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Examining associations between action game play and motor control☆

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ABSTRACT

The effects of playing action video games have been investigated across a wide range of attentional and cognitive abilities. However, few studies have examined the association between motor control and action gaming experience. We report data from two discrete pointing tasks, manipulating the index of difficulty (ID) by movement distance and target size, respectively. Participants' gaming experience ranged from non-players to individuals who played several hours a night. Our results indicated greater experience playing action games, but not video games in general, was associated with shorter movement times (MT), higher velocities, and shallower ID-MT slopes when difficulty was manipulated across increasingly further distances and smaller target sizes. Additionally casual players, those who only play action games a couple times a week, were able to achieve a similar level of performance as more experienced players.

1. Introduction

The hypothesis that playing action video games leads to improvements in cognitive abilities has garnered considerable attention in the literature for almost two decades. Yet it is still debated whether action games represent a type of cognitive training, and if so, which specific abilities are enhanced by action gaming experience. It is an old idea in psychology that transfer of training works better in near-transfer situations compared to far-transfer tasks (Thorndike & Woodworth, 1901). When training to perform a task, it is advantageous for the training task to be as similar as possible to the real task (see Baldwin & Ford, 1988, for a more recent review). Accordingly, Baniqued et al. (2013) performed a cognitive task analysis of several video games, to identify which cognitive abilities were required, demonstrating a link between the specific cognitive skills demanded by the games and the specific cognitive tasks improved in players of these games to support future cognitive training studies.

However, many studies have suggested that the action video games genre is broadly effective as a method of cognitive training due to their demands on many aspects of cognition (e.g., executive functioning, visual processing, & attentional control), and in laboratory tests these have all been shown to be enhanced in action video game players (Green, Gorman, & Bavelier, 2016; Howard, Wilding, & Guest, 2017; Strobach, Frensch, & Schubert, 2012; Strobach & Schubert, 2016). Evidence of far-transfer is apparent in studies showing that gamers outperform non-gamers in complex daily activities such as driving (Rupp, McConnell, & Smither, 2016; Stinchcombe, Kadulina, Lemieux, Aljied, & Gagnon, 2017).

Notably, motor skills have not been well studied within this literature – which is perhaps not surprising because as Rosenbaum (2005) noted, the study of motor control has fallen out of favor among cognitive psychologists despite it being a foundational component of human behavior. However, in many action video games, skilled movements are a major component of gameplay. For example, in a typical first-person shooter game, players navigate by controlling a viewpoint through a 3D environment and must aim and shoot at small and/or moving targets. These visually guided actions are performed using controllers that vary across gaming platforms but can include gamepad-type controllers equipped with thumb-operated joysticks (e.g., Xbox or PlayStation controllers), traditional hand-operated joysticks, motion-based controllers (e.g. Wii controllers), or computer mice. These actions, and the devices used to perform them, are similar to many laboratory-based pointing tasks (e.g., Blanch, Guiard, & Beaudouin-Lafon, 2004; Card, English, & Burr, 1978; Fitts & Peterson, 1964; Goodale, Pelisson, & Prablanc, 1986; MacKenzie, 1992).

Because of this, action video games may train overlapping skills or strategies that lead to improvements on aiming tasks. In laboratory tests action game players were shown to outperform non-players on tests of

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visuospatial attention, object tracking, visual search efficiency, spatial visualization, and speed of processing (Castel, Pratt, & Drummond, 2005; Dye, Green, & Bavelier, 2009; Feng, Spence, & Pratt, 2007; Green & Bavelier, 2006a, 2006b; Strobach et al., 2012), all of which may relate to improved performance on sensorimotor tasks. Only a few studies however, have directly examined action game experience and sensorimotor control directly. One study found action gamers performed better on tasks that require action planning and goal selection, processes which are important for motor performance. However, this study also failed to find a link between game play and inhibitory control, another important aspect of aiming performance (Steenbergen et al., 2015).

Another study found action video game players to have better hand-eye coordination using a pursuit rotor task. However, because performance did not correlate with participants' length of game play experience the authors concluded the findings may be due to a self-selection bias among video game players (Griffith, Voloschin, Gibb, & Bailey, 1983). However, a more recent study found improvements on a tracking task after five hours of action game training (Chen, Chen, & Li, 2015), suggesting that playing action games may affect motor skill. Another study found action gamers were more accurate and faster on an implicit sequence learning task, compared to non-gamers (Romano Bergstrom, Howard Jr, & Howard, 2012). Successful sequence learning is thought to rely on sensorimotor control brain regions (i.e., motor cortex, basal ganglia, & cerebellum; Penhune & Steele, 2012) which suggests a neurocognitive mechanism for how action games may improve aiming performance. However, similar findings have also been seen in players of the fighting game *Guilty Gear*, which may indicate an advantage, more broadly, for games that require learning specific button sequences (Ikeda et al., 2013), or even rapid button pressing. Action game players also outperformed non-gamers on a standardized motor skill test battery that evaluated participants on aiming accuracy in a non-speeded task, motor tremor, movement coordination, and wrist speed (Borecki, Tolstych, & Pokorski, 2012). In a study of medical students using a surgical simulator, video game experience was associated with improved performance on two of the three manual tasks employed (Chung et al., 2017). Other studies have found correlations between short video game play sessions or self-reported game play and psychomotor tasks suggested to relate to laparoscopic surgery skill (Kennedy, Boyle, Traynor, Walsh, & Hill, 2011; Ou, McGlone, Camm, & Khan, 2013; Rosenberg, Landsittel, & Averch, 2005). However, due to cross sectional designs and limited number of hours of gameplay these studies do not elucidate the nature of motor skill acquisition involved in video games.

In contrast is a recent paper that studied video game players' performance on a manual pursuit tracking task (Gozli, Bavelier, & Pratt, 2014). In their first experiment, gamers did not outperform non-gamers at the beginning of the task, but showed improvement on the later trials. Further, when the tracking pattern varied randomly in their second experiment, preventing the possibility of learning the tracking path, there was no difference in tracking accuracy between the groups. These authors concluded that gaming experience conferred no advantage to overall motor control, only to learning. Similar findings were also reported using a motor imagery task – gamers did not outperform non-gamers, but did learn the task faster (Vourvopolous, Badia, & Liarokapis, 2017).

One limitation of the study on tracking performance (Gozli et al., 2014) was that it only addressed spatial accuracy. While accuracy is an important part of motor skill, so is speed, as is highlighted by Fitts' law (Fitts, 1954) and the speed/accuracy tradeoff. It seems reasonable, then, to hypothesize that activities that boost cognition and speed of processing may lead to improved performance on a Fitts' task. Dye et al. (2009) reviewed studies of action video game players using tasks that required speeded responses – primarily tests of attention and memory. Using a meta-analysis, these authors concluded that the literature consistently shows that video game players have faster reaction times compared to non-gamers, and without a corresponding sacrifice in accuracy. While none of the reviewed tasks were tests of motor skills, the idea that speed of processing was increased without a decline in accuracy is relevant to Fitts' law, which provides a mathematical description of the speed/accuracy tradeoff in human movement.

Visually guided actions, such as the fast and accurate pointing movements employed in Fitts' task, place demands on one's physical, perceptual, and cognitive capabilities. Prior to the initiation of such actions, the perceptuomotor system must gather information about hand and target and plan at least the initial portion of the movement (Desmurget, Pélisson, Rossetti, & Prablanc, 1998). Evidence shows that task difficulty is associated with increased cognitive demands during movement preparation. For example, several classic studies have found that reaction time (RT), presumably during which movement planning occurs, increases as a function of the number of target stimuli (e.g., Donders, 1869/1969), especially when measured in terms of response entropy (Hick, 1952; Hyman, 1953). Fitts (1954) defined task difficulty in terms of his index of difficulty (ID), which depends on the movement distance and target size. While ID does not increase RT (Fitts & Peterson, 1964; Zaleski & Moray, 1986), a recent study found that it does alter the amplitude of EEG signals associated with movement preparation, suggesting that it influences some aspects of this stage (Kourtis, Sebanz, & Knoblich, 2013).

Fitts' ID has a well-known influence on movement time (MT). The linear relationship between ID and MT is known as Fitts' law and has been shown to apply to discrete reaching movements (e.g., Fitts & Peterson, 1964), underwater movements (Hancock & Milner, 1982; Kerr, 1978), movements viewed under magnification (Langolf & Hancock, 1974), and numerous computer-based pointing tasks (e.g., Card et al., 1978; MacKenzie, 1992). The fact that MT, rather than RT, is affected by ID is consistent with the idea that feedback processes are active during movement performance (see Elliott, Helsen, & Chua, 2001). Many studies suggest that some portion of the movement is planned in advance, and feedback is used only near the end of the movement when the hand is near the target (e.g., Elliott et al., 2001; Meyer, Abrams, Kornblum, Wright, & Keith Smith, 1988; Woodworth, 1899), while others emphasize that feedback can be used to correct for errors continuously throughout the movement (Saunders & Knill, 2004, 2005).

Together, these findings indicate that movement preparation and performance involve multiple types of information processing. Fitts' task is designed for participants to be both fast and accurate, with the goal of maximizing the amount of information processed during the task. As with many demanding cognitive tasks, performance on Fitts' task can be impaired in dual-task conditions (Kerr, 1978; Van Galen & Van Huygevoort, 2000; Vidulich, 1988) and in the presence of stressors (Van Galen & Van Huygevoort, 2000; Van Gemmert & Van Galen, 1997; 1998). Age-related declines in performance on Fitts' task have also been attributed to declines in information processing (e.g., Temprado et al., 2013; Van Halewyck et al., 2014, 2015).

These findings can support a few hypotheses regarding action game experience and performance on Fitts' task. First, because of the similarity of Fitts' task to the actions performed in many games, the principle of near-transfer suggests that experienced gamers would be expected to outperform non-gamers on this task, as measured by shorter MT. Second, because action games are thought to improve cognitive performance, this may include movement planning and feedback processing. Third, it may also be true that gaming experience improves motor skill at the effector level, in terms of improved coordination in the performance of the pointing movement.

It is possible to study the relative contributions of the effector and information processing by experimental design. Previous pointing studies have found a dissociation between pointing performance in Fitts' task when ID is manipulated by movement distance compared to target size (Heath, Samani, Tremblay, & Elliott, 2016; Heath, Weiler, Marriott, Elliott, & Binsted, 2011; Huys, Knol, Sleimen-Malkoun, Temprado, &

Jirsa, 2015; Sleimen-Malkoun, Temprado, Huys, Jirsa, & Berton, 2012). Decreasing target size results in an extension of the decelerative phase of the movement, as movements become more reliant on feedback processes (e.g., Chua & Elliott, 1993). This results in an overall change in the symmetry of the velocity profile of the movement, with greater asymmetry at smaller target sizes (Bootsma, Fernandez, & Mottet, 2004; Fernandez & Bootsma, 2004). Thus, the size of the target has been termed a task constraint, as it alters the underlying control and organization of the movement (Fernandez & Bootsma, 2004; Thompson, McConnell, Slocum, & Bohan, 2007). In contrast, increasing movement distance is considered an effector constraint, as it is associated with increasing movement velocities, but with no change in the relative durations of the accelerative and decelerative phases, and thus no change in the symmetry of the velocity profile (Fernandez & Bootsma, 2004; Thompson et al., 2007).

Accordingly, if gaming experience improves performance on Fitts' task because of improvements in information processing, then manipulations of target size while holding movement distance constant should reveal such differences in the form of the duration of the slow-velocity corrective phase of the movement. Experienced gamers should exhibit shorter durations of this phase, consistent either with improved movement planning that results in a more accurate initial impulse toward the target, or with improved feedback processing that shortens the duration of the corrective phase. If gaming experience improves performance because of improved effector coordination, then manipulations of movement distance while holding target size constant should reveal differences in the initial impulse, with higher peak velocities and shorter MT for experienced gamers. These are not mutually exclusive hypotheses, and so it remains possible that both sets of findings may be obtained.

2. Methods

2.1. Participants

Participants in the current study were selected as a part of a larger study on aging and motor control that contained a total of 189 participants (73 men; 116 women) between the ages of 18–86 years ($M = 47.37$, $SD = 23.36$, 95% CI: [43.97; 50.77]). From this participant pool, 51 healthy right-handed young-adult participants were identified as meeting the inclusion criteria for the current study which included no reports of visual or motor impairments and their previous gaming experience (see participant selection section for details on how this sample was obtained). The 51 participants fell into one of three action game player groups ($n = 17$ per group), non-players (NPs, $M_{\text{age}} = 24.29$, 95% CI_{age} [20.59, 28.00], 12 men, 5 women), casual-players (CPs, $M_{\text{age}} = 21.53$, 95% CI_{age} [19.25, 23.81], 12 men, 5 women), or heavy players (HPs, $M_{\text{age}} = 22.94$, 95% CI_{age} [19.39, 26.49], 13 men, 4 women) based on their self-reported gaming history over the previous year. NPs did not report any action video game play over the previous year. CPs reported playing between 2 and 8 h per week of action video games ($M_{\text{AVG}} = 4.47$, 95% CI_{AVG} [3.44, 5.50]) and HPs reported playing 10 h or more per week of action games ($M_{\text{AVG}} = 23.70$, 95% CI_{AVG} [18.25, 29.16]). The most popular action games played among gamers were games in the *Call of Duty*, *Fallout*, *Battlefield*, *Borderlands*, *Counter Strike*, and *Halo* franchises in that order. The most played non-action games were sports games (e.g., *NBA 2k16*, *FIFA 16*, & *Madden*, *Pokémon* [*3DS titles*]), console adventure/RPG games (e.g., *Witcher*, *Skyrim*, *Kingdom Hearts*), and casual or handheld games (e.g., *Pokémon Go*, *Candy Crush*, *Bubble Witch*). The work described herein was carried out in accordance with the Declaration of Helsinki, ethical guidelines of the American Psychological Association, and informed consent was obtained prior to participation.

2.2. Participant selection

Due to lack of video game play in the middle and older adults and to control for differences in motor and cognitive abilities only younger adults between the ages of 18–30 were selected. Participants were then selected for the current study based on their responses on a post study video game survey. On the survey, participants were asked to list all of the video games they remember playing over the last year, along with a self-reported estimate for how many hours per week they spent playing each game. The video game genre of each game listed was used to create an estimate of the hours per week of both action game and non-action game play. Participants were also asked if they had any periods of time longer than one month spent not playing any reported games and if their previous gaming history over the previous year was less, similar to, or greater than what was reported. Only gaming experience of participants that reported a similar amount of gameplay the previous year as what they reported was examined further. Based on these criteria, 34 individuals with action game experience ranging from 2 to 50 h per week were identified in the dataset. To examine differences between casual and heavy action gamers, a median split (*mdn* = 9) was used to divide action players into two equal groups. Although we used a median split to separate casual and heavy action gamers, we note that 47.05% of the casual gamer group and everyone in the heavy gamer group met the action game player criteria established by Green et al. (2016). Finally, 17 age-matched non-video game players were selected randomly from a potential group of 33 non-video game players as a comparison sample. These latter participants were required to have reported no video game play in the past year on the post study video game survey and to have self-identified as a non-video gamer.

2.3. Study recruitment

A common concern in the literature on the cognitive benefits of video games is covert vs. overt recruitment (Boot, Blakely, & Simons, 2011). Participants who know they are in a gaming study may experience a placebo effect while non-players may be demotivated (Rupp et al., 2016) leading to performance differences. To account for this, we designed our study as a part of a larger study on motor control and aging. Because the current study was a part of a larger one, all study correspondence stated that the goal of the study was to examine age differences on movement performance. Additionally, the gaming experience survey was administered at the end of the study only after all performance data was acquired to ensure participants were not primed. Thus, participants were not informed that they were being assessed for their video game experience.

2.4. Materials

Pointing tasks were completed using a Wacom Intuos XL digitizing tablet with pen stylus with the standard pen nib. Targets were presented on a BenQ XL2730Z LED monitor, with a resolution of 2560 × 1440 and 120 Hz vertical refresh rate. The control-display ratio between the tablet and display was set at unity. Stimulus presentation, data recording, data filtering, and kinematic analyses were accomplished using the MovAlyzeR application (Neuroscript, LLC). This software was installed on a Dell Precision T3500 workstation running Windows 7.

Movements were filtered using a 10 Hz low pass Butterworth filter with a sharpness of 1.75. Data collection began when the stylus first contacted the tablet and the target appeared, and ended upon liftoff of the stylus after successful target acquisition. Movement initiation was defined as the point where velocity achieved at least 5% of the peak for that trial. Movement termination was defined as the point where velocity dropped below 5% of the peak. Movement time (MT) was then calculated as the duration from initiation to termination. The software subdivided movements into primary and secondary phases (Meyer et al., 1988) by finding the first local minimum in the velocity profile after peak velocity. The time duration of each phase was then calculated as the primary submovement time (PT) and secondary submovement time (ST). Further analysis was completed using MATLAB. Trials that were identified as having a movement time (MT) > 2.5 SDs above or below the mean, or had a MT < 200 ms, or > 10,000 ms were removed as bas trials (in each condition < 5% of trials were removed). Variables of interest included MT, the proportion of time spent in the secondary phase (PropST), peak velocity (PV), and time to peak velocity (tPV). Participants were screened for Snellen visual acuity using an Optec 5500p tester and completed the PAR-Q+ survey (Warburton, Jamnik, Bredin, & Gledhill, 2014) to report any physical or health conditions.

Visual processing efficiency, was tested using the Useful Field of View test (UFOV; e.g., Edwards et al., 2005). The UFOV consists of three tests that increasingly place demands on participants' visual processing abilities. In the first test (processing speed), participants are presented with an empty circular array (8 potential target locations: 0°, 45°, 90°, 135°, 180°, 225°, 270°, & 315°) around a central fixation point containing a reference stimulus box. While participants maintain fixation one of two stimuli (car or truck) is shown in the reference box for a display period that ranged from 13 to 500 ms. Following this display period participants report which stimuli appeared in the box. In the selective attention test an additional car or truck stimuli is displayed around the circular array at a random location. Participants have to identify the central target and the location of the peripheral target. Finally, in the divided attention test participants see a field of triangles along with the peripheral target and participants must filter out the distracting stimuli. All stimuli presentations are followed by a brief mask It is important to note that for UFOV scores lower ones are better as they represent the time the stimuli were displayed on screen in milliseconds.

2.5. Design

The current study was conducted in two blocks: a manipulation of movement distance while holding target size constant (distance condition), and a manipulation of target size while holding distance constant (size condition). All participants completed both tasks and order was counter-balanced across participants. Trials within each block were presented in a randomized order. The distance and width parameters of each movement condition are shown in Table 1. Within each block 15 repetitions of each ID were presented in a random order for a total of 75 trials per block. The Fitts' law ID was calculated using the following equation:

Fitts' law index of difficulty (ID). D is the distance, or amplitude, of the movement and W is the width, or size, of the target.

$$ID = log_2\left(\frac{2D}{W}\right) \tag{1}$$

Table 1
Experimental design for effector and task constraint manipulations.

ID manipulated by W (size)			ID manipulated by D (distance)		
D	W	ID	D	W	ID
16	4	3	32	0.5	7
16	2	4	16	0.5	6
16	1	5	8	0.5	5
16	0.5	6	4	0.5	4
16	0.25	7	2	0.5	3

Note: ID = index of difficulty, D = movement distance, W = target width/size, and ID calculated using the Fitts (1954) formulation. Distances are in cm.

All trials were self-paced which allowed participants to take breaks as needed between trials and blocks. Fig. 1 shows examples of discrete aiming trials from both the distance and width conditions. For both conditions a simulated index of difficulty of ID = 3 and ID = 7 were shown to show the differences between trial types.

2.6. Procedure

Participants completed the vision and health screening following the informed consent. Next, participants completed all three Useful Field of View (UFOV; Ball & Owsley, 1993) subtasks (processing speed, selective, and divided attention) in that order. Following this assessment, participants completed all pointing trials for both blocks while seated approximately 65 cm from the display. Participants were given practice at the beginning of each block until the experimenter judged they understood the task and participants acknowledged they were ready to continue. All movement tasks required participants to use a Wacom XL Intuos Pro digital tablet and stylus to control an onscreen cursor displayed as a small gray dot on the screen. The cursor remained visible throughout all trials. The active area of tablet surface was mapped to the monitor display so that movements of the stylus on the tablet surface controlled the onscreen position of the cursor. On each movement trial, participants were required to press a button on the Wacom tablet with their left hand to begin each trial. Once this button was pressed, a start position was displayed on the screen as a 0.5 cm black circle aligned to the center left of the screen offset from the tablet's edge by 1.5 cm (Fig. 1). Once the start position was displayed, participants were trained to align the stylus on the tablet with their right hand, so that the cursor appeared in the center of the start position. The hand grip on the stylus was not controlled, but participants were instructed not to rest their hands on the tablet surface. After 1000 ms from the onset of the start position, the start position disappeared and simultaneously, a target would appear on screen. Participants were instructed to move as quickly as possible while still being accurate to the target position as soon as it appeared then lift the stylus off the tablet screen. The program registered the start of each trial as the appearance of the target onscreen and the end of each the trial as the time when the stylus was removed from the tablet screen (i.e., pen pressure = 0). The end of each trial was marked by a short audible beep. Once participants started a block of trials, they continued until all trials within each block were completed, taking breaks as needed.

In order to prevent experimenter bias and participant knowledge of the association between video game play and performance, demographic and gaming experience surveys were given after all experimental trials were finished. We asked participants to report if they played video games or not. Participants who answered affirmatively, were asked to name the video games they have played over the previous year and to estimate the number of hours spent playing each game on an average week. This list was coded to estimate the gaming experience of each participant.

3. Results

All statistical tests were conducted in JASP v.082 and R v.3.42. Variables were checked for assumptions of normality and homogeneity of variance prior to analysis. After removal of bad trials the data from the remaining trial repetitions were averaged together to yield 255 mean values in each of the distance and width tasks for further analysis which were enough to employ a multiple regression approach. The kinematic variables were significantly skewed and kurtotic. Therefore, the analysis was conducted on the log transformed values for each variable (the non-transformed data are presented in tables and figures for ease of understanding). A hierarchical multiple regression analysis, using the backwards method, was used to analyze the main effects of ID, AVG hours per week (AVG HpW), and the interaction between ID and AVG HpW. The default P_{in} of 0.05 and P_{out} of 0.10 were used as

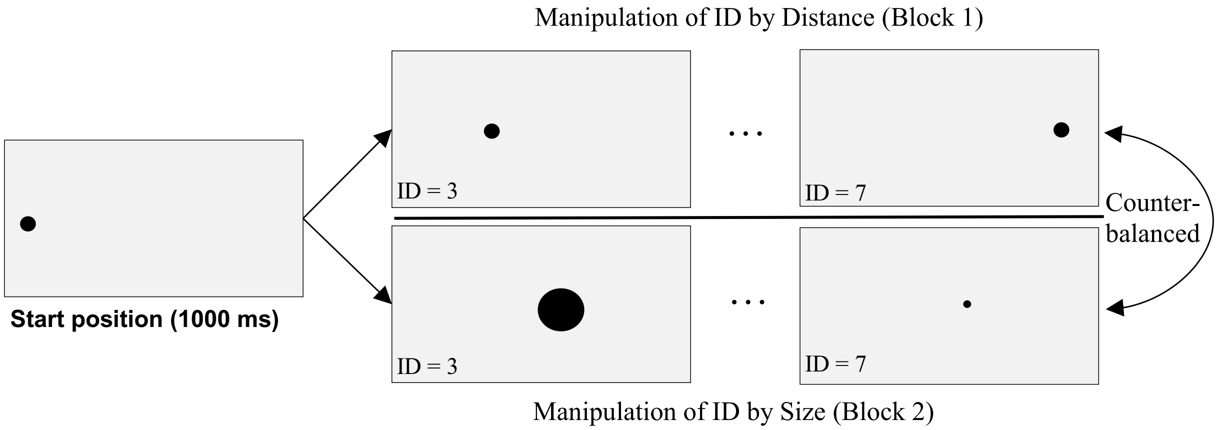

Fig. 1. Example of trials used in the discrete aiming task. ID = index of difficulty. All trials started with the stylus in start position. Participants completed either Block 1 or Block 2 followed by the remaining block. Trials were randomized within blocks across ID values.

entry and removal criteria in each model. We investigated the relationship between other non-AVG gaming hours per week as a potential covariate to each model to control for the influence of other video games. However, only AVG hours per week significantly correlated with study DVs and only a small correlation was found between AVG and non-AVG hours. This indicated that our gaming sample consisted of primarily action gamers, thus only AVG hours per week were included in each regression model. To determine differences between groups, 95% confidence intervals (CI's) between groups were examined and non-overlapping CI's were used as evidence for significant differences between groups. When CI's do not overlap between groups, this method produces good parity with traditional post-hoc methods and is easy to interpret; however, when effect sizes are small CI's may still somewhat overlap for significant differences (Schenker & Gentleman, 2001). Error bars represent 95% CI's for all figures. For clarity in the graphical depictions of the results, participants were subdivided into three groups: non-players, casual game players, heavy game players (see participants section for grouping criteria). The accompanying figures thus do not reflect the results of the regression analysis, but are consistent with it, while highlighting the CI of the group means.

3.1. Useful field of view

To examine differences in visual attention and speed of processing, we analyzed differences in reaction times during the three subtests of the UFOV (speed of processing, selective attention, & divided attention). Scores across all AVG groups were at ceiling for both the speed of processing and selective attention tests. Because the variance did not differ between the easier two subtests, we only analyzed differences for the divided attention test. Using a one-way ANOVA between AVG gaming groups and UFOV reaction time, we did not find any significant relationship between AVG play and UFOV performance, $F(2,48) = 0.52$, $p = .60$, $\eta^2 = 0.02$. Thus, while on average nonplayers ($M = 34.40$ ms; 95% CI = [26.65; 42.15]) and casual players ($M = 34.20$; 95% CI = [25.68; 42.72]) had slower reaction times on the divided attention subtest, these players did not differ from heavy players ($M = 26.17$ ms; 95% CI = [21.58; 30.76]).

3.2. Distance condition

An initial MANOVA examining ID, AVG HpW, and the ID × AVG HpW interaction using non-AVG HpW as a covariate was conducted on the five dependent variables of interest (MT, PropST, PV, tPV, & PD). The multivariate analysis revealed a significant main effect of ID, $F(20,952) = 51.97$, $p < .001$, Wilk's $\Lambda = 0.07$, partial $\eta^2 = 0.49$ and gaming group, $F(10,470) = 4.58$, $p < .001$, Wilk's $\Lambda = 0.87$, partial $\eta^2 = 0.07$, but not an ID × gaming group interaction, $F(40,1027) = 0.94$, $p = 1.00$, Wilk's $\Lambda = 0.95$, partial $\eta^2 = 0.01$ on the combined dependent variables.

3.3. Movement time (MT)

Intercorrelations between AVG HpW and study variables are shown in Table 2. In the first step of the model only ID was significant accounting for a large proportion of the variance accounted for ($\beta = 0.69$) and indicating movement time significantly increased as ID increased. In the second step of the model once the main effect of AVG HpW was removed we discovered a significant interaction between AVG HpW and ID ($\beta = -0.23$). This indicated that as movement time increased with ID this increase was attenuated for individuals with greater AVG hours per week. Confidence intervals for movement time for both CPs and HPs overlapped across all values ID indicating that there was no additional benefit for heavy play. Additionally, CIs of NPs overlapped CP and HPs at lower ID values (3 & 4) and separated for more difficult

Table 2
Correlations between gaming hours per week (HpW) and study DVs in the distance condition.

Variable	1	2	3	4	5	6	7	8
1. AVG HpW	–	0.25**	−0.224**	−0.187*	0.107*	0.009	0.16*	−0.06
2. Non-AVG HpW		–	−0.038	−0.036	−0.046	−0.04	−0.122*	−0.10
3. MT			–	0.519**	0.292**	0.474**	−0.211*	0.27**
4. PropST				–	0.278**	−0.29	−0.149*	0.18*
5. PV					–	0.227**	0.715**	−0.02
6. tPV						–	0.098	−0.09
7. PD							–	−0.08
8. UFOV divided attention								–

Note: HpW = hours per week, AVG = action video-games, MT = movement time, PropST = proportion of time spent in the secondary movement phase, PV = peak velocity, tPV = time to peak velocity, PD = peak deceleration, UFOV = useful field of view; **p* < .05, ***p* < .001, one-tailed.

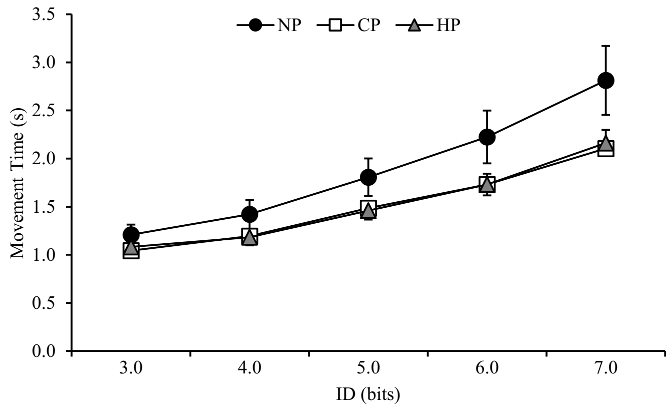

Fig. 2. Movement time (MT) in seconds is shown for all index of difficulty (ID) values in the distance condition. NP = nonplayers, CP = casual players, HP = heavy players.

movements indicating an overall gamer advantage and significant differences for ID values of 5, 6, & 7. Accordingly, non-players exhibited a steeper ID-MT slope, consistent with a reduced channel capacity (Shannon & Weaver, 1949) as shown in Fig. 2 and Table 3.

3.4. Proportion of secondary submovement time (PropST)

For the proportion of time spent in the secondary phase (PropST), the first step of the model found only a significant effect of ID ($\beta = 0.40$). This indicated that as target distance increased so did PropST. In the second step of the model, however, we found a significant AVG hours × ID interaction ($\beta = -0.20$). This indicated that individuals with greater hours of AVG play spent less time in the secondary movement phase as ID increased (Table 4), at least up to ID = 6. Beyond that, there may have been a ceiling effect limiting the proportion of time spent during the slow phase. This is consistent with a comparison of CIs across gaming groups, which do not overlap at ID values of 5 and 6 (Fig. 3, Table 4).

3.5. Peak velocity (PV)

For peak velocity, the first step of the model found only a significant effect of ID ($\beta = 0.88$). This indicated that as target distance increased participants scaled their velocities proportionally. In the second step of the model, however, we found a significant main effect of AVG hours ($\beta = 0.11$). Although this effect was small, it indicated that gamers scaled their velocities with distance to a greater degree than non-gamers (Table 5, Fig. 4).

3.6. Peak deceleration (PD)

For peak deceleration, the first step of the model found only a significant effect of ID ($\beta = 0.37$). This indicated that as target distance increased participants required greater deceleration due to the increased peak velocities required to achieve a farther distance quickly. In the second step of the model, however, we found a significant main effect of AVG HpW ($\beta = 0.16$). Thus, gamers were able to not only achieve greater velocities, but also to apply greater decelerative force than non-gamers (Table 6).

3.7. Width condition

An initial MANOVA examining ID, AVG HpW, and the ID × AVG HpW interaction using non-AVG HpW as a covariate was conducted on the five dependent variables of interest (MT, PropST, PV, tPV, & PD). The multivariate analysis revealed a significant main effect of ID, $F(20,952) = 2.72$, $p < .001$, Wilk's $\Lambda = 0.08$, partial $\eta^2 = 0.05$ and gaming group, $F(10,470) = 4.34$, $p < .001$, Wilk's $\Lambda = 0.83$, partial $\eta^2 = 0.09$, but not an ID × gaming group interaction, $F(40,1027) = 0.47$, $p = .99$, Wilk's $\Lambda = 0.92$, partial $\eta^2 = 0.02$ on the combined dependent variables.

3.8. Movement time (MT)

Intercorrelations between AVG HpW and study variables are shown in Table 7. In the first step of the regression model for movement time, ID was the only significant variable ($\beta = 0.27$). This indicated that movement time increased along with ID. In the second step, the interaction term was removed and the main effect of AVG HpW was found ($\beta = -0.32$). The effect of AVG HpW indicated that as individuals AVG gaming experience increased they took less time across all ID conditions (Table 8). Unlike the distance condition, HPs were found to have lower movement times than CPs at the highest values of ID, as indicated by non-overlapping error bars, which may indicate a slight advantage for increased AVG gaming experience (Fig. 5).

3.9. Proportion of secondary submovement time (PropST)

In the first step of the regression model for PropST, ID was the only significant variable ($\beta = 0.36$). This indicated that as ID increased participants spent more time in the control phase of the movement. In the second step, the interaction term was removed and the main effect of AVG HpW was found ($\beta = -0.29$). The effect of AVG HpW hours indicated that increased AVG gaming experience led to overall reductions in the time spent in the control phase of the movement (Table 9). While NPs take longer than CPs or HPs across all difficulty conditions, HPs showed the lowest PropST values at the most difficult ID (Fig. 6).

3.10. Peak velocity (PV)

In the first step of the regression model, ID was the only significant variable ($\beta = -0.13$). This indicated that unlike the distance condition peak velocity decreased as target size decreased indicating an increased need for online feedback correction during the movement. In the second step, a moderate main effect of AVG HpW was found ($\beta = 0.31$) showing the opposite pattern to the ID effect and indicating that gamers increased their peak velocity as size decreased (Table 10). Because the

Table 3
Regression statistics for movement time in the distance condition.

Step	Variable	*t*	*p*	*β*	R	Adj R^2	*F*	*df*	*p*
1	Intercept	7.65	< .001	–	0.69	0.48	77.44	3251	< .001
	ID	11.91	< .001	0.69					
	AVG HpW	−0.41	.69	−0.07					
	ID × AVG HpW	−0.97	.33	−0.17					
2	Intercept	9.44	< .001	–	0.69	0.48	116.46	2252	< .001
	ID	15.15	< .001	0.70					
	ID × AVG HpW	−5.02	< .001	−0.23					

Note: AVG HpW = hours per week spent playing action video games, ID = index of difficulty.

Table 4
Regression statistics for the proportion of movement time in the secondary submovement phase (PropST) in the distance condition.

Step	Variable	*t*	*p*	*β*	R	Adj R^2	*F*	*df*	*p*
1	Intercept	9.96	< .001	–	0.41	0.16	17.33	3251	< .001
	ID	5.48	< .001	0.40					
	AVG HpW	−0.17	.87	−0.04					
	ID × AVG HpW	−0.75	.46	−0.16					
2	Intercept	12.56	< .001	–	0.41	0.17	26.08	2252	< .001
	ID	6.96	< .001	0.41					
	ID × AVG HpW	−3.34	< .001	−0.20					

Note: AVG HpW = hours per week spent playing action video games, ID = index of difficulty.

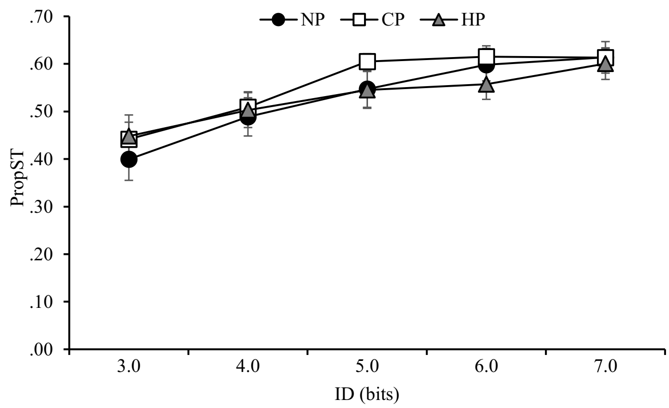

Fig. 3. The proportion of time spent in the secondary submovement phase (PropST) is shown for all index of difficulty (ID) values in the distance condition. NP = nonplayers, CP = casual players, HP = heavy players.

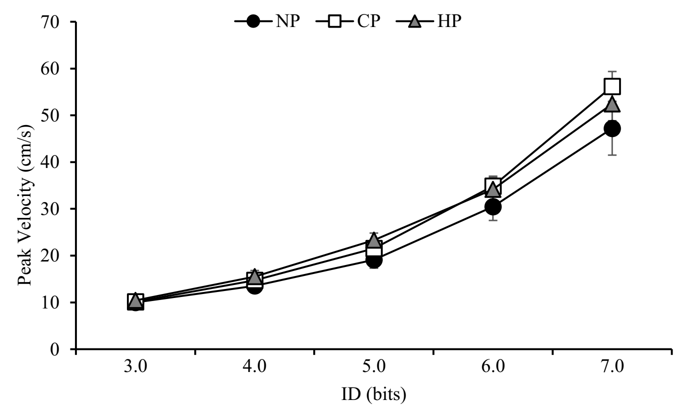

Fig. 4. Peak velocity (cm/s) is shown for all index of difficulty (ID) values in the distance condition. NP = nonplayers, CP = casual players, HP = heavy players.

target distance was held constant a much smaller effect of ID was seen for peak velocity in the width condition. Moreover, CPs and HPs show overlapping CIs across all IDs (Fig. 7).

3.11. Peak deceleration (PD)

Similar to the findings for peak velocity, ID was the only significant variable (β = −0.17) in the first step. While in the second step, a moderate main effect of AVG HpW was found (β = 0.31). This indicated that not only did gamers increase their velocity to all targets, but they were able to decelerate strongly so as to not overshoot the target and maintain a movement time advantage (Table 11).

3.12. Self-reported movement strategy

Self-reported movement strategy and performance was assessed using two single-item scales administered immediately following each experimental block which ranged from 0 to 100; between completely speeded to completely accurate and perfect to failure. Using separate one-way ANOVAs we compared the three gaming groups on each of these measures. In the distance condition, no evidence was found to support a conscious difference in strategy, $F(2, 48) = 0.99$. $p = .37$, $\eta^2 = 0.008$. But there was a difference in self-reported performance, $F(2, 48) = 3.10$. $p = .047$, $\eta^2 = 0.02$. Both non-players ($M = 45.15$, $SE = 2.11$) and heavy players ($M = 44.74$, $SE = 2.11$) reported performing worse than casual players ($M = 38.53$, $SE = 2.11$). However, using a Tukey HSD post-hoc test these differences were not significant ($t = 2.22$, $p = .07$).

In the width condition, we did find a difference in strategy for gamers, $F(2, 48) = 4.09$. $p = .018$, $\eta^2 = 0.03$. Non-players ($M = 61.03$, $SE = 7.23$) did not report a significant difference than casual players ($M = 65.44$, $SE = 7.23$, $t = 0.43$, $p = .90$), but heavy players ($M = 88.26$, $SE = 7.23$, $t = 2.67$, $p = .022$) reported emphasizing accuracy more than non-players, but not casual players ($t = 2.23$, $p = .06$). No differences were found for self-reported success ratings, $F(2, 48) = 1.90$. $p = .15$, $\eta^2 = 0.02$.

4. Discussion

We sought to evaluate three hypotheses regarding the relationship between action video game experience and movement performance on Fitts' task. First, we invoked the principle of near-transfer to argue that elements of game play are similar to the task at hand. This hypothesis

Table 5
Regression table for peak velocity in the distance condition.

Step	Variable	*t*	*p*	*β*	R	Adj R^2	*F*	*df*	*p*
1	Intercept	10.79	< .001	–	0.86	0.74	242.30	3251	< .001
	ID	21.51	< .001	0.88					
	AVG HpW	1.69	.09	0.19					
	ID × AVG HpW	−0.81	.42	−0.10					
2	Intercept	14.04	< .001	–	0.86	0.74	363.50	2252	< .001
	ID	26.78	< .001	0.86					
	AVG HpW	3.34	< .001	0.11					

Note: AVG HpW = hours per week spent playing action video games, ID = index of difficulty.

Table 6
Regression table for peak deceleration in the distance condition.

Step	Variable	*t*	*p*	*β*	R	Adj R^2	*F*	*df*	*p*
1	Intercept	21.21	< .001	–	0.39	0.14	15.63	3251	< .001
	ID	5	< .001	0.37					
	AVG HpW	0.87	.39	0.19					
	ID × AVG HpW	−0.12	.91	−0.03					
2	Intercept	26.53	< .001	–	0.40	0.15	23.53	2252	< .001
	ID	6.28	< .001	0.36					
	AVG HpW	2.77	.006	0.16					

Note: AVG HpW = hours per week spent playing action video games, ID = index of difficulty.

Table 7
Intercorrelations among gaming hours per week and study variables in the width condition.

Variable	1	2	3	4	5	6	7	8
1. AVG HpW	–	0.25**	−0.34**	−0.29**	0.31**	−0.02	0.31**	0.001
2. Non-AVG HpW		–	−0.04	−0.10	0.08	0.01	0.05	−0.008
3. MT			–	0.68**	−0.86**	0.52**	−0.72**	0.15*
4. PropST				–	−0.45**	−0.07	−0.45**	0.20**
5. PV					–	−0.50**	0.78**	0.25
6. tPV						–	−0.30**	−0.03
7. PD							–	−0.11
8. UFOV divided attention								–

Note: HpW = hours per week, AVG = action video-games, MT = movement time, PropST = proportion of time spent in the secondary movement phase, PV = peak velocity, tPV = time to peak velocity, PD = peak deceleration, UFOV = useful field of view; **p* < .05, ***p* < .001, one-tailed.

was upheld in the current study, as gamers consistently demonstrated reduced MTs compared to non-players, and is consistent with the idea of improved channel capacity (Shannon & Weaver, 1949). But to better understand the nature of gameplay-related improvements, we examined participants' UFOV performance and responses to manipulations of movement distance and target width, respectively.

Movement distance has been considered a constraint on the effector within the pointing-task literature (Fernandez & Bootsma, 2004; Thompson et al., 2007). Increasing the distance increases the demands on the limb, including an increase in the initial force impulse. Increased force is associated with an increase in spatial error (Schmidt, Zelaznik, Hawkins, Frank, & Quinn Jr, 1979), which may in turn increase the duration of the secondary phase, during which feedback is used to correct for error and acquire the target (Meyer et al., 1988). In the current study, game play was associated with reduced MT in this condition, a stronger initial force impulse (at least as measured by peak velocity achieved), and a stronger deceleration following peak velocity. Despite these increased forces, action game players spent less relative time in the secondary phase than did non-gamers. This suggests that action video game play may lead to the ability to produce more rapid, forceful movements without the concomitant increase in spatial error. This is consistent with the demands of many first-person shooter games, for example, which demand both rapid aiming movements and precise aiming control to small targets (e.g., head-shots). In most gaming platforms, these movements are generally small scale, performed using a game controller or computer mouse with a high sensitivity setting (i.e., control-display gain), so it is interesting that this skill extends to the larger scale movements employed in the current study. This may be suggestive that these benefits extend beyond these computer-based pointing tasks into improved manual coordination in daily tasks; this is an empirical matter that remains open to future investigation. Further, future research should examine differences between mouse (i.e., PC) and gamepad (e.g., PlayStation, Xbox) gamers to determine if these

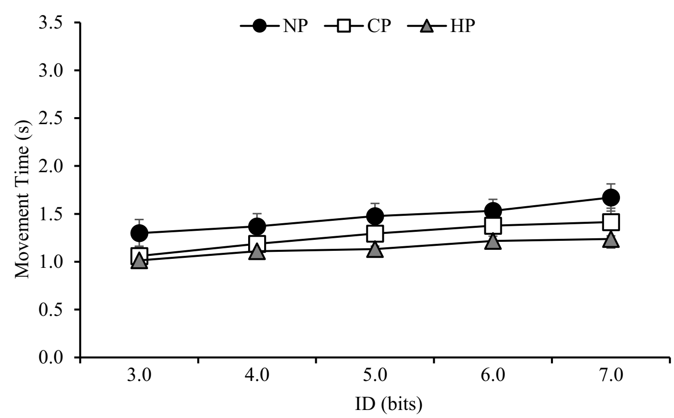

Fig. 5. Movement time (MT) in seconds is shown for all index of difficulty (ID) values in the width condition. NP = nonplayers, CP = casual players, HP = heavy players.

Table 8
Regression statistics for movement time in the width condition.

Step	Variable	*t*	*p*	*β*	R	Adj R^2	*F*	*df*	*p*
1	Intercept	13.26	< .001	–	0.41	0.16	17.04	3251	< .001
	ID	3.74	< .001	0.27					
	AVG HpW	−1.06	.29	−0.23					
	ID × AVG HpW	−0.49	.63	−0.11					
2	Intercept	16.89	< .001	–	0.41	0.16	25.52	2252	< .001
	ID	4.39	< .001	0.25					
	AVG HpW	−5.64	< .001	−0.32					

Note: AVG HpW = hours per week spent playing action video games, ID = index of difficulty.

Table 9
Regression statistics for the proportion of movement time in the secondary submovement phase (PropST) in the width condition.

Step	Variable	*t*	*p*	*β*	R	Adj R^2	*F*	*df*	*p*
1	Intercept	8.52	< .001	–	0.45	0.20	22.05	3251	< .001
	ID	5.05	< .001	0.36					
	AVG HpW	−1.19	.23	−0.25					
	ID × AVG HpW	−0.23	.82	−0.05					
2	Intercept	10.79	< .001	–	0.45	0.20	33.18	2252	< .001
	ID	6.26	< .001	0.35					
	AVG HpW	−5.21	< .001	−0.29					

Note: AVG HpW = hours per week spent playing action video games, ID = index of difficulty.

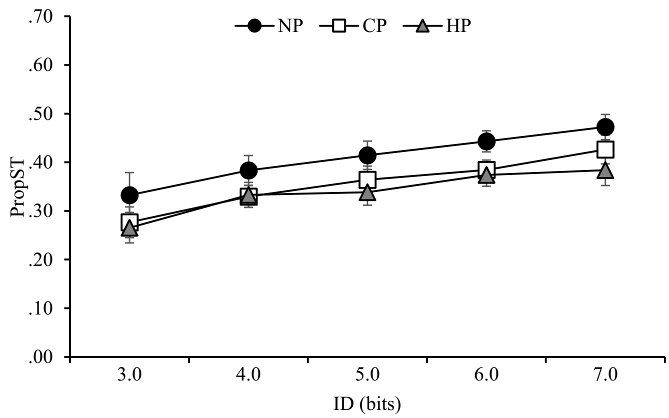

Fig. 6. Proportion of time spent in the secondary submovement phase (PropST) is shown for all index of difficulty (ID) values in the width condition. NP = nonplayers, CP = casual players, HP = heavy players.

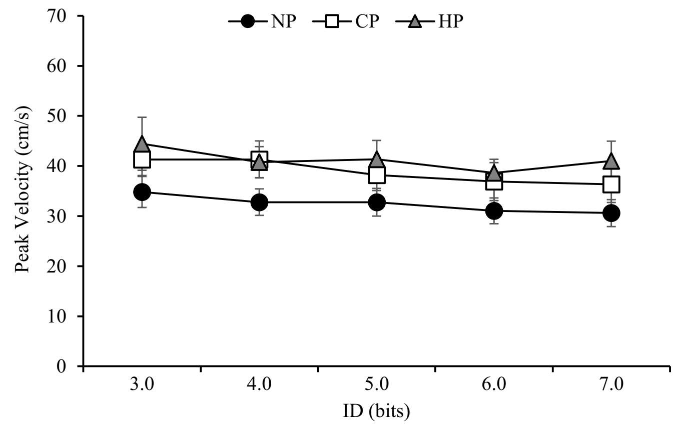

Fig. 7. Peak velocity (cm/s) is shown for all index of difficulty (ID) values in the width condition. NP = nonplayers, CP = casual players, HP = heavy players.

effects are dependent on tangible interface type and control order in a more controlled experimental setting such as a training study.

Target width is considered a task constraint: smaller targets increase the need for feedback control, by increasing the information processing demands of the task and thus lengthening the duration of the current control phase of the movement in relation to the duration of the initial impulse (Fernandez & Bootsma, 2004; Thompson et al., 2007). In the current study, experienced action game players exhibited reduced MT compared to non-gamers in response to manipulations of target width. While the proportion of time spent in the control phase increased as a function of ID for all participants, consistent with the task constraint idea, non-gamers spent more time in the feedback control phase for all values of ID. This can be interpreted as an improvement in feedback processing associated with gameplay, or it may mean that, as with the distance manipulation, gamers were able to achieve higher peak velocities and decelerations without a corresponding increase in the need for feedback-driven corrections.

Additionally, another explanation may be broad differences in speed of processing or visual attention as hypothesized in the action game literature. Our analysis of the UFOV data failed to support this conclusion. Thus, we conclude that differences between gamers and non-games cannot be related to overall differences in visual processing and attentional ability, but are specific to the aiming task.

Our results also replicated the dissociation between movement constraints found in previous research (e.g., Fernandez & Bootsma, 2004; Heath et al., 2016; Thompson et al., 2007). The average slope of the movement duration data was steeper in the distance condition indicating that effector constraints may impact movement more greatly than task constraints, supporting a differential effect of movement constraints (e.g., Sleimen-Malkoun et al., 2012). Consistent with this idea we found that increases in movement duration in the distance condition were driven by global variables, such as velocity and total MT. Although effector constraints are not expected to alter the symmetry of the velocity profile and thus were not expected to increase PropST, we observed that they did increase in the distance condition. This finding is consistent with Heath et al. (2011) who found greater increases in time after peak velocity in the distance condition as ID increased. Additionally, our findings may be attributed to that the fact that we employed an indirect pointing task with movements viewed on a computer screen, in contrast to other studies (e.g., Sleimen-Malkoun et al., 2012) that employed a direct pointing task with no separate display. Otherwise as expected, increases in movement duration in the width condition were driven by increases in the secondary movement

Table 10
Regression statistics for peak velocity in the width condition.

Step	Variable	*t*	*p*	*β*	R	Adj R^2	*F*	*df*	*p*
1	Intercept	36.77	< .001	–	0.34	0.10	10.63	3251	< .001
	ID	−1.7	.09	−0.13					
	AVG HpW	1.31	.19	0.29					
	ID × AVG HpW	0.12	.90	0.03					
2	Intercept	45.75	< .001	–	0.34	0.11	16.00	2252	< .001
	ID	−2.07	.04	−0.12					
	AVG HpW	5.27	< .001	0.31					

Note: AVG HpW = hours per week spent playing action video games, ID = index of difficulty.

Table 11
Regression statistics for peak deceleration in the width condition.

Step	Variable	*t*	*p*	*β*	R	Adj R^2	*F*	*df*	*p*
1	Intercept	25.73	< .001	–	0.35	0.11	11.67	3251	< .001
	ID	−2.27	.02	−0.17					
	AVG HpW	1.3	.20	0.28					
	ID × AVG HpW	0.13	.90	0.03					
2	Intercept	31.99	< .001	–	0.35	0.12	17.56	2252	< .001
	ID	−2.78	.006	−0.17					
	AVG HpW	5.23	< .001	0.31					

Note: AVG HpW = hours per week spent playing action video games, ID = index of difficulty.

phase more so than due to changes in velocity.

A potential limitation in this research is the specificity of the gaming effect. For example, do these effects occur for all types of games or only for the action gaming genre? And to what extent are effects specific to certain titles? We found no evidence that playing non-action video games led to improvements in motor control and feedback processing given the low correlations between our other video game HpW measure and the study dependent variables. However, the gamer participants in our study played mostly action games. Therefore, sampling bias may be at least partly responsible for these findings.

Another limitation is that we used a cross-sectional design by surveying users of their gaming habits instead of training them over time. It is possible that individuals who have better motor skill may self-select to play action games. A longitudinal training-based study would be suitable to address this question. One study found that a quick 6-week muscle coordination program elicited changes in the motor cortex that improved movements similar to the training (Tyč & Boyadjian, 2011). Following the principle of near-transfer, this may also apply to repeated action gameplay. Video-game based training has also been shown to be effective at providing motor improvements for those with chronic motor impairments (Ilg et al., 2012; Jannink et al., 2008). Another study used a discrete pointing task that required participants to curve their movement in an arc while not passing through a semicircular channel. After individuals completed 4 days of training using three sets of 120 trials each day, participants improved both their movement trajectory and made more effective use of online feedback to control their movements (Shmuelof, Krakauer, & Mazzoni, 2012). Although this study did not vary target size or distance, it provided evidence that completing repeated pointing movements can improve performance.

A final limitation of the current study is that we used a covert recruitment method which did not allow us to balance groups between gamers and non-gamers. While this method was used to reduce bias, the downside of our recruitment method was that it was more difficult to recruit individuals with specific amounts of gaming experience; thus, future training studies will be needed to follow up on our findings.

The current study is among the few to examine how AVG play may affect one's ability to perform goal directed aiming movements. We found advantages in both distance and width manipulations among AVG players, and conclude that gamers exhibited better effector control and use of feedback than non-players, supporting previous research on gaming and motor skill (Borecki et al., 2012; Chung et al., 2017). The main game element of an action game requires individuals to perform repeated and dynamic aiming tasks. Over time, this experience may speed up action gamers' ability to react in these situations or lead to faster movement strategies leading to gamers to move faster to both targets that were farther away and those that are smaller. For example, one of the best classifiers of skill among competitive players of Starcraft II was the average actions per minute taken (Avontuur, Spronck, & Van Zaanen, 2013). This is something that may be learned during gameplay as players that do not move or emphasize speed are not likely to progress very far. In the current study, we attempted to quantify such strategic differences by administering a post block survey – the results were not overly informative, however. We found only that, in the width condition, heavy AVG players tended to emphasize an accuracy strategy more than the other participants. It may be that these strategic differences are not explicit or by being able to perform faster they may feel they are in fact being more accurate. As we have described above, training studies will be appropriate to resolve such questions, as training instructions can be manipulated to emphasize and improve either speed or accuracy over time. Also, our findings may extend to improving motor rehabilitation or ameliorating age-related motor declines. In conclusion, our findings add to the growing body of research in favor of playing video games, but more research is needed to fully quantify the limitations of these benefits as well as the precise mechanisms underlying these effects.

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