TRAINING VISUAL ATTENTION WITH VIDEO GAMES: NOT ALL GAMES ARE CREATED EQUAL

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Abstract

Playing action video games enhances visual selective attention; however, little is known about the facets of video game play that contribute to such enhancements. To address this issue, participants with little to no previous gaming experience were trained on one of several video games. Each training game was selected to emphasize different aspects of typical game play that may contribute to learning. Participants were tested on two paradigms designed to explore dynamic aspects of visual selective attention. The first, the attentional blink task, measures the temporal resolution of visual attention; the second, the multiple object tracking task, measures the number of objects that can be simultaneously attended over a period of several seconds. Participants trained for 12 h on an action video game showed improvement on these two measures of visual attention. Individuals trained on a variety of other games showed comparatively less or no improvement. These results point out the combined requirements of monitoring several objects at once and being highly engaged in a very fast paced game as key factors in producing changes in visual selective attention.

1. Introduction

There is a substantial literature that demonstrates the positive effects that video game play can have on cognitive and perceptual abilities (see Green & Bavelier, 2006a for a review). For instance, previous studies of video games have shown that game play can lead to faster reaction times in healthy adults (Bialystok, 2006; Orosy-Fildes & Allan, 1989), young children (Yuji, 1996), and in the elderly (Clark, Lanphear, & Riddick, 1987; Goldstein et al., 1997). There are studies that have found evidence of enhanced

motor coordination related to video game experience (Griffith, Voloschin, Gibb, & Bailey, 1983) and produced by game training in the elderly (Drew & Waters, 1986). A number of video game training regimens have produced enhancements in skills such as spatial visualization, mental rotation, and distinguishing between trajectories of moving objects (Dorval & Pepin, 1986; Gagnon, 1985; McClurg & Chaille, 1987; Subrahmanyam & Greenfield, 1994). Several studies have demonstrated enhancements in various of aspects of visual attention, such as the number of objects that can be attended at once, the spatial and temporal distribution of visual selective attention, and the ability to divide attention (Green & Bavelier, 2003, 2006b,c, 2007; Greenfield, DeWinstanley, Kilpatrick, & Kaye, 1994). Finally, there is work that demonstrates that these enhancements may have real-world benefits, such as in the training of pilots or laparoscopic surgeons (Gopher, Weil, & Bareket, 1994; Rosenberg, Landsittel, & Averch, 2005).

The variety of different skills that can be modified by video game experience, and the degree to which they can be modified, is certainly striking. However, it is of great consequence to recognize that most of the studies comparing players and non-players have lumped together a wide variety of game types when determining which participants qualify as "video game players." This fact is of critical importance when attempting to interpret the results of these studies or make predictions based upon them. One could argue that considering the effect of "video game play" on a certain skill is roughly equivalent to considering the effect of "playing a sport" on a skill. The literature on the effect of sports on perceptual and motor skills (and in fact, the great majority of the literature on perceptual learning in general) has demonstrated that the nature of the training greatly influences the types of effects that are observed. For instance, baseball experience decreases Go/NoGo reaction times but tennis does not (Kida, Oda, & Matsumura, 2005), while soccer and volleyball players show enhancements in voluntary orienting that swimmers and track athletes do not (Lum, Enns, & Pratt, 2002). In this chapter, we ask whether the varied environments and demands offered by different types of games will lead to distinct cognitive effects on their players. For this chapter, the term "video games" refers to a game wherein players interact with objects on a screen (displayed by either a computer or game console) for entertainment purposes. All of these games involve a human player responding to images and/or sounds controlled by either the computer/console or other human players, with the ultimate goal of winning points or achieving a given mission.

The hypothesis that the characteristics of a game are directly related to the types of processes that are modified is implicitly acknowledged in the types of games that experimenters have chosen when training participants. For example, when testing mental rotation skills, McClurg and Chaille (1987) used The Factory (Kosel & Fish, 1983) as one of their training games because it explicitly requires the mental rotation of a figure as you plan the figure's progress through a series of virtual stamping and cutting machines to achieve a desired final shape. When looking to improve the speed of selection processing, Clark et al. (1987) chose Pac Man (Namco, 1979) and Donkey Kong (Nintendo, 1981) as their training games, because successfully playing these games requires the rapid selection of responses to sudden events. In an attempt to improve pilot performance, Gopher et al. (1994) made use of a modified version of the game Space Fortress (Donchin, Fabiani,

& Sanders, 1989), which was purposely altered to tap the types of attentional skills present during flight. In our work on visual attention (Green & Bavelier, 2003, 2006b,c), we have specifically looked at the effect of "action games," as these games make heavy demands upon the types of processes we have studied (efficient monitoring of the periphery for the occurrence of unpredictable events, tracking of many fast-moving objects, effective distractor rejection, etc.).

The hypothesis that games with different requirements should have different effects on cognitive processing is also represented by the video game we have chosen as a "control" video game in our studies. The game Tetris (Alexey Pajitnov, 1985) was chosen as a control because it places great demands on visuo-motor coordination, but otherwise makes very different demands on visual attention than the experimental action game. For instance, Tetris requires participants to pay attention to just one block at a time, only a few spatial locations have to be attended during the game, their locations are always predictable (the piece falling and the game board), and the trajectory of the attended piece is entirely under the control of the user (thus, unlike in the action game, Tetris players know at all times where their attention should be directed). Although Tetris was chosen as our control because it is unlikely to alter the specific visual attentional processes we have examined, were we to measure the effect of video game experience on mental rotation Tetris would be a good candidate for the experimental game (see Sims & Mayer, 2002).

In the only study (to our knowledge) that specifically attempted to measure the effects of different categories of games, Gagnon (1985) found a relationship between performance on a test of spatial orientation and successful training on the three-dimensional game Battlezone (Atari, 1980) but not the two-dimensional game Targ (Exidy, 1980) while measures of spatial visualization and visual pursuit were improved by playing either game. This result therefore supports the suggestion that game content or format determines the nature of cognitive and perceptual skills that can be acquired through video game experience.

While categories of video games available in 1985 could be broadly categorized by whether they were two- or three-dimensional, commercially available games today are often extremely complex and contain a variety of traits that may contribute to learning. Today's games range from those that require indiscriminate killing of enemies, to virtual versions of popular sports, to slow-paced turn-based strategy games, just to describe a few standard formats. Critically, these formats vary widely in the extent and nature of spatial and temporal attentional demands (as characterized, for example, by the number of attackers or the rate at which they appear), the players' emotional and cognitive engagement in the game, the predictability of events, and the visual complexity of the virtual environment. Games also vary in regard to whether the play is individual or team-based and interactive. Video game journals employ a rough classification scheme that divides games into a number of broad categories, including first-person shooter, third-person shooter, fighting, racing, role-playing, simulation, sports, and puzzle games; however, no system of categorization can cleanly partition all games as many incorporate more than one form of play. Furthermore, there is much variability to be found within

these semi-distinct genres as even games with similar basic premises differ widely in terms of speed, difficulty, violence, and optimal strategies of play.

The goal of the present study is to further characterize the components of the gaming experience that enhance visual selective attention. Visual selective attention allows the enhanced processing of elements of the visual scene that are relevant to a specific task and can minimize interference from task-irrelevant distractors. Visual attention can be seen as an interaction between an external visual stimulus activating low-level perceptual processes and top-down control based on experience and task-specific knowledge. These attentional mechanisms play an important role in perceptual learning. For example, Ahissar and Hochstein (1993) found that adult participants who practiced one task did not improve on an alternate task, despite the fact that both tasks presented the exact same visual stimuli. This lack of transfer, they argued, was in part due to requiring attention to different stimulus attributes across tasks. Thus, exposure to the stimuli was insufficient to produce learning; rather learning appears limited by the way visual attention is distributed over the scene. While there is some evidence that low-level perceptual learning can occur in the absence of attention or even awareness (Fiser & Aslin, 2001; Watanabe et al., 2001), most evidence in the literature points to highly enhanced perceptual learning for attended aspects of visual input (e.g., Ahissar & Hochstein, 1993; Ball & Sekuler, 1987; Fiorentini & Berardi, 1980; Ramachandran & Braddick, 1973; Shui & Pashler, 1992). The allocation of attention is greatly influenced by task demands including the spatial distribution of targets, speed of target presentation, and overall task difficulty. These changes in visual attention are then reflected in the extent of perceptual learning that can occur (Ahissar & Hochstein, 1997, 2000). Thus, the nature of the visual environment and the task demands presented by a specific video game are likely to be highly relevant to the aspects of visual processing that may be enhanced.

With so many game-related factors in play, it is highly impractical to design and carry out a study that tests every possible combination of game criteria, content, and level of challenge. Thus, for the present study, we selected games that are representative of four popular genres, as well as one clinical training paradigm. Training games were selected so as to place different demands on temporal and capacity-related aspects of visual selective attention, that is, they differ from one another in terms of game speed, the number of objects that must be kept track of during the course of the game, and the frequency, speed, and precision of responses required from players. The clinical training paradigm consisted of the Interactive Metronome rhythmicity-training (Interactive Metronome Inc., www.interactivemetronome.com). It was selected as it places very high demands on timing skills and motor coordination and has been associated with cognitive improvements while being otherwise very unlike typical video game play (see Section 2.2, for a detailed description of Interactive Metronome training and its posited effects). The training groups were as follows: *Experimental group* – played a standard first-person action game (Unreal Tournament 2004 – Epic Games Inc., 2004); *Control Group #1* – played a slower-paced, team-based, first-person shooting game (America's Army – Pragmatic Solutions Inc. and Army Game Project, 2002); *Control Group #2* – played a slower-pace, first-person, multi-ball sport game (Harry Potter: Quidditch World Cup – Electronic Arts Inc., 2003); *Control*

Group #3 – played a speeded visuo-motor puzzle game Tetris (Alexey Pajitnov, 1985), *Control Group #4* – received rhythmicity training (Interactive Metronome – Interactive Metronome Inc., 1993); and the *Baseline Group* – played a set of basic computer Card Games (Solitaire – Micosoft, 1990; Free Cell – Microsoft, 1992; Hearts – Microsoft, 1993) and Minesweeper (Microsoft, 1992).

Participants were tested before and after training on two different aspects of visual attention: the temporal dynamics of visual attention and the number of objects that can be attended. The temporal dynamics of visual attention was assessed by using the attentional blink paradigm (Raymond, Shapiro, & Arnell, 1992), which measures how attention, once allocated to an item, recovers over time. The number of objects that can be attended over time was investigated using the multiple object tracking task which tests the participants' ability to track multiple moving objects over the course of several seconds (Pylyshyn & Storm, 1988). Performance on the attentional blink and multiple object tracking before and after training was compared for each group. To control for test–retest improvements, change in performance was then compared between each game and the baseline control group (Card Games). This comparison also allows us to rule out any possible unforeseen effects of the training process, such as Hawthorne-like enhancements produced through attention and encouragement from the experimenters during training or changes in participants' expectations after completing training which they often deduce is meant to improve their post-test performance (Benson, 2001). Finally, to test the relative effectiveness of our selected experimental action game, improvements in participants trained on the experimental action game (Unreal Tournament) were compared to that of each of the other groups.

Although the training games shared many features, the standard action game proved more effective in improving performance on these two tests of the temporal dynamics of visual attention than the other training regimens.

2. Methods

2.1. Participants

All participants were undergraduate or graduate students at the University of Rochester with ages ranging from 18 to 29 years (mean age = 20.5). In a pre-screening interview, participants' vision was tested on a 10-ft Tumbling "E" eye chart. As all testing and training paradigms in the study were run binocularly, participants were accordingly allowed to use both eyes when viewing the eye chart. One participant was excluded because he was unable to correctly identify the E's orientation at a resolution of 20/20. Thus, all included participants were confirmed to have normal or corrected to normal vision. No participants reported any sensory, neurological, or attentional impairment. Written informed consent was obtained from each participant and all participants were paid $8 for each hour of participation. Participants were required to be non-action, non-sports video game players. The criterion for this classification was playing *less* than 1 h

per week of action or sports games in the preceding 12 months. Each participant filled out a survey, describing any gaming experience they had over the previous year, and were asked to estimate the number of hours per week they had spent playing different types of video games. Participants were asked to categorize their game experience in four different categories: action (examples: Unreal Tournament, Medal of Honor), sports (examples: NBA Live, Madden NFL), strategy (examples: The Sims, SimCity), and others. Because video games are rather ubiquitous in today's 20-something age group, some experience with slower paced games was permitted (0–1 h per week). Participants who reported playing action or sports games for more than 1 hour per week were not included in the study. All qualifying participants underwent training as described in the next section.

This study reports results for all participants that successfully completed pre-testing, training, and post-testing. Thus, the final experimental group: Unreal Tournament ($N = 11$, mean age $= 21.6$) included 5 females and 6 males, control group #1: America's Army ($N = 14$, mean age $= 19.9$) included 6 females and 8 males, control group #2: Harry Potter ($N = 14$, mean age $= 20.1$) included 7 females and 7 males, control group #3: Tetris ($N = 14$, mean age $= 19.5$) included 6 females and 8 males, control group #4: Interactive Metronome ($N = 19$, mean age $= 20.8$) included 9 females and 10 males, and the baseline group: Card Games ($N = 12$, mean age $= 21.5$) included 6 females and 6 males.

2.2. Training

Training was randomly assigned and consisted of playing the pre-determined video game, or performing the prescribed exercises, for 1 h per day for a total of 12 h with a minimum of 3 h and a maximum of 5 h of training completed per week. These time requirements were set in accordance with the suggested training rate for Interactive Metronome. All groups, except for the Interactive Metronome group, that did rhythmicity training, played their respective games on 20 inch Dell Flat Panel displays.

The 11 members of the *experimental group* played the game Unreal Tournament 2004 (henceforth referred to as the action video game). This game was chosen to be similar to those played by the expert video game player group in our previous studies. It has a relatively simple interface, uses first-person point of view and requires effective monitoring of the entire visual field (extent from fixation about 13°-height × 16°-width). Unreal Tournament 2004 was chosen, in part, because there is no "script." Instead, the game is controlled by the action of 32 AI agents rather than linear story development. This keeps the game from becoming predictable after multiple hours of play and thus maximizes the attentional demands placed on the player. Each hour session of the action game was divided into three 20-min blocks. The difficulty of each block was adjusted based upon the kill/death ratio achieved by the participant. If, in a block, the player scored more than twice as many kills than they had deaths, the difficulty level was increased one level. Participants were not permitted to move back down after achieving a given difficulty rating; they were instead required to attempt to master the new level.

The 14 members of *control group #1* played the game America's Army, a free access game created by the US army. While also a first-person shooter, with an equivalent interface and point of view, this game differed from the experimental action video game in several significant respects. First of all, participants had to go through a series of "basic training" exercises – such as firing range practice and an obstacle course – before being able to participate in an actual mission, reducing the time actually spent in a battle context. Secondly, this game places a much stronger emphasis on strategy and teamwork. It encourages such tactics as laying ambushes and sniping enemies, which, though cognitively engaging, are much less demanding for visual attention than constant engagement in a shootout. Thus, the pace of the game was generally slower than that of the experimental action game. Finally, participants played online against other human players. Although this adds a new, interesting dimension in the training, it prevents fine adjustments of the difficulty of each session as the number and skill level of the opponents our trainees faced could not be kept under experimental control. The size of the visual field used by the game was the same as that presented to the experimental group.

The 14 members of *control group #2* played Harry Potter: Quidditch World Cup. The first-person ball game is relatively fast-paced and, like the first two groups, creates a rich three-dimensional environment for the participant to navigate. It places strong demands on visual attention; it presents multiple balls, teammates, and opponents who must be kept track of for successful play. The game also presents the advantage of being much less violent and much more child and parent-friendly than the above two games. However, the fact that it is a children's game does reduce the general challenge and speed of the game. Also, like America's Army, Harry Potter requires the completion of training exercises that take away from actual game-time. Furthermore, it requires many hours of play and the collection of a variety of achievements before it allows players to advance to a more difficult level. It is therefore difficult to continually fully engage an adult player in this game. Again, the visual field used in the game was identical to that presented in the first two groups.

The 14 members of *control group #3* played the game Tetris. This game was selected to control for the effect of improved visuo-motor coordination, while placing little demand on the simultaneous processing of multiple items. Accordingly, the version of Tetris on which participants were trained had the "preview block" option turned off. The game was displayed to cover the entire extent of the screen. As such, the field of view of the Tetris game was actually slightly larger than that of the action game. The effective control game area extended $18°$-height $\times 13°$-width from fixation.

The 19 members of *control group #4* underwent rhythmicity training as designed by Interactive Metronome Inc. (*www.interactivemetronome.com*). This training paradigm requires extremely accurate timing. Participants are required to perform a set of simple physical movements (e.g., clapping) in synch with a slow steady beat. Accuracy feedback is provided in the form of guide sounds as well as numbers presented on a screen. The numbers represent the discrepancy, in milliseconds, between the participant's trigger hit and the given beat. Training was administered using the standard 12-session set format recommended by IM Inc. for unimpaired adults. To avoid confounds introduced by

extensive interactions between participant and experimenter, the "auto-train" feature was used. In this format, participants are automatically shown the desired movements by a video guide and are given text instructions as to the number of repetitions to be completed. The program provides positive reinforcement (Skinner, 1953), in the form of a video of fireworks, when a trainee breaks a previously established personal record. Interactive Metronome training has been tied to improvements in attentional and cognitive skills, including vigilance, temporal sequencing, and motor planning, at least in children with attentional problems (Schaffer et al., 2001). In this study, IM provides a way to look at the attentional enhancements produced by honing the precision and accuracy of timing skills while leaving out virtually all other components of typical video game play.

The 12 members of the *baseline group* played a set of games selected to place relatively low demands on visual attention (Card Games). To avoid extreme boredom, they were allowed to choose between four games during any given session: Solitaire, Free Cell, Hearts, and Minesweeper. While often cognitively demanding, these games do not require constant vigilance, distributed attention, tracking of multiple objects, or fast responses to suddenly presented stimuli. This group served to control for any unexpected effects produced by participation in the study or, in other words, any cognitive or perceptual changes produced by being required to play a game, on a computer, in a lab setting, for 12 h (spread over the course of several weeks) while logging the time played and game performance. Furthermore, this group served as a control for any possible effects due to familiarity with the attentional blink and multiple object tracking tasks. These attentional tasks are described in Sections 3 and 4, respectively.

2.3. Pre- and Post-Testing

Two experimental paradigms that measure different aspects of the dynamics of visual attention were tested within a week before the time participants began training and again within a week after the day they finished training (note: to avoid interpretations based on arousal, participants were always post-tested at least 24 h after their final video game training session). These paradigms are described in greater detail in Sections 3 and 4.

2.4. Analysis

All analyses proceeded by first looking at test–retest improvement within each training group separately on the totality of the data. Group comparisons were then performed on the task conditions that have been shown in our previous work, and that of others, to be most sensitive to training (intermediate range between ceiling and floor). The experimental and control groups were first compared to the baseline group to evaluate the source of any test–retest improvement, if present. Then, the control groups were compared to the experimental group to evaluate the relative efficiency of each of these new training regimens compared to that of the action video game we have used in our previous work. Given the high number of training groups (one experimental, four controls, and one baseline), multiple tests had to

be performed. We did not correct for multiple comparisons as each of these comparisons was fully planned; however, although the majority of our a priori hypotheses called for one-tailed statistics, two-tailed statistics were used to be more conservative.

3. Experiment 1: The Attentional Blink

The Attentional Blink paradigm was used to measure the effect of our different training regimens on how quickly attentional resources recover after being directed toward a target. In the attentional blink paradigm (Raymond et al., 1992), observers are exposed to a rapid serial visual presentation of items. In this study, we administered a version of the attentional blink task where participants viewed a stream of black letters and were required to identify a first target – a letter presented in white (Target 1) – and detect a second target – a black X (Target 2) – when present. The number of intervening letters between Target 1 and Target 2 was manipulated, and performance accuracy at the different Target 1-Target 2 intervals was measured. The term "attentional blink" refers to the finding that Target 2 is frequently not detected if it occurs just after Target 1; however, as the amount of time elapsed between Target 1 and Target 2 increases, detection of Target 2 improves, indexing that attention can again be summoned toward a new target. To control for changes in participants' baseline ability to detect Target 2, two control blocks were interleaved between the experimental blocks such that the tasks were completed in the following order: (1) control, (2) experimental, (3) control, (4) experimental. In the control blocks, the visual input was the same as in the experimental condition but participants were instructed to ignore the white letter and were only required to report the presence or absence of the X. Data from the control blocks were then used to correct for possible differences in baseline Target 2–detection rates in the dual condition; in other words, corrections were made to control for differences in the simple ability to parse the rapid, serial stream of letters and detect the "X" that could otherwise confound interpretations about the depth of the attentional blink.

Our past work has shown that action video game play results in faster recovery from the attentional blink (Green & Bavelier, 2003). We therefore predicted that attentional recovery would be more rapid for experimental action game players than for the card game group (baseline group) in which fast and accurate processing is not of the essence. Based on our previous findings, we also expect improvement in the experimental group to exceed that of the Tetris group (control group #3). The effects of control games #1 (America's Army), #2 (Harry Potter), and #4 (Interactive Metronome) on this measure are more difficult to predict. Although America's Army and Harry Potter do place a premium on selective visual attention skills, it is not clear that the speed and difficulty of these two games will be sufficient to produce measurable improvements on the attentional blink after only 12 h of play. The effectiveness of Interactive Metronome training will depend on whether or not extremely precise timing in cognitive and motor planning skills will be sufficient to produce changes in the temporal resolution of attention.

3.1. Stimuli and Procedure

The same set-up as in Green and Bavelier (2003) was used. Participants viewed the stream of letters displayed on a gray background in the center of a computer monitor. Their heads were positioned in a chin-rest fixed 57 cm away from the screen. The letters subtended 1° of visual angle and were presented for 15 ms at a rate of 1 per 100ms. Participants pressed a key to begin each trial. This key press was followed by the presentation of 7–15 black letters (randomly chosen but excluding X), then the first target (Target 1) was presented in white followed by 15–18 black letters (including an X 50% of the time). Four blocks were administered: in the first and third blocks, participants were only required to respond to the presence of an X while in the second and fourth blocks they needed to identify the white letter prior to indicating whether or not they had seen an X. In these cases, once stimulus presentation was complete, participants typed in the identity of the white letter and pressed a "Y" or "N" key to indicate whether or not they had seen an X. The time elapsed between the white letter and the X is termed lag and measured in terms of number of items (the letter presented immediately after Target 1 was labeled as being displayed at "Lag 1" while the second letter was displayed at "Lag 2" and so forth).

3.2. Results

All groups exhibited a marked attentional blink with worse "X detection" performance when the time elapsed between the white letter and the X was short and a gradual recovery of performance as that time lag increased. A main test–retest improvement was noted in the experimental group as well as in the Interactive Metronome group and, marginally so, in the America's Army group. In isolation, a test–retest improvement does not establish that the training was successful in inducing better performance. It merely demonstrates that participants doing the task for a second time improve their performance when compared to the first time, an effect that can be due to practice at the task itself, independent of the intervening training regimen. To establish a causal effect of a training regimen, it needs to be shown that the test–retest improvement found in the training group is larger than that of the baseline group. Results are given in detail in Appendix 1 (see also Tables A1 and A2).

The efficacy of each of the training regimens was evaluated by contrasting test–retest improvement from each training regimen with that seen in the baseline group. As a faster recovery from the attentional blink following training is best seen at those lags where the attentional blink is typically most pronounced (lags 2, 3, 4), these analyses focused on these three lags. While the Interactive Metronome and America's Army groups improved significantly at these lags following training (comparing their pre-test score to their post-test score), only the experimental group showed a level of improvement that was significantly greater than what was observed in the baseline group (Figure 1). Therefore, only the experimental group can convincingly be said to exhibit a faster recovery from the attentional blink than what one would predict from simple test/retest benefits.
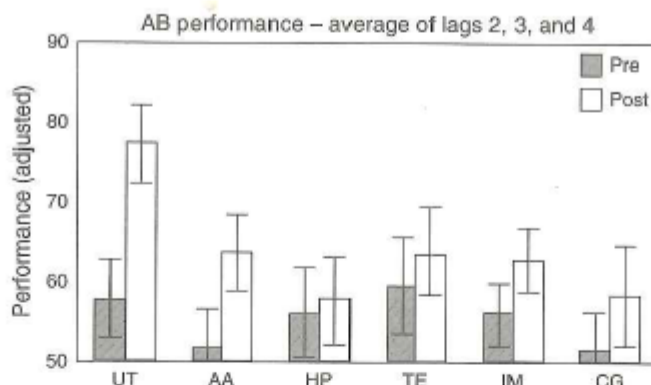
Figure 1. Only the experimental, action video game trained group demonstrated an improvement in performance greater than what was seen in the baseline group. The amount of improvement seen in the experimental group was greater than every other training game except America's Army.

In addition, when the test–retest improvement in the experimental group was compared to that seen in the other training regimens, the experimental group improved significantly more than all except America's Army. Taken together, the fact that the experimental group was the only group to improve significantly more than the baseline group and that this group improved significantly more than all but one of the other groups suggests that the experimental action game had the greatest effect on the speed of attentional recovery.

4. Experiment 2: Multiple Object Tracking

In the multiple object tracking paradigm, participants are required to track the movements of multiple moving objects. In this version of the task, participants viewed 16 randomly moving yellow circles. At the beginning of the trial, some subset of these circles was cued by being colored blue. After 2 s, the cued circles turned back to yellow, and participants were required to keep track of the circles that had been cued (now visually indistinguishable from uncued circles) as they continued to move randomly about the screen. After several seconds of tracking, one of the circles turned white and the participant was asked to decide whether or not it belonged to the cued set (yes/no decision). This method of response, rather than the more typical method of asking the participant to indicate each of the initially cued objects, was employed to reduce memory demands during the response process and thus allow a more accurate estimation of the tracking capabilities per se.

Based on our previous results, we expected significant improvements in the experimental – Unreal Tournament – group but little improvement in the Tetris group. Additionally, the Card Game and Interactive Metronome groups were not expected to improve much in multiple object tracking performance as these forms of training do not require participants

to deploy attention across multiple objects. Possible improvements were expected in the America's Army and Harry Potter groups as these games do require the player to keep track of multiple objects. However, it was not known whether the speed and difficulty of these two control games would be sufficient to produce measurable changes after only 12 h of play.

4.1. Stimuli and Procedure

The same set-up as in Green and Bavelier (2006b) was used, except cued circles were colored blue instead of red and non-cued circles were colored yellow instead of green. This change was made to avoid any complications produced by possible undiagnosed red–green color-blindness in our participant group. Furthermore, as previous work has found eye movements to have few implications for performance on this task (Pylyshyn & Storm, 1988) and our previous work indicates that fixation performance on this task is roughly equivalent for gamers and non-gamers (Green & Bavelier, 2006b), participants were not eye-tracked during the task.

Each observer viewed the display binocularly with his or her head placed in a chin rest at a test distance of 57 cm. Participants were instructed to fixate within a center ring (radius = 0.25 deg). Participants pressed a key to begin each trial. Each trial began with 16 circles (radius 0.5 deg) moving randomly at a rate of 5 deg/sec on a circular gray background (radius of circular background = 10 deg). The circles repelled one another before contact (0.5 deg minimum separation), were repelled by the outer edges of the background and by the center fixation circle. At the beginning of the trial, 1–7 of the circles were cued by being colored blue while the remaining circles were drawn in yellow. Participants were instructed to attend to the blue circles. Participants were warned that the blue circles would shortly change back to yellow, after which time they had to continue tracking the same circles that were previously cued. The cued circles changed to yellow after 2 s, leaving all 16 circles visually indistinguishable as they continued to move randomly about the screen. After 5 s of tracking, motion ceased and one of the circles was highlighted in white (probe circle). At this point the participant was asked to press a Yes or No key to indicate whether or not the probe circle had been cued at the beginning of the trial. The probe circle was one of the originally cued circles 50% of the time. Each number of cued circles (1–7) was presented 20 times (10 yes, 10 no) for a total of 140 trials.

4.2. Results

In all groups, the ability to correctly identify whether or not a given circle had been cued at the beginning of the trial decreased as the number of circles to track increased, replicating the standard performance on the multiple object tracking task. Three training groups improved significantly between pre- and post-testing; these included the experimental (Unreal Tournament), the Interactive Metronome, and the Tetris group. As discussed earlier, such test–retest improvements do not allow one to distinguish between a genuine
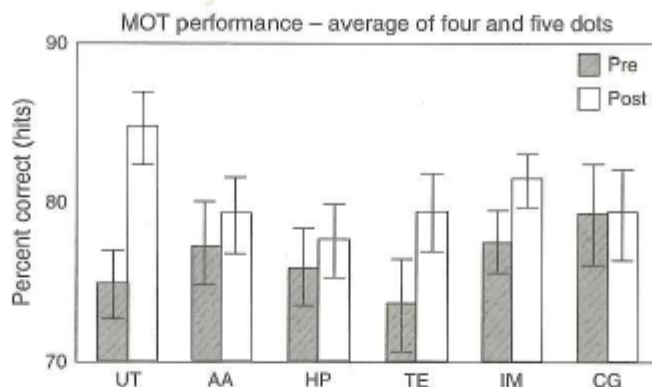
Figure 2. Only the experimental, action video game trained group demonstrated an improvement in performance greater than what was seen in the baseline group.

effect of training or a simple improvement as participants do the task for the second time. A causal effect of training regimen can only be shown by comparing test–retest improvements from the training group to that of the baseline group.

This was done by focusing the analysis on two critical attentional loads (4–5 circles) where performance is neither at ceiling nor at floor, and therefore most sensitive to experimental manipulation (Green & Bavelier, 2006b; Trick, Jaspers-Fayer, & Sethi, 2005). Only the experimental group showed a significantly greater test–retest improvement in accuracy than what was observed in the baseline group (Figure 2). When the improvement in the experimental group was compared to that in the other training groups, the experimental group was seen to improve significantly more than the Harry Potter group, with a discernable trend in the same direction also being seen for the America's Army and Interactive metronome groups. While the comparison between the experimental group and the Tetris group was not significant, previous research with approximately three times more training has demonstrated significant difference between these regimens (Green and Bavelier, 2006b). Taken together, these results suggest that the experimental action game is best suited to improving this aspect of attention. More detailed results are given in Appendix 2 (see Tables A3 and A4).

5. General Discussion

The goal of this study was to assess effects of a variety of training paradigms on dynamic aspects of visual attention, as represented by performance on the attentional blink and multiple object tracking tasks. On the attentional blink task, only the experimental action group showed significantly greater performance than the baseline group on the critical lags where recovery is occurring, suggesting that an enhancement in the temporal dynamics of visual attention occurred only as a result of playing the experimental action game. Other

groups did show improvements in their post-test performance, but these effects were not significantly different than what was observed in the baseline group, and thus are likely to represent simple test–retest enhancements. Furthermore, when the experimental action game group was compared to each of the four control games, the improvement in the action game group (Unreal Tournament) was significantly greater than that achieved by all of the other training groups other than the America's Army group that was not seen to differ from the experimental group. The fact that the improvement in the America's Army group was neither significantly greater than the baseline group nor significantly less than the experimental action game group suggests that America's Army had a small effect on the recovery of attention.

Similar results were found for the multiple object tracking task. When focusing on the critical attentional load of 4–5 to-be-tracked circles, only the experimental action game group showed a significantly greater improvement on these object tracking measures when compared to the baseline group. Although performance did improve in some of the other groups, the size of the effect in those groups was not different from the expected improvement due to simple test–retest effects.

Overall this work stresses the importance of well-tailored control groups in studies of training-induced learning. Although several training groups showed significant improvements on the tests of visual attention, it cannot be concluded that the training itself produced these enhancements. Some improvement is to be expected based purely on experience with the testing paradigms (test–retest effects). This factor needs to be removed by comparison to a baseline group that was equally exposed to the test paradigms but not trained in a way that should enhance performance on these paradigms. Only if greater improvement is established in the experimental group as compared to the control group can one conclude that training with the experimental regimen has had a causal effect on performance. The standard action game, Unreal Tournament 2004, was the only training that, in 12 h, produced significant improvements in our measures of the temporal resolution of visual attention and of the ability to track multiple objects over time as compared to the baseline group.

The other two control training games that were most similar to Unreal Tournament in terms of action gaming had relatively less effect. America's Army did not produce improvements greater than the baseline group in either experiment. However, the degree of improvement in this group on the attentional blink task was also not significantly less than the experimental group, suggesting that America's Army might have an intermediate effect on the temporal dynamics of attention. Harry Potter, despite its seemingly high attentional demands, also did not produce enhanced performance on either task. The lack of an effect of training observed in the America's Army and Harry Potter groups may in part be explained by our inability to maintain an adequate difficulty level to continue to engage our adult participants in the game, which is likely an important factor for learning. While the role of challenge in learning remains to be firmly established, the present study cautions against the use of a control group that is just asked to perform test–retest without intermediate training or which is trained on an "easy" version of the same task as the

experimental group as it is likely that any less challenging training will always lead to less learning, regardless of the nature of the training.

The other two control groups (Interactive Metronome and Tetris) bore little similarity to action gaming, except for the fact that they were quite engaging and challenging for the participants. Neither Tetris training, as in our previous studies (Green & Bavelier, 2003), nor Interactive Metronome training led to improvements in either experiment beyond what was observed in our baseline control group. The Card Games, as expected, produced no significant changes in performance on either task and functioned as a baseline for comparing the effects of the other groups.

This study highlights several key traits in computer games that may facilitate changes in visual attention. The most efficient game for training (Unreal Tournament) was the fastest and the least predictable one. It presented frequent, widely distributed, unexpected events that require a fast and accurate response from the player. Finally, it was formatted in such a way that players were not encouraged to use more passive strategies, such as sniping, which tend to reduce game pace and attentional load.

However, because the games used here are merely representative of several popular types of games and differ, from each other, in many respects, it is difficult at this stage to pinpoint precisely which criteria are essential for learning. This study instead serves to narrow our scope and highlight which games and which game traits are good candidates for training visual attention. Within this smaller range, it will now be feasible to select a specific game and vary only specific aspects of play, such as level of challenge or pace of the game, and observe the effect of these variations on the success of training.

Acknowledgments

Appendix 1: Results for Attentional Blink

Analysis of Ability to Detect Target 2 Given Target 1 Had Been Identified

In order to measure recovery from the attentional "bottleneck" produced by the identification of the white letter (Target 1), we looked at the percent of correct Target 2 detections as a function of the time elapsed between Target 1 and Target 2. The letter presented immediately after Target 1 was labeled as being displayed at "Lag 1" while the second letter was displayed at "Lag 2" and so forth. To ensure subjects were allocating attention to the white letter, only trials in which Target 1 was correctly identified were used in our analyses. Two-tailed *p*-values are reported throughout this section.

Correct Target 2 detection scores on the dual-task trials were adjusted using results from the X-detect-only task and the following formula was applied: performance = 100-([T2 alone] − [T2 given T1 correct]). Thus, this performance measure reflects subjects' ability to recover attention following successful identification of the first target and is not confounded by subjects' ability to detect the second target alone. It therefore provides a more direct measure of the recovery of attentional resources after they have been allocated to the first target.

Using this adjusted measure, separate ANOVAs for each training regimen with test (pre/post) and lag (1–8) as factors were performed for each of the training groups (Unreal Tournament: UT, America's Army: AA, Harry Potter: HP, Tetris: TE, Interactive Metronome: IM, Card Games: CG) which revealed significant effects of lag for all groups, with the expected gradual recovery at increasing lags (Table A1) (UT, $F(7, 70) = 19.75$, MSE $= 0.032$, p < 0.001, $\eta_p^2 = 0.66$; AA, $F(7, 91) = 44.68$, MSE $= 0.031$, p < 0.001, $\eta_p^2 = 0.77$; HP, $F(7, 91) = 25.09$, MSE $= 0.025$, p < 0.001 $\eta_p^2 = 0.66$; TE, $F(7, 84) = 20.73$, MSE $= 0.037$, p < 0.001, $\eta_p^2 = 0.63$; IM, $F(7, 126) = 48.88$, MSE $= 0.036$, p < 0.001 $\eta_p^2 = 0.73$; CG, $F(7, 77) = 31.58$, MSE $= 0.041$, p < 0.001, $\eta_p^2 = 0.74$).

Furthermore, the main effect of test was significant for the experimental group (UT, $F(1, 10) = 20.76$, MSE $= 0.020$, $p = 0.001$, $\eta_p^2 = 00.67$), the Interactive Metronome group ($F(1, 18) = 4.70$, MSE $= 0.035$, $p = 0.04$, $\eta_p^2 = 0.21$) and marginally for the America's Army group ($F(1, 13) = 3.89$, MSE $= 0.046$, $p = 0.07$, $\eta_p^2 = 0.23$). Finally, an interaction between test and lag was observed for the experimental group (UT, $F(7, 70) = 2.25$, MSE $= 0.032$, $p = 0.04$ $\eta_p^2 = 0.18$). This interaction highlights the fact that the speed at which subjects recover from the blink is best indexed by performance at the early lags. Accordingly to look at the difference in recovery across training, we performed another set of ANOVAs to examine group interactions at lags 2, 3, and 4. Lag 1 was not included as the AB paradigm we chose shows the typical saving from the blink at lag 1 ("lag 1 sparing" – Chun & Potter, 1995).

Separate ANOVAs for each training regimen using data from lags 2, 3, and 4 with test (pre/post) as the only factor revealed highly significant effects of test for the experimental group (UT, $F(1, 10) = 44.74$, MSE $= 0.005$, p < 0.001 $\eta_p^2 = 0.82$), and more modest effects for the America's Army group ($F(1, 13) = 6.46$, MSE $= 0.014$, $p = 0.025$, $\eta_p^2 = 0.33$), and marginally for the Interactive Metronome group ($F(1, 18) = 4.25$, MSE $= 0.010$, $p = 0.054$, $\eta_p^2 = 0.19$). The other training groups showed no significant improvement at these critical lags (see Figure 1).

A series of 2 (training group) ×2 (pre vs. post training) ×3 (lags 2, 3, 4) ANOVAs were run comparing each group to the baseline group (control group #5: CG) in order to estimate the effect of training above and beyond test–retest improvement. The experimental group was the only training group that showed significantly more improvement than the baseline group (pre vs. post-test by training group interaction) (UT, pre-test vs. post-test accuracy (lags 2,3,4): 57.72 ± 4.89 vs. 77.25 ± 4.94; CG, pre-test vs. post-test accuracy: 51.54 ± 4.33 vs. 58.23 ± 6.37) (CG vs. UT, $F(1, 21) = 6.44$, MSE $= 0.021$, $p = 0.019$, $\eta_p^2 = 0.23$). When the action group was compared to the five control groups, the action group improved significantly more than all of these, except America's

Table A1

Mean accuracy (standard error) at each of the eight lags before and after training (pre vs. post) for each training group.

Lag	1	2	3	4	5	6	7	8
Unreal Tournament								
Pre	74.47(7.79)	53.87(5.71)	50.67(6.06)	68.63(6.82)	91.74(7.05)	97.41(3.84)	103.67(5.87)	100.23(1.70)
Post	83.69(5.55)	67.33(7.54)	76.10(8.23)	88.33(3.23)	98.58(1.81)	102.73(2.92)	101.31(2.83)	101.10(1.16)
Difference	9.22	13.46	25.43	19.7	6.84	5.32	−2.36	0.87
America's Army								
Pre	64.47(7.17)	40.44(7.17)	50.73(6.52)	65.69(4.89)	85.81(6.08)	101.73(3.74)	102.82(2.00)	98.97(2.80)
Post	68.51(6.99)	53.69(6.24)	55.97(4.67)	81.31(4.95)	92.41(3.93)	104.38(2.29)	102.28(2.77)	97.50(1.12)
Difference	4.04	13.25	5.24	15.62	6.6	2.65	−0.54	−1.47
Harry Potter								
Pre	63.28(9.53)	41.25(5.75)	52.29(7.31)	74.09(7.36)	85.38(5.19)	97.69(3.94)	103.92(4.64)	104.3(2.03)
Post	70.91(7.90)	46.95(6.72)	48.68(7.54)	77.24(5.52)	89.64(4.76)	94.95(3.57)	95.61(3.22)	96.46(2.76)
Difference	7.63	5.7	−3.61	3.15	4.26	−2.74	−8.31	−7.84
Tetris								
Pre	69.39(6.15)	55.69(7.55)	58.03(7.99)	64.41(6.01)	91.47(3.89)	87.97(4.89)	96.40(5.57)	96.84(4.36)
Post	78.13(6.66)	52.57(7.98)	66.05(6.65)	72.12(5.91)	88.48(4.00)	101.01(3.97)	95.17(3.73)	100.61(2.15)
Difference	8.74	−3.12	8.02	7.71	−2.99	13.04	−1.23	3.77
Interactive Metronome								
Pre	65.17(4.64)	41.96(5.24)	51.80(5.86)	73.87(4.04)	84.18(4.45)	95.37(3.82)	101.58(3.67)	101.54(1.42)
Post	70.52(5.91)	51.56(6.35)	56.79(4.61)	79.33(4.16)	93.12(2.79)	99.59(2.37)	101.7(2.79)	100.02(1.26)
Difference	5.35	9.6	4.99	5.46	8.94	4.22	0.12	−1.52
Card Games								
Pre	63.94(8.67)	34.03(5.91)	49.68(4.60)	70.63(5.78)	88.34(4.39)	96.32(5.06)	106.71(3.63)	99.07(3.05)
Post	67.93(6.54)	50.51(8.27)	54.15(7.63)	70.03(7.26)	91.26(3.13)	95.86(3.10)	101.57(2.53)	99.07(0.71)
Difference	3.99	16.48	4.47	−0.6	2.92	−0.46	−5.14	0

To calculate accuracy, correct T2 detection scores on the dual-task trials were adjusted using results from the X-detect-only task according to the following formula: performance = 100−([T2 alone]−[T2 given T1 correct]). Thus, the measure reflects participants' ability to recover attention following successful id.

Army (AA vs. UT, $F(1, 23) = 2.06$, MSE $= 0.030$, $p = 0.164$, $\eta_p^2 = 0.08$; HP vs. UT, $F(1, 23) = 20.81$, MSE $= 0.014$, $p < 0.001$, $\eta_p^2 = 0.48$; TE vs. UT, $F(1, 22) = 5.18$, MSE $= 0.041$, $p = 0.033$, $\eta_p^2 = 0.19$; IM vs. UT, $F(1, 28) = 7.11$, MSE $= 0.024$, $p = 0.013$, $\eta_p^2 = 0.20$). Taken together, the fact that the experimental group was the only group to improve significantly more than the baseline group and that this group improved significantly more than all but one of the other groups suggests that the experimental action game had the greatest effect on the speed of attentional recovery. Finally, it should be noted that none of the training groups demonstrated a pre/post difference in performance on the target absent trials, which were analyzed separately. In fact, only the experimental group approached a significant improvement on X-absent trials (UT, $F(1, 10) = 4.25$, $p = 0.07$), thus eliminating the possibility that the experimental group's improvement on X-present trials was due to a shift in criteria rather than an increase in sensitivity.

Analysis of Ability to Detect Target 2-Only

Separate ANOVAs were carried out for each training group with test (pre/post) and lag (1–8) as factors on the % correct for Target 2 detection only. This corresponds to performance on the separate blocks of trials during both pre- and post-testing in which subjects were told to ignore the white letter and report only whether or not an X was present in the stream of letters. Because lag was included as a factor, only trials in which the target X was present could be used in this analysis, as "lag" is meaningless when no target is present. All groups improved significantly between pre- and post-testing in their ability to detect T2 when they were not required to identify the white letter (Table A2) (UT, $F(1, 10) = 9.02$, MSE $= 0.009$, $p = 0.013$, $\eta_p^2 = 0.47$; AA, $F(1, 13) = 10.17$, MSE $= 0.012$, $p = 0.007$, $\eta_p^2 = 0.44$; HP, $F(1, 13) = 18.59$, MSE $= 0.028$, $p = 0.001$ $\eta_p^2 = 0.59$; TE, $F(1, 13) = 15.08$, MSE $= 0.016$, $p = 0.002$, $\eta_p^2 = 0.54$; IM, $F(1, 18) = 13.64$, MSE $= 0.011$, $p = 0.002$, $\eta_p^2 = 0.43$; SO $F(1, 11) = 43.72$, MSE $= 0.006$, $p < 0.001$, $\eta_p^2 = 0.80$).

All groups showed a significant effect of lag, which reflects the white letter's ability to exogenously capture attention, even when it is not processed deliberately (Moroni et al., 2000; Raymond et al., 1992) (UT, $F(7, 70) = 4.83$, MSE $= 0.008$, $p < 0.001$, $\eta_p^2 = 0.33$;

Table A2

Mean accuracy (standard error) for the X-detect-only task before and after training (pre vs. post) for each training group.

	UT	AA	HP	TE	IM	CG
Pre	85.94(1.32)	87.78(1.07)	83.48(1.26)	83.98(1.39)	84.17(0.99)	85.42(1.10)
Post	90.20(1.13)	92.41(0.80)	93.14(0.83)	90.46(1.00)	88.61(0.88)	93.16(0.80)
Difference	4.26	4.63	9.66	6.48	4.44	7.74

AA, $F(7, 91) = 3.95$, MSE $= 0.008$, $p = 0.001$, $\eta_p^2 = 0.23$; HP, $F(7, 91) = 3.73$, MSE $= 0.009$, $p = 0.001$, $\eta_p^2 = 0.22$; TE, $F(7, 84) = 3.74$, MSE $= 0.009$, $p = 0.001$, $\eta_p^2 = 0.22$; IM, $F(7, 126) = 6.17$, MSE $= 0.011$, $p < 0.001$, $\eta_p^2 = 0.25$; SO, $F(7, 77) = 4.78$, MSE $= 0.005$, $p < 0.001$, $\eta_p^2 = 0.30$). There were no significant group-by-test interactions when groups were compared to either the experimental group or the baseline group. This finding also held true in a separate analysis for X-absent trials.

This improvement in baseline Target 2 correct detection that occurred across all the training groups reflects a more general test–retest improvement in the ability to segment the rapid stream of letters rather than an improvement in attentional recovery following the processing of Target 1. It is likely, however, to be an added source of variance when studying between-group differences in improvement of recovery from the attentional blink. Accordingly, this difference was corrected for as described in the previous section when analyzing Target 2 detection given the correct identification of Target 1, after ensuring that it was not the source of a significant difference across training groups.

Appendix 2: Results for Multiple Object Tracking

Object tracking performance was measured as the subject's percentage of correct responses to the yes (was cued)/no (was not cued) decision made about the given probe circle. The number of correct responses was recorded separately for each possible number of cued circles (1–7). There were no interactions found with expected response (yes vs. no) so performance measures were collapsed across "yes" and "no" trials. Separate ANOVAs with test (pre/post) and cued circles (1–7) as factors were performed for each training regimen. As expected, a main effect of number of circles to track was found for each group with accuracy decreasing with increasing number of circles (Table A3) (UT, $F(6, 60) = 47.02$, MSE $= 0.007$, $p < 0.001$, $\eta_p^2 = 0.82$; AA, $F(6, 78) = 55.19$, MSE $= 0.009$, $p < 0.001$, $\eta_p^2 = 0.81$; HP, $F(6, 78) = 69.66$, MSE $= 0.008$, $p < 0.001$, $\eta_p^2 = 0.84$; TE, $F(6, 78) = 81.73$, MSE $= 0.006$, $p < 0.001$, $\eta_p^2 = .86$; IM, $F(6, 108) = 52.91$, MSE $= 0.009$, $p < 0.001$, $\eta_p^2 = .75$; SO, $F(6, 66) = 25.54$, MSE $= 0.012$, $p < 0.001$, $\eta_p^2 = 0.70$).

Three training groups improved significantly between pre- and post-testing (Table A4): our experimental group, UT ($F(1, 10) = 5.32$, MSE $= 0.015$, $p = 0.044$, $\eta_p^2 = 0.35$), IM ($F(1, 18) = 5.90$, MSE $= 0.006$, $p = 0.026$, $\eta_p^2 = 0.25$) and TE ($F(1, 13) = 9.02$, MSE $= 0.006$, $p = 0.01$, $\eta_p^2 = 0.41$). There were no significant interactions between test and the number of circles for any of the groups.

It was consistently seen that while groups showed comparable performance with relatively few items, differences in performance emerged as some critical attentional load (4–5 circles) was reached. This pattern is consistent with our previous findings (Green & Bavelier, 2006b) as well as recent findings in children who play action video games (Trick et al., 2005). Accordingly, we ran a second set of 2 (training group) ×2 (pre vs. post training) ANOVAs, looking only at performance on trials where four or five circles were cued at the outset. A series of ANOVAs comparing each group to the baseline game

Table A3

Mean accuracy (standard error) at each number of circles to be tracked (1–7) before and after training (pre vs. post) for each training group.

No. of circles	1	2	3	4	5	6	7
Unreal Tournament							
Pre	97.73(1.04)	94.55(1.25)	90.00(1.65)	78.64(2.95)	71.36(3.64)	66.36(3.44)	65.00(1.91)
Post	98.18(1.02)	95.00(1.65)	93.64(2.44)	87.27(3.59)	82.27(2.27)	71.36(4.53)	68.18(4.68)
Difference	0.45	0.45	3.64	8.63	10.91	5	3.18
America's Army							
Pre	100(0)	94.29(1.56)	88.21(2.90)	85.36(2.94)	69.64(2.99)	71.43(3.21)	62.14(3.13)
Post	99.64(0.36)	97.50(1.01)	86.43(2.31)	83.21(2.75)	75.36(3.53)	67.86(4.22)	68.98(3.64)
Difference	−0.36	3.21	−1.78	−2.15	5.72	−3.57	6.84
Harry Potter							
Pre	96.79(1.45)	97.14(0.86)	83.93(2.35)	81.07(3.36)	70.71(2.91)	62.86(2.95)	63.57(1.92)
Post	98.57(0.82)	93.93(1.67)	89.29(2.02)	81.79(3.13)	73.57(2.94)	65.00(3.06)	64.29(3.35)
Difference	1.78	−3.21	5.36	0.72	2.86	2.14	0.72
Tetris							
Pre	96.79(1.13)	92.86(1.94)	87.86(1.72)	78.93(3.48)	68.57(2.64)	63.93(3.64)	62.86(3.62)
Post	96.79(1.35)	91.79(1.93)	90.71(2.21)	82.86(3.04)	76.07(2.88)	68.93(2.58)	67.50(3.22)
Difference	0	−1.07	2.85	3.93	7.5	5	4.64
Interactive Metronome							
Pre	97.37(0.89)	92.37(2.04)	87.37(3.00)	81.58(2.20)	73.42(3.27)	74.47(3.26)	64.47(2.56)
Post	97.89(0.79)	94.74(1.05)	88.95(1.69)	83.16(2.17)	80.00(2.06)	74.47(2.86)	67.89(2.92)
Difference	0.52	2.37	1.58	1.58	6.58	0	3.42
Card Games							
Pre	98.33(0.94)	95.00(1.74)	91.67(2.16)	79.17(4.39)	79.58(4.58)	74.17(2.88)	65.00(2.46)
Post	97.50(0.97)	93.75(2.05)	88.33(2.78)	82.08(3.77)	76.67(3.96)	75.00(3.43)	68.33(3.71)
Difference	−0.83	−1.25	−3.34	2.91	−2.91	0.83	3.33

Table A4

Mean accuracy (standard error) before and after training (pre vs. post) for each training group.

	UT	AA	HP	TE	IM	CG
Pre	80.52(1.70)	81.58(1.63)	79.44(1.61)	78.83(1.66)	81.58(1.34)	83.27(1.65)
Post	85.13(1.70)	82.70(1.60)	80.92(1.60)	82.09(1.43)	83.87(1.16)	83.10(1.57)
Difference	4.61	1.12	1.48	3.26	2.29	.17

on four and five cued-object trials indicated that only the action group improved significantly more that the baseline group (pre vs. post-test by training group interaction) (UT vs. CG, $F(1, 21) = 6.60$, MSE $= 0.008$, $p = 0.02$, $\eta_p^2 = 0.24$ with pre-test vs. post-test % accuracy of 75.00 ± 2.02 vs. 84.77 ± 2.30 for UT and 79.38 ± 3.10 vs. 79.38 ± 2.73 for CG). None of the other training groups showed a significantly greater improvement on object tracking performance when compared to our baseline group (see Figure 2). On these critical trials, the action game trainees (UT) also outperformed subjects trained on Harry Potter ($F(1, 23) = 4.46$, MSE $= 0.009$, $p = 0.046$, $\eta_p^2 = 0.16$). The greater improvement of the action group also approached significance when compared to that of the America's Army group ($F(1, 23) = 3.53$, MSE $= 0.011$, $p = 0.073$, $\eta_p^2 = 0.13$), but less so when compared to the Interactive Metronome group ($F(1, 28) = 2.12$, MSE $= 0.011$, $p = 0.157$, $\eta_p^2 = 0.07$).

Surprisingly, there was no pre–post by group interaction between the action group and the Tetris-playing controls ($F(1, 23) = 1.09$, MSE $= 0.009$, $p = 0.31$, $\eta_p^2 = 0.05$). However, there is a consistent trend for greater improvement in the action group, as would be expected based on our previous work which employed nearly three times as much training (Green & Bavelier, 2006b).

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