DO THE TWO CEREBRAL HEMISPHERES HAVE INDEPENDENT TRACKING RESOURCES? EVIDENCE FROM UNDERGRADUATE POPULATIONS AND A SAMPLE OF VIDEO GAMERS AND NON-GAMERS

by

Scott P. McLean

A thesis submitted to the Faculty of the University of Delaware in partial fulfillment of the requirements for the degree of Master of Arts in Psychology

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ABSTRACT

Information in each visual field is initially processed in visual areas located in the contralateral hemisphere. This segregation of information between the two hemispheres quickly gives way to integrated representations that result from the rapid sharing of information across the corpus callosum. An exception to this integration process is provided by split brain patients who have had their corpus callosum severed (Myers and Sperry, 1958). This operation results in superior performance of split-brain patients compared to controls on several visual tasks, such as the ability to search for targets in the two visual fields simultaneously resulting in a doubling of search speed compared to controls (Luck, Hillyard, Mangun and Gazzaniga, 1989). In contrast, presenting bilateral displays to normal observers generally results in an advantage relative to unilateral presentation but one that is considerably less than the doubling of performance seen in split-brain patients. An exception to this rule was reported by Alvarez & Cavanagh (2005) who found that bilateral presentation in a multiple object tracking task (MOT) allowed observers to track twice as many objects relative to unilateral presentation. They suggested that the two cerebral hemispheres acted as independent object tracking systems in MOT. In the first experiment evidence for independent tracking systems were investigated. However, only a bilateral advantage that fell well short of the doubling of performance predicted by independent tracking

systems was found. In a second experiment a population with extensive experience playing video games was compared to non-gamers on measures of independent tracking resources. Video gamers have increased visual skills in tasks such as MOT (Green and Bavelier, 2006). Our results show video gamers outperformed non-gamers during bilateral tracking. This suggests that some individual differences may be associated with the bilateral hemispheric advantage. However, evidence for completely independent resources in the two cerebral hemispheres is still lacking. Video gamers in our study only showed a bilateral advantage for tracking objects in two visual fields and not independence. Examining individual differences in a population shown to have high performance on MOT was insufficient to replicate results of Alvarez and Cavanagh (2005).

Chapter 1

INTRODUCTION

The structure of the brain is divided into two cerebral hemispheres, interconnected by a bundle of neurons known as the corpus callosum. Seminal research by Myers and Sperry (1958) sparked interest in the function of the hemispheres. They demonstrated that cutting the corpus callosum, in effect splitting the brain, resulted in separate processing systems in the two hemispheres with somewhat different strengths and weaknesses. (See Gazzaniga, 2005 for a review of the split brain literature). These ‘split brain’ subjects have allowed researchers to investigate questions regarding the role of the two hemispheres in attention. For example, in Luck, Hillyard, Mangun and Gazzaniga (1989) demonstrate that split brain subjects can search bilateral displays of objects (i.e. distributed across the two visual fields) twice as fast as normal control subjects. This suggests that there are two independent foci of attention that can be deployed independently in split brain subjects whereas normal controls have integrated control of attention across the two hemispheres.

Luck et al. (1989) showed that split brain patients have independent ‘spotlights’ of attention in the two cerebral hemispheres. In their search task a group of patients with severed corpus callosa and a group of matched controls searched for a target rectangle consisting of a blue and red square. The target object had a red square on top and distractors a blue square on top. This required participants to conduct their search for the target based on feature information. They manipulated whether the target and distractors were isolated to one visual field or were distributed in both visual fields. They showed that both controls and patients were faster when their search was distributed in the two visual fields but the patients with separated cerebral hemispheres were significantly faster than controls on the bilateral displays as the number of distractors increased. They concluded that splitting the corpus callosum results in independent spotlight for attention controlled independently by each hemisphere.

Banich (1998) reviewed research on inter-hemispheric interactions. In one study particularly important to the current investigation Banich & Belger (1990) had participants perform matching tasks of different complexity. For example, in the simple task, participants had to determine whether two digits were identical, which requires simple perceptual information. In the complex task, participants had to determine whether the sum of the two digits was equal to 10. Performance in the complex task, but not the simple task, was better when the two digits were presented in separate visual fields. They suggested that complex tasks place demands on limited capacity mechanisms and that presenting stimuli to separate hemispheres effectively increases overall capacity by allowing each hemisphere to work in parallel.

A bilateral advantage in subjects with intact corpus collosa has also been reported in tasks involving elementary visual tasks such as detecting the orientation or presence of gabor patches (Reardon, Kelly and Matthews, 2009), visual enumeration of briefly presented objects (Delvenne, Castronovo, Demeyere, Humphreys, 2011), working memory for orientation information (Umemoto, Drew, Ester and Awh, 2010), and insensitivity to crowding effects in visual search (Chakravarthi and Cavanagh, 2009). These findings show a significant performance advantage for bilateral displays; however the magnitude of this advantage does not reach the level of hemispheric independence that has been demonstrated in split brain patients.

An exception was reported by Alvarez and Cavanagh (2005), who found a bilateral advantage during a multiple object-tracking task (Pylyshyn and Storm, 1988) that reflected independent hemispheric tracking in the two hemispheres. They reported that participants were able to track four objects evenly divided across the visual fields as accurately as they could track two objects in a single visual field. In other words, they found that participants could track twice as many objects presented bilaterally as they could when stimuli were presented unilaterally. It appears as though each cerebral hemisphere can independently track two objects whereas four objects in one hemifield exceeds attentional resources in one cerebral hemisphere, resulting in a decrease in tracking accuracy. This is one of the few studies using normal participants that have reported a hemispheric advantage that reached the level of independent processing in the two cerebral hemispheres.

Evidence for hemisphere-based independent resources for attention was also recently reported for certain visual search tasks. Alvarez, Gill and Cavanagh (2012) used a modified visual search task in which participants were directed to search for a target ‘T’ rotated 90° amongst distractor stimuli either presented in a bilateral or unilateral configuration. In separate experiments subjects were either cued to the location of the target or had to use features such as color to guide their search. They found that with location cueing, search was faster when target and distractors were presented across the two hemispheres than when the displays were presented in a single hemifield. In contrast, there was no bilateral advantage for feature-guided search. Alvarez et al. (2012) suggest that attentional guidance of attention to spatial locations depends on separate control mechanisms in the two cerebral hemispheres while feature based attention is integrated across the hemispheres.

Alvarez et al. (2012) point out that the finding that independent “spotlights of attention” can be deployed in the two visual fields supports the claim that spatial attention can be divided into separate “beams”. This lends credence to “multifocal spatial attention” theories (Alvarez and Franconeri, 2007) which propose that tracking multiple objects is achieved by separate attentional spotlights being allocated to each tracked object.

Awh and Pashler (2000) reported a similar finding in a visual search task where subjects were tasked to report the identity of two digits imbedded in a grid of distractor letters. The display was preceded by a cue that either indicated the locations of the targets (valid cue) or pointed to distractor locations (invalid cue). Invalid cues could point to locations that were between the two targets or to other equally distant locations. They reasoned that if attention can be split in a multifocal manner between the two targets, then on invalid cueing trials, detection of a target located between the two cued locations shouldn't be any better than targets located elsewhere. They confirmed this prediction suggesting that participants can divide attention between different locations. Interestingly, the ability to split attention between two locations was much better when the two locations were in different visual fields, supporting the idea that there are separate mechanisms for allocating attention in the two hemispheres.

Recent work suggests that a bilateral advantage, but not complete independence, can be extended to processing stages involving maintenance and storage of information in visual working memory (Umemoto, Drew, Ester & Awh, 2010). In a recall procedure participants were more accurate at remembering briefly presented orientation information when stimuli were presented in bilateral arrays. This evidence is particularly relevant as VWM may play a role in MOT (Fougnie and Marois, 2006). Perhaps total independence only applies to early stages of attention allocation in tracking when one selects objects by location, while later processes in VWM facilitate the advantage seen in Umemoto et al. (2010) that falls short of independence.

Despite the theoretical importance of the findings of Alvarez and Cavanagh (2005) for understanding how attentional resources in the two hemispheres are coordinated, there have been no published replications. Experiment 1 provides an attempted replication. Experiment 1 consists of five separate experiments that differ only in minor details of method. Our first two experiments (Experiments 1a and 1b) were aimed at developing ERP measures of hemispheric independent tracking and simply assumed that this phenomenon would be easy to obtain. Therefore, no attempt was made to precisely duplicate the methods and displays used by Alvarez and Cavanagh (2005). After initial failures to replicate their results, later experiments in the series adopted methods that were aimed at duplicating experiment 3 in Alvarez and Cavanagh as precisely as possible. To anticipate our results, none of these minor variations in methods made any difference; all experiments produced remarkably similar results that show an advantage for bilateral presentation but one that falls well short of hemispheric independence.

The general method that was common to all these studies is reported first followed by a brief description of how each experiment differed from the general method.

Chapter 2

EXPERIMENT 1

Methods for Experiments 1a-e

Participants completed an MOT task based on the method in experiment 3 of Alvarez and Cavanagh (2005) in which objects appeared in four quadrants, each containing four independently moving black dots (see figure 1). Participants were cued to track a subset of the dots by briefly changing their color to either red or green (target color was counterbalanced across subjects) at the beginning of the trial. After the tracking duration, all of the dots became stationary and one dot was cued with the color of the target. Participants pressed a button labeled ‘Same’ and ‘Different’ to indicate whether the test dot was a target. Target and distractor dots served as the test equally often over trials.

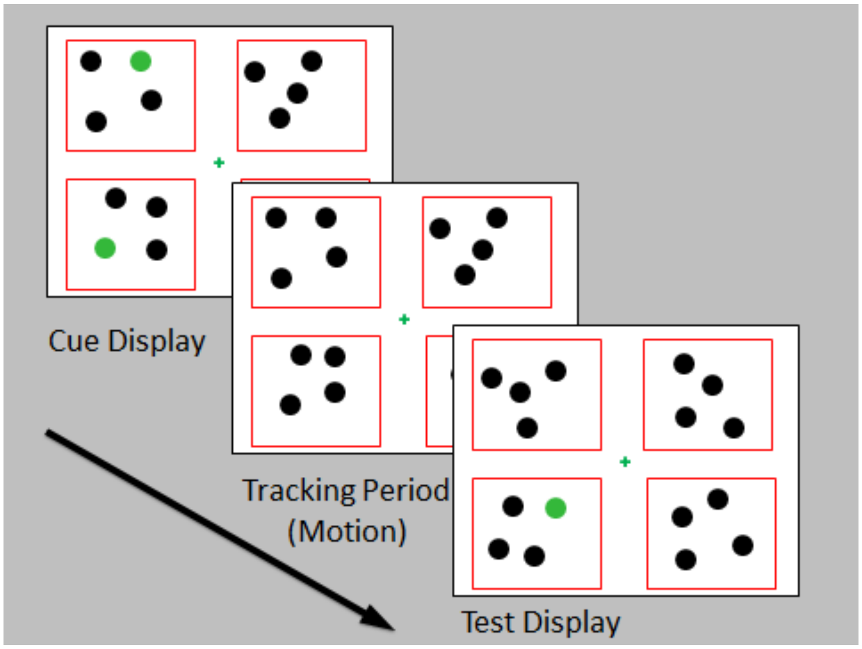


Figure 1 Example of MOT Procedure in Experiment 1a-b

Participants were instructed to track objects appearing in one visual field (unilateral tracking) or both visual fields (bilateral tracking). In the unilateral condition, the combinations of visual field of the tracked objects (left vs. right), the number of objects tracked (2 or 4), and the location of the test object (upper vs. lower quadrant) occurred equally often over trials. For bilateral displays, the objects in the two visual fields both appeared in the upper or lower quadrant on each trial. This variable was crossed with the number of objects tracked (2 vs. 4) and the location of the test object (left vs. right visual field), see figure 2.

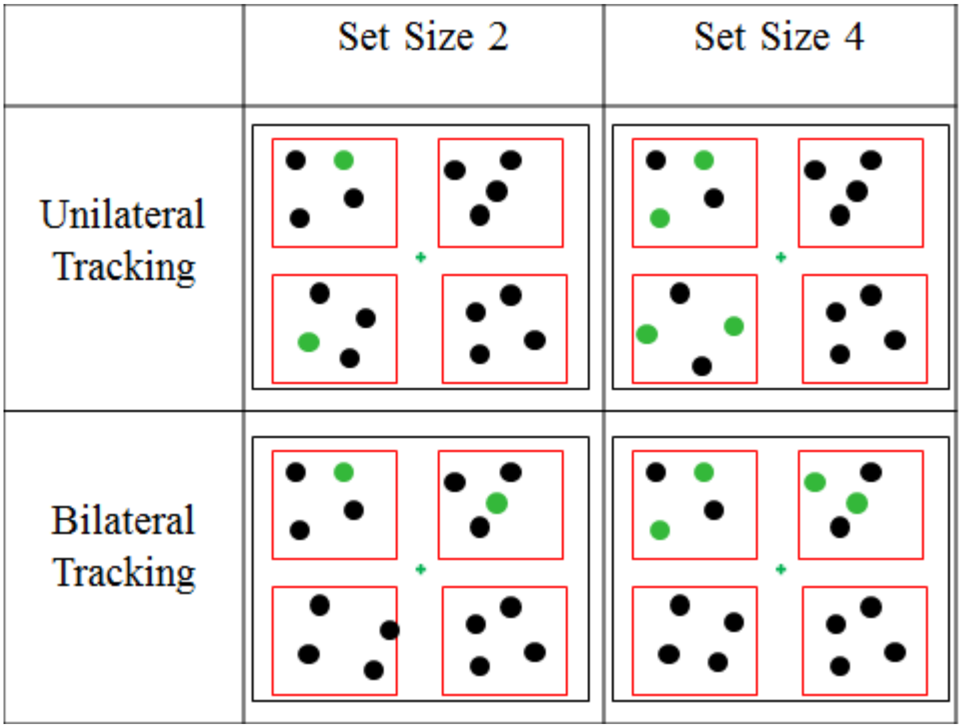


Figure 2 Example of tracking conditions in Experiment 1a-b.

Participants

We describe participant characteristics for each experiment separately. Across all five experiments there were a total of seventy eight participants (45 female, 33 males) who were recruited from the university subject pool and the university online classifieds system at the University of Delaware. Participants' ages ranged from 18-48 (*M*= 21.96, *std*= 4.33) and they were compensated with either course credit or paid $10 per hour for their participation.

Experiment 1 General Apparatus and Procedure

At the beginning of each trial, participants were instructed to fixate a cross in the center of the display and initiate a trial by pressing a button on the mouse. They were then shown 16 (experiment 1a-b) or 8 (experiment 1c-e) dots on each trial. On each trial, either 2 or 4 of the dots were cued as targets. In the unilateral condition, target dots were all located in a single visual field whereas in the bilateral condition, targets were divided evenly across both visual fields (see experiment 1c for an exception). The particular cueing color (red or green) assigned to an observer was counterbalanced across participants. This method of cueing makes it unlikely that any obtained hemispheric effects are due to imbalances in sensory events across the two hemispheres (see Vogel and Machizawa, 2004).

All experiments were controlled by a Dell computer using custom software written in Blitz3D (Sibly, 2005). The timing of the color change varied by experiment and is detailed separately for each experiment. Following the cueing period, the dots moved within their quadrants for a duration that varied across experiments. Velocity of the dots was held constant at 3.98° per second unless otherwise stated. Minimum distance between dots was 3° unless otherwise stated. Dots bounced off each other as well as the borders of the boxes. Following the motion period, one of the dots in an attended quadrant changed color and participants indicated whether or not it was a target by clicking one of two onscreen buttons. They received immediate feedback on the accuracy of their response as well as their average accuracy for the experiment. If eye movements were detected, participants were presented with a playback of their eye movements and the experimenter reminded subjects to maintain fixation. Breaks were given approximately every 80 trials, during which participants received feedback on their average tracking accuracy. Eye tracking feedback was also given and observers were warned if their eye movements exceeded 10% of trials.

Experiment 1a

Participants

Nineteen subjects (12 females, 7 males) completed this experiment. Age ranged from 18-48 (*M*= 23.52, *std*=6.22).

Apparatus and Procedure

In experiment 1a target objects were cued for one second and tracking duration was two seconds. Stimuli in this experiment appeared on an 18” Dell CRT monitor (1,024x 768 pixel resolution; 75-Hz frame rate) controlled by a Dell 2.99-GHz computer. Eye fixation was monitored using a Tobii x50 50-Hz eyetracker (Tobii Technology, Stockholm, Sweden) controlled by a Sony 2.86-GHz computer. A chinrest was used to maintain a 70 cm viewing distance resulting in total viewing area subtending approximately 27.5º X 21.1º. The fixation cross measured .20 º, tracked objects measured .92º in diameter with minimum center to center dot spacing of 1.8 º. Velocity of the dots was held constant at 5.73° per second. Minimum distance between dots was 3°. Each of the four boxes was square and measured 8 º on a side. Participants completed 768 trials.

Experiment 1b: A longer cueing period

Participants

Sixteen participants (11 females, 5 males) were recruited from the University of Delaware Community (Age *M*=22.94, *std*=3.67). Subjects were compensated at a rate of $10 per hour.

Apparatus and Procedure

This experiment was identical in methods of Experiment 1a, except that the cueing period was increased to two seconds followed by a two second tracking period.

Experiment 1c: Unilateral Tracking in one Quadrant

Participants

Fifteen participants (6 females, 9 males) were recruited from the University of Delaware Community (Age *M*=21.13 *std*=3.69). Subjects were compensated at a rate of $10 per hour.

Apparatus and Procedure

Viewing distance was approximately 53 cm from a Mitsubishi Diamond Pro 710s CRT display with a viewable screen area subtending 28.4° X 22.2°. Eye fixation was monitored with an ISCAN 60-Hz eyetracker controlled by a Dell System Gxa 233M EM computer. The center of each box was 7.87° from fixation. Dots measured 1.28° in diameter had a minimum center-to-center spacing between dots of 3°. Four rectangular quadrants measuring 10.16° X 14.09° contained target and distractor dots. The fixation cross measured .24°. These dimensions were used to replicate experiment 3 of Alvarez and Cavanagh (2005). Subjects were always cued to track red targets. Two second cue duration was followed by a three second tracking period. Velocity of the dots was held constant at 7.6° per second.

Unilateral displays were critically different in this experiment. The two target objects were always presented within one box (i.e. in one quadrant of the screen). This was done because one interpretation of the methods in experiment 3 in Alvarez and Cavanagh (2005) was that on unilateral set size two trials both targets were present in one quadrant only, as opposed to two targets in individual quadrants. Beginning in experiment 1 c the quadrants in the opposite to target and distractor dots were left empty. Targets were always cued in red and distractors were always green. (See figure 3). Participants completed 512 trials.

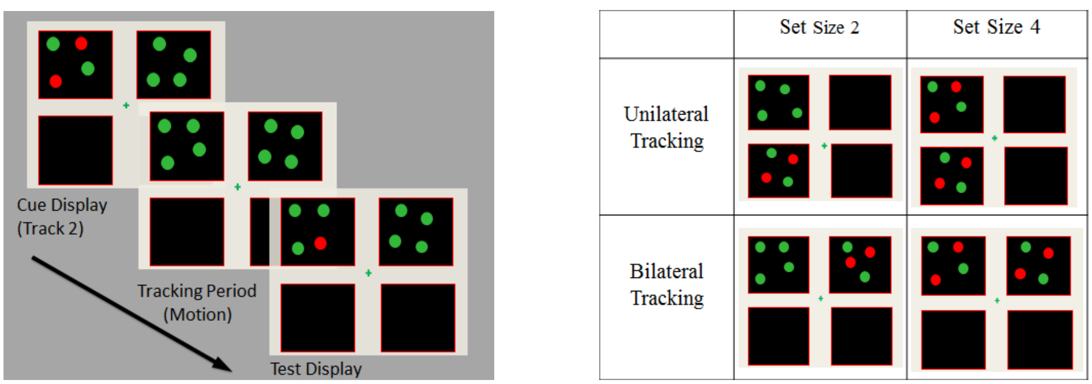


Figure 3 Example of MOT Procedure and Conditions in Experiment 1c

Experiment 1d: Velocity of Objects Depends on Staircase Procedure

Participants

Sixteen participants (9 females, 7 males) were recruited from the University of Delaware community (Age *M*=22.25, *std*=3.07). Subjects were compensated at a rate of $10 per hour.

Apparatus and Procedure

The display and procedure was the same as described in experiment 1c except in this experiment as well as in 1e, the two target objects in the unilateral condition were distributed across two quadrants, as was the case in experiments 1a and b. (see figure 4) Like Alvarez and Cavanagh, we used a staircase procedure to adjust tracking speed individually for each subject in an initial block of trials where participants only had to track two objects. Speed varied to converge on a mean tracking accuracy of 85% correct in the set size 2 unilateral condition. This velocity was used for the remainder of the experiment. The average velocity of the dots was 13.26° per second. Target objects were cued for 2 seconds followed by a 3 second tracking duration. Participants completed 416 trials.

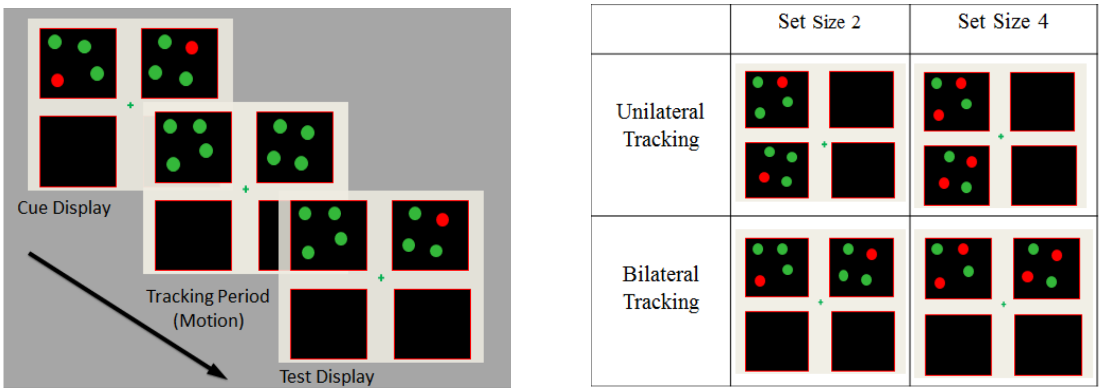


Figure 4 Example of MOT Procedure and Conditions in Experiment 1d-e and Experiment 2

Experiment 1e: Replication of Timing in Alvarez and Cavanagh (2005)

Participants

Twelve participants (7 females, 5 males) were recruited from the University of Delaware Psychology Department Subject Pool (Age *M*=22.94, *std*=3.67). Subjects were compensated with course credit for introductory Psychology courses.

Apparatus and Procedure

This experiment was designed to replicate as closely as possible the methods employed in experiment 3 of Alvarez and Cavanagh (2005). Stimuli appeared on an SAMSUNG 2233RZ LCD Monitor (Wang & Nikolic, 2011) (1,680 x 1,050 pixel resolution; 120-Hz frame rate) controlled by a Dell 2.99-GHz computer. Eye fixation was monitored using a Tobii x50 50-Hz eyetracker (Tobii Technology, Stockholm, Sweden) controlled by a Sony 2.86-GHz computer. Participants were seated in a chinrest in order to maintain a 70cm viewing distance resulting in a total viewing area subtending approximately 34º X 24.4 º. The four quadrant boxes each measured 10.85° x15.33°. Dots had a diameter of 1.37°. A staircase procedure was used to adjust the speed of the dots for each participant to achieve an average tracking accuracy of 85% as in experiment 1d. Average speed of the dots was 6.87° per second. Cue duration lasted 2 seconds and tracking duration was 5 seconds to match the conditions of experiment 3 in Alvarez and Cavanagh (2005).

Experiment 1 Results

A mixed model ANOVA was conducted on the raw percentage of trials where participants correctly identified the test dot from Experiment 1 with experiment number (1a-e) as a between-groups variable and tracking type (bilateral or unilateral) and set size (2 or 4) as repeated measures variables. There was a main effect of experiment ($F(1,4)=2.902$, $MSE=288.177$ $p=.028$) reflecting overall lower tracking accuracy in experiment 1e (74.5%, $STE= 2.56$) compared to 84.47% ($STE=1.95$) in Experiment 1a, 82.06% ($STE= 2.12$) in Experiment 1b, 84.23% ($STE=2.19$) in Experiment 1c and 80.54% ($STE=2.122$) in Experiment 1d. The significant interaction of tracking type and experiment ($F(4,72)=3.079$, $MSE=17.35$, $p=.021$) and follow up analyses verified the effects of experiment were driven by performance in unilateral tracking conditions from experiment 1e. One-way ANOVA with Unilateral tracking four objects and experiment as factors yielded a significant interaction ($F(4,72)= 4.334$, $MSE=89.630$, $p=.003$) and one-way ANOVA analyses with Unilateral tracking two objects and experiment as factors showed ($F(4,72)= 2.798$, $MSE= 86.552$, $p= .032$). LSD follow ups revealed that experiment 1e showed significantly lower means (Unilateral 4, 61.18% ; Unilateral 2, 79.37%) than all experiments ($p<.05$)except for experiment 1d (Unilateral 4, 66.77% , $p=.137$; Unilateral 2, 86.54%, $p= .053$). Similar performance in these conditions likely occurred because experiment 1d and 1e shared the staircase procedure that level out tracking accuracy at 85% driving their accuracy below that of experiments 1a-c. Importantly though, there was no three way interaction between tracking type, set size and experiments ($F(4,72)=1.269$, $MSE=13.166$, $p=.29$).

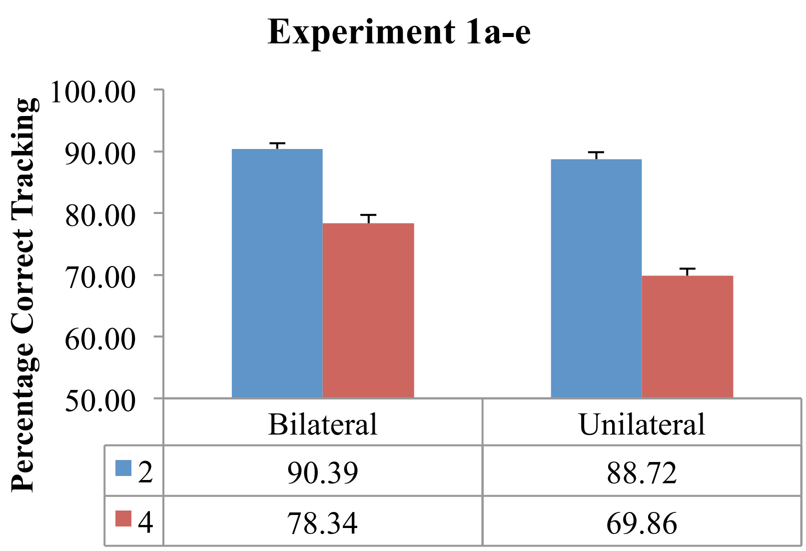


Figure 5 Tracking Accuracy in Experiment 1.

There was a significant interaction of tracking type x set size ($F(1,72)=38.406$, $MSE=13.166$, $p< .001$), see figure 5 depicting combined accuracy data for experiments

1a-e. There was a main effect of tracking type reflecting a higher accuracy for bilateral (84.14%, *STE*= 1.03) versus unilateral tracking (78.15%, *STE*=0.99), $F(1,76)=154.253$, $MSE=19.25$, $p< .001$). As would be expected in MOT, there was a main effect of set size in which tracking two objects (M= 88.51%, *STE*= .98) was more accurate than tracking four (M= 73.78%, *STE*= 1.13), $F(1,76)=341.73$, $MSE=47.82$, $p< .001$).

Relevant to evidence for hemispheric independence, there was an interaction of tracking type by set size ($F(1,76)=41.59$, $MSE=14.35$, $p< .001$). There was a significant difference between tracking accuracy for set size two in the unilateral condition (88.72%) and set size four in the bilateral condition (78.34%), $t(76)= 9.785$, $p<.001$. This shows that tracking four objects divided across the two visual fields resulted in poorer tracking than two objects appearing in a single visual field, inconsistent with the results of Alvarez and Cavanagh (2005). Independent hemispheric tracking predicts that accuracy should be the same for tracking four objects in two visual fields vs. two objects in one visual field.

In previous research claiming hemispheric independence (Alvarez and Cavanagh, 2005), accuracy in tracking four objects bilaterally was equivalent to tracking two objects unilaterally. In our experiments, there was a clear advantage for tracking objects bilaterally vs. unilaterally. For example, participants were 78.3% correct in bilateral tracking of four objects compared to 69.9% in the corresponding unilateral condition. However, bilateral tracking should have been at 88.7% to match the unilateral 2 tracking accuracy which is what independent hemispheric tracking predicts. So although there is an advantage for tracking objects in two visual fields compared to one visual field, it falls well short of what we would predict based on independent tracking in the two hemispheres.

Chapter 3

EXPERIMENT 2

We failed to replicate the results of Alvarez and Cavanagh (2005) even when we used methods and procedures modeled on theirs. We are unable to account for this failure to replicate and we can only speculate that perhaps there may be systematic individual differences between their participants and ours. What kind of individual differences might be important in determining multiple object tracking ability? Clues are provided by Bavelier and colleagues who reported that participants identified as "gamers" (defined as having extensive experience in playing "first person shooter" video games such as *Halo*, *Call of Duty* and *Battlefield*) performed better than non-gamers in a variety of basic laboratory tasks that involve visual attention, including Flanker Compatibility, Attentional Blink, Object Enumeration, and Multiple Object Tracking. (Green and Bavelier, 2003; 2006a; 2007).

In addition, a causal role for video game experience is suggested by the finding that non-gamers who were tested on these tasks before and after a controlled training period involving experience with action video games also showed enhanced performance following training (Green and Bavelier, 2003). After training subjects with an action video game for as little as 5 hours per week totaling 30 hours of training, performance in MOT was significantly higher in tracking 4, 5 and 6 objects compared to pre-training performance.

Action video games appear to enhance the spatial resolution and acuity of visual attention as demonstrated by an advantage for tracking multiple objects during crowding at high tracking loads (Green and Bavelier, 2007).Video game training has also been shown to increase contrast sensitivity to low level visual stimuli (Li, Polat, Makous and Bavelier, 2009) suggesting the possible application of video game training to improve poor eyesight.

We speculate the superior performance of experienced video gamers in attentionally demanding tasks, including MOT, may result from increased independence of hemispheric control of attention which could result in greater capacity for tasks such as multiple object tracking. Although previous studies reporting hemispheric independence have not specifically recruited video gamers, it is possible that Alvarez and Cavanagh, who used a small sample (n=8) may have inadvertently included a high proportion of the "gamers" population in their study. If this was the case, the prediction is that gamers would produce a pattern of results consistent with independent hemispheric tracking resources while non-gamers would not.

In Experiment 2 we directly investigate the role of individual differences in hemispheric independence during MOT. In particular, we compare the size of the bilateral tracking advantage in participants who vary in their experience with video games.

Methods

Participants

Twenty-five undergraduate students from the University of Delaware Psychology Department subject pool were included in this study and were compensated with course credits in Introductory Psychology courses. Participants were identified and grouped for analyses based on their weekly gaming habits. Gamers (*n*=13, *mean age* = 19.3, *std.* = 1.72, range = 3 females=2, males=11), were identified as playing more than 5 hours of action video games per week (*M* = 8.55, *std*= 2.33, range = 7, non-gamers (*n*=12, mean age = 19.6, *std*. = 2.2, females=3 males =7) played less than 3 hours of action games per week (*M*= .25, *std*. = .87, range = 3). The one non-gamer with who reported some gaming experience said they did so only during the summer and not during the academic year when this study was conducted. Overall then, gamers averaged 9 hours per week of playing video games vs. an average of 0.3 hours/week for non-gamers.

Apparatus and Procedure

Experiment two followed the same method and procedures as Experiment 1e. As in experiment 1e, a staircase procedure was used adjust the speed of the dots where subjects achieve tracking accuracy at 85%. Average speed of the dots was 10.08° per second. Participants completed 320 trials.

Experiment 2 Results

Tracking accuracy for video game players and non-video game players were entered into a mixed model ANOVA with video game experience as the between subject variable and tracking (bilateral or unilateral) and set size (2 or 4) as the within subject variables yielded a significant three way interaction of tracking type (bilateral or unilateral), set size (2 or 4) and video gamer status (gamer or non-gamer), ($F(1,23)=7.448$, $MSE=18.82$, $p=.012$), see figure 6. There was a significant interaction of Tracking (Bilateral vs. Unilateral) and Set Size (2 vs. 4), ($F(1,23)=10.416$, $MSE=18.82$, $p=.004$). This effect was driven by the finding that overall performance was worse tracking four objects unilaterally ($M=63.16\%$, $STE= 1.181$) than two objects unilaterally ($M=83.45\%$, $STE= 1.475$).

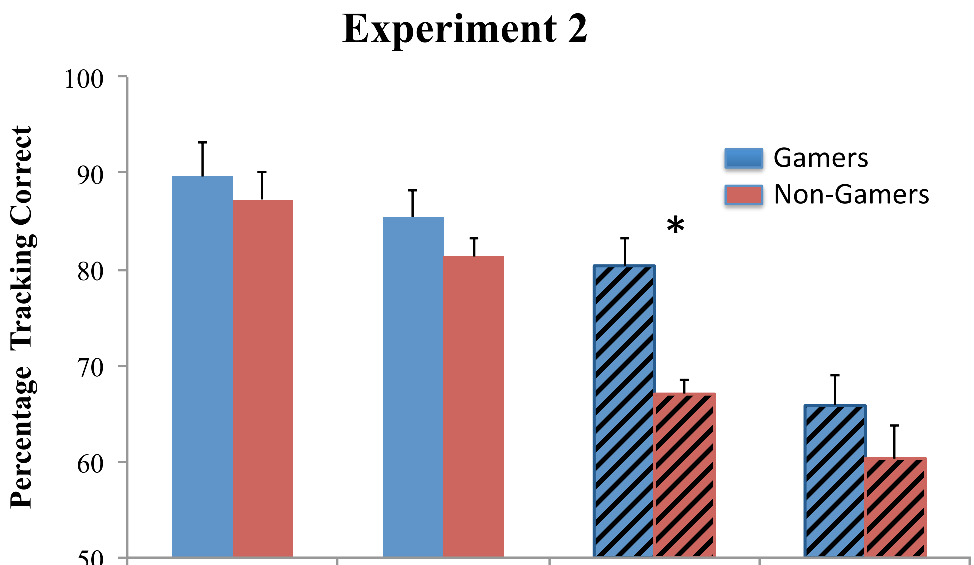
Examining the main effects in these results showed video gamers (n=13) with an overall higher tracking accuracy of 80.31% compared to Non-gamers (n=12) 73.94%, $F(1,23)=9.209$, $MSE=110.003$, $p=.006$, Mean difference = 6.37, $STE=2.010$ $p=.006$. Video gamers and non-gamers tracked two targets equally well in both unilateral displays ($t(23)=1.435$, $p<.165$) and bilateral displays ($t(23)=.984$ $p<.335$).

Crucial to our demonstration that video gamers in experiment 2 showed the bilateral advantage as seen in previous studies there was an interaction of set size x video gamer status ($F(1,23)=9.690$, $MSE= 23.930$, $p=.005$). Here video gamers showed a smaller mean difference in tracking scores when tracking load increased from 2 to 4 compared to non-gamers. There was no difference in gamers ($M=87.54\%$) and non-gamers ($M=84.215\%$) for set size 2 ($F(1,23)= 1.881$, $MSE= 73.245$, $p= .183$), but at set size 4 video gamers (*M*= 73.08%) outperform non-gamers (*M*= 63.657%) $F(1,23)= 18.242$, $MSE= 60.688$, $p<.001$). The tracking results from our experiment replicate the advantage video gamers have shown in previous studies where their tracking performance is higher at tracking high load.

Further investigation of this interaction suggested that for the critical comparison for the video gamer group of tracking accuracy in the unilateral set size 2 condition (*M*=85.43%) and the bilateral set size 4 condition (*M*=80.35%) there was still a significant difference in the gamer group where there was a significant drop in accuracy in tracking 4 objects bilaterally compared to 2 objects unilaterally despite similar means ($t=2.958$, $p=.012$).

Critically, video gamers showed significantly higher tracking accuracy when tracking four objects bilaterally (80.35%) compared to non-gamers (67.01%), $t(23)=4.8$, $p<.001$. This comparison shows that video gamers are superior to non-gamers, particularly in their ability to track four objects presented bilaterally. Video gamers also showed a significant advantage for tracking four objects in unilateral conditions overall (65.80%) compared to NVGPs (60.30%), $t(23)=2.59$, $p=.016$ although their advantage here is much smaller compared to the case of bilateral tracking of four objects.

Previous research has shown evidence for independent tracking mechanisms as significantly lower accuracy during set size four in unilateral tracking compared to four objects tracking bilateral across hemifields. If there were evidence for independent tracking resources than one would expect a significant drop off in tracking accuracy when four objects were presented unilaterally but not when they are presented bilaterally. Both gamers and non-gamers did show a drop off in accuracy in unilateral four tracking, although gamers did not show as a dramatic of a dip in accuracy in bilateral four tracking compared to tracking two objects.



	Bilateral 2	Unilateral 2	Bilateral 4	Unilateral 4
Gamer	89.64	85.44	80.35	65.80
Non-Gamer	87.14	81.29	67.01	60.30

Figure 6	Tracking Accuracy for gamers and non-gamers in Experiment 2. Solid bars indicate tracking two objects; striped bars indicate tracking four objects.

Independent resources as measured by how many objects you can track?

In order to clarify the number of objects participants were able to track in various conditions, we converted tracking accuracy into the *estimated number of objects tracked* using Cowan's *K* formula: *number of objects tracked = set size*(2*(tracking accuracy/100)-1)* (Cowan, 2001). Estimates of number of objects tracked were calculated for Experiment 1 and Experiment 2 (see figures 7 and 8).

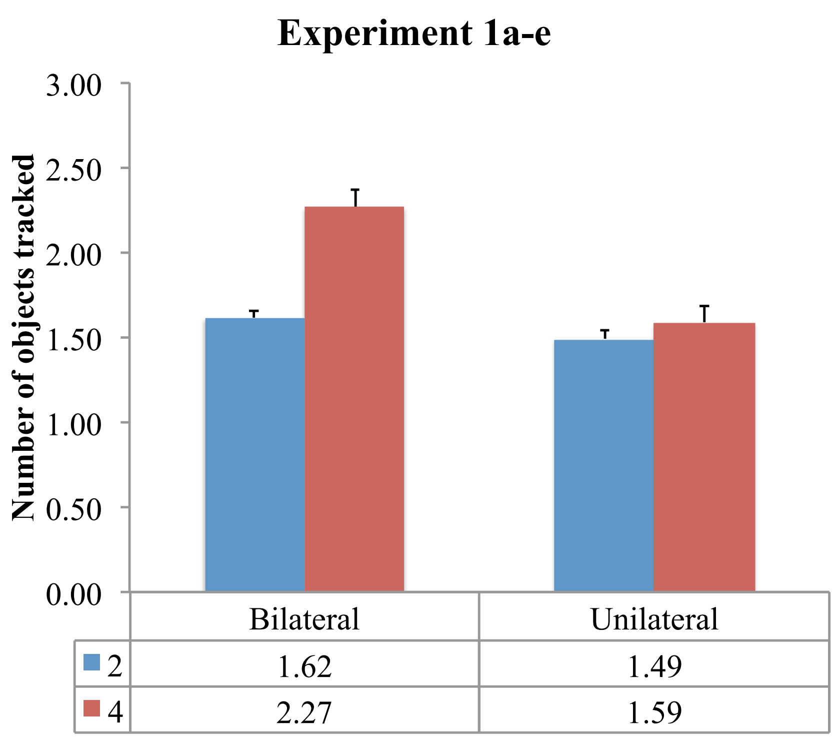
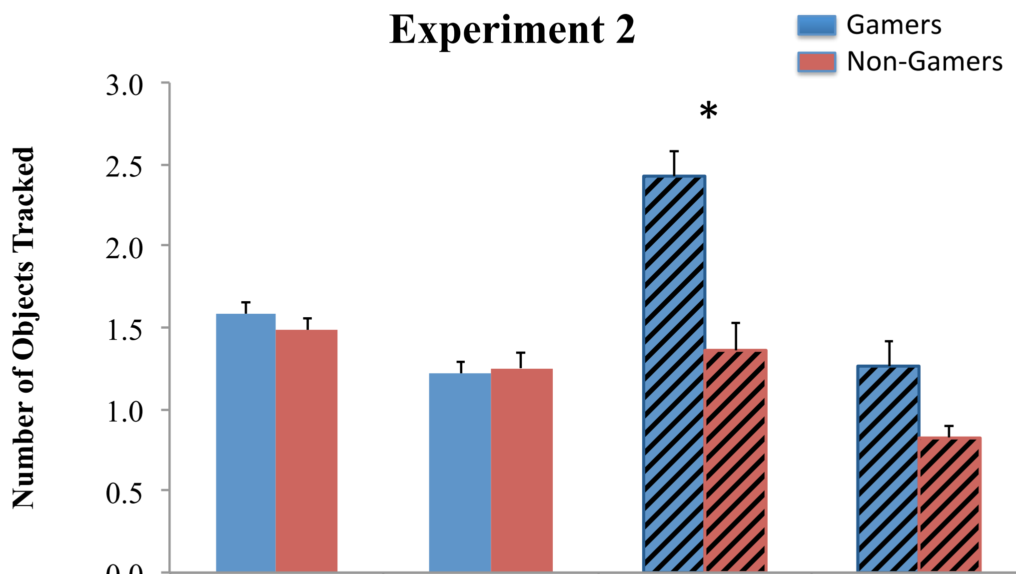


Figure 7 Number objects tracked in experiment 1.



	Bilateral 2	Unilateral 2	Bilateral 4	Unilateral 4
Gamer	1.59	1.21	2.43	1.26
Non-Gamer	1.49	1.25	1.36	0.82

Figure 8 Number of objects tracked in experiment 2. Solid bars indicate tracking two objects; striped bars indicate tracking four objects.

Independent tracking of objects in the left and right hemifields would be reflected in a 2:1 ratio of number of objects tracked in bilateral 4 compared to unilateral 2. We calculated this ratio for participants in each experiment (Experiment 1 and for Gamers and Non-gamers in Experiment 2) and found significant differences in this ratio between the groups (See figure 9). Experiment 1 ratio (*M*= 1.55, *STE*=0.58), Gamers ratio (*M*= 1.77, *STE*= .094), Non-gamers (*M*=1.091789, *STE* .102). A one-way ANOVA with subjects from estimates of number of objects tracked in experiment

1, Gamers and Non-Gamers as factors showed a significant interaction *F*(2,102)= 5.014, *MSE*= .285, *p*= .008). Follow up comparisons using LSD revealed equivalent mean differences between experiment 1 subjects and gamers (*p*= .235) and significant different ratios comparing Gamers and Non-gamers (*p*= .003) as well as for experiment 1 subjects and Gamers (*p*= .007).

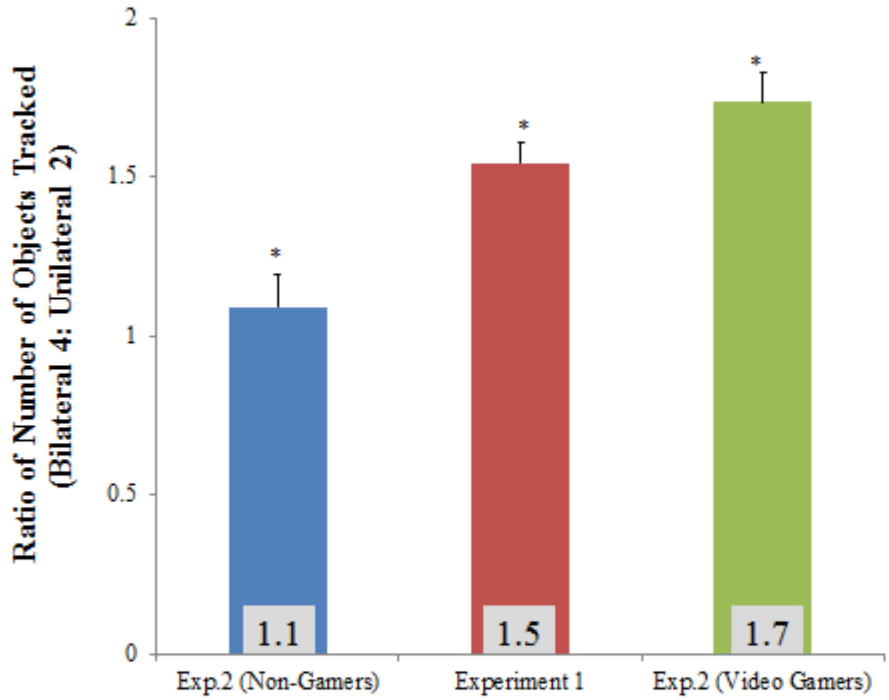


Figure 9 Ratio of Number of objects tracked in conditions: Bilateral tracking two objects and Unilateral tracking four objects in Experiments 1 & 2. Evidence for independence would be a 2:1 Ratio.

Recall that the percent correct analyses yielded a bilateral advantage in tracking four objects but not independence in video gamers; the numbers of objects tracked estimates are consistent with this result. Non-video gamers had a ratio of about

1:1 indicating little hemispheric advantage for bilateral displays (i.e. non-gamers always tracked about two objects in the bilateral four condition despite objects being displayed in two visual fields).

Chapter 4

DISCUSSION

The results of five experiments involving a total of 78 participants, failed to replicate the finding of independent object tracking in the two cerebral hemispheres reported by Alvarez and Cavanagh (2005). We did find a significant advantage for bilateral compared to unilateral tracking in experiment 1 but it did not approach the level predicted by hemisphere independence. We found that, on average, experiment one participants tracked about 1.6 objects in the unilateral 4 condition compared to 2.3 objects in the bilateral 4 condition where independent hemispheric tracking predicts 3.2 objects tracked (i.e twice as many objects in bilateral condition compared to unilateral).

We were unable to unequivocally identify the reasons for our failure to replicate the results of Alvarez and Cavanagh (2005). One potentially important variable in hemispheric independence is individual differences. Previous research by Bavelier and colleagues showed that extensive experience with fast-paced video games improves performance in a wide variety of laboratory tasks involving visual attention, including MOT. We wondered whether this training improvement might at least partially reflect an increase in independent control of visual attention in the two visual fields. We directly compared two groups of participants in the MOT task:

gamers, defined as participants who reported playing more than 5 hours of video games per week, and non-gamers who reported less than 3 hours per week of game play.

We adjusted the speed of the tracked objects separately for each group to yield tracking performance of approximately 85% in the Unilateral 2 condition. This matching procedure resulted in performance for the two groups that was similar in all conditions except one: tracking four objects presented across both visual fields and here, video game players showed a large performance advantage vs. non-gamers (80.31% vs. 67.01%). In fact, performance in this condition approached that predicted by the hypothesis of independent tracking in the two hemispheres. Data estimating the number of objects tracked in gamers and non-gamers suggest that gamers can track significantly more objects during bilateral displays than non-gamers, suggesting that gamers but not non-gamers have a stronger advantage for tracking four objects in two visual fields.

The finding that video gamers showed a significant advantage over non-gamers in tracking and a stronger bilateral advantage for tracking objects split between two visual fields may suggest a more efficient use of resources in the left and right hemispheres for controlling visual attention. When we specifically recruited non-gamers with little experience the effect of tracking four objects in two visual fields was significantly attenuated compared to subjects in experiment 1 and gamers. Video gamers and subjects in experiment 1 did not show evidence for hemisphereic independent tracking resources and only an advantage for tracking objects in bilateral displays over non-gamers. The evidence here does not support the possibility that including video gamers in experiment 3 of Alvarez and Cavanagh (2005) resulted in the hemisphereic independent tracking resources observed in their study.

The advantage that video gamers show over non-gamers presents itself dramatically in high load conditions. Green and Bavelier (2006a) showed that when tracking objects at set size 3, 4 and 5 items tracking performance is significantly increased after training on action video games. The results in experiment 2 replicate the advantage for video gamers at a tracking load of four objects (Video gamers, 80.31% vs. Non-gamers, 67.01%). The finding that the video gamer advantage for tracking four objects occurred in the bilateral tracking condition and less so in the unilateral tracking condition may support the notion that the overall advantage observed in MOT by Green and Bavelier (2003; 2006a; 2007) that results from video game play is related to the emergence of more efficient use of resources in the left and right visual fields.

It may be that the bilateral advantage for tracking objects in separate visual fields and increased tracking skills linked to video games go hand-in-hand. However, a notable difference in the current study and previous research using video gamers is that our participant gamers were self-reported where much of the literature have used training protocols to expose naïve subjects to large amounts of video game experience to compare before and after training effects. Additional training experiments where the amount of gameplay can be controlled across all subjects should be conducted to provide converging evidence on the findings related to the nature of hemispheric tracking resources in video gamers.

These experiments failed to replicate evidence for independent tracking resources in the two cerebral hemispheres. Results here would suggest that individual differences were not a factor in the results of experiment 3 of Alvarez and Cavanagh (2005). One significant difference in the procedures of Alvarez and Cavanagh (2005) and the current study was the inclusion of 128 practice trials before test trials where the current study did not include extensive practice. Additional studies should be conducted to investigate if practice in this MOT task leads to the emergence of independent tracking resources in the two hemispheres.

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IRB APPROVAL LETTER

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RESEARCH OFFICE

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DATE: March 8, 2012

TO: James Hoffman, PhD
FROM: University of Delaware IRB

STUDY TITLE: [316030-1] Individual differences in multiple object tracking across the two cerebral hemispheres

SUBMISSION TYPE: New Project

ACTION: APPROVED
APPROVAL DATE: March 8, 2012
EXPIRATION DATE: March 7, 2013
REVIEW TYPE: Expedited Review

REVIEW CATEGORY: Expedited review category # 7

Thank you for your submission of New Project materials for this research study. The University of Delaware IRB has APPROVED your submission. This approval is based on an appropriate risk/benefit ratio and a study design wherein the risks have been minimized. All research must be conducted in accordance with this approved submission.

This submission has received Expedited Review based on the applicable federal regulation.

Please remember that informedconsent is a process beginning with a description of the study and insurance of participant understanding followed by a signed consent form. Informed consent must continue throughout the study via a dialogue between the researcher and research participant. Federal regulations require each participant receive a copy of the signed consent document.

Please note that any revision to previously approved materials must be approved by this office prior to initiation. Please use the appropriate revision forms for this procedure.

All SERIOUS and UNEXPECTED adverse events must be reported to this office. Please use the appropriate adverse event forms for this procedure. All sponsor reporting requirements should also be followed.

Please report all NON-COMPLIANCE issues or COMPLAINTS regarding this study to this office.

Please note that all research records must be retained for a minimum of three years.

Based on the risks, this project requires Continuing Review by this office on an annual basis. Please use the appropriate renewal forms for this procedure.