Human Movement Science 38 (2014) 152–162

Contents lists available at ScienceDirect

Human Movement Science

journal homepage: www.elsevier.com/locate/humov

The effect of action video game playing on sensorimotor learning: Evidence from a movement tracking task

Davood G. Gozli [a,*], Daphne Bavelier [b,c], Jay Pratt [a]

[a] Department of Psychology, University of Toronto, Ontario, Canada
[b] Department of Psychology and Education Sciences, University of Geneva, Switzerland
[c] Department of Brain and Cognitive Sciences, University of Rochester, New York, USA

ARTICLE INFO

Article history:
Available online 6 November 2014

PsycINFO classification code:
2330
2320
2300

Keywords:
Action video games
Manual motion tracking
Plasticity

ABSTRACT

Research on the impact of action video game playing has revealed performance advantages on a wide range of perceptual and cognitive tasks. It is not known, however, if playing such games confers similar advantages in sensorimotor learning. To address this issue, the present study used a manual motion-tracking task that allowed for a sensitive measure of both accuracy and improvement over time. When the target motion pattern was consistent over trials, gamers improved with a faster rate and eventually outperformed non-gamers. Performance between the two groups, however, did not differ initially. When the target motion was inconsistent, changing on every trial, results revealed no difference between gamers and non-gamers. Together, our findings suggest that video game playing confers no reliable benefit in sensorimotor control, but it does enhance sensorimotor learning, enabling superior performance in tasks with consistent and predictable structure.

1. Introduction

Over the past several years, there has been much interest in research on the effect of video game playing on various aspects of cognitive and perceptual performance, triggered in part by the study of

* Corresponding author at: Department of Psychology, University of Toronto, 100 St. George Street, Toronto, Ontario M5S 3G3, Canada.

E-mail address: d.gharagozli@mail.utoronto.ca (D.G. Gozli).

http://dx.doi.org/10.1016/j.humov.2014.09.004
0167-9457/

Green and Bavelier (2003) indicating differences between highly practiced action video game players (VGPs) and non-video game players (NVGPs) across a series of visual attention tasks (perceptual load, enumeration, useful field of view, attentional blink). To ensure that the between-group difference was due to video game experience, the authors also used a training paradigm, wherein NVGPs were randomly assigned to either an action video game or a control non-action game training phase. Results showed the action-game training increased subjects' useful field of view and speed of encoding visual targets from a rapid serial display. Dozens of follow up studies have confirmed that VGPs benefit from enhanced visual attention, whether in space, time, or to objects (Green & Bavelier, 2006a,b; Spence & Feng, 2010; Sungur & Boduroglu, 2012). Over the years, evidence documented improvements in tasks as varied as mental rotation (Feng, Spence, & Pratt, 2007), multisensory temporal estimation (Donohue, Woldorff, & Mitroff, 2010), task switching (Andrews & Murphy, 2006; Boot, Kramer, Simons, Fabiani, & Gratton, 2008; Cain, Landau, & Shimamura, 2012; Colzato, Waszak, Nieuwenhuis, Posthuma, & Hommel, 2010; Green & Bavelier, 2012; Karle, Watter, & Shedden, 2010; Strobach, Frensch, & Schubert, 2012), backward masking (Li, Polat, Scalzo, & Bavelier, 2010), visual search (Bavelier, Achtman, Mani, & Fockert, 2011; Hubert-Wallander, Green, & Bavelier, 2010; Krishnan, Kang, Sperling, & Srinivasan, 2012; but see Castel, Drummond, & Pratt, 2005), change detection (Clark, Fleck, & Mitroff, 2011), attentional capture (Chisholm, Hickey, Theeuwes, & Kingstone, 2010; West, Stevens, Pun, & Pratt, 2008), oculomotor capture (West & Pratt, 2013), as well as higher representational acuity for space and objects (Sungur & Boduroglu, 2012; but see Boot, Blakely, & Simons, 2011 and Kristjánsson, 2013 for general criticisms of this line of work). What is most puzzling is the robust generality of the action video game training advantage, especially in light of a body of work, which suggests the benefit of expertise is often task-specific and not transferrable (Bavelier, Green, Schrater, & Pouget, 2012). By contrast, the advantage of VGPs seems sufficiently general to be captured across a wide range of tasks.

A recent account posits that the VGPs advantage is due to a stronger top-down attentional control (Chisholm & Kingstone, 2012; Colzato, van den Wildenberg, Zmigrod, & Hommel, 2013; Green & Bavelier, 2012). This account has gained converging support from recent behavioral and imaging findings, suggesting that playing action video games may allow VGPs to more effectively filter out task-irrelevant information due to more effective inhibitory processes (Krishnan et al., 2012; Mishra, Zinni, Bavelier, & Hillyard, 2011; Wu et al., 2012), as well as to more flexibly allocate attention as task demands vary (Bavelier, Achtman, Mani, & Fockert, 2011; Bavelier, Green, Schrater, & Pouget, 2012). In turn, these skills would allow VGPs to more efficiently extract task-relevant statistics and outperform NVGPs on a variety of tasks (Bavelier et al., 2012).

Although video game research has focussed mostly on perceptual, attentional, and cognitive tasks, action video games offer more than just perceptual and attentional challenges to the people playing them. Success in first-person shooter video games also requires high levels of motor performance, as various targeting weapons must be rapidly and accurately brought to bear on a wide range of dynamic visual targets. Despite the connection between motor control and video game playing, relatively little research has been done on the topic beyond measuring keypress responses (e.g., Clark, Lanphear, & Riddick, 1987). In an earlier study that focused on hand-eye coordination using a pursuit rotor task, Griffith, Voloschin, Gibb, and Bailey (1983) found that VGPs outperformed NVGPs. More recently, Romano Bergstrom, Howard, and Howard (2012) examined the effect of video gaming on learning stimulus sequences (also see Ikeda et al., 2013). They exposed VGPs and NVGPs to high- and low-frequency sequences of stimuli and found a greater advantage of high-frequency sequences for VGPs relative to NVGPs. It is worth noting that Romano Bergstrom et al. used a set of four discrete stimuli each assigned to a separate response, extending the work of Clark et al. (1987) to sequences of key presses in young adults. No study, to the best of our knowledge, has studied the effect of chronic video game playing on a measure of sensorimotor control. We do so in the present study, due to the advantages that such a measure offers in terms of sensorimotor control and learning.

We chose to examine performance on a visually guided manual tracking task (e.g., Hah & Jagacinski, 1994; Wickens, 1976; Wulf & Schmidt, 1997). In our version of the task, a target object moves along the horizontal midline of the display, varying in speed and direction of movement, and subjects are asked to track it by moving a mouse-driven cursor. This task has several advantages for determining the effect of video game playing on sensorimotor control and learning. First, it uses an extremely simple display (one target dot, one cursor dot), which is quite unlike any action video game, creating a level playing field for both groups. Second, this task does not involve presenting the subjects with irrelevant or distracting information, and thus does not involve any sort of top-down control over information acquisition (which, as noted above, VGPs appear to have an advantage over NVGPs). Third, both VGPs and NVGPs will have had years of experience using computer mice, thus limiting differences due to the movement apparatus. Fourth, it provides a sensitive measure of motor performance, as the difference between the target dot and cursor can be measured across the entirety of each trial. Thus, minor changes in tracking performance can have large numerical consequences. Fifth, this task provides ample opportunity to see sensorimotor learning and improvement in performance over trials. Sixth, it is possible to separate differences in sensorimotor learning from differences in sensorimotor control. This is accomplished by having the motion of the target following a consistent (Experiment 1) or inconsistent (Experiment 2) pattern. With a consistent (i.e., repetitive) motion pattern, aside from overall sensorimotor control, sensorimotor learning can also contribute to task performance. Given that the pattern of motion repeats, better learning would enable participants to predict target motion at any given moment and track the target with higher accuracy. On the other hand, with inconsistent motion patterns, target motion will be unpredictable and, therefore, task performance would be driven by participants' overall sensorimotor control. The last two benefits are particularly important in light of the recent proposal that the advantage of action video game playing is in an enhanced ability to learn (Bavelier et al., 2012). This proposal makes the critical prediction that, it is the rate at which the two groups learn a consistent pattern of motion that results in a VGP advantage.

2. Experiment 1

In this experiment, participants were asked to simply track a moving dot across the display using a mouse-driven cursor. Unbeknownst to the subjects, the dot moved according to a complex waveform that was repeated every 5.2 s (i.e., following a periodic function). Because of the repetition, tracking performance is expected to improve over the course of trials as people learn the pattern through intrinsic (i.e., watching the proximity of their cursor to the target) and extrinsic feedback (i.e., a numeric representation of their accuracy at the end of each trial). In light of the recent proposal that action video game playing enhances the ability to learn (Bavelier et al., 2012), we predicted that VGPs and NVGPs would perform similarly at the start of the task but VGPs faster motor learning rate would allow them to outperform NVGPs over the course of the trials.

2.1. Method

2.1.1. Participants

Eighteen VGP (mean age = 24, SD = 8) and 18 NVGP (mean age = 22, SD = 4) gave their informed consent and performed the task in exchange for $10. All participants were male. The criterion for being considered a VGP was playing first-person shooter games (e.g., Call of Duty) a minimum of 3–4 times per week during the past six months, with a minimum of two hours of playing time on each day. The criterion to be considered a NVGP was little or no video game usage in the past two years.

2.1.2. Apparatus and stimuli

The task was performed in a quiet and dimly lit room, on Windows-run PC. Visual stimuli were presented on 19″ CRT monitors set at 1024 × 768 resolution and 85 Hz refresh rate. The experiment was run in MATLAB (MathWorks, Natick, MA), using the Psychophysics toolbox (Brainard, 1997; Pelli, 1997; version 3.0.8). Participants were instructed to control a green, square-shaped (.4° × .4°) cursor using a corded computer mouse, and try to keep the cursor at the center of a white, square-shaped (1.6° × 1.6°) moving target at all times. The green cursor and the white target were displayed against a black background.

The motion of the target square was along the horizontal axis (i.e., constant along the vertical axis; $Y = Y_{center}$) and determined by the periodic function $X(i) = X_{center} - 50\sin(i) + 30\cos(i) - 35\sin(2i) - 40\cos(2i) + 35\sin(3i) + 45\cos(3i) + 20\sin(4i) + 10\cos(4i) - 35\sin(5i) - 35\cos(5i) + 10\sin(6i) + 25$

cos(6*i*). This function outputs the location of the moving target in pixels, ranging from 382 to 675 (i.e., covering 11.7° of visual angle). The function input (i) increased in steps of .06 every 50 ms, and thus the function went through a full periodic cycle every 5.2 s. A sample of this motion is shown in Fig. 1 (black line). The motion of the cursor, controlled by the participant, was also sampled every 50 ms. Fig. 1 shows an example of this response motion (gray line).

The goal of the task was to stay as close to the moving target as possible. It would not be enough to simply mimic the motion pattern (with a delay), but the aim is to position the controlled cursor at the actual position of the moving target, as much as possible. Consequently, the average deviation from the target (i.e., the target-cursor distance) provides an index of performance, with small values indicating small deviation from the target motion, and higher accuracy. As described below, we averaged this deviation across the periodic cycle of the target motion.

2.1.3. Procedure and design

Each participant performed one practice trial as part of the instructions, and nine test trials. Each trial contained exactly 10 periodic cycles of the target motion and lasted just under a minute. At the end of each trial, participants were given feedback on their accuracy (i.e., average deviation from the target) and were given an opportunity to take a short break.

2.2. Results and discussion

As noted above, the deviation from the target motion was sampled every 50 ms The absolute values of deviations were then summed over each periodic cycle. This is the equivalent of a Riemann sum over the interval, which approximates the total area between the line graphs (or the area underneath their difference function) over one cycle of the function, with smaller areas indicating less deviation from the target and higher accuracy. The mean deviation per cycle was then calculated for each trial (Fig. 2).

Based on the expectation of a steady improvement in performance (i.e., steady decrease in deviation per cycle), we submitted the data to a trend analysis, with trial (1–9) and group (NVGP vs. VGP) as

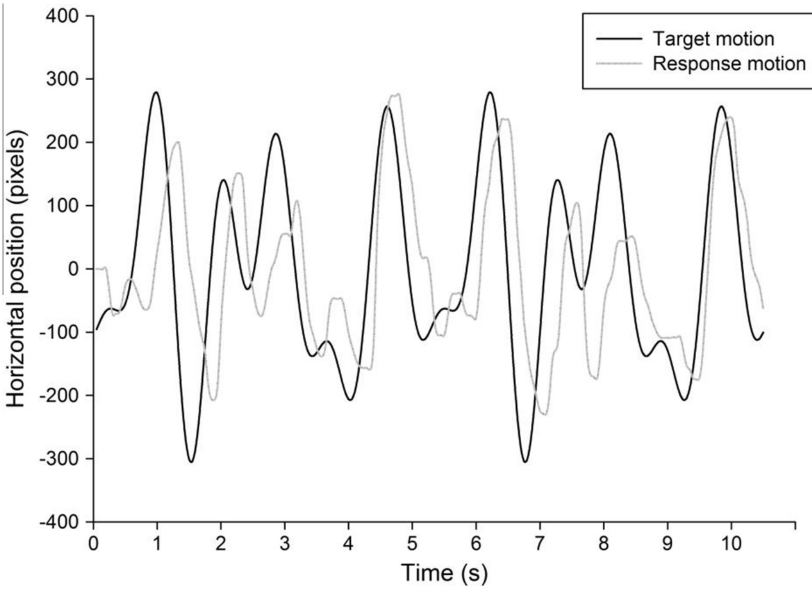

Fig. 1. Illustrates the target motion and the response motion (i.e., participant's tracking the target motion) in a period of 10 s, which contains about 2 periodic cycles of the target motion. Each trial of the experiment consisted of 10 periodic cycles. Performance was measured as the average deviation from the target per cycle.

factors. As expected, this analysis revealed a highly significant linear main effect of trial [$F(1,34) = 151.31$, $p < .001$, $\eta_p^2 = .817$], and none of the higher-order components reached significance. Most importantly, the linear decrease in deviation was modulated by group type [$F(1,34) = 4.67$, $p = .038$, $\eta_p^2 = .121$]. The estimated linear coefficients (using the *polyfit* MATLAB function) were −99.1 and −141.5 for the NVGP and VGP groups, respectively, indicative of a faster improvement in the VGP group. Finally, the main effect of group also reached significance [$F(1,34) = 4.34$, $p = .045$, $\eta_p^2 = .113$].

When comparing the two groups on each individual trial, using paired-samples *t*-tests, the two groups did not differ on the first 3 trials (*p* values >.1), which suggests that the two groups could not be distinguished at the beginning of the experiment. By contrast, the last 3 trials showed a significant difference between the two groups (*p* values = .050, .015, and .025, respectively, for the last three trials). Contrasting the groups over the last three trials combined yielded significantly better performance for VGPs ($p = .024$, Cohen's $d = .79$).

We should, of course, address the possibility that the inter-group differences might be driven by a few outliers. To do so, we set outlier criteria defined as scores that fall 2*SD* above or below the group Mean. The criteria were calculated separately for VGP (Mean = 3404; SD = 448) and NVGP (Mean = 3892; SD = 886) groups and resulted only one outlier in the NVGP group, whose performance (score = 5819) was poor relative to the rest of the group (see Fig. 3). Exclusion of this participant weakened, but did not eliminate, the interaction ($F[1,33] = 4.29$, $p < .05$, $\eta_p^2 = .115$). Contrasting VGPs and NVGPs in the last three trials confirmed better performance in VGPs ($p < .05$, Cohen's $d = .70$). Also of note, the distribution of scores shown in Fig. 3 also reveals the difference in variance between the two groups (Levene's test of homoscedasticity: $F[1,33] = 5.16$, $p = .03$). To address the concern about variances we repeated the analysis after calculating $\log_{10}$ transform of the deviation scores, which reduced the difference in variance [Levene's test: $F[1,33] = 2.98$, $p = .094$). Once again, this transform weakened but did not eliminate the interaction ($F[1,33] = 4.02$, $p = .05$, $\eta_p^2 = .109$). Once

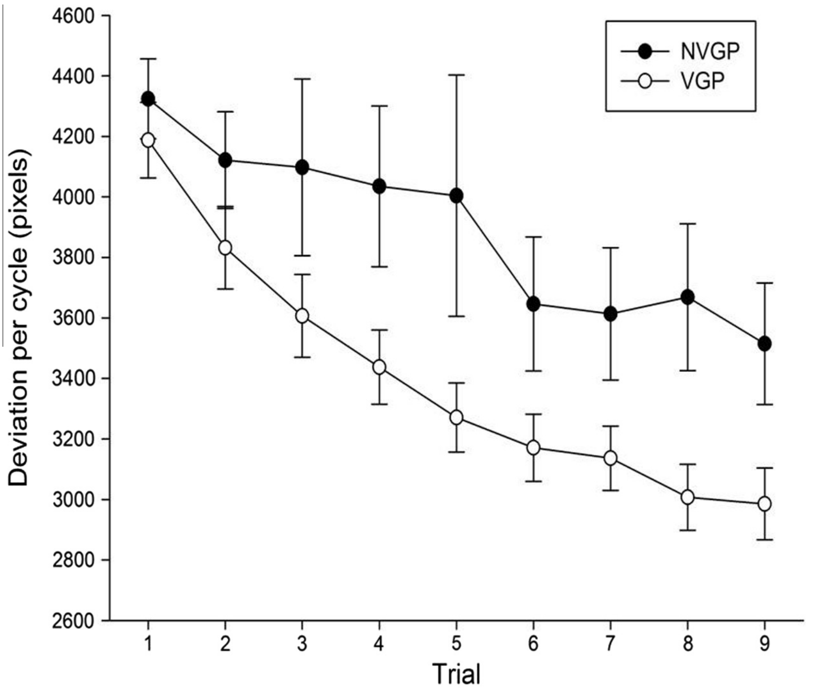

Fig. 2. Performance in Experiment 1 (mean deviation per cycle) graphed as a function of time (trial) and group (VGP vs. NVGP). Error bars show the standard error of the means.

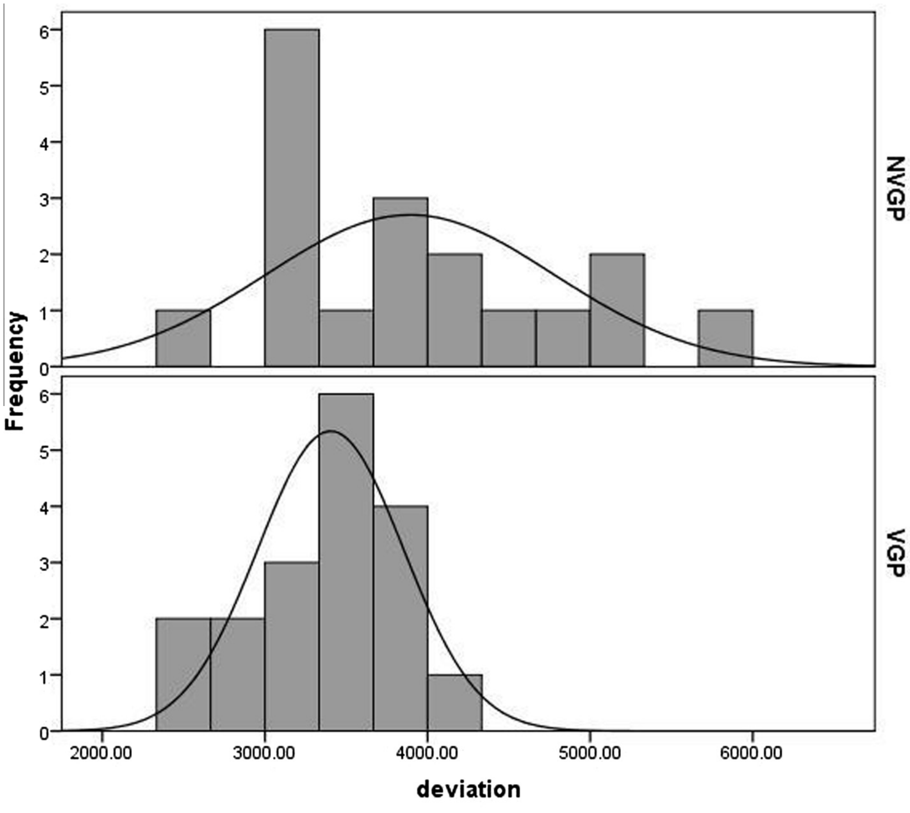

Fig. 3. Distribution of deviation scores for subjects in Experiment 1 separated by group (VGP vs. NVGP).

again, contrasting the groups over the last three trials combined showed better performance for VGPs ($p < .05$, Cohen's $d = .67$). Therefore, the difference between the two groups cannot be attributed to outliers or to the inter-group difference in variance.

Two important findings come from this experiment. The first finding concerns the data from the very first trials, where VGP performance was not significantly better than NVGP performance. This suggests that while chronically playing action video games requires constant motor control, playing these games does not confer a reliable advantage in a novel sensorimotor task. Therefore, the fact that two groups did not differ at the beginning is inconsistent with the possibility that the difference is due to a between-group difference in sensorimotor control. The second finding is that by the end of the experimental session, VGPs were significantly more accurate in following the repetitive motion of the dot than NVGPs. This difference between the two groups is likely due to the VGPs superior ability to learn the novel sensorimotor task.

3. Experiment 2

The VGP advantage seen in the first experiment is likely due to superior sensorimotor learning of the repetitive pattern of motion. Nevertheless, the benefit might also reflect, to some degree, better sensorimotor control in the VGP group. To test if a difference in sensorimotor control is at work, the present experiment also required participants to track a moving dot, but now the pattern of motion was unique on every trial. Due to the inconsistent pattern of motion, the contribution of learning would be minimal throughout the session. If VGPs show superior performance, this superiority could be primarily attributed to better overall sensorimotor control. The lack of an inter-group difference, however, would support the notion that the intergroup difference observed in Experiment 1 was due to the VGPs enhanced ability to learn the predictable pattern of motion.

3.1. Method

These were identical to Experiment 1, with the exception that the motion pattern of the target changed on every trial. The same twelve trigonometric functions were used to make-up the motion, but this time the coefficients were drawn randomly from a normal distribution (mean = 0, SD = 30). These coefficients were set at the beginning of each trial and remained constant until the end of the trial. Naturally, this means that the difficulty level varied, and was unique for, each trial., Also, the same trial (e.g., trial 1) did not have the same difficulty level across all participants. A total of twenty-four new male participants took part in this experiment in exchange for $10. Based on the same criteria as Experiment 1, 12 participants (mean age = 20, SD = 4) were VGPs and the other 12 were NVGPs (mean age = 23, SD = 5). Each participant performed one practice trial as part of the instructions, and nine test trials. Each trial contained exactly 10 periodic cycles of the target motion and lasted just less than 1 min. Similar to the previous experiment, at the end of each trial, participants were given feedback on their accuracy and were given an opportunity to take a short break.

3.2. Results and discussion

The mean deviation per cycle was calculated for each trial (Fig. 4). Given that the target motion pattern changed across trials, we did not expect a steady learning pattern. Indeed, a trend analysis of deviation as a function of Trial and Group revealed significant second-, fifth-, and seventh-order relationship between deviation and Trial (F values > 18, p values < .001, $\eta_p^2 > .45$), while the linear effect of

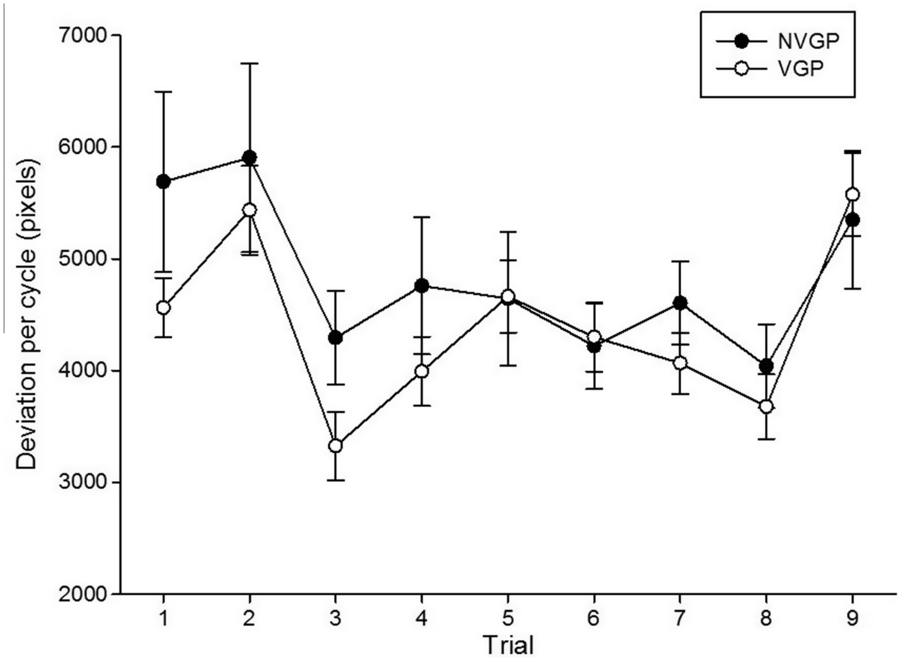

Fig. 4. Performance in Experiment 2 (mean deviation per cycle) graphed as a function of time (trial) and group (VGP vs. NVGP). Error bars show the standard error of the means.

Trial just reached significance ($F[1,22] = 4.34$, $p = .049$, $\eta_p^2 = .165$). Interestingly, the linear component was modulated by Group [$F(1,22) = 6.02$, $p < .05$, $\eta_p^2 = .215$). The estimated linear coefficients (using the *polyfit* MATLAB function) were -1.90×10^{-3} and 1.00×10^{-4} for the NVGP and VGP participants, respectively. Although both linear coefficients are extremely small and should be interpreted with caution, the non-negative coefficient for the VGP group clearly establishes that unlike in Experiment 1 performance in VGPs did not improve as time went by. Finally, no main effect of Group was found [$F(1,22) = .67$].

Even when comparing the two groups on each individual trial, using paired-samples *t*-tests, the two groups did not differ on any of the trials (p values > .05), suggesting that the two groups could neither be distinguished at the beginning nor at the end of the experiment. Failing to find an inter-group difference refutes the possibility that VGPs possess enhanced overall sensorimotor control.

4. General discussion

In the present study, VGPs and NVGP performed a manual motion-tracking task to determine the effect of action-video game playing experience on sensorimotor control and sensorimotor learning. In Experiment 1, a complex target waveform pattern was repeated over several trials, whereas in Experiment 2 the target waveform changed on every trial. Two important findings come from these experiments. The first finding concerns an inter-group difference found in Experiment 1; VGPs outperformed NVGPs during the last trials of the first experiment. The second finding concerns Experiment 2, as well as the very first trials of Experiment 1, where VGP performance was not significantly better than NVGP performance. Therefore, while chronically playing action video games requires constant motor control, playing these games does not confer a reliable advantage in a novel sensorimotor task. The fact that two groups did not differ with regard to a novel pattern of motion pattern suggests the inter-group difference is not due to a difference in sensorimotor control. Instead, we propose that the difference between the two groups at the end of the Experiment 1 should be attributed to a difference in sensorimotor learning.

At this point is worth a reminder that an important characteristic of the present experiment was the simplicity of the display, which consisted of only a target and a cursor. This display did not require subjects to inhibit task-irrelevant distractors and, therefore, any advantage that is based on enhanced distractor suppression would not have affected the present task. It is possible, that with a more cluttered display, a reliable difference would have been observed even at the very beginning. But in a task without any perceptual or attentional selection processes, VGPs did not show a reliable advantage over NVGPs in terms of sensorimotor control.

An important concern in studying the effect of chronic video game playing is that any differences found in the experimental task may be due to innate differences between the groups and not due to exposure to gaming. The lack of differences across the first three trials in Experiment 1, and the null effect of group in Experiment 2, both suggest that the VGPs were not inherently different from the sample NVGPs with respect to basic perceptual or motor capacities. The present study utilized a very sensitive measure of fine manual motor performance and a task with clear regularities. We were able to show that although VGPs do not initially show better motor tracking performance, they more rapidly improve their tracking performance than NVGPs, outperforming NVGPs in less than seven minutes of task practice. Thus, while training studies are certainly necessary to unambiguously establish the impact of action game play on performance, the finding of group differences when regularities are present but not otherwise weakens any explanation of our main result in terms of differences in subjects motivation or of a bias introduced by subject selection (see Boot et al. (2011) and Green, Strobach, and Schubert (2013) for different views on this issue).

Given the present findings, we propose that VGPs exploited the consistent pattern of motion over the course employed in Experiment 1 to better anticipate the motion trajectories and thus show a greater decrease in tracking error. A way of characterizing the outcome of this learning is in terms of an enhanced dynamic representation of the target, which at any given moment would result in an accurate *representational momentum* (e.g., Hubbard, 1995, 1997, 1998). Whereas representational momentum is often described as a perceptual phenomenon, namely as anticipating a target's movement properties based on its current state, this form of representation may also interact with knowledge of the moving target acquired from previous exposure to the entire pattern.

In anticipating motion trajectory at any given moment, both perceptual and motor systems could have contributed, and the precise contribution of each system is unclear based on our results. That is, both the perception of the moving target at any moment, as well as the participants' kinesthetic-proprioceptive state could act as retrieval cues for the upcoming changes to the target trajectory. Hence, we use the general term sensorimotor learning in describing the finding. Regardless of the contribution of the perceptual and motor systems, the findings are consistent with the "learn to learn" hypothesis proposed Bavelier et al. (2012). In reviewing the video game literature, these authors suggested that greater attentional control may allow VGPs to learn new task patterns more efficiently, which would explain transfer to a rather wide range of skills. The ability to learn novel patterns is essential in successful performance in action video games, allowing VGPs to devote processing resources in a manner consistent with the demands of a game. These demands can range from short-term (e.g., strike an enemy) to long-term goals (e.g., complete the mission). An enhanced ability to extract patterns from noise and/or discover goal-relevant task statistics would allow players to better predict upcoming events and to allocate perceptual and cognitive resources in a manner to take advantage of those predictions.

In the present context, the literature on laparoscopic surgery training is interesting to consider. Rosser et al. (2007) were the first ones to describe a potential positive impact of being a VGP on laparoscopic surgery skills, which involve high precision manual control of remote surgery tools through a computer interface. Regardless of prior experience with surgery, young surgeons who reported playing video games regularly completed the laparoscopic task faster and more accurately. Since then, the role of video game and in particular action video game training on laparoscopic surgery skill has been considered. In particular, Schlickum, Hedman, Enochsson, Kjellin, and Felländer-Tsai (2009) performed a training study in which surgical novices were trained on one of two interventions, including an action game playing, and tested in an endoscopic surgical simulator. Those trained in an action game outperformed those trained in the control intervention (chess), confirming the causal role of action game play (for a review, see Lynch, Aughwane, & Hammond, 2010). One of the advantages conferred by action game play may be the enhanced ability to precisely learn the dynamics of new sensorimotor control tasks, a skill that would clearly facilitate laparoscopic surgery skills. Recently, the comparison of computer literates versus computer illiterates has documented changes in visuo-motor capacity. Specifically, when computer literates learn a new rule that coordinates their hand movements with movements of a computer cursor, they learn the coordination in a directionally general manner compared to computer illiterates (Wei et al., 2014). While the use of new technologies appear to alter our visuo-motor capacity, the precise nature of these changes appears rather specific with the type of technology use, calling for more studies if we are to understand the type of use that confers specific versus transferrable motor skills. We recognize that our study is only a first step in that direction; but contrasting visuo-motor learning and visuo-motor control as a function of technology use should be an interesting avenue for future work.

References

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

Bavelier, D., Achtman, R. A., Mani, M., & Fockert, J. (2011). Neural bases of selective attention in action video game players. *Vision Research, 61*, 132–143.

Bavelier, D., Green, C. S., Schrater, P., & Pouget, A. (2012). Brain plasticity through the life span: Learning to learn and action video games. *Annual Reviews of Neuroscience, 35*, 391–416.

Boot, W. R., Blakely, D. P., & Simons, D. J. (2011). Do action video games improve perception and cognition? *Frontiers in Psychology, 2*.

Boot, W. R., Kramer, A. F., Simons, D. J., Fabiani, M., & Gratton, G. (2008). The effects of video game playing on attention, memory, and executive control. *Acta Psychologica, 129*, 387–398.

Brainard, D. H. (1997). The psychophysics toolbox. *Spatial Vision, 10*, 433–436.

Cain, M. S., Landau, A. N., & Shimamura, A. P. (2012). Action video game experience reduces the cost of switching tasks. *Attention, Perception, & Psychophysics, 74*, 641–647.

Castel, A. D., Drummond, E., & Pratt, J. (2005). The effects of action video game experience on the time course of inhibition of return and the efficiency of visual search. *Acta Psychologica, 199*, 217–230.

Clark, K., Fleck, M. S., & Mitroff, S. R. (2011). Enhanced change detection performance reveals improved strategy use in avid action video game players. *Acta Psychologica, 136*, 67–72.
Clark, J. E., Lanphear, A. K., & Riddick, C. C. (1987). The effects of videogame playing on the response selection processing of elderly adults. *Journals of Gerontology, 42*, 82–85.
Chisholm, J. D., Hickey, C., Theeuwes, J., & Kingstone, A. (2010). Reduced attentional capture in action video game players. *Attention, Perception & Psychophysics, 72*, 667–671.
Chisholm, J. D., & Kingstone, A. (2012). Improved top-down control reduces oculomotor capture: The case of action video game players. *Attention, Perception & Psychophysics, 74*, 257–262.
Colzato, L. S., van den Wildenberg, W., Zmigrod, S., & Hommel, B. (2013). Action video gaming and cognitive control: Playing first person shooter games is associated with improvement in working memory but not action inhibition. *Psychological Research, 77*, 234–239.
Colzato, L. S., Waszak, F., Nieuwenhuis, S., Posthuma, D., & Hommel, B. (2010). The flexible mind is associated with the catechol-O-methyltransferase (COMT) Val 158 Met polymorphism: Evidence for a role of dopamine in the control of task-switching. *Neuropsychologia, 48*(9), 2764–2768.
Donohue, S. E., Woldorff, M. G., & Mitroff, S. R. (2010). Video game players show more precise multisensory temporal processing abilities. *Attention, Perception, & Psychophysics, 72*, 1120–1129.
Feng, J., Spence, I., & Pratt, J. (2007). Playing an action video game reduces gender differences in spatial cognition. *Psychological Science, 18*, 850–855.
Green, C. S., & Bavelier, D. (2003). Action video games modify visual selective attention. *Nature, 423*, 534–537.
Green, C. S., & Bavelier, D. (2006a). Effect of action video games on the spatial distribution of visuospatial attention. *Journal of Experimental Psychology: Human Perception and Performance, 32*, 1465–1478.
Green, C. S., & Bavelier, D. (2006b). Enumeration versus object tracking: Insights from video game players. *Cognition, 101*, 217–245.
Green, C. S., & Bavelier, D. (2012). Learning, attentional control and action video games. *Current Biology, 22*, 197–206.
Green, C. S., Strobach, T., & Schubert, T. (2013). On methodological standards in training and transfer experiments. *Psychological Research*. http://dx.doi.org/10.1007/s00426-013-0535-3 [epub ahead of print].
Griffith, J. L., Voloschin, P., Gibb, G. D., & Bailey, J. R. (1983). Differences in eye-hand motor coordination of video-game users and non-users. *Perceptual and Motor Skills, 57*(1), 155–158.
Hah, S., & Jagacinski, R. J. (1994). The relative dominance of schemata in a manual tracking task: Input patterns, system dynamics, and movement patterns. *Journal of Motor Behavior, 26*, 204–214.
Hubbard, T. L. (1995). Cognitive representation of motion: Evidence for representational friction and gravity analogues. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 21*, 241–254.
Hubbard, T. L. (1997). Target size and displacement along the axis of implied gravitational attraction: Effects of implied weight and evidence of representational gravity. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 23*, 1484–1493.
Hubbard, T. L. (1998). Representational momentum and other displacements in memory as evidence for nonconscious knowledge of physical principles. In S. R. Hameroff, A. W. Kaszniak, & A. C. Scott (Eds.), *Toward a science of consciousness II: The second Tucson discussions and debates* (pp. 505–512). Cambridge, MA: MIT Press.
Hubert-Wallander, B., Green, C. S., & Bavelier, D. (2010). *Stretching the limits of visual attention: The case of action video games*. WIREs Cognitive Science: Wiley. 1.
Ikeda, H., Kasahara, K., Tanaka, S., Hanakawa, T., Honda, M., Kato, R., & Watanabe, K. (2013). Visual-motor sequence learning by competitive fighting game experts. In: *5th international conference on Knowledge and Smart Technology (KST), 2013* (pp. 178–181). IEEE.
Li, R., Polat, U., Scalzo, F., & Bavelier, D. (2010). Reducing backward masking through action game training. *Journal of Vision, 10*, 1–13.
Lynch, J., Aughwane, P., & Hammond, T. M. (2010). Video games and surgical ability: A literature review. *Journal of Surgical Education, 67*, 184.
Karle, J. W., Watter, S., & Shedden, J. M. (2010). Task switching in video game players: Benefits of selective attention but not resistance to proactive interference. *Acta Psychologica, 134*, 70.
Krishnan, L., Kang, A., Sperling, G., & Srinivasan, R. (2013). Neural strategies for selective attention distinguish fast-action video game players. *Brain Topography, 26*, 83–97.
Kristjánsson, Á. (2013). The case for causal influences of action videogame play upon vision and attention. *Attention, Perception, & Psychophysics, 75*, 667–672.
Mishra, J., Zinni, M., Bavelier, D., & Hillyard, S. A. (2011). Neural basis of superior performance of video-game players in an attention-demanding task. *The Journal of Neuroscience, 31*, 992–998.
Pelli, D. G. (1997). The VideoToolbox software for visual psychophysics: Transforming numbers into movies. *Spatial Vision, 10*, 437–442.
Romano Bergstrom, J. C., Howard, J. H., & Howard, D. V. (2012). Enhanced implicit sequence learning in college-age video game players and musicians. *Applied Cognitive Psychology, 26*(1), 91–96.
Rosser, J. C., Lynch, P. J., Cuddihy, L., Gentile, D. A., Klonsky, J., & Merrell, R. (2007). The impact of video games on training surgeons in the 21st century. *Archives of Surgery, 142*, 181.
Schlickum, M. K., Hedman, L., Enochsson, L., Kjellin, A., & Felländer-Tsai, L. (2009). Systematic video game training in surgical novices improves performance in virtual reality endoscopic surgical simulators: A prospective randomized study. *World Journal of Surgery, 33*, 2360–2367.
Spence, I., & Feng, J. (2010). Video games and spatial cognition. *Review of General Psychology, 14*, 92–104.
Strobach, T., Frensch, P. A., & Schubert, T. (2012). Video game practice optimizes executive control skills in dual-task and task switching situations. *Acta Psychologica, 140*, 13–24.
Sungur, H., & Boduroglu, A. (2012). Action video game players form more detailed representations of objects. *Acta Psychologica, 139*, 327–334.
West, G., & Pratt, J. (2013). Action video game experience affects oculomotor performance. *Acta Psychologica, 142*, 38–42.

West, G., Stevens, S., Pun, C., & Pratt, J. (2008). Visuospatial experience modulates attentional capture: Evidence from action video game players. *Journal of Vision, 8*(13), 1–9.

Wei, K., Yan, X., Kong, G., Yin, C., Zhang, F., Wang, Q., et al (2014). Computer use changes generalization of movement learning. *Current Biology, 24*, 82–85.

Wickens, C. D. (1976). The effects of divided attention on information processing in manual tracking. *Journal of Experimental Psychology: Human Perception and Performance, 2*, 1–13.

Wu, S., Cheng, C. K., Feng, J., D'Angelo, L., Alain, C., & Spence, I. (2012). Playing a first-person shooter video game induces neuroplastic Change. *Journal of Cognitive Neuroscience, 24*, 1286–1293.

Wulf, G., & Schmidt, R. A. (1997). Variability of practice and implicit motor learning. *Journal of Experimental Psychology: Learning, Memory & Cognition, 23*, 987–1006.