NORTHWESTERN UNIVERSITY

Multiple Modes of Voluntary Visual Attention:

Analysis of Within Test Reliability, Between Group Differences, and the Interrelationships Among Tests of Voluntary Visual Attention.

A DISSERTATION

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KatieAnn R. Skogsberg

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Abstract:

The majority of research on voluntary visual attention has focused primarily on specific attentional processes. While we know much about individual attentional abilities such as shifting attention among spatial locations, tracking multiple objects and maintaining attention for specific targets, we know little about how these attentional processes relate to one another. Therefore, we designed a series of tasks to test multiple modes of voluntary visual attention (an attention battery) and examined the interrelationships among them.

Our first goal was to select tasks that represented a variety of distinct attentional processes and to ensure that the tasks had sufficient reliability to be useful in correlational analyses. Our results indicated that two of the most commonly used tests lacked sufficient reliability to be useful in correlational studies, but the remainder of our attentional tasks were sufficiently reliable.

Our second goal was to demonstrate the utility of the attention battery for testing differences in abilities between groups. To do this we compared performance scores between men and women and found that men out performed women on tasks that required strong spatial-temporal abilities. We also tested observers with behavioral traits related to attention deficit hyperactivity disorder (ADHD). Our results indicated that they performed within the normal range on the majority of our tasks but made considerably more errors on our center focusing task suggesting a select visual-spatial attentional deficit.

Our third goal was to examine the interrelationships among attentional abilities. We used pair-wise correlational analyses to examine the relationships between pairs of tasks, and Revelle's ICLUST algorithm (1979) to examine the hierarchical clustering of tasks. The results suggested that the reliable tasks from our attention battery formed distinct clusters. The first

cluster formed around tasks that required strong spatial/temporal abilities, the second formed around tasks that required vigilance/target detection skills, a third formed around tasks that involved global/local abilities and a fourth may exist for the ability to rapidly re-engage attention. These results suggest that there are at least three distinct domains for voluntary visual attentional abilities. Additionally, our results match well with previous research in that the tasks that formed clusters also appear to share similar regions of brain activity.

MULTILPLE MODES OF VISUAL ATTENTION

Introduction

Every day, we are bombarded with a wide range of dynamic, salient, subtle and complex visual stimuli. Some items, like a red stoplight, require our attention while others are best ignored (e.g. flashing road side advertisement). For those of us with normal sensory systems, the ability to voluntarily direct our visual attention towards a specific object, its attributes or spatial location (while inhibiting competing stimuli) is essential to successfully navigate, comprehend and understand our environment. The importance of understanding these visual processes has lead to literally thousands of empirical studies designed to test the limits, properties and behavioral consequences of voluntary visual attention. As a result, a number of specific aspects of voluntary visual attention have been identified, including (but not limited to): allocating attention to spatial locations, maintenance of attention and target detection, shifting attention among spatial locations or objects, parameters of visuotemporal processing, attending to local details or global configurations, attention to image attributes (e.g. color, shape and direction of motion), and attentive tracking of motion. Each of these individual processes has been explored with a wide range of methodological approaches ranging from single cell recordings in animals to behavioral and neuroimaging studies of humans (for a review of this literature see (Desimone & Duncan, 1995; Kastner & Ungerleider, 2000; Posner & Petersen, 1990). However, much of the research on these individual attentional processes has remained just that, investigations of individual attentional processes. If our goal is to develop a general working model of voluntary visual attention, then it is important to know not only the individual processes but also the interrelationships among them. To use an analogy, while it is important for an auto mechanic to know the role and function of each of the individual parts of the automobile, he must also have knowledge of how those individual parts fit together and relate to one another be successful at his trade. Thus we propose an alternative approach towards investigating voluntary visual attention processes by examining the interrelationships among them.

Related theoretical approaches towards the function and organization of attention.

Previous researchers have made important theoretical advances in our understanding of the functional role and potential structural organization of voluntary visual attention. For example, early work by Kahneman (1973) focused on the relationship between attention and cognitive resources. This idea continues to influence current theories regarding attention as a limited resource. Treisman's and Gelade's (1980) Feature Integration Theory introduced the concept that attention is the mechanism by which we organize and bind the properties of objects (e.g. color, shape, spatial location) for categorization and identification.

During a similar time frame, Posner and colleagues advocated the "spotlight" analogy, indicating that the function of attention is to enhance detection of behaviorally relevant stimuli and improve the efficiency of signal processing (Posner, Snyder, & Davidson, 1980). In subsequent publications, using evidence from neurophysiological and behavioral studies, Posner and colleagues have suggested that attention consists primarily of three functionally and anatomically distinct networks. The "alerting" network consists of structures within the frontal and parietal regions of the right hemisphere and is responsible for maintenance of an attentive state (e.g. vigilance). A second network, the "orienting" system, consists of the superior parietal lobe, temporal-parietal junction and frontal lobes and is involved in the orientation to and selection of relevant sensory input. The third network, the "executive control" system, involves the lateral prefrontal cortex (primarily the anterior cingulate cortex) and is involved selection of an appropriate response (Fan, McCandliss, Sommer, Raz, & Posner, 2002; Posner & Petersen, 1990).

In their review of neurophysiolgoical and neuroimaging studies, Kastner and Ungerleider (2001), similarly report that there is converging evidence of an independent attentional network that consists of the frontal and parietal regions (superior parietal lobule, frontal eye fields and supplementary eye fields). According to Kastner and Ungerleider these regions become activated during a variety of visuospatial tasks and there "appears to be a general attention network that operates independent of the specific requirements of the visuospatial task," even in the absence of a visual stimulus (Kastner & Ungerleider, 2001, p. 1272). However, these researchers also stress the importance of bottom up influences on visual attentional processes. It has been well documented that when two stimuli are presented simultaneously within the same receptive field of a single neuron, the neuronal response is a weighted average of what the two stimuli would have produced had they been presented separately. In other words, there is a mutual suppression, or competition for representation, among stimuli even at the earliest levels of visual processing. Additionally, the deployment of attention towards a particular stimulus may suppress the activity representing nearby distractors or, in the absence of a visual stimulus, enhance sensitivity to an attended location by raising the baseline activity. These findings support the "biased competition model" of attention that focuses on the processes by which multiple stimuli compete for representation in the visual cortex, and top-down feedback networks modulate which stimuli reach the level of awareness (Kastner & Ungerleider, 2001).

The idea of biased competition model of visual attention has received considerable theoretical and empirical support. For example, Desimone and Duncan (1995) used evidence from neurophysiological recordings to argue that attention is the product of multiple iterations of interactions between brain regions. They suggest that what we experience as attention is the product of biased competition between the stimulus-based bottom up processes and higher order top down processes that direct us towards behaviorally relevant stimuli. Shipp (2004) also supports this view with an additional emphasis on the influence that the saliency and context of the visual stimulus has on the end result of the process. Additionally, like Desimone and Duncan, Shipp argues that attention is "a dynamic, emergent property," rather than a distinct entity (Shipp, 2004, p. 228). The biased competition model of attention is also supported by computational modeling methods that simulate visual attentional processes, particularly the influence of the saliency of the objects and the re-entrant feedback loops from higher-level processes (Itti & Koch, 2001). This brief review illustrates that although there is a considerable amount of evidence supporting both the independent network model of attention, and the biased competition model, there remains room for further elucidation of the processes of voluntary visual attention.

Select modes of voluntary visual attention and their related regions of neuronal activity.

While previous theoretical approaches have sought to find an overall explanation for the structural organization of attention, other researchers have focused on examining the regions of activity that are involved in specific types of voluntary visual attentional processes. By using techniques ranging from single cell recordings of individual neuronal responses, to examining the changes in brain activity as measured by the BOLD response (changes in blood flow) obtained from functional magnetic imaging studies (fMRI), researchers have been able to isolate regions that appear to be related to specific attentional processes. As noted above, a number of visual attentional processes have been extensively investigated: allocating attention to spatial locations, maintenance of attention and target detection, shifting attention among spatial locations or objects, the parameters of visuotemporal processing, attending to local details or global configurations, attention to image attributes (e.g. color, shape and direction of motion), and attentive tracking of motion. Since our goal is to understand the interrelationships among these attentional processes, it may be informative to first review these attentional processes and their purportedly related regions of neuronal activity.

Allocation, maintenance, and shifting of attention

Yantis and Serences (2003) used fMRI to study the changes in brain activity of observers doing either a spatial attention task, where attention shifted between spatial locations, or one involving overlapped images with no spatial shifting. Their results indicated that the right superior parietal lobule (SPL) is involved in both shifting attention among spatial locations and among overlapped objects. This activity was distinct and separate from that related to the maintenance of attention at a particular locus or in a specific state of attention, which appears to involve activation of intraparietal sulcus (IPS) (Corbetta, Kincade, & Shulman, 2002; Yantis & Serences, 2003). Vanderberghe, Gitelman, Parrish and Mesulam (2001) also used fMRI to record brain activity while observers attended to an item that appeared to spontaneously move from one location to the next. Their results indicated when this particular task produced a bilateral increase in activation of the superior parietal gyrus (SPG). From this evidence, they concluded that this region is involved in attending to spatial location, shifting attention among spatial locations, and attentively tracking the motion of an object. Other researchers have found that the temporal parietal junction (TPJ) also plays an important role in the shifting of attention, particularly in response to novel or unexpected stimuli (Downar, Crawley, Mikulis, & Davis, 2000; Marois, Leung, & Gore, 2000; Posner & Petersen, 1990).

Parameters of visuotemporal processing

In contrast to focusing attention on spatial locations or objects, other researchers have focused on the temporal dynamics of visual attention. A classic example of a visuotemporal task is a rapid serial visual presentation (RSVP) paradigm, where the goal is to measure how quickly an observer can capture a stimulus and processes it, then re-engage their attention to process the next item. For most observers, there is an attentional refractory period, or "attentional blink" that occurs between 180 ms and 270 ms after the presentation of the first stimulus during which they are unable to re-engage or process additional information (Raymond, Shapiro, & Arnell, 1992). A study conducted by Shapiro, Hillstrom and Hussain (2002) found that patients with lesions of the inferior parietal lobe (IPL) and superior temporal gyrus (STG) have a prolonged refractory period, although it does not interfere with their ability to capture individual items. These findings suggest that the IPL and STG regions may be involved in the ability to rapidly re-engage ones attention in the temporal domain.

Attending to local details, global configurations and item attributes.

Allocation of attention towards a particular object or location may also involve the inhibition of other potentially distracting stimuli. There is evidence that both the dorsal lateral prefrontal cortex (DLPFC) and the dorsal region of the anterior cingulate cortex (dACC) play a role in directing attention towards the behaviorally relevant stimuli while inhibiting non-relevant stimuli. Wiessman, Gopalakrishnan, Hazlett and Woldorff (2005) measured the changes in brain activity of observers as they were cued to direct their attention towards either the global or local components of Navon letters. The Navon task involves the identification of a hierarchical stimulus, such as a large H (global) made up of small Ss (local). The observers were cued before each trial whether to attend to the global or local letters. The observers were to respond with one key press if the cued stimulus was an H or an S, a different key press for an X or an O, and no response for all other letters. The stimuli consisted of congruent (a global H made up of small Ss), neutral (a global F made up of small Ss) and incongruent (conditions a global O made up of small Ss). Their results indicated that on the interference trials, there was greater the activation of both the dACC and DLPFC. Additionally, they found that the greater the activation of the dACC, the faster the observer's responses. Thus, the dACC and the DLPFC appear to play a role in tasks that require resolving conflict between global and local components of a visual stimulus. The pulvinar nucleus of the thalamus may also play a role in the inhibition of distracting stimuli. LaBerge and Buchsbaum (1990) used positron emission tomography (PET) measures of blood flow to study the changes in activity of the pulvinar nucleus. Their results indicated that when observers were engaged in a task that required the filtering out of nearby distractors to identify a target imbedded among them, there was an increase in activity of the pulvinar nucleus.

Taking a different approach, other researchers have sought to identify where in the visual processing stream individual items come together to form a coherent shape or object. Research in this area has revealed that when the visual display is arranged such that a shared attribute (e.g. color, contour or motion) among items can be combined to form a coherent shape or object, there is an increase in activation of the lateral occipital complex (LOC). Additionally, this activation appears have a reciprocal inhibitory effect on the earlier visual processing regions, V1 in particular (Altmann, Bulthoff, & Kourtzi, 2003; Murray, Schrater, & Kersten, 2004).

Attentive tracking of motion

There is also considerable evidence of an attentional domain dedicated to the perception of motion. It has been well established that the middle temporal (MT) and medial superior temporal regions (MST) of the visual cortex are selectively sensitive to certain patterns of motion (e.g. translation, expansion, contraction and rotation) and play an important role in spatial navigation (Tanaka & Saito, 1989; Vaina, 1998). Additionally, there is evidence that these cells are responsive to attentional modulation. In an fMRI study of the effects of attention on activity in the MT and MST regions, O'Craven, Rosen, Kwong, Treisman and Savoy (1997) utilized a paradigm wherein their participants were presented with a stimulus containing both moving and stationary dots. The observers were instructed to alternate their attention between the two conditions, based upon the colors of the dots (moving in one color, stationary in another). Their results indicated that when participants were instructed to attend to the moving stimuli, activity levels in the MT/MST regions increased even though the visual stimulus had not changed. Furthermore, even though activity in the unattended condition was lower than in the attended one it was still considerably greater than in a condition where there were no moving dots. Thus, as with other visual attentional processes, it is possible to selectively and voluntary attend to or inhibit activity within the regions that are selective for motion.

Rationale for present study

Posner and colleagues have proposed that by using their Attentional Network Test (ANT), they can successfully provide a "measure of the operation of each of the three attentional networks" (Fan et al., 2002, p. 344). Specifically, the ANT involves having participants engage in modified Eriksen flanker task (Eriksen & Eriksen, 1974), which involves four different cuing paradigms (no-cue control, center cue, double cue and spatial cue). These cuing paradigms were designed to selectively engage the alerting, orienting or executive functioning networks. According to their results the performance scores between cuing paradigms were uncorrelated, indicating that they provide measures of different (unrelated) attentional processes (Fan et al., 2002). However, there is one important limitation of this study. Although the tasks used in this study uses four different cuing paradigms, it consists of just one type of visual attentional task (i.e. Eriksen flanker task). Therefore, it is difficult to interpret whether the results can be generalized to all types of visual attention tasks or if they are exclusive to the spatial attentional demands of this specific task.

This brings us back to the goal of the present study: to develop a series of tasks that involve a variety of visual attentional processes, so that we may investigate the interrelationships among them. The first step will be to select tasks that represent a variety of known visual attentional processes and identify those that are reliable enough to provide meaningful correlations (or, just as meaningful, lack there-of). This series of visual attentional tasks will from here forward be referred to as our “attention battery.” Secondly, because there is some evidence that there are differences between the sexes in their performance on select visual attentional tasks and their related regions of brain activation (Gur et al., 2000; Jordan, Wustenberg, Heinze, Peters, & Jancke, 2002), we will examine our data for performance differences between men and women. Additionally, there is the potential for our attention battery to be used as a tool for the investigation of not only normal visual attentional processes, but the study of attention deficits as well. Previous studies have found that adult observers who have been diagnosed with Attention Deficit Hyperactivity Disorder (ADHD) perform poorly on tasks that require either visuospatial (Epstein, Conners, Erhardt, March, & Swanson, 1997) or visuotemporal attention (Armstrong & Munoz, 2003; Hollingsworth, McAuliffe, & Knowlton, 2001). Therefore, we will include in a comparison of performance scores between randomly selected observers and a sample of observers who have been screened and selected for having a high number of traits related to ADHD.

Our third and overarching goal will be to investigate the interrelationships among visual attentional tasks. By testing a large group of observers on tasks that demonstrate sufficient reliability, we can examine the correlations between performance scores and from these infer relationships (or lack there of) between visual attentional tasks. If there is indeed one independent attentional network that executes top down control over all other attentional processes, then our expectation is that performance scores on all of our tasks will be highly correlated. In other words, if the ability to control voluntary visual attention is a single construct, then all of our tasks should be highly intercorrelated. However, if there are multiple modes of attention that have independent influences on voluntary visual attentional processes, then only those tasks that share similar attentional demands should show similarities in performance scores. There is also the possibility that the relationships among our voluntary visual attentional tasks may be hierarchical, and there may be relationships between tasks that cannot be fully elucidated using a strictly pair-wise comparison. Hierarchical Cluster Analysis (ICLUST, Revelle, 1979), can provide an elegant solution that reveals not only pair-wise relationships between tasks, but also higher order relationships (further details on the ICLUST algorithm provided in the results section).

Methods:

Selection of observers and general procedure

Observers:

A total of 223 observers participated in this study. The majority of the observers (n=189) were introductory psychology students who earned course credit for participation. An additional 34 observers were from an upper division psychology course and earned course credit for their participation. Data collection took place over the course of eight university quarters between September 2005 and March 2008. For the first five quarters, observers were selected at random from the psychology department participant pool. This random selection procedure yielded a larger proportion of women than men. Thus, for the last two quarters we restricted our selection from this pool to men only. All observers reported having normal, or corrected-to-normal vision. Observers' ages ranged from 18-26 with an average age of 18.78.

Additional subsets of observers from the same introduction to psychology courses were selected to participate in our study based upon their responses to an Attention Deficit Hyperactivity Disorder (ADHD) screening form (Barkley & Murphy, 2006). This survey is based on the DSM-IV-TR checklist for the diagnosis of ADHD (American Psychiatric Association [DSM-IV-TR] 2000) adapted for use as a self-report form (Appendix A). The survey consists of two sections, each made up of 18 items. The first section contains questions regarding current symptomatic behaviors and a second section is reworded to prompt recall of symptomatic behaviors from childhood. The items include questions such as "Leave my seat in situations in which seating is expected," and "Avoid, dislike or am reluctant to engage in work that requires sustained mental effort." (Barkley & Murphy, 2006). Responses are in the form of a scale ranging from 0 (Never or rarely) to 3 (Very often). Both the current symptoms and childhood recall sections are scored on three subscales that reflect the three subtypes of the disorder, namely ADHD predominantly inattentive (ADHDi), ADHD predominantly hyperactive-impulsive (ADHDh), or ADHD combined (ADHDc). Scoring consists of summing the responses for each subscale, and comparing the individual's responses to the group averages. Scores 1.5 standard deviations (*SD*) greater than the mean on any one subscale are considered "clinically significant" (Barkley & Murphy, 2006). In our initial selection process, any score that was 1.5 *SD* greater than the published norms for any one of the subscales was considered sufficient for inclusion in our study. These means and standard deviations are detailed in table 1. Initially, 69 (28 men) of our observers met this criterion. However, after the completion of our data collection process we adjusted our inclusion criterion to reflect the means and standard deviations of our university student sample. Thus, only those participants whose scores were 1.5 *SD* greater than the average from the university's experimental participant pool, on any one subscale for both childhood and adult symptoms were included in our analyses. Additionally, whereas the published norms collapse the measures across the sexes for the adult scales, we calculated our adult cutoff scores for men and women separately (see table 2). A total of 35 (13 men) of our observers who reached this new criterion were included in our final data analyses. The data collected from these observers was kept separate from the participants who were randomly assigned to our study and not utilized in the analysis of the reliability of the tasks, gender differences, correlational relationships between tasks or cluster analysis.

Table 1

Thresholds for clinically significant symptoms of ADHD from published norms. [a]

Subtype	Combined					
	Mean	*SD*	Threshold			
Adult Inattentive	6.3	4.7	13.4			
Adult Hyperactive	8.5	4.7	15.6			
Adult Combined	14.7	8.7	27.8			
	Men			Women		
	Mean	*SD*	Threshold	*Mean*	*SD*	Threshold
Childhood Inattentive	11.1	6.0	20.1	8.2	5.9	17.1
Childhood Hyperactive	10.7	6.0	19.7	9.0	6.0	18.0
Childhood Combined	21.8	11.3	38.8	17.3	11.4	34.4

[a] From Barkley & Murphy, 2006.

Table 2

Thresholds for clinically significant symptoms of ADHD derived from sample.

Subtype	Men			Women		
	Mean	*SD*	Threshold	*Mean*	*SD*	Threshold
Adult Inattentive	6.80	4.39	13.38	6.22	4.26	12.61
Adult Hyperactive	7.19	4.21	13.51	7.07	4.32	13.55
Adult Combined	13.99	7.85	25.76	13.30	8.01	25.31
Childhood Inattentive	7.15	5.13	14.85	5.24	4.76	12.37
Childhood Hyperactive	7.67	5.24	15.54	6.43	5.36	14.47
Childhood Combined	14.82	9.73	29.41	11.67	9.36	25.71

General Procedure:

Of the 223 observers, 129 of them (75 women) completed 9 of the visual attention tasks (Rapid Identification, Center Attention, Attentional Blink, Object Shifting, Tracking Multiple Objects, Spatial Shifting, Object Vigilance, Peripheral Attention and Global Attention). An additional 94 observers (48 women) completed an extended attention battery that included three additional tasks (Spatial Vigilance, Attentional Grouping, and Controlling Perception of

Motion). The observers selected for high ADHD traits completed all 12 of the tasks, but are not included in this number.

Observers first gave informed consent then completed a color vision-screening questionnaire before beginning the experiment. Of the 317 observers that participated in our study, two had anomalous color vision. Although these two observers completed the attention battery their data were excluded from color relevant tasks. All observers were seated in a light and sound attenuated room in an adjustable height chair positioned 65 cm from the display monitor (nasion to monitor center). All tasks in the attention battery were controlled using a Macintosh (Power PC 8600/300), tasks were programmed in Vision Shell Software, (micro ML, Inc.) and presented on a 17” CRT color monitor. Luminance and color (CIE coordinates) were measured with a Minolta Chromameter CS-100.

To ensure that all observers had the same experience the tasks were presented in a fixed order. Observers completed the attention battery and the pen and paper surveys within 2 hours. Additionally, to reduce eyestrain and fatigue observers were allowed to take brief breaks between the tasks. The specific tasks, their requirements and measures are detailed below in the order that they were presented.

Specific Tests of Visual Attention

Rapid Identification:

Purpose: This task was included as a general measure of the observer's perceptual abilities for object recognition with brief presentation and was used as a comparative measure to our attentional tasks.

Stimuli: The central fixation point consisted of concentric circles (a target) drawn with one-pixel-width black lines subtending 0.44^0 visual angle. A placeholder box drawn with 1-pixel-width black lines and subtending 3.5^0 x 3.5^0 visual angle from center fixation remained on the screen during the entire task. Test stimuli consisted of gray-scale photographs of common objects (n=10) and animals (n=28), presented against an achromatic gray background (CIE [.277, .302]) with a luminance of 44.2 cd/m^2. The images of common items used in the practice trials were: goggles, airplane, jacket, ice skates, umbrella, guitar, violin, lamp, car and clock. The images of animals used in the 28 experimental trials were: seahorse, chicken, rabbit, cow, swan, kangaroo, giraffe, camel, raccoon, sheep, hose, zebra, dolphin, fish, walrus, dog, cat, penguin, deer, turtle, monkey, panda, pig, hippo, peacock, elephant, squirrel and owl (See appendix B for original images). Masks were generated within the placeholder box using randomly assigned dot pixels ranging from black to white, with an average luminance of 15.3 cd/m^2, and average CIE coordinates of .227, .305.

Procedure: Observers completed two blocks of trials. They were informed that the first block would be practice trials and the items would all be common objects. At the beginning of the second block observers were informed that all of the items would be animals. Each trial began with a center fixation point and placeholder box present on the screen. Observers initiated the beginning of each trial with a button press. The delay between the button press and stimulus onset was 134 ms, followed by a 40.26 ms presentation of the stimulus, then a 215 ms random-dot mask (figure 1). Response time was not limited, however if the observer hesitated for several seconds, the experimenter would encourage them to make their “best guess.” The experimenter recorded the observers’ responses and then advanced to the next trial. The order of presentation was the same for all observers. This was done to control for potential priming effects that might occur as a result of the random ordering of the items.

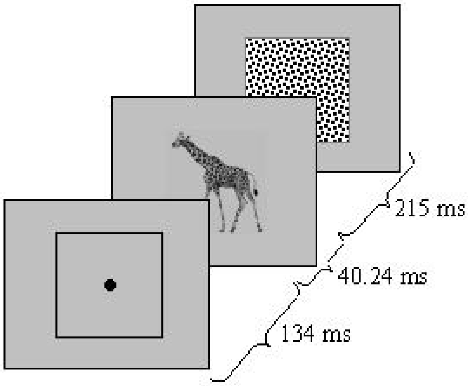


Figure 1. Example of stimulus and presentation display times for rapid identification task.

Measure: Performance was calculated on the proportion of correct items identified for the experimental trials. A post-hoc evaluation of observers’ performance to detect outliers was used to examine the data for scores 3 standard deviations below the mean for proportion correct (*M* = 0.37, *SD* = 0.20). None of the observers met or exceeded this criterion so all of the scores remained in the dataset for further analyses. Additionally, we estimated the reliability of this task using Cronbach’s alpha (Cronbach, 1951) and examined the correlations between the individual items and the overall score for the task (item-to-task correlation) to ensure that only reliable items were used in our analyses. The initial alpha coefficient for this task (n= 28 items) was 0.80, with an average inter-item correlation of 0.13. Seven of the items had item-to-task correlations below 0.30 [Seahorse (0.25), Cow (0.14), Raccoon (0.16), Walrus (0.20), Dog (0.26), Peacock (0.11) and Elephant (0.29)]. These low values suggest that the individual items were not representative of the overall score and thus were omitted from further statistical analyses of this task. After removal of these items, the alpha remained at 0.80 and the average inter-item correlation (for n = 21 items) was 0.16.

Center Focusing:

Purpose: To test the observers' ability to focus at a central location while inhibiting close peripheral distractors, we used a modified Erickson-flanker task.

Stimuli: Center fixation consisted of an achromatic gray circle subtending 0.26^0 visual angle that remained visible throughout the entire task. The stimuli consisted of triads of letters (e.g. T S T, or S T S in the interference trials) or triads of letter and number combinations (e.g. 4 S 4 or 3 T 3 in the neutral trials), in a black Helvetica font against an achromatic gray background (CIE [.277, .302], luminance 44.2 cd/m^2). The central letter was smaller than the flankers, subtending 0.79^0 x 0.44^0 visual angle from center fixation point. The flanker items were aligned horizontally with the center letter at 1.3 cm eccentricity (1.14^0 away from fixation) and individually subtending 1.41^0 vertically x 0.97^0 horizontally (figure 2). The presentation order of the neutral and interference trials was randomly generated.

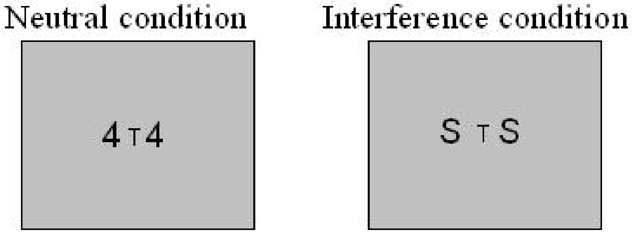


Figure 2. Example of center focusing task stimulus.

Procedure: Observers were instructed to remain focused on the central fixation point while responding to the triads of letters and digits that were presented briefly on the computer monitor. The observers' task was to respond as quickly and accurately as possible by indicating via a button press, which of two possible target letters (T or S) was present at the central fixation point while ignoring the simultaneously presented flanker items.

Each trial began with a 1.5 second presentation of the central fixation point, followed by a 214 ms presentation of the stimulus triads and a return to the blank fixation screen. Termination of the trial was determined by the observer's button press, which in turn initiated the next trial. The task included both neutral and interference trials presented in random order. In the interference trials, the to-be-ignored flankers were the opponent target item (e.g. S T S or T S T). In the neutral trials, the flankers were randomly selected neutral digits (e.g. 4 S 4 or 3 T 3). Observers indicated their response by pressing either the 5 or the 2 (labeled S and T respectively) on the number pad of a computer keyboard. Note that these numbers were selected because of their vertical orientation to reduce response bias. Observers were given 10 practice trials to become accustomed to the location of the keys and the speed of the task, followed by 80 experimental trials.

Measure: Performance was measured by calculating an index of interference (IOI_{RT}) based upon the response time (RT) by subtracting the RT for the neutral trials (NRT) from the RT for the interference trials (IRT) and dividing by the RT for the neutral trials: $IOI_{RT} = (IRT-NRT)/NRT$. This formula results in a measure where smaller values indicate stronger attentional focusing and the denominator normalizes differences in baseline RTs. Additionally, for each individual observer, if any one trial exceeded 3 standard deviations in RT from their within-task average, the trial (and excessive RT) was discarded. An error-based index of interference (IOI_{ERR}) was also computed by subtracting the proportion of correct responses for the interference trials (Icorr), from the proportion of correct responses for the using neutral trials (Ncorr): $IOI_{ERR} = [Ncorr – Icorr]$, where a smaller value indicates greater accuracy.

In a post-hoc evaluation to detect outliers we examined the observer’s performance scores for individual scores that were 3 standard deviations greater than the mean for each of the measures obtained from this task: NRT (*M* = 493.12 ms, *SD* = 76.36 ms), IRT (*M* = 505.74 ms, *SD* = 76.02 ms), IOI_{RT} (*M* = 0.027, *SD* = 0.045), Ncorr (*M* = 0.95, *SD* = 0.05) and Icorr (*M* = 0.93, *SD* = 0.07), and IOI_{ERR} (*M* = 0.024, *SD* = 0.056). Of the 223 observers that completed this task 13 (9 men) exceeded this criterion and were eliminated from further statistical analyses of this task.

To ensure that use of the reaction time was an appropriate measure, we examined the correlation between the IOI_{RT} and IOI_{ERR} for a speed-accuracy trade-off relationship. There was a positive correlation between the IOI_{RT} and IOI_{ERR} ($r(193)= 0.15$, $p = 0.03$), indicating that the observers who slowed more on the interference trials (relative to the neutral trials) also made more errors on the interference trials (relative to the neutral trials). Thus we retained the IOI_{RT} as our measure of interest for this task.

To examine the reliability of this measure, we first subdivided the task into 20-trial "bins" and averaged the scores within each bin for each observer, yielding four data points per observer for our reliability analysis. We used 20 trial bins to ensure that each subdivision contained a relatively equal number of interference and neutral trials. The alpha coefficient estimated for this task using this technique was 0.05, with an inter-item correlation of 0.01. This very low alpha coefficient is likely the product of a ceiling effect, wherein the task produced very little variability between individuals but a considerably larger within individual variability. Despite the low reliability of this task we choose to keep the task as part of our attention battery for our comparisons between groups because it is very similar to the type of "focused attention" tasks (Erickson-flanker tasks) that are commonly used in attention research. However, because of the low reliability of this task, it is unlikely that it would correlate significantly (or in a meaningful way) with our other attentional tasks. Therefore this task will not be included in our analyses of the relationships among attentional abilities.

Temporal Focusing and Rapid Re-engagement: (Attentional Blink).

Purpose: To test our observers' abilities to focus temporally and rapidly re-engage their attention we used a traditional attentional blink paradigm.

Stimuli: The central fixation point consisted of an achromatic gray circle (CIE [.289, .131], luminance 7.53 cd/m^2) subtending 0.13^0 visual angle. Stimuli consisted of letters and numbers in black Helvetica font centered at fixation and subtending 0.71^0 vertically x 0.44^0 horizontally against an achromatic gray background (CIE [.280, .307], luminance 30.2 cd/m^2). The letters I, O, Q and Z were omitted from the list of potential letters while all digits (0 to 9) were used.

Procedure: In this task the observers were instructed that they would see a series of letters and numbers presented very rapidly, one at a time, at the center of the screen. Their task was to ignore the numbers and attend only to the two “target” letters in the sequence. At the end of the trial, they were to report to the experimenter the two letters that they saw in the order that they appeared. The experimenter initiated each trial with a mouse click, which in turn triggered a brief (67ms) tone accompanied by the onset of the center fixation point that remained on the screen for 132.2 ms. This was immediately followed by a series of randomly generated letters and numbers presented at 80.52 ms per item and 26.84 ms inter stimulus interval (ISI). The serial position of the 1st target letter (T1) varied randomly between the sixth and fourteenth positions (inclusive) in the series. The serial position of the second target letter (T2) varied randomly at intervals (i.e. “lags”) of 1, 2, 3 or 4 positions after T1. The total length of the sequence was determined by the position of T1 + 9. That is, if T1 appeared in serial position 7, T2 could appear in positions 8, 9, 10 or 11 and the total number of items in the trial would equal 16 (figure 3). The number of trials for each lag was randomly determined by the computer program but was roughly equivalent for all observers: T2-Lag2 (M = 11.20, SD = 1.00), T2-Lag3 (M = 11.28, SD = 0.89), and T2-Lag4 (M = 11.26, SD = 0.88). Additionally, T1 and T2 were always different letters within the trial ($T1 \neq T2$). At the end of each trial, the experimenter recorded the observers’ responses and initiated the beginning of the next trial.

Response time was not measured. The observers were given 4 practice trials to become accustomed to the speed and demands of the task, followed by 48 experimental trials.

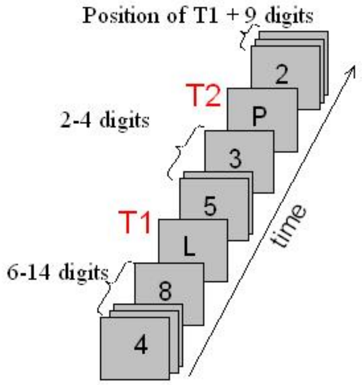


Figure 3. Example of stimulus and presentation order for the temporal focusing and rapid re-engagement (attentional blink) task.

Measure: This task yielded six separate measures of performance, proportion correct for T1 items (T1), proportion correct for each of the possible lag positions of T2 (T2-Lag2, T2-Lag3, T2-Lag4), the average proportion correct for all 3 lag positions, and the difference score between T1 and T2 (T1-T2). Although the observers were instructed to give the letters in the order that they appeared, either order was accepted. Thus, if the target letters were T1="A" and T2="X" and the participant responded "X, A" the T1 was recorded as correct. The second measure, rapid re-engagement, was measured by calculating the proportion of T2 items correctly identified after correct identification of the first item (T1-T2). Thus, correct identification of T1 was a prerequisite for the acceptance of T2 as a correct item. For example, if the correct response was "A, X" and the observer reported "X, V," neither response was accepted as correct. Since lag 1 usually does not fall within the attentional blink refractory period (called lag 1 sparing), T2 was calculated as the average of lags 2, 3 and 4 (cf. Shapiro et al., 2002).

Our two primary measures of interest were the proportion correct T1 (temporal focusing) and the difference score T1-T2 (rapid re-engagement). In a post-hoc analysis we examined these scores to reject individual observers with scores 3 standard deviations or greater than the mean for the measures of T1 (*M* =0.92, *SD* = 0.08), for the average of all lags (*M* =0.58, *SD* = 0.21), and for T1-T2 (*M* =0.35, *SD* = 0.19). None of the 233 observers who completed this task exceeded our criterion on any of these three measures. However 3 observers (2 men) were excluded due to missing or incomplete data.

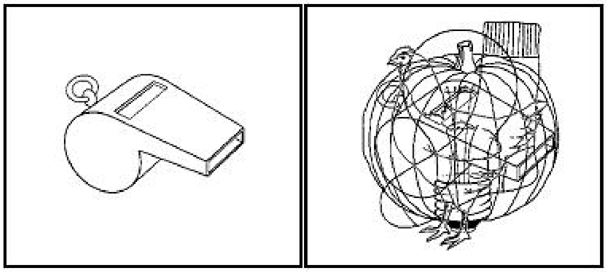
To examine the reliability of the T1 measure we first subdivided the task into bins consisting of 12 trials (i.e. trials 1-12, 13-24, 25-36 and 37-48), and averaged the scores within each bin to yield four data points per observer. The bin size of 12 trials was used to ensure that the three critical time lags for T2 were represented. The alpha coefficient estimated for T1 using this technique was 0.45, with an inter-item correlation of 0.17, suggesting that this task is marginally reliable. Since attentional blink is commonly used in attention research we retained this measure for our between groups analyses. However, because of the relatively low reliability of the task (when compared to our other attention tasks), we did not include this measure in our analyses of the relationships among attentional tasks.

To examine the reliability for the T1-T2 re-engage measure we averaged across the same subsets of trials for all lags (average of all lags) and subtracted this value from the equivalent bins for T1, yielding 4 data points per observer. The alpha coefficient estimated for T1-T2 using this technique was 0.75, with an inter-item correlation of 0.43, suggesting that this measure was reliable.

Object Shifting:

Purpose: This task is unique to our attention battery and was created for the specific purpose of measuring the observer's ability to shift attention among overlapped objects.

Stimuli: The central fixation point consisted of concentric circles (target) drawn with one-pixel width black lines subtending 0.44^0 visual angle, against an achromatic gray background (CIE [.277, .302], luminance $44.2\ cd/m^2$). Two separate sets of stimuli were created for this task. Both sets of images were centered at fixation and subtended 10.55^0 vertical x 10.55^0 horizontal visual angle and all were set against the same achromatic gray background as the fixation screen. The first set of stimuli consisted of 90 individual line drawings of common objects (Snodgrass & Vanderwart, 1980). The second set of stimuli consisted of 18 compilation images where 5 of the prior images were superimposed on each other (figure 4, see appendix C for composite images).



Single Object Trials Multiple Object Trials

Figure 4. Example of stimuli used in the object-shifting task.

Procedure: This task consisted of two blocks. In the first block observers were presented with the series of 90 individual line drawings and instructed to name them as quickly as possible while simultaneously entering a key press to advance to the next trial. Each trial began with a central fixation point that remained on the screen for 150 ms, followed by the stimulus onset and a 67 ms alerting tone. The stimulus remained on the screen until the observer responded. Previous studies conducted in our lab demonstrated that synchronized naming with key-press provides a consistent and reliable measure of reaction time (Suzuki & Grabowecky, 2002) Using a list of the items, the experimenter tracked the observers' responses and made notes of any alternative names used (e.g. when the observer used "tool" for "wrench" or "clip" for "clothespin"). The second block consisted of 18 trials of the overlapped images. The observers' task was to press the space bar as they identified (named out loud) each of the items. Naming was deemed correct as long as the observer was consistent in their use of names between the single and overlapped blocks. Following the same procedure as the single item block, each trial began with 150 ms fixation followed by the 67 ms alerting tone and a 5-item image that remained on the screen until the observer provided five separate responses. Once five button presses had been executed the computer advanced to the next trial. The order of presentation was fixed for all observers in both blocks. Observers who were non-native speakers were instructed to perform the task to the best of their ability. (English fluency was not required for inclusion in our study. Thus observers who were non-native English speakers completed all tasks, but if their performance scores on this particular task exceeded 3 standard deviations from the sample mean their data were excluded).

Measure: This task yielded three different measures. The first block provided a measure of the observer's reaction time while naming single objects (SRT) and was obtained by averaging the individual reaction times across 85 of the original 90 trials. (Note, because the first trial of the second block was considered a practice trial, and omitted from the analysis, the corresponding items from the single item block were also omitted. Thus the actual number of trials for which reaction times were measured in the first block was 85). The second block provided a measure of the observer's reaction time while naming multiple overlapping objects (MRT). Each of the 17 trials in this block resulted in five separate response times: stimulus onset to response 1 (R1), response 1 to response 2 (R2), response 2 to response 3 (R3), response 3 to response 4 (R4), and response 4 to response 5 (R4). These values were first averaged for each trial (MRT_i) and then averaged over the entire block to yield a composite measure of reaction time for the multiple object trials (MRT_{ave}). The primary measure of interest in this task was the index of interference based on reaction time that was calculated using data from both blocks: $IOI_{RT} = (MRT- SRT_{ave})/SRT$.

In a post-hoc analysis, we examined the individual scores to identify observers with scores 3 standard deviations or greater than the mean for the measures of SRT (M = 869.57 ms, SD = 259.33 ms), MRT_{ave} (M = 1344.87 ms, SD = 330.21 ms), and for the IOI_{RT} (M =0.6048, SD = 0.3596). Of the 223 observers who completed this task, 7 (5 men) exceeded this criterion and were excluded from further data analysis. Two additional participants, (1 man) exceeded this criterion and were also non-native English speakers.

To examine the reliability of this task we calculated the IOI_{RT} for each of the 17 MRT experimental trials, which yielded 17 data points per observer. Using these values, the alpha coefficient for this task was 0.90, with an inter-item correlation of 0.34, suggesting that this measure was reliable. The low inter-item correlation reflects the range of difficulty in the overlapped items, with some trials being more difficult than others.

Tracking Multiple Objects:

Purpose: To test the ability to track multiple moving objects, we used a task that required the observers to attend to and track 4 target dots within a display of 20 identical and randomly moving dots.

Stimuli: Central fixation consisted of a green (CIE [.296, .401], luminance 23.2 cd/m^2) fixation-cross (0.617 x 0.617 ^{0} visual angle) that remained visible throughout the entire task. Stimuli for this task consisted of 20 blue (CIE [.146, .070], luminance 1.3 cd/m^2) dots, 8 mm in diameter, (subtending approximately 0.705^0 visual angle from fixation) presented against a black background. During the trials the dots moved with random motion at an initial speed of 5.8cm per second, within an invisible 14.5 x 10.5cm rectangle, subtending 12.729^0 horizontally and 9.235^0 vertically (figure 5). The movement of the dots obeyed the laws of physics, assuming perfectly elastic collisions and no occlusions (although they were allowed to pass behind the small fixation cross).

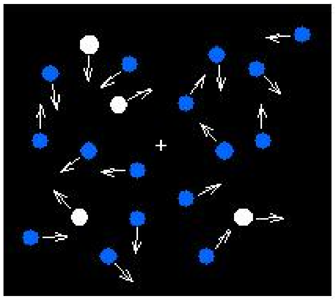


Figure 5. Example of stimuli used in the multiple object-tracking task.

Procedure: The observers were informed that they would be observing a display of 20 moving dots and that their task was to keep their eyes on the center fixation cross and, using only their attention, track the four target dots. Observers initiated each of the 6.3-second trials with a key press (spacebar). At the beginning of each trial, the four “target” dots would flash from blue to white for 1.5 seconds, then returned to blue for the rest of the trial. At the end of each trial, the dots froze in place and remained visible until the observer used four separate mouse-clicks to identify the four target dots. They completed 20 trials. The experimenter monitored the observers’ eye movements using a small night vision camera focused tightly on the observers’ eyes. If the observers displayed excessive eye movement at any time during the task, they were warned by the experimenter between trials to keep their eyes on the central fixation cross.

Measure: Performance was measured as the average of correctly clicked dots over all 20 trials. Post-hoc evaluation to detect outliers, of the observers’ performance was used to examine the data for scores 3 standard deviations less than the mean (*M* = 1.73, *SD*= 0.45). Of the 223 observers who completed this task, none exceeded this criterion. However, 3 of the observers (2 men) were excluded due to equipment failure.

For the reliability analyses for this task, 20 trials were used (i.e. 20 data points per observer). The alpha coefficient for this task was 0.81, with an inter-item correlation of 0.18 suggesting that this measure is reliable, although possibly multidimensional. The low inter-item correlation may be the result of the randomness of the difficulty of the trials. Since the dots were allowed to move and collide randomly (resulting in acceleration of movement), some trials may have had several collisions that in turn would have made the task much more difficult, while others may have had few collisions, which would make the task much easier.

Spatial Shifting:

Purpose: As with the object shifting task, the attention-shifting task originated in our lab. However whereas the previous task was designed to test the observers' ability to shift their attention between objects, this task was designed to test their ability to quickly shift their attention between spatial locations.

Stimuli: Fixation consisted of an achromatic gray circle (CIE [.287, .316], luminance 45.1 cd/m^2) that subtended 0.176^0 visual angle against a black background. Stimuli consisted of pairs of numbers (1 through 9), presented in white Helvetica font (same CIE coordinates and luminance as fixation) presented horizontally at 3.3cm eccentricity from the central fixation point, subtending 3.481^0. The individual numbers were 1.145 horizontal x 1.673^0 vertical visual angle with a line thickness of 3mm (figure 6).

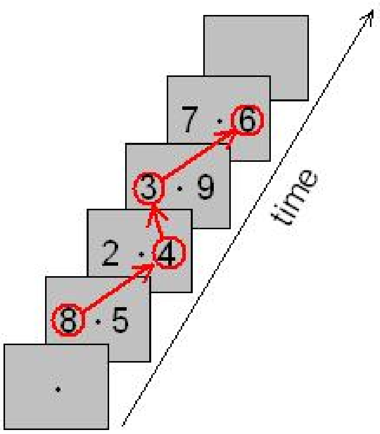


Figure 6. Example of stimuli and sequence of presentation used in the spatial shifting task.

Procedure: In this task, the observers were presented with a series of 8 numbers, appearing two at a time (one on each side of the fixation point). The observers' task was to attend to the numbers on alternating sides of the fixation point beginning with the number on the left in the first pair, followed by the number on the right in the second pair, the number on the left in the third pair and on the right again for the last pair. At the end of the trial the observers reported the four target numbers, in the order that they appeared. For example, if the 4 pairs of numbers presented were [2 • 4], [3 • 8], [7 • 1] and [9 • 3] (where [•] represents the fixation point) the correct response would be: [2-8-7-3]. Observers were informed that the numbers would appear more quickly than they could move their eyes so they would need to keep their eyes focused on the center fixation point and use their attention only to keep track of the numbers. Additionally, a small night vision camera was used to allow the experimenter to closely monitor the observers eye movements. If the observers displayed excessive eye movement at any time during the task, they were warned by the experimenter between trials to keep their eyes on the central fixation point. The experimenter initiated the first trial with a mouse click. After a 2.54 second delay, a 67.1 ms warning tone accompanied the onset of the center fixation point which in turn preceded the first pair of numbers by 1.77sec. In the first trial the pairs of numbers were presented for 442.86 ms each with a 26.84 ms ISI between pairs. After all 4 pairs of numbers were presented the observer reported the numbers in the order that they appeared to the experimenter who recorded their response using the computer keypad. The experimenter's entry into the computer in turn initiated the beginning of the next trail. If the observer responded to the first trial correctly, the stimulus presentation rate for the next trial was decreased by 40.26 ms (e.g. from 442.86 to 402.6 ms per pair with a 26.84 ms ISI). If the observer responded incorrectly the stimulus presentation rate was increased by 40.26 ms (e.g. from 442.86 to 483.12 ms per pair with the same 26.84 ms ISI). This staircase procedure was used to adjust the speed of the task on each trial until 6 reversals occurred (correct to incorrect or vice versa), at which time the block ended. The observers completed two blocks in this manner.

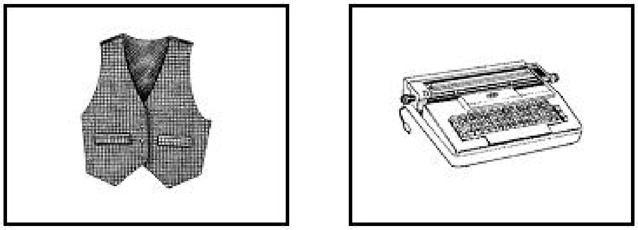
Measure: The measure of performance for this task was taken from the average of the last four reversals for each of the two blocks [(Average Block 1 + Average Block 2)/2] with faster average times indicating better performance. A post-hoc evaluation to detect outliers, of the observers' performance was used to examine the data for scores 3 standard deviations or greater than the mean (M = 301.78 ms, SD= 55.78 ms). Of the 223 observers who completed this task, a total of 3 (1 man) exceeded this criterion and were excluded from further analysis of this task.

The reliability of this task was evaluated using the average of the last four reversals from each block, yielding two data points per observer. Using this technique, the alpha coefficient for this task was 0.77 with an inter-item correlation of 0.62 suggesting that this task was reliable.

Object Vigilance:

Purpose: To measure our observers' ability to remain vigilant for target objects, separate from their ability to remain vigilant to targets in spatial locations, we designed two separate vigilance tasks. In the object vigilance task, the observers were required to remain vigilant over an extended period of time, for items that belonged to three target categories while rejecting distractor objects.

Stimuli: A center fixation point consisted of a small black dot that subtended 0.411^0 visual angle against an achromatic gray background (CIE [.277, .302], luminance 44.2 cd/m^2). Stimuli consisted of a series of 210 grayscale drawings of common objects adjusted to fit within an invisible square subtending 7.043^0 x 7.043^0 visual angle against the same background as the fixation screen (figure 7).



Target item Non-target item

Figure 7. Example of stimuli used in the object vigilance task.

Procedure: The observers were informed that they would be seeing a series of pictures presented one at a time and that their task would be to identify whether or not the object belonged to one of three target categories (e.g. furniture, clothing and animals). The distractor items in the task were drawn from a variety of non-target categories (e.g. food, buildings, transportation, electronic appliances, etc.). Each trial began with a 67.1 ms alerting tone that accompanied the appearance of one of the 210 images. The images remained on the screen until the observers provided a response in the form of a button press. Following the button press there was a 1.65 second delay before the next trial. The fixation point remained on the screen between trials. The observers were instructed to respond as quickly and as accurately as possible by pressing the backslash key (labeled “Y” for “yes”) if the item belonged to one of the three target categories, or pressing the “Z” key (labeled “N” for “no”) if the item was a non-target. Additionally, feedback was provided to the observers in the form of a low tone (67.1 ms duration) for incorrect responses. Observers completed a total of 210 trials consisting of 21 rare target items and 189 frequent distracter items. Pure-randomization of trials can sometimes result in unequal distribution of target trials. Thus, to ensure that the target items were distributed equally, yet unpredictably, throughout the entire task we used a pseudoramdomized presentation order. The task was presented in this order to all observers.

Measure: Seven different measures were collected from this task including the reaction time for the target trials (TRT), distractor trials (DRT), an index of slowing (IOS_{RT}) calculated using the formula (TRT-DRT)/DRT), proportion correct responses for target trials (Tcorr) and distractor trials (Dcorr), which in turn were used to calculate A prime (A'), [1/2 + (Tcorr - (1 - Dcorr)) * (1 + Tcorr - (1 - Dcorr)) / (4 * Tcorr * (1 - (1 - Dcorr))] as an unbiased measure of accuracy.

In a post-hoc evaluation to detect outliers, we examined the data for scores 3 standard deviations or greater than the mean for each of the measures: TRT (*M* = 668.62 ms, *SD*= 196.89 ms), DRT (*M* = 590.93 ms, *SD*= 170.09 ms), IOS_{RT} (*M* = 0.144, *SD*= 0.153), Tcorr (*M* = 0.877, *SD*= 0.124), Dcorr (*M* = 0.995, *SD*= 0.007), and A' (*M* = 0.967, *SD*= 0.034). Of the 223 observers that completed this task, a total of 7 (2 men) exceeded this criterion and were excluded from further analysis of this task.

To ensure that use of the reaction time was an appropriate measure, examined the correlation between the IOS_{RT} and A' for evidence of a speed-accuracy trade-off. Because there was a negative correlation between the IOS_{RT} and A' (r (201)= -0.52, $p < 0.001$), there was no indication of a speed-accuracy trade off. Rather, this relationship indicates that the observers who performed more slowly on the task also made a greater number of errors. Thus we retained the IOS_{RT} as our measure of interest for this task.

Thus, to evaluate the reliability of the task we subdivided the task into four bins based on the occurrence of the target trials. Because the order was fixed for all participants the target items always appeared on trials 13, 25, 33, 36, 40, 50, 58, 63, 88, 92, 104, 123, 126, 135, 145, 149, 157, 170, 184, 192 and 203. To ensure the target trials were relatively equally distributed among the four bins, we subdivided the task so that the first three bins contained five target trials and the fourth contained an additional sixth target trial. Thus the IOS_{RT} was calculated for each of the bins consisting of trails 1-40, 41-92, 93-145, and 146-210, yielding four data points per measure for each observer. The coefficient alpha estimated for this task using this technique was 0.70, with an inter-item correlation of 0.36 suggesting that the measure was reasonably reliable.

Peripheral Focusing:

Purpose: To test our observers' ability to attend to target items presented in the periphery while inhibiting distracter items presented at central fixation, we used a modified flanker task similar to the one used in our central focusing task.

Stimuli: As in the center-focusing task, a circular central fixation point subtending 0.264^0 visual angle remained visible at all times, presented against the same achromatic gray background used in the other tasks, (CIE [.277, .302], luminance 44.2 cd/m^2). Additionally, two 6.6 cm x 6.6 cm placeholder boxes were positioned horizontally on either side of the fixation point, with their centers positioned at 7.482^0 visual angle eccentricity on either side of the center fixation point, with their outer most corners at 10.198^0. Stimuli consisted triads of the letters X, S and T, or letters and numbers (e.g. X S 4 or 3 T X) in black Helvetica font. The central letter was smaller than the flankers, subtending 2.644^0 x 1.675^0 visual angle. The flanker items were presented inside of the placeholder boxes, aligned horizontally with the center fixation and subtending 3.071^0 horizontally x 3.929^0 vertically (figure 8). In the interference condition, the to-be-ignored central item was the opponent target letter (e.g., [T] S [X] or [X] T [S]), whereas in the neutral condition, the central item was a randomly selected digit (e.g., [T] 4 [X] or [X] 7 [S]).

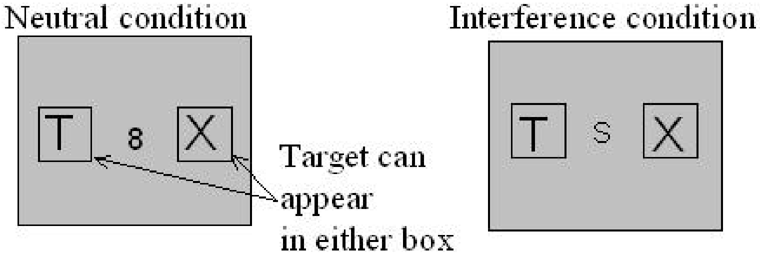


Figure 8. Example of stimuli used in the peripheral focusing task.

Procedure: The observers were instructed maintain fixation at the central fixation point, ignoring the letters presented at that location, and simultaneously monitoring the two peripheral locations for the presence of the "target" letters. As in the center-focusing task, the target letters were T or S and the observers were instructed to respond using the same 5 (labeled "S") and 2 (labeled "T") keys on the numerical keypad. To enforce central eye fixation, the target letters were flashed unpredictably (randomly) in the left or right peripheral locations. Presentation rates and trial durations were the same as in the center-focusing task (1.55 seconds fixation, followed by 214.72 ms stimulus presentation, with trial termination determined by the observers key press, which in turn initiated the beginning of the next trial).

Measure: Performance on this task was measured in the same way as in the center focusing task, by calculating indices of interference based on reaction time (IOI_{RT}) and error (IOI_{ERR}). Additionally, for each individual observer, if any one trial exceeded 3 standard deviations in RT from their within task average, the trial (and excessive RT) was discarded.

In a post-hoc evaluation to detect outliers, we examined the observer's performance scores for individual scores that were 3 standard deviations greater than the mean for the measures NRT (*M* = 571.7 ms, *SD* = 101.83 ms), IRT, (*M* = 610.51 ms, *SD* = 118.16 ms), IOI_{RT} (*M* = 0.068, *SD* = 0.073), Ncorr (*M* = 0.96, *SD* = 0.04) Icorr (*M* = 0.95, *SD* = 0.05), and IOI_{ERR} (*M* = 0.01, *SD* = 0.05). Of the 223 observers that completed this task 12 (6 men) exceeded this criterion and were eliminated from further statistical analyses of this task.

To ensure that use of the reaction time was an appropriate measure, we conducted an additional post-hoc analysis to check for a speed accuracy trade-off by estimating the correlation between the IOI_{RT} and IOI_{ERR}. This relationship was non-significant (r (197)= 0.09, p = 0.23). Thus we retained the IOI_{RT} as our measure of interest for this task.

To examine the reliability of this task we subdivided the task in to four bins (20 trials each) and averaged the scores within each bin to yield four data points per observer. The IOI_{RT} was calculated for each bin, yielding four data points per observer for use in our reliability analysis. The alpha coefficient estimated for this task using this technique was 0.34, with an inter-item correlation of 0.12. As with the center focusing task, this very low alpha coefficient is likely the product of a ceiling effect. Because this task is complimentary to our center focusing task, we choose to include the task in our analyses of between group differences. However because of the low reliability, it is unlikely that the task would correlate with our other measures of attention, and was not included in our analyses of the relationships among attentional tasks.

Attention to global motion:

Purpose: This task was designed to test the observers' ability to attend to global patterns of coherent motion within an environment of random movement. Specifically, the observers were required to attend to the global pattern of motion of a subset of very small moving dots among the random movement of identical distractors.

Stimuli: A central fixation point consisted of a white circle (CIE [.287, .316], luminance 45.1 cd/m^2) subtending 0.176^0 visual angle, against a black background. Test stimuli were created using an annulus shaped array of 150 white single-pixel dots moving at 2cm per second against a black background. The inner edge of the annulus was positioned at 7.262^0 eccentricity from the center fixation point, and the outer edge at 10.329^0 visual angle (figure 9). On any given trial, a subset of the dots (either 20%, 40% or 60%) were moving coherently, (i.e. on the same trajectory), either linearly (horizontally, vertically or diagonally), or radially (moving towards or away from the center), while the reminder of the dots moved randomly. Additionally, to prevent the observer from using a tracking strategy, the subset of coherently moving dots changed every 143.15ms. In other words, the “life span” of the individual dots was approximately 1/3 of the trial duration.

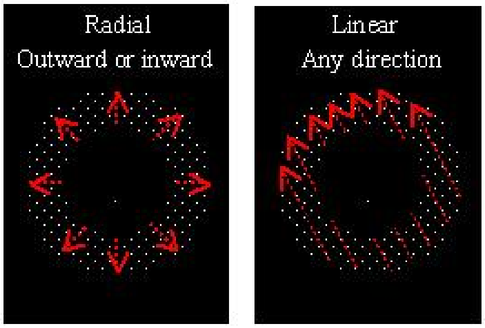


Figure 9. Example of stimuli used in the global attention to motion task.

Procedure: The observers were instructed to keep their eyes at the central fixation point and respond using a key-press to indicate whether the coherently moving dots were moving radially (by pressing the "/" key) or linearly (by pressing the "z" key). Each trial began with a blank fixation screen (1.5 sec) followed by the 429.44ms presentation of the moving dots and a return to the blank fixation. Each trial terminated with the observer's key-press that in turn initiated the next trial. Observers were given 10 practice trials to become accustomed to the task. During the practice trials the number of coherently moving dots was held constant at 80%, but type of motion (radial or linear) was distributed randomly. The practice trials were followed by 100 experimental trials where the type of motion and percentage of coherently moving dots were both randomly determined. Additionally, the observers were informed that their accuracy was more important than their reaction time and to wait until the stimulus disappeared before entering their response.

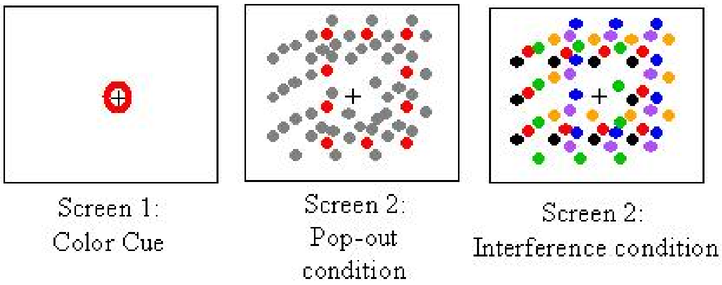
Measure: Thirteen measures were calculated from this task including: proportion correct for each of the three levels (Corr20, Corr40, Corr60), and an average for all three levels (AveCorr). The average proportion correct for all observers at the 40% and 60% levels were 0.70 (*SD* = 0.12) and 0.82 (*SD* = 0.13) respectively. However for the 20% level the average proportion correct was only 0.55 (*SD* = 0.019). Since the observers performed no better than at chance for this level of coherence, we chose to omit this level from our further data analyses. For our measures of interest, we created two composite measures, averaging only the proportion correct for the 40% and 60% trials (Ave40.60). To exclude outliers, we examined these composite measures for individual observers with scores 3 standard deviations less than the mean: Ave40.60 (*M* = 0.76, *SD* = 0.11). Of the 223 observers that completed this task 4 (1 man) exceeded this criterion and were eliminated from further statistical analyses of this task. Four additional participants were excluded (2 men) due to equipment failure and one was excluded for failing to follow the instructions.

To examine the reliability of this task, we subdivided the remaining 40% and 60% trials into four bins (25 trials each) and averaged the proportion correct scores within each bin yielding four data points per observer. The alpha coefficient for this measure was 0.69, with an inter-item reliability of 0.36, suggesting that it was a reasonably reliable measure. The low inter-item reliability likely reflects the difference in difficulty between the 40% and 60% trials.

Attentional grouping:

Purpose: Our observers abilities to attend to groups of items was tested using a two-block task where they were required to group the items by color and identify their configuration while ignoring distractors of different colors but similar configurations.

Stimuli: Center fixation consisted of a black cross subtending 0.411^0 x 0.411^0 visual angle, against an achromatic gray background (CIE [.277, .302], luminance 44.2 cd/m^2). The fixation cross remained visible and the background remained the same throughout the entire task. The “color cue” screens consisted of a circle drawn with a line 2mm in width, subtending 1.322^0 visual angle centered around the fixation point. This circle was presented in 6 different colors: Blue (CIE [.146, .073], luminance 5.1 cd/m^2), Red (CIE [.616, .334], luminance 8.2 cd/m^2), Purple (CIE [.228, .118], luminance 6.3 cd/m^2), Orange (CIE [.471, .118], luminance 20.5 cd/m^2) or Green (CIE [.299, .579], luminance 17.9 cd/m^2). The “response” screens consisted of 60 circles, each 5mm in diameter, (approximately 0.441^0 visual angle depending on eccentricity from center) arranged to form 6 overlapping rectangles. Each rectangle consisted of 10 evenly spaced circles, 4 on the long side, 3 on the short side, subtending 5.637^0 x 3.877^0 visual angle respectively. For the “pop-out” condition, 10 circles of all one color were used to delineate one full rectangle, and the remaining 50 circles were of a different color (e.g. 10 circles would appear in blue while the other circles were green). For the “grouping” condition, all 6 colors were used, delineating 6 separate rectangles (figure 10). We constructed six unique configurations of overlapped rectangular arrays, each consisting of three vertical and three horizontal arrays so that any of the six rectangles could be the target within each configuration (yielding 6 x 6 = 36 trials). Stimuli were counterbalanced across trials such that each color was equally likely to be associated with a vertical or horizontal target, and each specific rectangle was never assigned the same color more than once.


Screen 1:
Color Cue

Screen 2:
Pop-out
condition

Screen 2:
Interference condition

Figure 10. Example of stimuli used in the attentional grouping by color task.

Procedure: Observers were informed that they would be seeing a series of screens, each starting with a color “cue” followed by a second screen that would consist of an array of colored dots. They were instructed that their task was to respond by using a key press to indicate whether the dots in the cued color formed a rectangle whose long sides were oriented vertically (by pressing the “/” key), or horizontally (by pressing the “z” key). If the observer made an incorrect response, they received feedback in the form of a brief low tone (67.1 ms in duration). Each trial began with a 1.55 second fixation, followed by a 750 ms presentation of one of the six color cues and a 1.38 ms delay before the onset of the "response" screen. The first block of trials consisted of "pop-out" screens where only 10 of the circles (one rectangle) were of a different color. In the second block of the task (the "grouping" condition), the circles in the "response" display were presented in a variety of colors so that they formed 6 distinct rectangles. In both cases the response screen remained on until the observer provided a response that in turn initiated the beginning of the next trial. Each block consisted of 6 practice trails followed by 30 experimental trials. The experimental trials were presented in a pseudorandomized order to ensure an unpredictable, yet even distribution of horizontal and vertical trials.

Measure: Six measures were calculated from this task, including the reaction time for the pop-out trials (PRT), grouping trials (GRT), and an index of interference calculated using the formula: IOI_{RT} = (GRT-PRT)/PRT. The other three measures were the proportion of correct responses for the pop-out trials (Pcorr), grouping trials (Gcorr) and an error index calculated using the formula: IOI_{ERR} = Pcorr-Gcorr. If the RT for any one trial was 3 standard deviations or greater from the individuals average RT for this task, the trial was discarded.

In a post-hoc analyses to identify outliers, we examined the data for individual observers with scores 3 standard deviations or greater than the mean for each of the measures obtained from this task: PRT, (M = 688.61 ms, SD = 113.29 ms), GRT, (M = 875.41 ms, SD = 170.48 ms), IOI_{RT} (M = 0.277, SD = 0.175), Pcorr (M = 0.959, SD = 0.054), Gcorr (M = 0.946, SD = 0.056), and the IOI_{ERR} (M = 0.013, SD = 0.053). Of the 94 observers that completed this task 7 (3 men) exceeded this criterion and were eliminated from further statistical analyses of this task. Two additional participants, both men, had anomalous color vision and were thus excluded from further analyses of this task.

To ensure that use of the reaction time was an appropriate measure, we conducted post-hoc analyses for speed accuracy trade-offs by estimating the correlation between the IOI_{RT} and the IOI_{ERR}. This relationship was non-significant ($r (74) = -0.05$, $p = 0.67$). Thus we retained the IOI_{RT} as our measure of interest for this task.

To examine the reliability of this task, we subdivided each block of the task in to four bins (trials 1-7, 8-15, 16-22, 23-30) and averaged the scores within each bin. Our primary measure of interest was the IOI_{RT}, yielding four data points per block for each observer. Using this technique, the alpha coefficient for this task was 0.70, with an inter-trial reliability of 0.36, suggesting that this task was reliable.

Spatial Vigilance:

Purpose: Whereas the object vigilance task tested the observer's ability to remain vigilant for items belonging to specific categories of objects, in the spatial vigilance task observers were required to remain vigilant for the appearance of a target item at any one of four spatially distinct locations.

Stimuli A center fixation point consisted of a small circular black dot that subtended 0.411^0 visual angle against an achromatic gray background (CIE [.277, .302], luminance 44.2 cd/m^2). The fixation circle remained visible and the background remained the same throughout the entire task. An invisible 7.8 cm x 7.8 cm grid centered at fixation was used to create each of the individual stimulus screens. Each box within the grid was 1.3 cm x 1.3 cm (1.146^0 x 1.146^0 visual angle) with the outer most corners of the grid at 4.858^0 visual angle. The center most box in each quadrant of the grid was designated as the "target" location and was delineated using a black, 1 pixel width line. In the "target" trials, a black dot (9mm in diameter, 0.193^0 visual angle) was positioned in the center of one of these four target boxes. In the non-target trials, the black dot could appear in any one of the other 32 grid locations (figure 11).

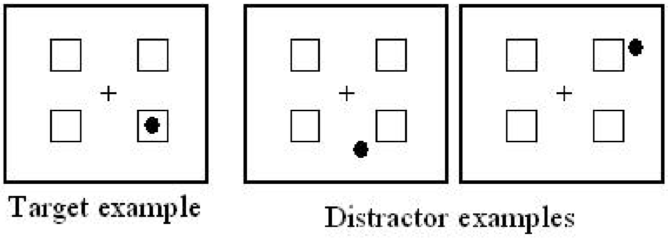


Figure 11. Example of stimuli used in the spatial vigilance task.

Procedure: Each trial began with a 67.1 ms alerting tone that accompanied the appearance of the one of the black dots either in one of the target or non-target locations. The dot remained visible until the observer provided a response in the form of a button press. Following the button press, there was a 1.65 second delay before the next trial. The observers were instructed to respond as quickly and as accurately as possible, pressing the backslash key (labeled “Y” for “yes”) if the dot appeared in a box, or pressing the “Z” key (labeled “N” for “no”) if the dot was not in a box. Additionally, feedback was provided to the observers in the form of a low tone (67.1 ms duration) for incorrect responses. Observers completed a total of 240 trials, consisting of 24 rare target trials, and 216 frequent distractor (non-target) trials. Since pure-randomization of trials could result in unequal distribution of target trials we used a pseudoramdomized presentation order to ensure that the target items were distributed equally, yet unpredictably, throughout the entire task. The task was then presented in this same fixed order to all observers.

Measure: As with our object vigilance task, seven different measures were collected from this task including the reaction time for the target trials (TRT), distractor trials (DRT), an index of slowing (IOS_{RT}), proportion correct responses for target trials (Tcorr) and distractor trials (Dcorr), which in turn were used to calculate A prime (A') as an unbiased measure of accuracy. Additionally, if the RT for any one trial was 3 standard deviations or greater from the individuals average RT for this task, the trial was discarded.

In a post-hoc evaluation, of observers' performance to detect outliers we examined the data for scores 3 standard deviations less than the mean for TRT ($M = 538.71$ ms, $SD= 121.57$ ms), DRT ($M = 391.13$ ms, $SD= 67.56$ ms), IOS_{RT} ($M = 0.382$, $SD= 0.217$), Tcorr ($M = 0.858$, $SD= 0.125$), Dcorr ($M = 0.997$, $SD= 0.004$), and A' ($M = 0.964$, $SD= 0.032$). Of the 94 observers that completed this task 5 (2 men) exceeded this criterion and were eliminated from further statistical analyses of this task.

To ensure that use of the reaction time was an appropriate measure, we conducted a post-hoc analysis for speed accuracy trade-offs by estimating the correlation between the IOS_{RT} and A'. There was a negative correlation between the IOS_{RT} and A' ($r(82)= -0.40$, $p < 0.001$). As with our object vigilance task these results indicate that the observers who performed more slowly on the task also made a greater number of errors and therefore, which is the opposite of a speed-accuracy trade-off. Thus we retained the IOS_{RT} as our measure of interest for this task.

To evaluate the reliability of the task we subdivided the task into four bins based on the pseudo-randomized order of the target trials. Because the order was fixed for all participants the target items always appeared on trials 10, 21, 29, 43, 56, 64, 68, 78, 87, 90, 109, 121, 125, 150, 155, 163, 173, 177, 180, 188, 200, 213, 230, and 238. To ensure that the target trials were relatively equally distributed among the four bins, we subdivided the task so that each bin contained six target trials. Thus for the reliability analysis an IOS_{RT} was calculated for each of the bins consisting of trails 1-64, 65-121, 122-177, and 178-240, yielding four data points per measure for each observer. The alpha coefficient for this measure was 0.78 with an inter-item correlation of 0.47 suggesting that it was a reliable measure.

Controlling (biasing) perception of motion direction:

Purpose: Besides the commonly considered functions of attention related to stimulus selection, tracking and grouping, attention can also control (or bias) perception. For example, when a motion signal is ambiguous as to its direction, one can generate perception of a specific direction of motion with attentional effort. We designed a task to test the observers' ability to control their attention and maintain their perception of the direction of motion of an ambiguously moving stimulus.

Stimuli: The central fixation point consisted of concentric circles (target) drawn with one-pixel width black lines subtending 0.44^0 visual angle against an achromatic gray background (CIE [.277, .302], luminance 26.0 cd/m^2). Additionally, a black ring (line thickness of 1 mm) subtending 8.797^0 visual angle from the center fixation point served as a place holder upon which four dots (1 cm diameter, 0.88^0 visual angle when corrected for eccentricity), were placed equidistantly from each other. The background remained the same and the fixation cross and placeholder ring remained visible throughout the entire task. During the movement induction phase of the task two opposing dots were presented in black and the other two dots were presented in red (CIE [.618, .333], luminance 8.3 cd/m^2). During the maintenance phase of the trial all four dots were black (figure 12).

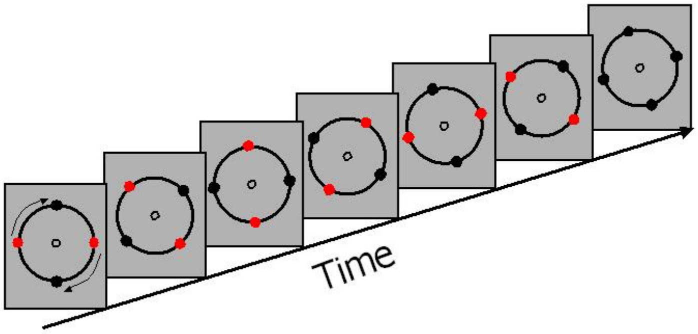


Figure 12. Example of stimuli and sequence of presentation in the controlling perception of motion task.

Procedure: This task consisted of 10 trials, the first and last of which were “catch trials” to ensure that the observers were executing the task correctly. Each trial began with a movement induction phase where the dots were presented in a diamond array, 2 black, 2 red, for 410ms, immediately followed by a second array that displayed the dots shifted 42^0 in the clockwise direction. The red and black arrangement persisted for the first 5 shifts, after which all four dots turned black and remained black for the duration of the trial. During the catch trials, the dots were advanced by 42^0 for the first ten shifts then the shift angle increased by 3^0 on each subsequent shift, reaching a maximum of 66^0, at which time the process was reversed until the shift angle returned to the original 42^0. In the experimental trials, the shift angle remained a constant 42^0 throughout the entire trial. Observers were first given a demonstration of the task where the dots shifted at intervals of 45 degrees. As observers viewed this demonstration trial, they were instructed by the experimenter to use their attention to bias their perception so that the dots appeared to be moving in a clockwise rotation. Once the observers indicated that they perceived the dots as moving clockwise, the experimenter then pointed out that they could bias their attention so that the dots appeared to be rotating counter-clockwise, or rocking back and forth. Participants were asked to confirm that they were able to attain all three percepts of motion before the experimental trials began. Additionally, they were instructed that on the experimental trials, there would be one pair of dots that would appear in red for the first few frames, then turn black like the other dots. Their task would be to keep their eyes focused on the central fixation point, and using their attention, keep track of the two red dots for as many frames as they were able. They were instructed that at the moment that it appeared that the dots were no longer rotating clockwise, they were to press the space bar to end the trial. The observers completed a series of 10 trials, both initiating and ending the trial with a key-press. The maximum number of shifts possible was set at 77 frames, at which time the trial would simply time out. As indicated above, the first and last trials were used as "catch trials" where the angle of rotation was remained at 45^0 for the first 5 shifts, then progressively increased by 3^0 until reaching a maximum of 66^0, at which time the process was reversed until the shifts angle was again 42^0. This change in degree of rotation typically induces the perception of the reversal of motion. If observers failed to indicate that their perception of the motion had changed during the increasing stage of the catch trial, the experimenter would repeat the instructions and repeat the first catch trial. If the observer failed the second catch trial, the task was terminated. Similarly, if they failed the last catch trial, their data were excluded from our analysis. Additionally, to ensure that the observers were maintaining fixation, a small night vision camera was used to monitor eye movement. If at any point during the task the observer demonstrated excessive eye movement, they were reminded between trials to keep their eyes fixated on the center fixation point.

Measure: Performance was measured as an average of the duration of frames which the observer maintained the clockwise rotation for trials 2 through 9 (catch trials excluded), where a larger number of frames indicates a greater ability use ones attention to maintain the direction of motion of an ambiguously moving object. Post-hoc evaluation of observers' performance to detect outliers was used to examine the data for scores 3 standard deviations less than the mean ($M = 17.78$, $SD = 8.07$). Of the original 94 subjects that completed this task none of them exceeded this criterion. However, 30 observers (14 men) were removed due to experimenter error, and 2 (both men) were removed for failing the catch trials.

The analysis of reliability was estimated using the 8 experimental trials (8 data points per observer). The alpha coefficient for this task was 0.91, with an inter-item correlation of 0.42 suggesting that this was a very reliable.

Results:

Comparisons of Attentional Abilities Between Groups:

Differences in attentional abilities between men and women:

One of our primary interests in developing the attention battery was to examine whether men and women differ in their attentional abilities. To test for differences in performance between the men and women in our sample we conducted between group two-tailed t-tests for each of the measures of interest (e.g. response time, indices of interference, index of slowing and A'). The results of these comparisons, including the means and standard deviations, are detailed in table 4. To avoid Type I errors, we applied a Bonferroni correction for multiple comparisons ($n = 19$) which resulted in an adjusted p value of 0.0026. Using this conservative criterion significant differences between men and women were found in only two of the tasks, Tracking Multiple Objects, $t(218) = 4.07$, $p = 0.0001$, and Spatial Shifting $t(217) = 3.51$, $p < 0.0005$. These limited differences suggest that while men and women perform differently on select visual attention tasks, the differences may be related to very specific attentional skills or processes, rather a general or broad difference in attentional abilities. Had we tested our observers on single tasks, where the level of significance would have been the usual $p < 0.05$, we would have reported significant sex differences in the Peripheral Focusing $\mathrm{IOI}_{\mathrm{RT}}$ (t (211) = 2.27, $p < 0.0245$) and Controlling Perception of Motion (t (62) = 4.17, p <0.0453) as well.

Table 3

Differences in attentional abilities between men and women

Task	Measure of Interest	Women *M* (*SD*)	Men *M* (*SD*)	p =
Rapid Identification	Proportion Correct	0.37 (0.20)	0.38 (0.19)	0.9392
Center Focusing	$\mathrm{IOI}_{\mathrm{RT}}$	0.03 (0.04)	0.03 (0.04)	0.8971
	$\mathrm{IOI}_{\mathrm{ERR}}$	0.02 (0.05)	0.01 (0.04)	0.2489
Temporal Focusing	T1 Correct	0.92 (0.06)	0.93 (0.05)	0.3023
Rapid Re-engagement	T1 Correct -T2 Correct	0.36 (0.18)	0.33 (0.19)	0.3205
Object Shifting	$\mathrm{IOI}_{\mathrm{RT}}$	0.61 (0.36)	0.61 (0.33)	0.9051
Tracking Multiple Objects	# of Tracked Dots	1.63 (0.39)	1.87 (0.50)	0.0001*
Spatial Shifting	Average Shift Speed	308 (44.30)	286 (49.42)	0.0005*
Object Vigilance	$\mathrm{IOS}_{\mathrm{RT}}$	0.14 (0.12)	0.13 (0.12)	0.6609
	A’	0.97 (0.03)	0.97 (0.02)	0.9861
Peripheral Focusing	$\mathrm{IOI}_{\mathrm{RT}}$	0.05 (0.07)	0.08 (0.07)	0.0245
	$\mathrm{IOI}_{\mathrm{ERR}}$	0.00 (0.04)	0.01 (0.04)	0.3157
Attention to Global Motion	Proportion Correct	0.77 (0.10)	0.76 (0.10)	0.2812
Attentional Grouping	$\mathrm{IOI}_{\mathrm{RT}}$	0.25 (0.14)	0.29 (0.18)	0.2273
	$\mathrm{IOI}_{\mathrm{ERR}}$	0.01 (0.05)	0.01 (0.05)	0.7203
Spatial Vigilance	$\mathrm{IOS}_{\mathrm{RT}}$	0.37 (0.14)	0.35 (0.14)	0.6448
	A’	0.96 (0.03)	0.97 (0.02)	0.2528
Controlling Perception of Motion	Duration of Trial	15.80 (5.49)	19.89 (9.79)	0.0453

* Significant after correcting for multiple comparisons: $p < 0.0026$

Differences in performance abilities for observers with high ADHD traits:

An additional goal of the development of the attention battery was the investigation of whether individuals with self-reported attention deficits would demonstrate performance differences on the visual attention tasks that make up our attention battery, and whether the defects would be general or task specific. As with the comparison between the sexes, we examined this question by conducting between group two-tailed t-tests for each of the measures of interest and related measures of error. These comparisons were made within gender, that is, women with high ADHD traits were compared only to women from our randomly selected observers, and likewise for the men. Additionally, we compared each of the subtypes (ADHDc, ADHDi and ADHDh) separately. The results of these comparisons are detailed in tables 5and 6. To correct for multiple comparisons, (n =19) we used an adjusted p level of 0.0026. When comparing women with a high number of ADHD traits to our sample of non-selected observers, there were only two measures that revealed significant differences in performance. Specifically, women with a high number of ADHDh traits made a larger number of errors on the Center Focusing task, as indicated by a significant difference in their IOI_{ERR} measures, t (136), = 3.44, p = 0.0008, suggesting that they had a considerable amount of difficulty inhibiting their attention to the flanker items. Additionally, for the Peripheral Focusing task, women with a high number of ADHDc traits had significantly slower reaction times to the interference trials as indicated by a difference in IOI_{RT}, t (132), = 3.35, p = 0.0011, suggesting that while they were just as accurate as the non-selected observers, this accuracy came with a cost of slowing responses. Combined, these results suggest that the deficits in visual attention for these particular groups are not broad and far-reaching, but instead are very specific to both the task and ADHD subtype.

When examining the differences in performance between the men with a high number of

ADHD traits to our non-selected male sample we found that all three subtypes (ADHDc, ADHDi and ADHDh) made significantly more errors on the Center Focusing task as measured by our IOI_{ERR}: ADHDc, t (98) = 5.41, $p = 0.0001$, ADHDi, t (96) = 3.82, $p = 0.0002$, and ADHDh, t (98) = 5.19, $p = 0.0001$ (see table 6 for means and standard deviations for all tasks). These findings suggest that men with a high number of traits in any of the three ADHD subtypes of have more difficulty inhibiting the interfering letters that are presented in the periphery on this particular task, thus making a greater number of errors. Additionally, because this is the only measure where men with a high number of ADHD traits performed significantly worse than our non-selected sample, these results suggest that their attention deficits are very task specific as opposed to a general attention deficit.

Table 4

Differences in attentional abilities between women with high ADHD traits.

Task	Measure of Interest	Non-Selected *M* (*SD*) N = 123	Combined *M* (*SD*) N = 17	p=	Inattentive *M* (*SD*) N = 12	p=	Hyperactive *M* (*SD*) N = 19	p=
Rapid Identification	Proportion Correct	0.37 (0.20)	0.26 (0.13)	0.0273	0.28 (0.13)	0.1279	0.30 (0.15)	0.1363
Center Focusing	IOI_{RT}	0.03 (0.04)	0.03 (0.04)	0.7397	0.04 (0.04)	0.3640	0.04 (0.04)	0.3536
	IOI_{ERR}	0.02 (0.05)	0.05 (0.06)	0.0341	0.06 (0.08)	0.0115	0.06 (0.06)	0.0008*
Temporal Focusing	T1 correct	0.92 (0.06)	0.94 (0.04)	0.2313	0.94 (0.04)	0.2476	0.94 (0.04)	0.1075
Rapid Reengagement	T1corect - T2 correct	0.36 (0.18)	0.44 (0.25)	0.0861	0.44 (0.27)	0.1415	0.45 (0.25)	0.0653
Object Shifting	IOI_{RT}	0.61 (0.36)	0.68 (0.29)	0.4041	0.60 (0.29)	0.9386	0.71 (0.40)	0.2367
Tracking Multiple Objects	# of Tracked Dots	1.63 (0.39)	1.42 (0.53)	0.0561	1.36 (0.49)	0.0297	1.53 (0.58)	0.3753
Spatial Shifting	Average Shift Speed	308 (44)	309 (58)	0.9131	320 (65)	0.4062	308 (59)	0.9915
Object Vigilance	IOS_{RT}	0.14 (0.12)	0.18 (0.17)	0.1642	0.19 (0.16)	0.1630	0.19 (0.16)	0.0988
	A’	0.97 (0.03)	0.96 (0.03)	0.1145	0.96 (0.03)	0.0712	0.96 (0.03)	0.0923
Peripheral Focusing	IOI_{RT}	0.05 (0.07)	0.12 (0.10)	0.0011*	0.09 (0.11)	0.0594	0.10 (0.09)	0.0046
	IOI_{ERR}	0.00 (0.04)	0.01 (0.03)	0.4278	0.02 (0.04)	0.2800	0.02 (0.05)	0.0605
Attention to Global Motion	Proportion Correct	0.77 (0.10)	0.82 (0.08)	0.0956	0.82 (0.09)	0.1613	0.82 (0.08)	0.0689
Attentional Grouping	IOI_{RT}	0.25 (0.14)	0.27 (0.23)	0.5745	0.33 (0.25)	0.1618	0.29 (0.22)	0.3213
	IOI_{ERR}	0.01 (0.05)	0.03 (0.04)	0.4280	0.02 (0.04)	0.8859	0.02 (0.05)	0.4604
Spatial Vigilance	IOS_{RT}	0.37 (0.14)	0.36 (0.12)	0.8403	0.32 (0.11)	0.0491	0.35 (0.12)	0.6421
	A’	0.96 (0.03)	0.95 (0.03)	0.0803	0.95 (0.03)	0.2330	0.95 (0.03)	0.3286
Controlling Perception of Motion	Duration of Trial	15.80 (5.49)	17.14 (5.17)	0.5008	13.78 (6.67)	0.3116	17.02 (5.17)	0.4976

* Significant after correcting for multiple comparisons: $p < 0.0026$

Table 5

Differences in attentional abilities between men with high ADHD traits.

Task	Measure of Interest	Non-Selected *M* (*SD*) N = 100	Combined *M* (*SD*) N = 9	p=	Inattentive *M* (*SD*) N = 7	p=	Hyperactive *M* (*SD*) N = 9	p=
Rapid Identification	Proportion Correct	0.38 (0.19)	0.29 (0.21)	0.2104	0.48 (0.21)	0.1544	0.28 (0.19)	0.1349
Center Focusing	IOI_{RT}	0.03 (0.04)	0.03 (0.04)	0.7782	0.03 (0.05)	0.8428	0.01 (0.06)	0.3677
	IOI_{ERR}	0.01 (0.04)	0.11 (0.09)	0.0000*	0.09 (0.08)	0.0002*	0.11 (0.09)	0.0000*
Temporal Focusing	T1 correct	0.93 (0.05)	0.94(0.06)	0.5436	0.94 (0.06)	0.5876	0.93 (0.07)	0.9951
Rapid Reengagement	T1 correct - T2 correct	0.33 (0.19)	0.45 (0.19)	0.0820	0.47 (0.18)	0.0682	0.37 (0.10)	0.5273
Object Shifting	IOI_{RT}	0.61 (0.33)	0.54 (0.50)	0.5577	0.61 (0.56)	0.9941	0.75 (0.64)	0.2765
Tracking Multiple Objects	# of Tracked Dots	1.87 (0.50)	1.43 (0.42)	0.0116	1.59 (0.52)	0.1509	1.37 (0.46)	0.0048
Spatial Shifting	Average Shift Speed	286 (49)	321 (62)	0.0473	296 (42)	0.6018	309 (64)	0.1958
Object Vigilance	IOS_{RT}	0.13 (0.12)	0.15 (0.14)	0.5841	0.20 (0.19)	0.1626	0.11 (0.15)	0.7437
	A’	0.97 (0.02)	0.96 (0.03)	0.3294	0.96 (0.03)	0.4845	0.97 (0.03)	0.4795
Peripheral Focusing	IOI_{RT}	0.08 (0.07)	0.08 (0.05)	0.9714	0.09 (0.07)	0.6557	0.05 (0.05)	0.2748
	IOI_{ERR}	0.01 (0.04)	0.01 (0.04)	0.7860	0.02 (0.04)	0.6147	0.02 (0.05)	0.3902
Attention to Global Motion	Proportion Correct	0.76 (0.10)	0.70 (0.09)	0.0931	0.72 (0.09)	0.3981	0.76 (0.11)	0.9690
Attentional Grouping	IOI_{RT}	0.29 (0.18)	0.40 (0.31)	0.1660	0.47 (0.32)	0.0413	0.24 (0.19)	0.4745
	IOI_{ERR}	0.01 (0.05)	0.03 (0.09)	0.2951	0.07 (0.06)	0.0110	0.03 (0.09)	0.4647
Spatial Vigilance	IOS_{RT}	0.35 (0.14)	0.29 (0.10)	0.1851	0.27 (0.10)	0.1486	0.31 (0.09)	0.3881
	A’	0.97 (0.02)	0.97 (0.03)	0.8539	0.97 (0.03)	0.9161	0.96 (0.04)	0.5062
Controlling Perception of Motion	Duration of Trial	19.89 (9.79)	21.97 (6.75)	0.5565	24.41 (5.52)	0.2501	25.79 (10.50)	0.1273

* Significant after correcting for multiple comparisons $p < 0.0026$

Relationships among attentional tasks:

Correlation relationships among tasks.

While the differences in performance abilities between groups are important to our understanding of individual attentional skills, our main goal of the development of the attention battery was to examine the relationships among attentional tasks. Our expectations were that if attention was a unitary construct, then we should find at least a moderate level of correlation between a majority, if not all of our tasks. However, if we were successful at selecting tasks that represented independent attentional processes, then the relationships between tasks should be sparse and limited to those tasks that have similar demands on attentional processes.

It is important to note that tasks with very low reliability (i.e. greater variability within individuals than between) are unlikely to correlate in a meaningful way with other tasks. Thus, for this stage of our analysis we included only those tasks that attained a Chronbach's alpha coefficient of 0.65 or better. The tasks that failed to reach this criterion were Central Focusing, Peripheral Focusing and Temporal Focusing. Additionally, because the Rapid Object Identification task was included in our attention battery as a general measure of perceptual-cognitive abilities (object processing speed), as opposed to being an attentional task per-se, it was also not included in this stage of the analyses.

To examine the pair-wise relationships between individual tasks we used the robust correlation method as described by Wilcox, (1997). For tasks where larger numbers represent worse performance (e.g. reaction time measures), the sign of the measure was inverted. Thus, larger positive numbers always represent superior performance in all tasks. The results of these comparisons are presented in table 7. To avoid making a Type I error, we corrected for multiple comparisons (9 tasks yielding 36 comparisons) by adjusting our level of significance from $p <$

0.05 to $p < 0.0014$. Of the 36 possible relationships, only three of the tasks were significantly correlated at this level.

Table 6

Correlations between tasks for all observers.

	1	2	3	4	5	6	7	8
1. Rapid Re-engagement	--							
n =								
2. Object Shifting	0.03							
n =	211							
3. Tracking Multiple Objects	-0.07	-0.07						
n =	217	211						
4. Spatial Shifting	0.08	0.06	0.35*					
n =	216	210	216					
5. Object Vigilance	-0.01	0.05	0.06	0.07				
n =	213	208	213	214				
6. Attention to global motion	0.06	0.18	-0.04	0.02	0.15			
n =	212	206	213	211	208			
7. Attentional grouping	0.00	0.11	-0.03	0.07	-0.02	0.11		
n =	83	81	83	83	82	82		
8. Spatial Vigilance	-0.15	-0.05	0.06	0.09	0.37*	-0.06	0.05	
n =	87	86	86	87	87	86	82	
9. Controlling Perception of Motion	0.19	-0.09	0.37*	0.09	0.25	0.09	-0.07	-0.12
n =	60	61	61	61	59	60	56	60

* Significant after correcting for multiple comparisons: $p < 0.0014$

The strongest relationship was between Spatial Vigilance and Object Vigilance ($r = 0.37$, $p < 0.0001$), suggesting that the shared attentional component between the two tasks (i.e. ability to respond to the rare target item with little slowing of reaction time) was an essential skill for both tasks. Additionally, we found a significant positive relationship between performance on the Tracking Multiple Objects and Spatial Shifting tasks, ($r = 0.35$, $p < 0.0001$), suggesting that the observers who were the most successful at tracking multiple objects were also faster at shifting their attention between spatial locations. Performance on Tracking Multiple Objects was also positively correlated with Controlling Perception of Motion ($r = 0.37$, $p < 0.0001$), suggesting that those who were more successful at tracking multiple objects were also better able to maintaining their perception of the direction of motion of an ambiguously moving object. These sparse and limited relationships indicate that we were successful in selecting tasks that represent distinct attentional abilities as opposed to a general attentional ability.

Additionally, because that we found significant differences in performance between men and women, it was important to also examine whether these patterns of relationships between tasks differed significantly between the sexes. For this analysis we calculated the robust correlations (Wilcox, 1997) between each of the tasks for men and women separately then tested for significant differences between the correlations. Using an adjusted p value of 0.0014 to correct for multiple ($n = 36$) comparisons we found no significant differences in the correlational relationships between the two groups. Thus, we determined that pooling of the data for both men and women in our investigation of the relationships between tasks is sufficient.

Relationships with a common visual object recognition task.

The purpose of including the Rapid Object Identification task was to provide an example of how our series of visual-attentional tasks relate to another visual processing task. To examine this question we estimated the robust correlations (Wilcox, 1997) between Rapid Object Identification and each of the nine reliable measures from our series of visual attention tasks. Results of these correlations are detailed in table 8. To correct for multiple comparisons ($n = 9$) we adjusted the level of significance to $p < 0.01$. Our expectations were that this task would be most likely to correlate with tasks that demanded efficient temporal attentional processing (e.g.

rapid re-engagement) or object processing (Object Shifting) abilities. However, our results indicate that Rapid Object Identification was positively correlated with Spatial Shifting ($r = 0.16$, $p = 0.001$) and Spatial Vigilance ($r = 0.29$, $p = 0.002$) and did not significantly correlate with any of the other visual attentional tasks. These results are surprising and may require further investigations that are beyond the scope of the current paper.

Table 7

Correlations between Rapid Object Identification and Attention tasks for all observers.

Attention Task		Rapid Object Identification
1. Rapid Re-engagement		-0.05
	n =	220
2. Object Shifting		0.06
	n =	214
3. Tracking Multiple Objects		0.12
	n =	220
4. Spatial Shifting		0.16*
	n =	219
5. Object Vigilance		-0.01
	n =	216
6. Attention to global motion		0.00
	n =	215
7. Attentional grouping		0.01
	n =	85
8. Spatial Vigilance		0.29*
	n =	89
9. Controlling Perception of Motion		0.14
	n =	62

* Significant after correcting for multiple comparisons: $p < 0.01$

Hierarchical cluster analysis of relationships between tasks.

While correlation analyses give us an idea about the relationships between pairs of tasks, they fail to give us an overall picture of the underlying or possible hierarchical structure of the relationships between our attentional tasks. One approach to examining these relationships is the use of Revelle’s ICLUST algorithm (Revelle, 1979), an alternative to principle components and factor analyses that provides a very straightforward and elegant solution to reveal the relationships among multiple variables. This algorithm uses two estimates of reliability to determine the internal consistency of the composite clusters. The first estimate is Chronbach’s alpha, which we introduced earlier as a general estimate of reliability. However, since alpha takes into consideration both the within and the between task variability, it may over-estimate the general factor saturation and obscure potential sub-factors. Thus the ICLUST algorithm also uses a second estimate of reliability, Revelle’s beta, which is more sensitive to the variability that may exists between tasks (Revelle, 1979). The ICLUST algorithm clusters variables in a hierarchical fashion, where two variables or clusters are be combined if and only if the alpha and beta coefficients for the new cluster are greater than the value that the two variables attain on their own. In other words, the variables are allowed to cluster if the resulting composite cluster has better reliability and internal consistency than if the variables were to remain as individuals. Essentially, the algorithm asks the question “Does joining these two variables make the measure better?” The ICLUST algorithm first finds the pairs of tasks that most tightly cluster together, and then continues to add variables together until some set criterion is reached. Generally, the clustering is terminated when adding additional clusters or variables causes the reliability of the measure to drop precipitously, however the parameters of the clustering algorithm can be modified to fit specific requirements as explained below.

Using the ICLUST algorithm, we analyzed our results for the combined sample of both men and women, allowing the clusters to form until no single variables (i.e. tasks) remained. In other words, the clusters were allowed to form until all tasks were joined into at least one cluster. The results of this clustering solution are depicted in figure 13. From this figure it is clear that there are at most three small clusters consisting of no more than three tasks each. The first cluster to identified by the process was between Tracking Multiple Objects and Controlling Perception of Motion (alpha = 0.54, beta = 0.54). A second, but equally strong cluster formed between Object Vigilance and Spatial vigilance (alpha = 0.54, beta = 0.54), and a third, somewhat weaker cluster formed between Object Shifting and Global Attention to Motion (alpha 0.31, beta 0.31). These clusters reflect relationships that are similar to those found in our pair-wise correlations, with the exception of the Object Shifting and Global Attention to motion that in the pair-wise analysis was conservatively non-significant, although it reached the conventional 0.05 level of significance. In this case also the correlation of the individual task with the cluster (r = 0.23) and reliability are also relatively low.

For this particular analysis we allowed the ICLUST algorithm to continue to combine clusters until no individual items remained. Using this procedure a second level of clusters were developed, providing a representation of the hierarchical relationships between tasks. At this level, a fourth cluster forms by joining Spatial Shifting with the first cluster to form a larger and relatively reliable cluster (alpha = 0.53, beta = 0.43). This relationship is also similar to what we found in our pair-wise analysis indicating a strong relationship between Spatial Shifting and Tracking Multiple Objects. Two additional second order clusters were also formed, joining Rapid Re-engagement with the second cluster and Attentional Grouping with the third cluster. However, the Rapid Re-engagement joins with a negative relationship, suggesting that it is the antithesis of vigilance as opposed to having a shared attentional ability. Additionally, in both cases, adding the third node to the cluster causes a considerable drop in both the alpha and beta estimates for the composite clusters suggesting that they do not share a general or common attentional process (or common factor).

The ICLUST algorithm also provides a “cluster fit” estimate of how well the cluster reproduces the correlation matrix. The cluster fit for this model is 0.17, which is exceptionally low. However if the ICLUST algorithm is processed using only the first level clusters (clusters 1, 2 and 3), and allowing Spatial Shifting, Attentional Grouping and Rapid Re-Engagement to remain as individual items, then the cluster fit increases to 0.49.

Combined, these cluster analyses results suggest that our attention battery tasks represent at least four different attentional abilities: 1) a spatial temporal component consisting of Tracking Multiple Object, Controlling Perception of Motion and Spatial Shifting, 2) a vigilance component, represented by the Object and Spatial Vigilance tasks, 3) a global attentional component consisting of Object Grouping, Attention to Global Motion, and possibly Attentional Grouping, and 4) a temporal component as represented by the Rapid Re-Engagement aspect of the attentional blink task.

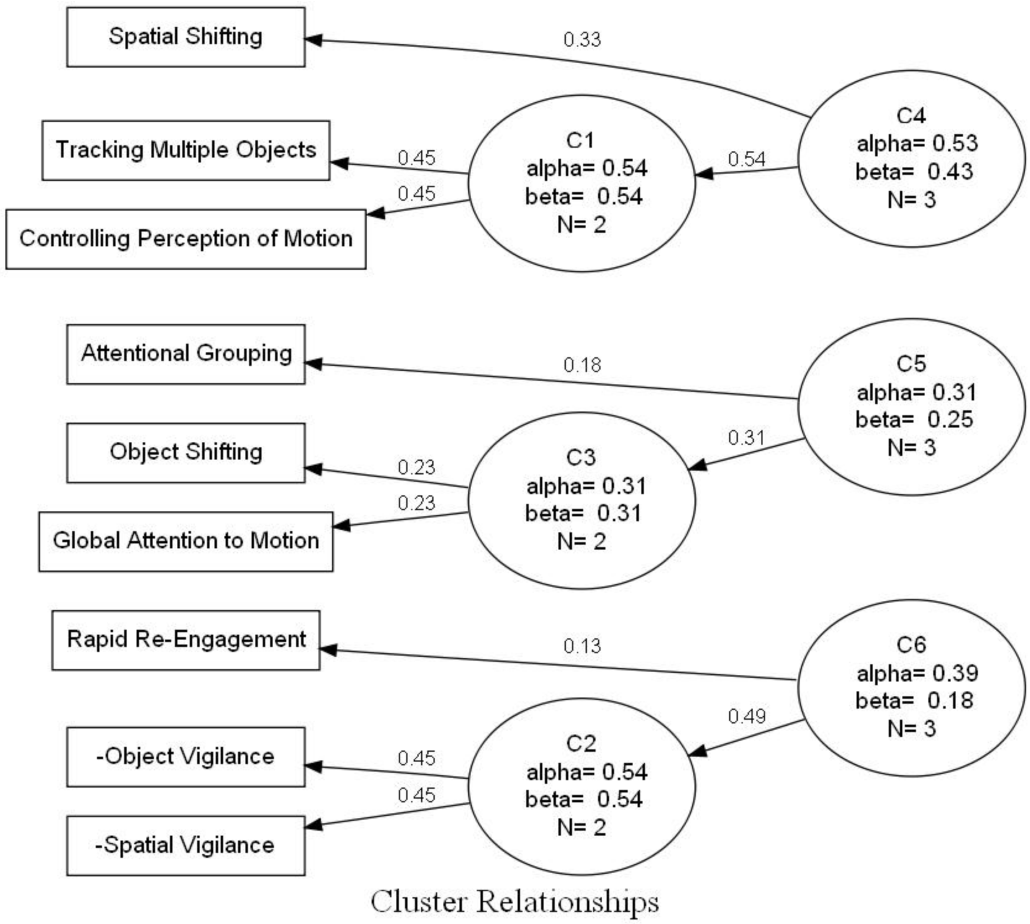


Figure 13. ICLUST clustering solution.
Alpha and beta values within each node represent the reliability of the cluster, where as the edges (numbers above the lines) represent the task to cluster correlation.

Discussion

The purpose of the present study was three fold. Our first goal was to select tasks that involve a variety of visual attentional processes and examine their reliability. The second goal was to examine the differences in performance abilities between select groups of observers (i.e. men versus women and observers with high ADHD traits and non-selected observers). The third and overarching goal of the development of this attention battery was to examine the interrelationships among voluntary visual attentional tasks. Our expectation is that that the results from this study may provide us with insights about the relationships among visual attentional tasks and an alternative approach towards studying voluntary visual attentional processes.

Task selection and reliability.

The tasks that we selected to study were based upon three premises. First we wanted to select tasks that represented a variety of distinct voluntary visual attentional processes. Thus, we based the selection of our tasks on the research literature that suggested that certain types of tasks elicited brain activity in specific brain regions (suggesting a relationship between the attentional ability and the activated brain region). Additionally, we selected tasks that have been used extensively in attention research (e.g. the attentional blink paradigm and Ericksen flanker tasks), and others that we created in our own lab (e.g. spatial shifting and object shifting) to test specific visual attentional abilities. The results of our analyses of these data were surprising in that we found that the two tasks based upon the Ericksen flanker paradigm were un-reliable measures. Their within subject variability was greater than the between subject variability. Because of this lack of reliability, it is unlikely that this task will correlate, in any meaningful way with any other task. Additionally, we found that the T1 component of the attentional blink paradigm was unreliable, although the T2 component was. These results suggest that the T1 component of this task is not a suitable measure to use in correlational studies. The remainder of our tests did prove to be sufficiently reliable to be useful in examining the correlations between tasks.

Analysis of performance scores between groups.

Differences between men and women:

Our analysis of the differences in attentional abilities between men and women revealed some interesting results. On the majority of the tasks, performance was similar for both men and women. The two measures where performance scores differed were Tracking Multiple Objects and Spatial Shifting, with men out performing women on both of these tasks. However, recent research has linked performance on visual spatial tasks to exposure and experience playing video games (Feng, Spence, & Pratt, 2007; Green & Bavelier, 2003, 2006). Ogletree and colleagues have found that among college students, men are significantly more likely to engage in video game playing than women (Ogletree & Drake, 2007). Thus the difference in performance scores may be more due to experience playing video games than to a specific gender difference. Although we did not control for video game playing experience, we have begun collecting this data and it will be included in future studies of our attention battery.

The following tasks did not reach significance at the Bonferroni corrected level for multiple comparisons, but they may be of interest to researchers investigating the differences between men and women during specific attention tasks. Of particular note, women appeared to out perform men on the peripheral focusing task with less slowing in response to the interference trials as compared to the neutral trials. This suggests that the women were better able to inhibit the interference of the item presented at the center of their visual field while attending to peripheral locations. We are unaware of any other studies that have found similar results. Further research on this difference in attentional abilities may reveal important visual processing differences between men and women. Controlling Perception of Motion was an additional task that did not reach corrected significance, but may be of note. On this task, men appeared to out perform women in how long they were able to maintain the direction of an ambiguous rotation. This task also involves visual spatial tasks similar to those of tracking and may also have been influenced by gender differences in videogame playing as opposed to an actual gender difference, so this result should be interpreted with caution.

Differences in high ADHD trait groups:

Based upon our review of related research, we anticipated that individuals with a high number of ADHD traits would perform more poorly on tasks that required visual spatial and visuotemporal attention (Armstrong & Munoz, 2003; Epstein et al., 1997; Hollingsworth et al., 2001). One difficulty in the interpretation of these previous studies is that their results were collapsed across gender, diagnosis subtypes, or not differentiated among subtypes or gender at all. Based upon the view that there are distinct subtypes of ADHD and that they manifest differently between the sexes (Barkley, 1998), we evaluated performance scores separately for each sex and subtype. In doing so, the largest differences in performance abilities that we observed were in the error rates for the Center focusing task for both sexes. As noted in the introduction, the ability to attend to local elements and inhibit interfering stimuli has been associated with activation of the DLPFC and dACC (Weissman et al., 2005). These regions of the brain have also been found to have deficient activation and structural anomalies in other studies of ADHD and attention (Bush et al., 1999; Seidman, Valera, & Bush, 2004). Thus, observers with high ADHD traits may have had an especially difficult time focusing their visual attention on only the center item and inhibiting the close peripheral distractors, leading to a greater number of errors on this task.

One alternative explanation for this result is that a number of studies have found that individuals with ADHD generally have considerable difficulty in response inhibition tasks (Barkley, 1998; Nigg, 1999; Pliszka, Liotti, & Woldorff, 2000). However, if the high number of errors in this task was due purely to a general difficulty in response selection then we would anticipate that our high ADHD trait observers would have had significantly greater error rates for both the Center focusing and Peripheral focusing versions of this task, which was not the case. Thus it is possible that observers with a high number of ADHD traits have a specific attentional deficit for attending to stimuli presented at the center of their visual field while inhibiting close, proximal items.

We also found that women with a high number of ADHDc traits demonstrated a greater amount of slowing in response to the interference trials on the peripheral focusing task. Women with ADHDi and ADHDh traits also had a greater IOI_{RT} than our non-selected sample, but these results did not reach significance when corrected for multiple comparisons. Men however did not show this deficit, suggesting that it may be specific to women with high ADHD traits. It is also interesting to note that peripheral focusing was the one task for which women in the normative sample appeared to out-perform men.

Previous research also indicates that individuals with ADHD generally perform worse on tasks that use the Attentional Blink paradigm, in that they have a protracted refractory period

(Armstrong & Munoz, 2003; Hollingsworth et al., 2001). In the present study, we did not find significant differences for either men or women of any subtype. One explanation for this difference is that in the previous studies, the observers had received a formal diagnosis of ADHD and were tested without the benefit of ADHD medications. Our sample however consisted of a sub-clinical sample of participants, based upon a self-report screening form. Formal diagnosis was not confirmed and we did not control for use of medication. We have since started collecting data on formal diagnoses and on whether our observers are currently taking ADHD medications so that in future studies we can control for these variables, and compare differences among them.

Relationships among voluntary visual attentional tasks

The third and overarching goal of our study was to investigate the relationships among voluntary visual attentional tasks. Our expectation was that if all aspects of voluntary visual attention are regulated by a single, separate attentional system, then performance on all of our tasks should be highly correlated. Alternatively, if voluntary visual attention consists of multiple interactions among a number of distinct attentional processes, then only those tasks with largely shared attentional processes should be highly correlated.

Pair-wise correlations between tasks

For our examination of the pair-wise correlations between tasks, we used only those tasks that demonstrated sufficient reliability to provide meaningful correlations and used Wilcox's method for robust correlations (Wilcox, 1997). Using these methods we found that that the relationships among tasks were sparse, suggesting that there was no single attentional ability that was shared among all of our visual attentional tasks. Among the individual tasks, the strongest relationship found was between performance on the Spatial and Object Vigilance tasks. Although these tasks differ in the object versus spatial domain, they are both primarily vigilance tasks. This strong correlational relationship suggests that the vigilance demands of the both tasks outweighed any influence that may have resulted from differences in abilities to attend to spatial locations as opposed to object properties.

We also found that successful performance on the Tracking Multiple Objects task was related to success on both the Spatial Shifting and Controlling Perception of Motion tasks. Both Tracking Multiple Objects and Spatial Shifting tasks require attending to spatial/temporal domains and the correlation between these two tasks may be driven by this shared attentional ability. Tracking Multiple Objects and Controlling Perception of Motion on the other hand both share the properties of attending to multiple objects and attentive tracking of motion.

There were three additional relationships between tasks that did not reach significance when corrected for multiple comparisons, but that were conventionally significant, that may be of note. The ability to Attend to Global Motion appeared to be related to both Object Shifting and Object Vigilance. Both Attending to Global Motion and Object Shifting tasks involve the ability to attend to the global/local properties of an object, whereas Object Vigilance and Attending to Global Motion may share the ability to maintain attention throughout a long task (vigilance) towards a particular object feature (e.g. object identity or direction of motion). The third relationship of note was between Object Vigilance and Controlling the Direction of Perception. These tasks both involve the ability to maintain attention, however if this were the driving relationship between these two tasks, we would also expect a correlation between Controlling Direction of Perception with Spatial Vigilance and possibly Attention to Global Motion.

The lack of correlations between tasks may also provide us with important information about the relationships among attentional abilities. For example, both Rapid Re-engagement and Attentional Grouping did not form strong correlational relationships with any of our other tasks. Therefore, these two tasks may represent attentional abilities that are distinct from the abilities required to perform well on our other voluntary visual attentional tasks.

Hierarchical cluster analysis:

Although the pair-wise correlations provide us with information regarding the individual relationships between tasks they are limited and reveal only pairs of related tasks. Hierarchical cluster analysis provides an alternative approach that allows us to examine whether or not there are several tasks that are related to one another, or clusters of tasks that appear to involve the same attentional abilities. Using Revelles ICLUST algorithm (Revelle, 1979) we examined only those tasks that demonstrated sufficient reliability to produce significant correlations. Using this method we found that the tasks that make up our attention battery appear to represent at least three (possibly four) distinct clusters of visual attentional abilities.

Spatial/Temporal: The first and most tightly related cluster that we found was one that consisted of the tasks Tracking Multiple Objects, Controlling Perception of Motion and Spatial Shifting. These tasks all share the attentional ability to quickly shift attention among spatial locations. Based upon our earlier review of the literature, previous researchers have identified specific brain regions related to these tasks, namely the Superior Parietal Lobule (SPL), Superior Parietal Gyrus (SPG), and Temporal Parietal Junction (TPJ), which all have been associated with spatial shifting of attention (Downar et al., 2000; Marois, Leung et al., 2000; Posner et al., 1980; Vandenberghe et al., 2001; Yantis & Serences, 2003). It may be that the relationships among these tasks are based upon shared attentional processes mediated by these regions. Additionally, tracking multiple objects and controlling perception of motion have both been shown to activate the MT/MST region in addition to the SPL, SPG, and TPJ (O'Craven et al., 1997; Tanaka & Saito, 1989; Vaina, 1998), while Spatial Shifting has been related to activation of the Inferior Parietal Lobule (IPL) and Superior Temporal Gyrus (STG) (Shapiro et al., 2002). The cluster analysis reflects these shared and diverging brain regions in that Tracking Multiple Objects and Controlling Perception of Motion formed the initial first clustering solution and Spatial Shifting was added at as a second order cluster with lower item to cluster correlational values.

Vigilance and Target Detection: A second and separate cluster was formed around the tasks of object and spatial vigilance. As discussed above, these two tasks both require the ability to remain vigilant for rare target items, but differ in whether the attention is focused on spatial location or object properties. Previous studies indicate that the maintenance of attention has been related to activation of the intraparietal sulcus (IPS) (Corbetta et al., 2002), and that shifting attention to rare (novel or unexpected) stimuli involves activation of the temporal parietal junction (TPJ) (Downar et al., 2000; Marois, Leung et al., 2000; Posner & Petersen, 1990). Thus the relationship between these two tasks may originate from these shared attentional processes and their related brain regions. Our cluster analysis also suggests that if we allow for a very low clustering criterion (i.e. allow new items to join a cluster, even if it lowers the beta values), Rapid Re-engagement also joins in this cluster, but as an opponent process. Although deficits in attentional blink have been associated with the inferior parietal lobule and superior temporal gyrus regions (Shapiro et al., 2002), other studies have found that brain activity in the intraparietal sulcus and anterior cingulate are related to performance on attentional blink tasks (Marois, Chun, & Gore, 2000). Therefore, the relationship between performance on the vigilance tasks and the attentional blink task might be due to this involvement of the IPS. However, because the relationship is an opponent one, it may represent a distinct process.

Global/Local attention: A third cluster was formed around the tasks of Object Shifting and Global Attention to Motion. Both of these tasks require the ability to identify a coherent object imbedded in an array of distractors. Additionally, with a low clustering criterion, Attentional Grouping also joins this cluster. This task too involves both the ability to recognize a coherent shape based upon a shared property (i.e. rectangles made up of small same colored circles). Previous studies indicate that activation of the lateral occipital complex (LOC) is related to the ability to recognize a coherent shape or property (e.g. coherent motion, color or contour) (Altmann et al., 2003; Murray et al., 2004). Therefore, the relationships among all three of these tasks may involve activation of the LOC.

Conclusions

The present study was intended to address three main goals. 1) To identify tasks that are reliable measures of a variety of distinct voluntary attentional processes, 2) to examine the differences between groups on their visual attentional abilities and 3) to examine the relationships among performance scores on voluntary visual attentional tasks. To our surprise, two of the most common tasks used to measure voluntary visual attention (the Erickson Flanker Task and the T1 component of the Attentional Blink paradigm) were found to have very low within task reliability, making them unsuitable for use in studies of relationships between attentional abilities. When examining the differences between groups, we found that men out performed women on tasks that required strong spatial-temporal abilities. However, these findings should be interpreted with caution in light of previous studies that indicate that men have greater experience with videogame play and that this experience can enhance visual-spatial abilities (Feng et al., 2007; Green & Bavelier, 2003, 2006; Ogletree & Drake, 2007).

Our main objective was the examination of the relationships among reliable voluntary visual attentional tasks. From our results it appears that voluntary visual attentional abilities fall into distinct groups: 1) Spatial/Temporal abilities, 2) Vigilance/Target Detection, 3) Attention to Global/Local details and possibly 4) Rapid Re-engagement of attention. Our behavioral results appear to map on well to previous neuroimaging and neurophysiological studies that indicate that there are distinct brain regions that mediate each of these types of visual attentional processes. These relationships should also be interpreted with caution as there is a considerable amount of overlap between the attentional demands of our tasks and the regions of brain activity that we have identified as being related to these tasks. For example, the SPL is not the only brain region involved in shifting attention between spatial locations, and the Attentional Blink paradigm involves the activation of several brain regions, not just the IPS, IPL and STG (Desimone & Duncan, 1995; Downar et al., 2000; Marois, Chun et al., 2000; Marois, Leung et al., 2000; Posner & Petersen, 1990; Shapiro et al., 2002; Vandenberghe et al., 2001; Yantis & Serences, 2003).

Nonetheless, we hope that these findings will inspire other researchers to take an alternative approach to the investigation of voluntary visual attentional processes. We hope that by studying the relationships among a variety of tasks that involve different attentional abilities we will advance both the empirical and theoretical knowledge underlying structures and mechanisms of voluntary visual attention.

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"Appendix A": ADHD Screening form (adapted from Barkley & Murphy 2006)

A) Instructions:

Please circle the number next to each item that ***best describes your behavior during the past six months.***

	Never or Rarely	Sometimes	Often	Very Often
1 Fail to give close attention to details or make careless mistakes in my work	0	1	2	3
2 Fidget with hand or feet or squirm in seat	0	1	2	3
3 Have difficulty sustaining my attention in tasks or fun activities	0	1	2	3
4 Leave my seat in situations in which seating is expected	0	1	2	3
5 Don't listen when spoken to directly	0	1	2	3
6 Feel restless	0	1	2	3
7 Don't follow through on instructions and fail to finish work	0	1	2	3
8 Have difficulty engaging in leisure activities or doing fun things quietly	0	1	2	3
9 Have difficulty organizing tasks and activities	0	1	2	3
10 Feel "on the go" or "driven by a motor"	0	1	2	3
11 Avoid, dislike, or am reluctant to engage in work that requires mental effort	0	1	2	3
12 Talk excessively	0	1	2	3
13 Lose things necessary for tasks and activities	0	1	2	3
14 Blurt out answers before questions have been completed	0	1	2	3
15 Am easily distracted	0	1	2	3
16 Have difficulty waiting turn	0	1	2	3
17 Am forgetful in daily activities	0	1	2	3
18 Interrupt or intrude on others	0	1	2	3

If you answered 2 or 3 to any of the above, how old were you when these problems first began to occur? Age:__________

B) Instructions: Please circle the number next to each item that best describes your behavior *when* ***you were 5-12 years old.***

	Never or Rarely	Sometimes	Often	Very Often
1 Failed to give close attention to details or made careless mistakes in my work	0	1	2	3
2 Fidgeted with hand or feet or squirmed in seat	0	1	2	3
3 Had difficulty sustaining my attention in tasks or fun activities	0	1	2	3
4 Leave my seat in classroom or in other situations in which seating is expected	0	1	2	3
5 Didn't listen when spoken to directly	0	1	2	3
6 Felt restless	0	1	2	3
7 Didn't follow through on instructions and failed to finish work	0	1	2	3
8 Had difficulty engaging in leisure activities or doing fun things quietly	0	1	2	3
9 Had difficulty organizing tasks and activities	0	1	2	3
10 Felt "on the go" or "driven by a motor"	0	1	2	3
11 Avoided, disliked, or was reluctant to engage in work that required mental effort	0	1	2	3
12 Talked excessively	0	1	2	3
13 Lost things necessary for tasks and activities	0	1	2	3
14 Blurted out answers before questions were completed	0	1	2	3
15 Was easily distracted	0	1	2	3
16 Had difficulty waiting turn	0	1	2	3
17 Was forgetful in daily activities	0	1	2	3
18 Interrupted or intruded on others	0	1	2	3

Have you ever been diagnosed with Attention Deficit / Hyperactivity Disorder? (ADD or ADHD)

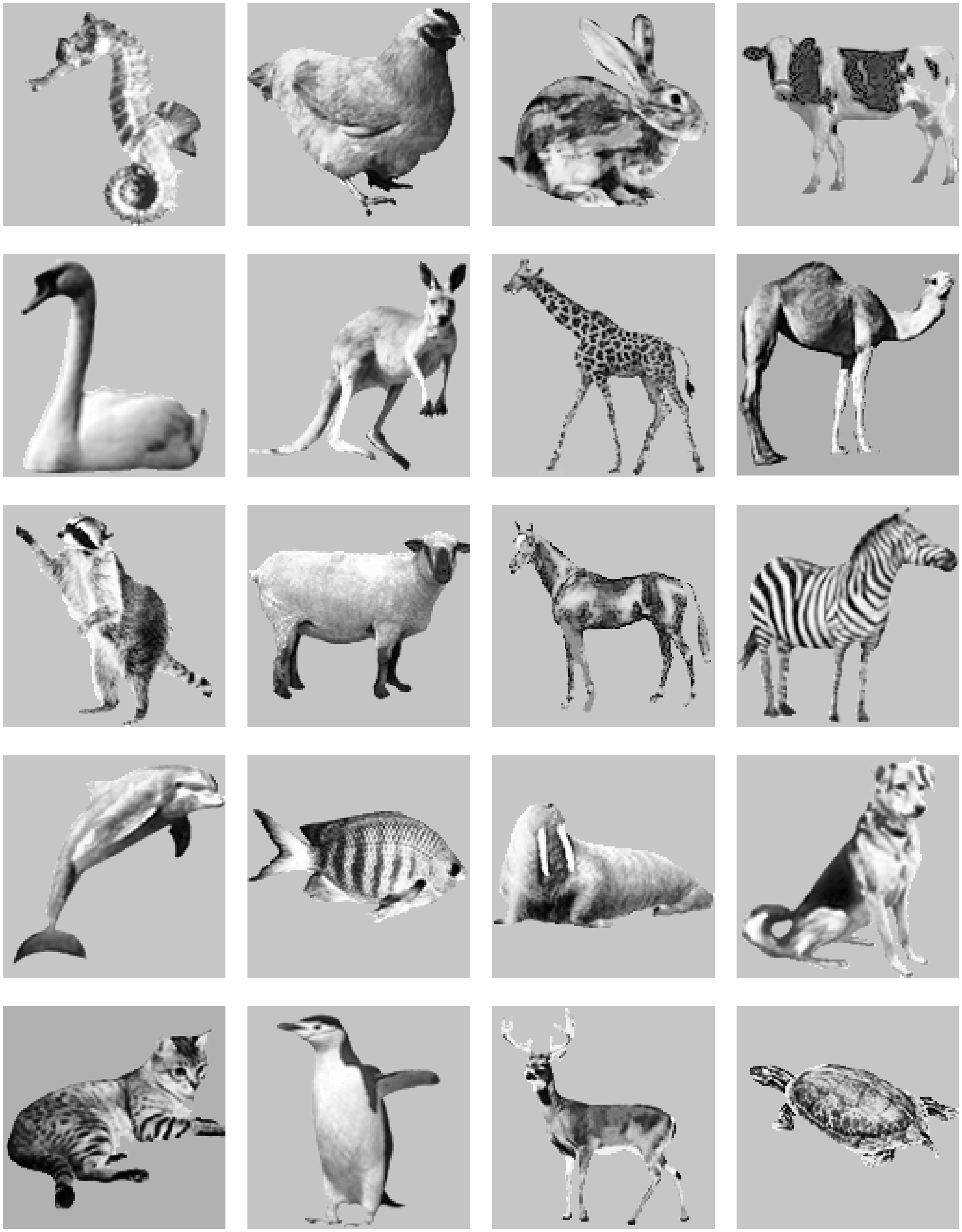
☐ Yes ☐ No ☐ Not Sure

If so, who provided the diagnosis (please check all that apply)?

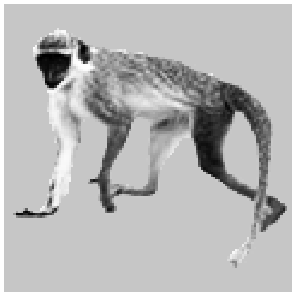
☐ Physician ☐ Mental Health Professional ☐ Self ☐ Other (specify)______________________________

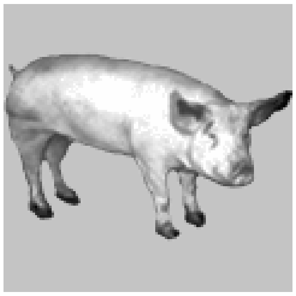
Are you currently taking any medications to treat ADD or ADHD? ☐ Yes ☐ No ☐ Not Sure

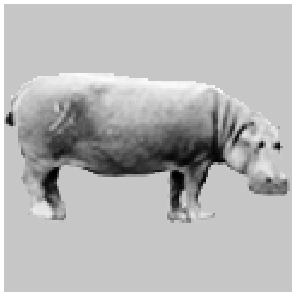
“Appendix B”: Images used in Rapid Identification Task

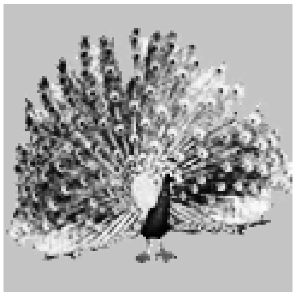


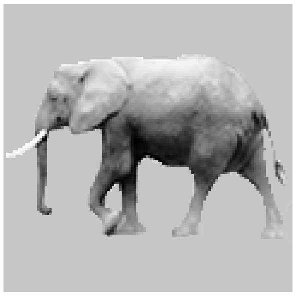
“Appendix B”: continued

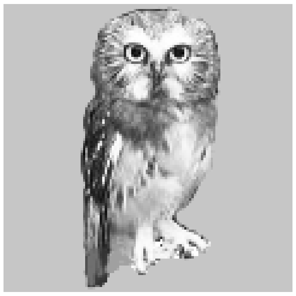




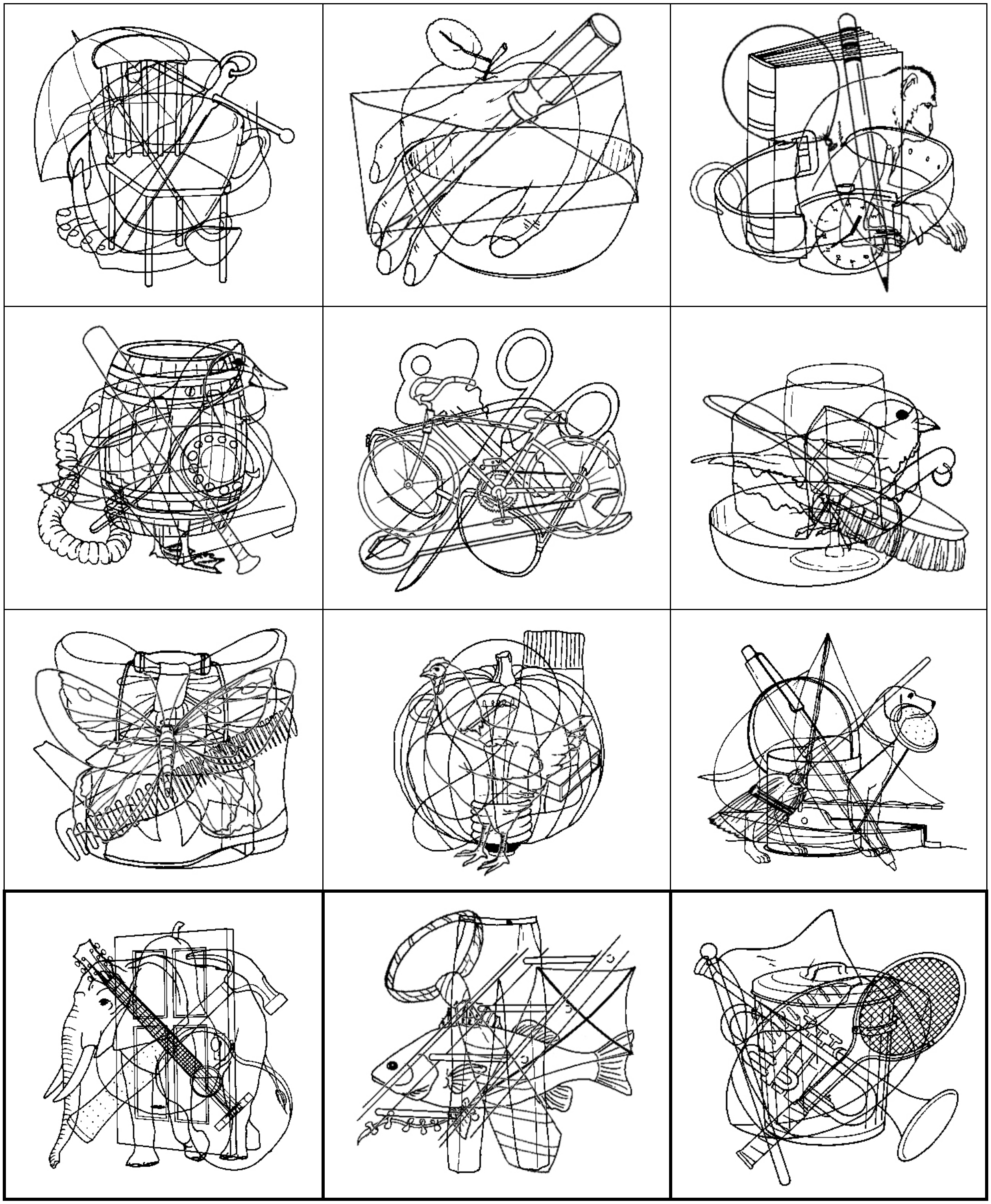




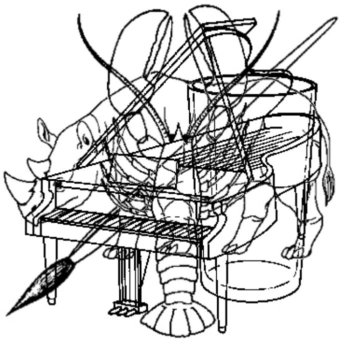
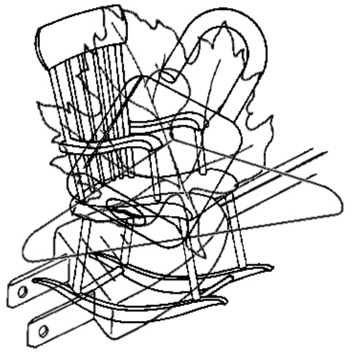
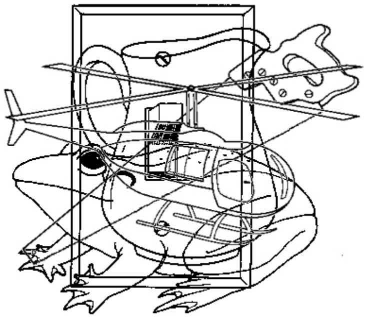
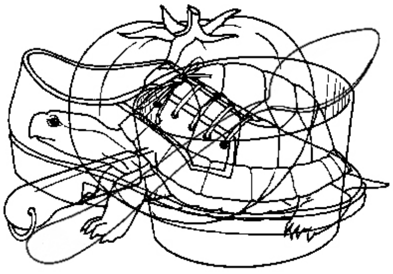




"Appendix C" Images used in Object Shifting Task



“Appendix C: *continued*

Vita

KatieAnn R. Skogsberg

Department of Psychology/ Northwestern University
2029 Sheridan Road, Evanston, IL, 60208-2710
Telephone: (208) 631-6495
Email: k-skosberg@northwestern.edu

EDUCATION:

2008	Ph.D.	Northwestern University: Psychology: Brain, Behavior and Cognition Dissertation Title: Multiple Modes of Voluntary Visual Attention: Analysis of Within Test Reliability, Between Group Differences, and the Interrelationships Among Tests of Voluntary Visual Attention. Committee: Satoru Suzuki, Marcia Grabowecky & Steve Franconeri
2005	M.S.	Northwestern University: Psychology: Brain, Behavior and Cognition Thesis Title: P300 Latency does not Parallel Stroop Effect in Paradigms using Oddball and Rare Target Stimuli. Committee: J. Peter Rosenfeld, Satoru Suzuki & Ken Paller
2003	B.S.	Boise State University: Psychology (Biology Minor)
1994	B.A.	Boise State University: Theatre Arts

RESEARCH GRANTS and FELLOWSHIPS:

Fall 2007	Graduate Research Grant $3,000 Northwestern University Graduate School
Fall 2007	Graduate Assistantship for Instructors in the School of Continuing Studies Northwestern University Weinberg College of Arts & Sciences, & Northwestern University School of Continuing Studies
2004- 2007	Training Grant Fellowship: Multidisciplinary Program in Education Sciences Institute of Education Sciences & Northwestern University School of Education and Social Policy

PUBLICATIONS:

Rosenfeld, J.P. & Skogsberg, K (2005). P300 based Stroop study with low probability and target Stroop oddballs; The evidence still favors response selection hypothesis. *International Journal of Psychophysiology*.

Skogsberg, K., & Clump, M. (2003). Do psychology and biology majors differ in their study processes and learning styles? *College Student Journal, 37*(1), 27-33.

Clump, M., & Skogsberg, K. (2003). Are there differences in the learning styles of college students attending similar universities in different geographic locations? *College Student Journal, 39*(4), 501-508.

PRESENTATIONS & PUBLISHED ABSTRACTS:

Skogsberg, K, Iordanescu, L., Grabowecky, M., Suzuki, S. (June, 2007) *Attention deficits in women with high-ADHD-traits are not limited to vigilance and inhibition*. Poster presented at the Institute of Education Sciences Annual Meeting, Washington, D.C.

Skogsberg, K, Iordanescu, L., Grabowecky, M., Suzuki, S. (May, 2007). *Male superiority in aspects of dynamic visual-spatial attention.* Poster presented at the Cognitive Neuroscience Society Annual Meeting, New York, NY.

Skogsberg, K., Kim, Y., Lui, M., Iordanescu, L., Grabowecky, M., Suzuki, S. (2006). *Quantitative EEG activity as a predictor of performance on visual attention tasks.* [Abstract] Psychophysiology, 43,(supplement 1), s92.

Skogsberg, K. (May 2006). *Investigation of brain based intervention to improve performance on multiple attention based tasks.* Poster presented at the Institute for Education Sciences Annual Meeting, Washington, D.C.

Grabowecky, M., Iordanescu, L., Skogsberg, K., Novis, S., Rock, M., & Suzuki, S. (2006). *An investigation of relationships among visual-attention processes* [Abstract]. Journal of Vision, 6(6), 949a, poster presented at the 6th annual meeting of the Vision Sciences Society, Sarasota, FL.

Rosenfeld, J.P., Lui, M., Skogsberg, K., Scher, S. (2005). *A novel P300 based concealed information detector. Combined probe and target trials*. [Abstract] Psychophysiology, 42(supplement 1), s107. *Poster presented at the Society for Psychophysiological Research Annual Meeting, Lisbon, Portugal.*

Rosenfeld, J.P. & Skogsberg. K. (2004). *P300 Latency does not parallel Stroop effect in paradigms using oddball and rare target Stroop stimuli.* [Abstract] Psychophysiology, 41(supplement 1), s86. Poster presented at the Society for Psychophysiological Research Annual Meeting, Santa Fe, NM.

Skogsberg, K. (2003). *Treatment Options for ADD and ADHD: Is EEG Biofeedback recognized as an Alternative to Medication?* [Abstract] Applied Psychophysiology and Biofeedback, 28(4), 313-314. Poster presented at the Association for Applied Psychophysiology and Biofeedback Practitioners Annual Meeting, Jacksonville, FL.

Skogsberg, K., & Clump, M. (2003, May). *Do Psychology and Biology Majors Differ in their Study Processes and Learning Styles?* Poster presented at the Council of Teachers of Undergraduate Psychology portion of the annual meeting of the Midwestern Psychological Association, Chicago, IL.

Clump, M., & Skogsberg, K. (2003, May). *Are there differences in the learning styles of college students attending similar universities in different geographic locations?* Poster presented to the Council of Teachers of Undergraduate Psychology portion of the annual meeting of the Midwestern Psychological Association, Chicago, IL.

INVITED TALKS:

Jan. 2008	Centre College	*Invited Talk for Mykol Hamilton's course in Applied Psychology, for Students and Faculty.*
Dec 2007	Northwestern University	*Multidisciplinary Program in Education Sciences: Fellows and Faculty Meeting*
April 2007	Family Institute: Northwestern University	*Training seminar on Collecting Physiological Data.*
April 2007	Eastern Kentucky University	*Psychology Department Colloquium*
April 2007	Northwestern University	*Cognitive Psychology Department Brown Bag*
Nov. 2006	Northwestern University	*Multidisciplinary Program in Education Sciences: Fellows and Faculty Meeting*
April 2006	Northwestern University	*Panel Discussion for "Life as a Graduate Student" Series*
Sept. 2005	Northwestern University	*Multidisciplinary Program in Education Sciences: Fellows and Faculty Meeting*

PROFESSIONAL MEMBERSHIPS:

2004-2007	Society for Psychophysiological Research
2006-2007	Cognitive Neuroscience Society
2003	Psi Chi Honor Society

TEACHING EXPERIENCE:

Winter 2008	Introduction to Psychology (Instructor) Northwestern University School of Continuing Studies
Fall 2007	Cognitive Psychology (Instructor) Northwestern University School of Continuing Studies
Summer 2007	Sports Psychology (Co-Instructor) Northwestern University School of Continuing Studies
Fall 2005	Neurobiology and Behavior: Guest Lecturer Northwestern University

TEACHING RELATED COURSEWORK & TRAINING:

Fall 2007 to Present	Graduate Student Teaching Certificate Program: Participant Northwestern University Searle Center for Teaching Excellence
Summer 2007	Teaching with Technology Northwestern University Searle Center for Teaching Excellence
Summer 2007	Preparing to Teach a Psychology Course University of New Hampshire (On-line)
Winter 2004 to Present	Multidisciplinary Program in Education Sciences (MPES): Fellow Institute of Education Sciences Training Grant & Northwestern University School of Education and Social Policy

TEACHING ASSISTANTSHIPS:

Spring 2005	Neuroscience Lab: Primary Lab Instructor (Northwestern University)
Spring 2004	Neuroscience Lab: Primary Lab Instructor (Northwestern University)
Fall 2004	Brain Damage and the Mind (Northwestern University)
Winter 2004	Introduction to Psychology (Northwestern University)
Spring 2000	Introduction to Psychology (Boise State University)

RELATED COURSEWORK:

Course:	Instructor:
Northwestern University: Brain, Behavior and Cognition	
Neurobiology of Behavior I, II	J. Peter Rosenfeld
Neuroscience Instrumentation	James Baker
Neurobiology of Learning and Memory	Katherine Wooley
Functional Neuroanatomy	Patrick Wong
Cognitive Neuroscience	Ken Paller
Readings in Attention and Perception (audit)	Steve Franconeri
Fundamentals of Statistics	Satoru Suzuki
Linear Models & Regression	Michael Bailey
Statistics in Experimental Design	Steve Smith
Psychometric Theory	William Revelle
Northwestern University: Multidiciplinary Program in Education Sciences	
Cognitive Development	David Uttal
Adolescent Development	Bart Hirsch
Culture, Language and Cognition	Doug Medin
Social Opportunities and Education Policy	Jim Rosenbaum
Field Methods in Education and Social Policy	James Spillane
Analyzing Education Policy	James Spillane
Regression Analysis for Human Development Research	Greg Duncan
Hierarchical Linear Models	Spyros Konstantopoulos

Boise State University: Molecular Neuroscience, Cell Biology, Organic Chemistry, Anatomy and Physiology, Physiological Psychology, Sensation and Perception, Cognitive Psychology, Psychology of Health, Research Methods, Psychological Measurement, Introduction to Neurofeedback, Abnormal Psychology, Advanced Statistics.
Other – College Reading & Learning Association Certified Tutor.