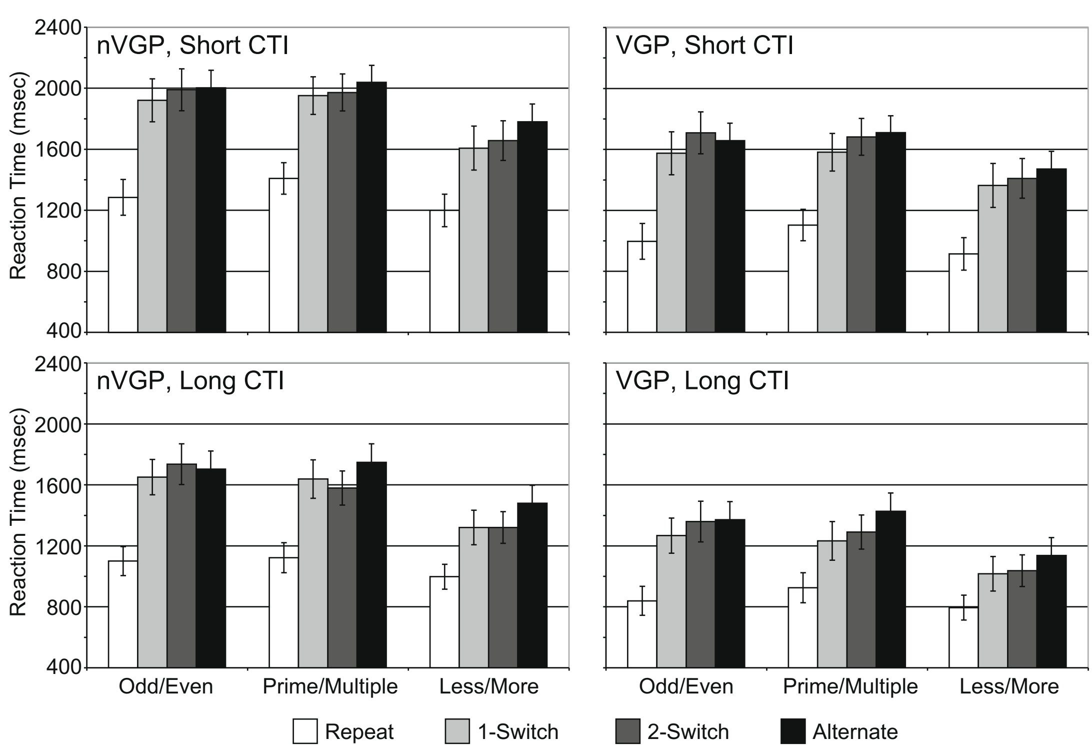

Fig. 2. Mean reaction time data for Experiment 2. Within a single panel, data are divided by task type (odd/even, prime/multiple or less/more) and task switching type (repeat, 1-switch, 2-switch and alternate). These data are grouped by cue-to-target interval (CTI; short = 100 ms, long = 1000 ms), and video gaming participant group (VGP = video game players, nVGP = non-video game players). Error bars represent standard error of the mean. Despite an overall main effect of faster responses for gamers, no interactions between overall task effects and gaming expertise group were observed.

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and 2-switch trials were present in less/more and prime/multiple trials, but not apparent in odd/even trials, $F(4, 152) = 2.68$, $p < 0.05$. Strong main effects of task type, $F(2, 76) = 33.95$, $p < 0.001$, and cue-to-target interval, $F(1, 38) = 136.12$, $p < 0.001$, were still observed. However, the previously observed interaction of switch type with cue-to-target interval was absent here, $F < 1$, suggesting that this interaction was driven primarily by repeat trial performance becoming relatively faster with long cue-to-target intervals. Results for video gaming expertise were not altered, with a comparable main effect for video gaming group, $F(1, 38) = 6.74$, $p < 0.05$, and no interactions of gaming expertise with any of our task factors, Fs < 0.8.

Error rate data for Experiment 2 were calculated based on the individual trials on which participants made an incorrect response. The overall mean error rate for Experiment 2 was 4.23%. Participants were less errorful overall on repeat trials compared to 1-switch, 2-switch and alternate trials (M = 3.22%, 5.08%, 4.05% and 4.57%, respectively), reflected by a main effect of switch type, $F(3, 114) = 5.15$, $p < 0.01$, and were less errorful overall for less/more trials compared to prime/multiple or odd/even trials (M = 3.06%, 4.76% and 4.87%, respectively), $F(2, 76) = 6.67$, $p < 0.01$. Switch type and task type were observed to interact, with different tasks apparently more sensitive to error depending on task switching situation, $F(6, 228) = 5.10$, $p < 0.001$. There was no main effect of video gaming expertise, $F(1, 38) = 0.37$, $p = 0.54$. Mean error rates for nVGPs were 4.06% and 3.94%, and for VGPs were 3.88% and 5.03%, for short and long cue-to-target intervals, respectively. A marginal interaction of gaming group and cue-to-target interval, $F(1, 38) = 3.55$, $p = 0.07$, reflected this approximately 1% more errorful performance by VGPs in the long cue-to-target interval condition. No other interactions with gaming group approached significance, Fs < 1.

3.3. Discussion

Video game experts were again generally faster than non-video game players, and characteristic task switching and task alternation costs were observed for both groups. However, VGP participants showed no selective benefit for task switching compared to nVGPs, in contrast to Experiment 1. Further, while all participants showed a reduction in switch costs and overall reaction times with long cue-to-target intervals, the VGP group showed no selectively better ability to reduce their reaction times with a longer pre-stimulus preparation time, again in contrast to Experiment 1.

The addition of substantial task overlap in Experiment 2 appeared to remove any task switching-related benefit that VGP participants demonstrated over nVGP participants in Experiment 1. In Experiment 2, every trial had an informative cue, and so part of the overall faster performance observed for VGPs may have been facilitated by better cue-driven endogenous task preparation. On the basis of Experiment 1, we may have expected to see selectively better performance and relatively smaller switch costs for VGPs at long cue-to-target intervals given this cuing, but observed only equivalent effects across gaming groups.

Given the critical differences in design between our two experiments, we suggest that Experiment 2 likely involved substantially greater trial-to-trial proactive interference than was produced with the minimally overlapping tasks in Experiment 1. While VGPs still showed substantial performance benefits compared to nVGPs, this benefit did not appear to extend to the cognitive control processes required to deal with the increased degree of switching-related proactive interference in Experiment 2. As such, we suggest that VGPs' apparent task switching benefit may be limited to a relative benefit in the control and allocation of selective attention, and not in other cognitive control processes underlying task switching.

4. General discussion

The present study compared the performance of video gaming experts versus non-video game players in two different task switching situations. In Experiment 1, there was no overlap of stimuli or responses between tasks, and a direct univalent 1-to-1 mapping of all six stimuli to individual responses. In Experiment 2, six stimuli were mapped to two alternative responses in each of three different tasks, creating a substantial degree of overlap between task sets. We suggest that considerable cognitive control was required by participants to counter the substantial degree of trial-to-trial proactive interference in Experiment 2, but that this was negligible in Experiment 1. In Experiment 1, while all participants were able to respond faster and reduce their switching costs with informative cues, longer cue-to-target intervals, and simpler response mappings, VGP participants were able to additionally speed up their task performance and reduce switching costs relative to nVGPs under subsets of these particular conditions. In Experiment 2, longer cue-to-target intervals in the presence of informative task cues again allowed both VGPs and nVGPs to decrease their reaction times, and also to reduce their switching costs. However, in this situation, there was no apparent benefit of video gaming expertise on task switching performance.

Our primary interpretation of these findings is that the apparent advantage in task switching performance for video game experts compared to non-video game players is due to a superior ability to control selective attention, akin to some of the conclusions of Castel et al. (2005). This kind of benefit in controlling selective attention could lead to generally observable task switching benefits in many situations, through the modulation of effortful endogenously driven *advance reconfiguration* processes of task set representations (Mayr & Kliegl, 2000; Meiran, Chorev, & Sapir, 2000; Rogers & Monsell, 1995). In contrast, video gaming expertise appears not to afford any selective advantage in reducing the effects of proactive interference between task set representations (Wylie & Allport, 2000) on task switching costs, even when a substantial VGP advantage is observed for other aspects of speeded performance within the same trials. From these data, we suggest that there is no good evidence for a generalized task switching-related cognitive control benefit in expert video game players, and that the observed task switching benefits in this and other studies (Andrews & Murphy, 2006; Boot et al., 2008) are a result of a benefit in controlling selective attention.

Our present findings appear to be consistent with previous data showing a VGP benefit in task switching, though not necessarily consistent with previous conclusions regarding the cognitive basis for this benefit. Andrews and Murphy (2006) used a task switching paradigm closely following Rogers and Monsell (1995), with bivalent stimuli composed of both a number and a letter, with task cuing (vowel/consonant judgement on letters, or odd/even judgement on numbers) based on trial sequence and screen position cues. Andrews and Murphy (2006) observed a VGP benefit in task switching when stimuli were bivalent and congruent for a particular response (i.e., when the manual response for the irrelevant stimulus character under the other task was the same as the response for the current task-relevant stimulus character), and in a univalent situation when a neutral character (non-letter, non-number) was presented in place of the task-irrelevant stimulus character. In contrast, they observed no VGP benefit when stimuli were bivalent and incongruent (i.e., when the manual response for the irrelevant stimulus character under the other task was different to the response for the current task-relevant stimulus character). Andrews and Murphy's (2006) data appear to be consistent with a task switching benefit for VGPs under relatively low-interference conditions, with the disappearance of this benefit with

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increased interference from competing task set representations. Boot et al. (2008) also employed bivalent stimuli with their task switching paradigm, with parity or magnitude judgement tasks on single digit stimuli cued by background screen colour, although with responses for each task separated to different hands as in our present Experiment 1. Their observation of VGP benefits in task switching involved a situation with less task set overlap, and presumably a lesser degree of trial-to-trial proactive interference than in our Experiment 2.

We suggest that from previous studies and our present data, expert video game players display an advantage in controlling selective attention, similar to the conclusions of Castel et al. (2005). When switching task sets requires relatively little cognitive control to resolve interference from competing task sets, VGPs may be faster at instantiating new task sets due to a facilitation of endogenous reconfiguration processes due to a relative benefit in selective attention compared to nVGPs. We suggest that an increasing need for cognitive control processes to mediate the resolution of interference between overlapping task set representations would reduce the effect of this gaming-related attentional benefit on the speed of task set reconfiguration, to the point where no benefit would be observed with substantial degrees of interference between tasks. If expert gamers did indeed have a more generalized benefit in task switching-related cognitive control processes, one would expect to observe a VGP benefit in task switching to persist with increased task set overlap and resultant greater interference—the opposite of which seems to be the case in both our present data and data from previous task switching studies.

As in any study, there are a number of caveats that must be considered along with our experimental findings and their interpretation. One important question involves the source of between-groups differences – whether benefits in VGP versus nVGP performance are due to some self-selection to play video games because of initial differences in cognitive or other attributes, or whether the experience of playing video games is responsible for the development of observed enhanced abilities. While exploring these causal distinctions was not a focus of our study, a number of interesting possibilities might be considered. For example, experience playing immersive first-person video games may specifically train individuals' ability to deploy selective attention, but not their ability to resist proactive interference from prior situations. Experience and training in demanding high-interference situations might result in a different set of abilities than currently appear to be typical of expert action video game players.

Several specific caveats with respect to our experimental design should also be noted. While we believe that the degree of task overlap and the resulting degree of proactive interference was the primary difference in task switching-related performance demands between Experiments 1 and 2, several other factors also varied. While both experiments used informative cues, Experiment 1 alternated between informative and uninformative cues every four blocks (128 trials). The observed VGP benefits in mean RT and task switching costs under informative cue conditions could have been due to nVGP's inability to flexibly make use of informative cues when only sometimes available, rather than a more basic difference in ability to use informative cues to speed performance. Similarly, differences in VGP benefits across experiments could have been more directly related to differences in flexibly adapting to changes in response mappings (alternating every 64 trials in Experiment 1, constant in Experiment 2). Both these factors could have diminished apparent differences between VGPs and nVGPs in Experiment 2 compared to Experiment 1. To the extent that these issues may reflect differences in ability to endogenously direct selective attention, we would suggest that they would be further evidence toward our suggested conclusions – that VGPs appear to have a discrete benefit in deploying selective attention compared to nVGPs. We note also that our overall conclusions are based partly on the absence of task switching-related group differences in Experiment 2. While always a logical concern, we were reassured by our ability to observe large and systematic predicted effects in task switching, cue-to-target timing, and other factors in both VGP and nVGP groups, with no suggestion of gaming group interactions on task switching costs.

Finally, our discussion of task switching differences as arising from processes not selectively involved with task switching performance may seem counterintuitive, especially considering the typical framing of task switching as a fundamental function of cognitive control. Along with monitoring and updating of working memory ("Updating"), and the controlled, deliberate inhibition or suppression of prepotent responses ("Inhibition"), the shifting of mental set ("Shifting"), now increasingly studied as task switching, has been identified as a related but separable executive function via latent variable analysis (Friedman et al., 2006; Miyake et al., 2000). Recent work has additionally identified several other dissociable executive functions, including a separable component of selective attention, distinct from Updating, Inhibition and Shifting (Fournier-Vicente, Larigauderie & Gaonac'h, 2008). The executive function of Shifting in this sense is defined by the commonalities in the tasks used to measure it—mostly a series of task switching experiments using a variety of different tasks (e.g., Friedman et al., 2006; Miyake et al., 2000). The question of what particular processes this separable executive function represents, however, is less clear. As discussed by Miyake et al. (2000), the executive function of Shifting may primarily reflect processes involved in resolving proactive interference from prior task sets, in addition or alternatively to simple engagement/disengagement of task set representations. What is clear is that typical individuals (including both VGPs and nVGPs) appear to have an executive control ability of Shifting, partially correlated with but distinguishable and separable from other executive abilities such as updating working memory, effortfully suppressing incorrect prepotent responses, and the deliberate control of selective attention.

Framed in this way, we have observed this Shifting ability and seen it modulated by a range of factors in all our participants in both experiments in the present study. We have also observed a selective VGP benefit in an intersection of conditions most susceptible to the benefits of controlled selective attention in both experiments. In conditions requiring executive Shifting processes to resist substantial proactive interference, we observed no selective VGP benefit in task switching costs, despite a concurrent VGP benefit for other factors; only with conditions of lower proactive interference and concurrent opportunity for endogenously driven preparation for performance did we observe a VGP benefit in task switching. We suggest that these data represent a dissociation of selective attention and executive Shifting processes, both of which are involved with the performance of typical task switching paradigms. While VGPs may demonstrate reduced task switching costs relative to nVGPs in some situations, we suggest that this is representative of a superior ability to control the allocation of selective attention, and not a more general benefit in cognitive control abilities underlying task switching performance.

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