

## REDUCING ATTENTIONAL BLINK: COLOR VS. SOUND

By Sonia G. Singh

Prior research on attentional blink (AB) has demonstrated that although this attention diminishes with exposure to different stimuli, attention training paradigms to reduce AB are still being explored. Questions remain as to whether training with the odd-ball paradigm on an AB task, using features like color and audio will benefit performance and optimize mental resource allocation. The current study compared the effects of color-visual training, audio-visual training and no training (controls) on performance, using Rapid Serial Visual Presentation, in an AB task. Behavioral measurements of interest were: detection accuracy of target 1(T1) and target 2(T2) as a function of the different time lags (relative to T1); and neurological measurements of interest were the amplitude and latency of P300 in response to T1-as measured by event related potentials (ERPs).

Behavioral and EEG data were collected from 60 undergraduate psychology participants who were tested individually and for the training were randomly placed in any of the three groups mentioned above.

Behavioral results did not reveal evidence of lag 1 sparing and were characterized by a partial AB effect overall – although the audio-visual group was most reflective of the typical AB curve across experimental phases. The data suggests that training effects were observed across groups, as performance significantly increased from pre-test to post-test and performance was also significantly higher for single compared to dual target trials. Recorded EEG data is in the process of being analyzed, hence EEG data are forthcoming.

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## **Reducing Attentional Blink: Color vs. Sound**

While scanning the arrival and departure displays at an airport for a flight number we must focus on retrieving only a fraction of available information, but at the same time discount any irrelevant audio announcement or attend to an important phone call. We use the same kind of selective attentional capacity during what is known as the “cocktail party effect” (Strayer, Drews, & Johnston, 2003), when we listen intently only to what one person is saying over all the other conversations in a room. Thus attention can be defined as a cognitive process which involves selectively concentrating on specific characteristics of the environment while simultaneously ignoring other things (Anderson, 2004).

Although the brain is adept at juggling a number of tasks at any given point in time, we do not always react with perfect accuracy while performing multiple demanding or complex tasks. Recently, there has been a growing interest in ‘training’ the human brain to deal with taxing ‘cognitive load’. Currently, successful training to adequately allocate attentional resources to a particular event is the subject of much controversy (Leber, Kawahara & Gabari, 2009; Slagter et al., 2007; Salminen, Strobach & Schebert, 2012). In addition, while it is clear that sensory information can be integrated and processed very rapidly, it remains unclear whether information received from one sense is processed faster or more accurately than that received from another sense (eg. auditory vs. visual perception). This is in fact the goal of the current study – to investigate whether

individuals exposed to colored characters within a character sequence will be more likely to attend to ‘certain’ characters, or whether an auditory stimulus paired with the same ‘certain’ characters (uncolored) will be better attended to. Past research has focused simply on visual and auditory attention, both separately and in tasks involving focusing on one modality over the other, rather than more specific training. Although current literature has turned towards the impact of cognitive brain training generically, more research that focuses on attention and working memory (WM) such as the current study is the need of the hour. New research hints at the possibility of attention and working memory being the crux of executive functioning. For example, a recent meta-analysis of results from meditation and mindfulness studies highlight the need to further examine attention and working memory training (Chiesa, Calati & Serretti, 2011). Studies have reported ameliorations in a variety of cognitive functions (Rueda et al., 2005; Schellenberg, 2004; Wandell et al., 2008) such as music and arts training which target attention and working memory improvement. However, there is no current consensus that such training programs are successful in producing transfer of skills from one cognitive domain to another. This is most likely due to the heterogeneity of cognitive functions that have been measured and tasks that have been applied in most commercially accepted or experimental brain training programs.

## **Aspects of Attention**

Current understanding of attention arises from both cognitive psychology and neuroscience, which are fields that have increasingly overlapped in the past two decades. Cognitive psychology models are primarily based on the type and amount of information being attended to while performing a certain task. Neuroscience models commonly describe neural networks underlying attention, and not only those related to higher cognitive processes, but also those of basic sensory processes that project to higher order regions.

## **Cognitive Characteristics**

Interestingly, the main cognitive models characterize attention along several dimensions based to some extent on the polar opposites of each of three dimensions: selected/divided, bottom-up/top-down processing, and covert/overt.

### **Selective and Divided Attention.**

Selective attention results from limitations in the mental capacity to process complex aspects of multiple perceptual stimuli. It is said to operate as a two-stage process. In the first stage, attention is widely distributed over the auditory and/or visual environment, and the individual is faced with too much information to be processed at once. Thus, in the second stage, a specific area of the visual or auditory environment becomes the focus of information processing (Jonides, 1983). Selective attention within the auditory system has often been investigated using 'dichotic listening' studies

(Broadbent, 1958 de Bode et al., 2007; Kimura, 1961). During a dichotic listening task a participant is presented with two different auditory stimuli over headphones. The participant is asked to pay attention to one or both of the stimuli and later respond to questions asked (by the experimenter) about the content of the auditory stimuli to which they were told to attend or ignore. Dichotic listening tasks have also been used as a test for hemispheric lateralization of auditory perception (Ingram, 2007).

In terms of visual perception, a study by Luck and Ford (1998) found evidence that visual-spatial attention modulates perceptual processing in extrastriate visual areas, beginning within 100 ms of stimulus onset. In order to understand how selective attention operates at an early stage in the visual domain, they presented participants with an array of 15 green letters and 1 red letter. Participants reported whether the red letter was a T. Such a task is generally easy to perform successfully because the distinctive color of the target item allows the participant to focus attention onto a single item. However, occasionally asking the participant to report the identities of the green letters showed that recall was poor for these items, indicating that attention was focused on the one red item. But one wonders why the participant is unable to report the green letters. One possibility is that attention operates at a very early stage such that the observer only possesses the green letters at a non-conscious level. This goes hand in hand with Broadbent's filter model of attention. According to this theory, a filter is required to cope with a surplus of information needed to be processed, resulting in some information (i.e. the green letters) being filtered out of conscious awareness (Broadbent, 1958). A second possibility is that

low-level, feature-based processing occurs for all items, but integrated object representations are formed only for attended items. This makes it possible for the observer to report the letters as green but not to correctly identify them. This alternative corresponds roughly to Treisman's feature integration theory. According to Treisman and Gelade (1980), when perceiving a stimulus, features are registered automatically at an earlier stage but objects are identified separately and processed later. A third possibility is that every item in the sequence is individually identified, but only attended items are stored in working memory so that they can be reported. This kind of explanation has been emphasized by Duncan and Humphreys (1989) who use the term "pop out" to describe the salience of the red letter among the green ones during bottom-up (stimulus-driven) processing of features. Yet a fourth explanation comes from Von Restorff's isolation effect, a phenomenon which predicts that an item that stands out from the rest is more likely to be remembered because it is segregated from other items. We can also observe this as a bias to remember the unusual (Von Restorff, 1933).

Divided attention, on the other hand involves actively paying attention to more than one task at any given point of time - for example, talking on the phone while driving (Hunt & Lansman, 1982). Unlike selective attention, divided attention is not limited to selecting a single object or location at a time, but can also be deployed to monitor simultaneously appearing multiple objects and/ or locations. This monitoring of multiple objects/locations typically results in processing inefficiency which has been documented both behaviorally and neurophysiologically (Castiello & Umiltá, 1992; Eriksen & St

James, 1986; McMains & Somers, 2004, 2005; Müller et al., 2003). The nature of costs involved in divided attention is associated with increased demands of top-down processing (see below) signals from high-level control areas (e.g., frontal eye fields {FEF} or the parietal cortex) to lower-level sensory areas during divided attention (McMains & Somers, 2004) and to limited processing capacity of the high-level control systems (Driver, 2001; Nebel et al., 2005). These demands may arise because dividing attention requires maintaining multiple target representations in WM (Fagioli & Macaluso, 2009; Kastner et al., 2007; Luck & Vogel, 1997). Accordingly, WM would play a direct role in divided attention control, with the two systems (WM & divided attention) utilizing a common pool of processing resources. Neuroimaging studies have supported this view as areas in the fronto-parietal cortex engage both during divided attention and WM tasks. Fagioli and Macaluso (2009) found that dividing attention between multiple object-categories or multiple locations activates a fronto-parietal (FP) attention network, including the prefrontal cortex (PFC) bilaterally, the middle and dorsal premotor cortex (comprising the frontal eye-fields), and the intraparietal sulcus (IPS).

### **Bottom-up and Top-down Attention.**

Visual information available at any one moment in time almost always exceeds the information processing capacity of the visual system. Selective attention, regulated by specialized brain networks (Posner & Petersen, 1990), enables focusing on those portions of sensory input that are relevant for completing the task at hand. Thus attentional resources can either be selectively allocated to features or spatial locations, or both, of

specific stimuli. This type of allocation is thought to be controlled by “bottom-up” and “top-down” processes (Hahn, Ross & Stein, 2006). In bottom-up processing, attention is stimulus-driven or is automatically oriented towards an incoming stimulus. Bottom-up processing can be summed up in the following example - "if many apples fall upon our heads we may conclude that a general force is pulling objects towards earth". In contrast, top-down processing is intentional and directed by knowledge, expectation and current goals (Desimone & Duncan, 1995; Egeth & Yantis, 1998). Simply put, "If I touched a hot stove and burned my hand before, and if I touch the hot stove again, then I will burn my hand" is an example of top-down processing.

Neuroanatomically, bottom-up processing is thought to involve parietal and temporal cortices, in addition to the brainstem (Posner & Peterson, 1990), while top-down processing is mediated primarily by the frontal cortex and the basal ganglia (Posner & Peterson, 1990). Hahn, Ross and Stein (2006), devised a way to further our understanding of brain networks mediating bottom-up and top-down control of visuo-spatial attention. They used a paradigm that parametrically varies demands on these two processes. The spatial predictability of peripheral targets (target location) was varied by centrally cueing one, two, three or four out of four possible locations, and reaction time decreased with more location-relevant cueing of the target and increased with less relevant cueing. On one hand, they found that top-down processing was characterized mostly by a left-hemispheric network consisting of the left intraparietal sulcus, inferior and superior parietal lobule, bilateral precuneus, medial frontal gyri including superior

frontal sulci, and medial occipital gyri. This network displayed blood-oxygenation level-dependent (BOLD) responses to cues that increased with more location-relevant cueing. This was indicative of engagement by top-down spatial selective attention. On the other hand, the bilateral temporoparietal junction, cingulate gyrus, right precentral gyrus, anterior and posterior insula, bilateral fusiform gyri, lingual gyri and cuneus displayed increased BOLD responses to targets with low spatial predictability, a circuit associated with bottom-up processing.

### **Overt and Covert Attention.**

Spatial attention can be directed to peripheral visual events in two ways. One way states that head and eye movements can be employed to gaze directly at an item. This is often referred to as an overt shift of attention. Overt attention requires directing sense organs towards the source of a stimulus, or its spatial location. Indeed, the brain has attention mechanisms that can select where to orient the high resolution processors of the visual (fovea) and auditory (vertical midline of head) systems (Geisler & Cormack, 2010). By contrast, covert attention concerns attention mechanisms that do not involve explicit movement of the sensory organs (Geisler & Cormack, 2011). Thus, a covert shift of attention spatial attention is directed towards the relevant stimulus without explicit movement of the eyes (Wright & Ward 2008). For example, while reading, a covert attention shift involves shifting focus from semantic processing of a word to processing the font or color of the word. Attention shifting (both covert and overt) is further divided into reflexive externally driven (exogenous) shifts and strategic (endogenous) shifts. An

example of the former would be when abruptly appearing letters capture attention and are responded to faster than gradually appearing letters (Jonides & Yantis, 1988). In contrast, the voluntary decision to look both directions before crossing a street would reflect an endogenous overt shift of attention.

While it seems logical that the relationship between covert and overt shifts of attention would lie on a continuum from complete neural independence to complete neural interdependence, the literature advocates three possible relationships. On one end of this continuum, Posner & Petersen (1990), with their modular theory, suggest covert and overt shifts of attention are completely independent of one another, with brain regions activated by covert shifts of attention being completely different from brain regions activated in overt shifts of attention. Corbetta (1998), on the other hand, argues that covert and overt shifts of attention are interdependent, while Rizzolatti et al. (1987) state that covert and overt shifts of attention use the same neural circuitry.

De Haan, Morgan & Rorden, (2008) concluded that the increase in neural activation in occipital areas indicates that during eye movements made in the overt shifts of attention task, the image on the retina changed. Instead, during the covert shifts of attention task the image on the retina did not change. In addition, the inferior frontal operculum was activated bilaterally during overt, but not covert, shifts of attention. By contrast Coull and colleagues (2000) reported bilateral activation of the inferior frontal operculum during both covert and overt shifts of attention. These results mirrored previous findings that have recorded neural activation in the inferior frontal gyrus with

both visually guided saccades and memory guided saccades (Kastner et al., 2007; Özyurt, Rutschmann, & Greenlee, 2006).

With the above information as context, the current view on the neurological substrates of attention is presented below.

### **Attention's Neural Networks**

#### **Alerting.**

The alerting network is responsible for producing and maintaining optimal vigilance and performance during tasks. The alerting network originates in the brainstem, specifically the locus coeruleus (LC), which releases norepinephrine (NE) into parietal and frontal cortical areas through a network that is responsible for projecting warning signals related to the occurrence of a target. There are two types of alerting; tonic – referring to a neural response that is slow; and phasic – which refers to a much faster type of response. An imaging study (Sturm & Willmes, 2001) found that a common set of right hemisphere and thalamic areas are involved in both phasic and tonic alerting. In contrast, other studies have found that warning signals rely more strongly on left cerebral hemispheric mechanisms (Coull et al. 2000,). See Figure 1 for the pathways that comprise the alerting network.

In the present study, it is hypothesized that the alerting network of the brain will be heavily involved since, during alerting, a phasic signal occurs based on the time during which important stimuli are thought to be present (Seitz & Watanabe, 2005).



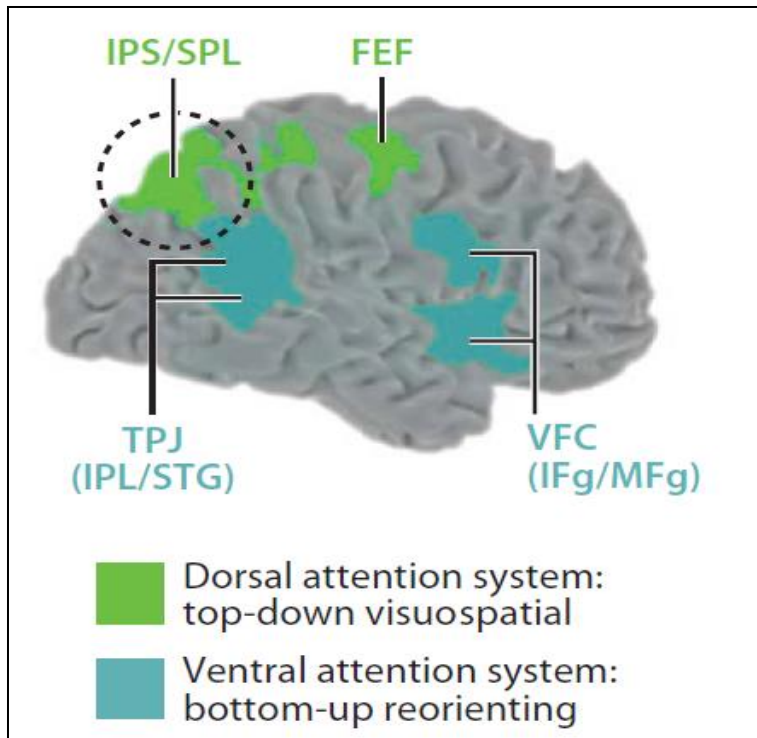
*Figure 1.* Alerting Network: The locus coeruleus (black circle) projections of the alerting system shown on a macaque brain. The diffuse connections interact with other, more strongly localized systems. The alerting system also includes regions of the frontal and parietal cortices (not shown). (Reproduced from Aston-Jones & Cohen (2005); Peterson & Posner, 2012)

### **Orienting.**

This network (refer to figure 2) prioritizes sensory input by selectively allocates attention to a relevant area of the visual field or an object, and enhances its perceptual processing (Callejas et al. 2005). In the orienting network, two brain systems are involved. One of these is a dorsal system including the FEF and the intraparietal sulcus. This area corresponds to the superior parietal lobe and contains cells influenced by cues regarding spatial location. The second and more ventral set of pathways, including the temporoparietal junction, is part of a network that is responsive to sensory events. The orienting network operates via bottom-up processing and produces synchronization between activity in the dorsal attention areas and the ventral visual areas resulting in

greater sensitivity in the visual system. This sensitivity leads to faster responses to visual targets and hence improves the processing of targets and there is agreement in the imaging literature that frontal and posterior areas are associated with orienting (Desimone & Duncan, 1995). There exist important connections between modalities, too; i.e., orienting to a specific location will provide priority not only to the anticipated modality but even to information present at the same location from other modalities (Driver & Spence, 2004 2004). Also, both human and animal studies have found that the FEF is an important part in this process (Corbetta et al. 1998, Thompson, Biscoe, & Sato, 2005).

Relevant to the proposed study, the orienting of attention to target locations in a rapidly presented visual string of stimuli could potentially help participants to concentrate on that area and ignore the incongruent distracters, thus producing a quick and accurate response (Callejas et al. 2005).



*Figure 2.* Orienting Network: The dorsal and ventral orienting networks (Corbetta & Shulman 2002). The dorsal attention network (light green) consists of frontal eye fields (FEF) and the intraparietal sulcus/superior parietal lobe (IPS/SPL). The ventral attention network (teal) consists of regions in the temporoparietal junction (TPJ) and the ventral frontal cortex (VFC). (Peterson & Posner, 2012)

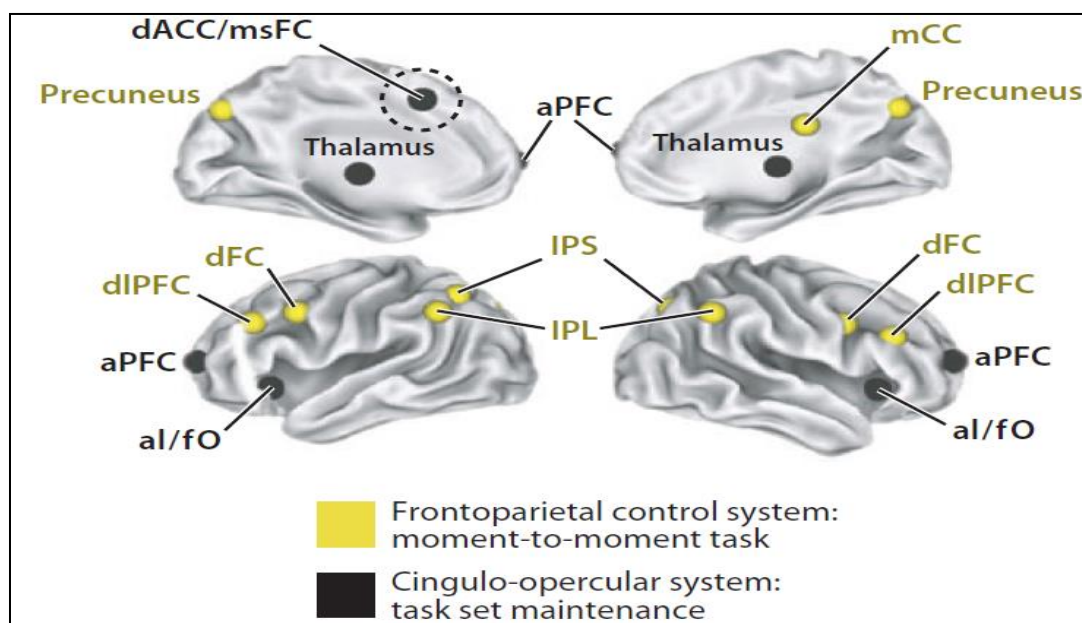
### **Executive.**

There are two views on what makes up the executive network (refer to figure 3): cognitive control and dual network. In general, the network is responsible for target detection during an attention task or more specifically the moment of target detection that captures awareness (focal attention) in a precise manner. The cognitive control view posits a single fundamental executive system including top-down control signals

provided by the lateral prefrontal cortex, and is guided by performance monitoring signals that are generated by midline structures. The dual network view (Dosenbach et al., 2008) states that two executive systems, the frontoparietal and the cingulo-opercular, operate independently in producing top-down control. The cingulo-opercular control system is responsible for performance during attention tasks (task set maintenance), and the frontoparietal system controls task switching, or adjusting one's focus in real time (from moment to moment). The brain areas associated with these target detection networks include the medial frontal cortex (mFC) and the anterior cingulate cortex (ACC). These areas are activated during attention, particularly during conflict or when one is required to withhold a dominant response in order to perform a subdominant response (Botvinick et al., 2001). Similar activity in the mFC and ACC is found during physical (Rainville et al., 1997) or social (Eisenberger, Lieberman, & Williams, 2003) pain, processing of reward (Hampton & O' Doherty, 2007), and error detection (Dehaene et al., 1994).

It is important to note that these three networks described above have been studied to further understand the process of attention as a whole. In no way is one network truly independent of the other, but each has different effects on stimulus processing. For instance, (in light of the present study) when a participant is performing an attention demanding task (such as identifying a target among many stimuli), the alerting attention subsystem is activated by a cue, such as the occurrence of a target stimulus, which serves as a temporal signal further enhancing processing of all the

stimuli, including task-irrelevant ones (which may or may not be filtered out). The orienting attention subsystem, however, directs attentional resources to the location of the task target. The orienting network aids in target detection. Finally, the executive network aids in decision making about the identity, time, and position in sequence of the target & non-target stimuli.



*Figure 3.* Executive Network: Two networks of the executive control system-The circled region indicates the original member of the executive control system from Posner & Peterson (1990). The remaining regions come from the elaboration of the original cingulo-opercular system (black) and the addition of the frontoparietal system (yellow) (adapted from Dosenbach et al. 2007; Peterson & Posner, 2012)

## **Neural Activity and Attention**

Researchers study brain activity related to attention using various neurological measures like electroencephalography (EEG) (Koivisto & Revonsuo, 2007, Kranczioch, Debener, & Engel, 2003), MEG (magnetoencephalography) (Liu et al., 2012) and fMRI (functional magnetic resonance imaging) (Choi et al., 2012). Different techniques reveal the way in which different cortical networks are engaged in task performance in an attention experiment and this helps reveal the neural mechanisms and circuitry behind attentional capacity. EEG is advantageous as it has fine time resolution and is rather simple to use. It is cheaper than other high-end brain scanning technique and is a convenient tool for when the participant has to perform some behavioral task. Unlike other brain scanning techniques, EEG measures the primary, i.e., electrical, effects of neural excitation and can thus reveal one of the main parameters of neural activity - its rhythmic properties. It is thought that different frequency bands in the EEG spectrum may reflect particular cognitive conditions and EEG is used for evaluating brain functioning in patients with cognitive deficits (Luck, 2005) as well as normals.

## **EEG and Event-Related Potentials as Neural Correlates of Attention**

An EEG is a recording (via electrodes attached to the scalp) of voltage fluctuations resulting from the flow of ionic currents across neuronal membranes within the brain (Niedermeyer, 2004). It is a minimally-invasive procedure that uses small flat metal discs attached to the scalp that detect electrical activity across the surface of the

cortex. EEG signals have two basic characteristics: frequency and amplitude. Frequency (Hz ) and amplitude ( $\mu\text{V}$ ) are recorded and plotted across time. Frequency and amplitude are detected by the electrodes, transmitted to amplifiers and then fed to a computer monitor for viewing and analysis. Different frequencies/amplitude combinations have been designated as alpha, beta, delta or theta waves. An event-related potential (ERP) is the measured brain response (a component of the overall EEG signal) that is a direct consequence of a specific sensory, cognitive, or motor event. In the case of EEG and attention, the main ERP of interest is the P300, a positive potential which is evoked in response to a sporadically presented, recognized, meaningful stimulus (PolichJ., 2007)

### **EEG During Attention**

Observation of the P300 component serves as evidence that recognized items are the focus of attention. Its amplitude varies with the predictability of the targets and its latency varies with the difficulty of differentiating between the odd stimulus and the standard stimulus (Picton, 1992). In the present context, the P300 ERP is of particular interest, since this component is typically seen as an electrophysiological process connected with working memory (Donchin & Coles, 1988; Kok, 2001; Verleger, 1997). Thus, ERPs like the P300 can serve as real-time neural evidence of target detection during attentional tasks, such as attentional blink (AB – discussed below), the paradigm to be used in the current study.

## **Brain Systems Involved in Attention to Visual and Auditory Stimuli**

As some of the stimuli to be used in the proposed study are colors and sounds, a brief review of attention to these types of stimuli is presented below.

### **Attention to Visual Stimuli and Color**

The objective of the human visual system is not only to process what occurs but also when and where it occurs (Koivisto & Revonsuo, 2007). This is well explained by the two-stage process of attention (described below). The ability to keep visual information in an accessible state is vital to cognitive functioning, since it allows us to successfully interact with our visuo-spatial world. As our visual short term memory (VSTM) is very limited in storage capacity (Luck & Vogel, 1997), only a subset of the information we receive from the outside world can be transferred to this limited storage space at any given point of time. The selection of this subset of information is made by attentional mechanisms that might be enhanced by stimulus features such as colors or sounds.

In terms of selective attention by color, some visual searches have shown that a stimulus differing in color from homogenous background items appears to pop-out (referred to as pop-out effect, explained below) and is easily detected by the observer (Duncan and Humphreys 1989; Theeuwes, 1990; Treisman and Gelade, 1980). Research on functional specialization in the primate brain has identified a neural pathway that encodes wavelength changes connected with color perception. This pathway starts with

retinal receptors (cones) that respond to different wavelengths of the visible portion of the electromagnetic spectrum. The cones connect to retinal color-opponent ganglion cells and eventually reach the blob regions of the primary visual cortex (V1; occipital lobe) via the parvocellular layers (or koniocellular, depending on the color, or spatial frequency) of the thalamic lateral geniculate nucleus (Livingstone and Hubel, 1982). From V1, neural information is transmitted to extrastriate areas V2 (prestriate cortex; surrounds V1) and V4 (the third cortical area in the ventral stream; lying ventral to V2) and then to inferotemporal (IT) cortical regions (Komatsu et al., 1992; Schein and Desimone, 1990; Schiller, Logothetis, & Carles, 1990) which integrate color information with shape and form. Color information is combined with information from the other visual association areas and becomes a component of the whole (perceived) stimulus. It is likely that, upon its entry into conscious awareness, we use this sensory information to help describe a stimulus (a red light at a traffic signal).

### **Attention to Sound**

In the auditory system, the first cortical region to receive auditory input is the primary auditory cortex (temporal lobe). Prior to this, sound waves are reflected when they reach the pinna (the folds of cartilage surrounding the ear canal) and are transferred to the inner ear's cochlea via the tympanic membrane and ossicles. Cochlear hair cells transduce the sound-pressure waves into action potentials. These signals travel to auditory brain stem nuclei, the medial geniculate nucleus of the thalamus, and

subsequently reach the primary auditory cortex (Kendal et al., 2005). Neurons in the primary auditory cortex have receptive fields that cover a wide spectrum of auditory frequencies and integrate information from both ears, each covering a particular region of auditory space.

### **Attentional Capacity**

The theories and studies centered on attentional capacity seek to uncover the mechanisms involved for both cognitive and perceptual aspects of this capacity. Below is a short explanation that expands further on attention as a capacity, its parameters and integrated systems.

### **Studying Attentional Capacity**

Scientists study neural aspects of attentional capacity using several different cognitive neuroscience paradigms (described below) and primarily using techniques such as EEG and fMRI.

#### **Attention Network Test.**

The attention network test (ANT) is a battery of tests that measure attention shift and executive control, which can serve as a comparison across individuals. It examines the effects of cues and targets within a single reaction time task to provide a means of exploring the efficiency of the alerting, orienting, and executive control networks involved in attention as described by Peterson and Posner (2012, Posner & Peterson,

1990). It also provides an opportunity to examine the brain activity of these three networks as they operate in a single integrated task (Fan et al., 2002). Here, conflict is introduced by having *flankers* surrounding the target which are pointing in either the same (congruent) or opposite (incongruent) directions as the target. Cues presented prior to the target provide information as to where or when the target might appear.

### **The Stroop task.**

In 1935 John Ridley Stroop developed the Stroop task, which examines the difficulties encountered when naming the ink color of words which spell conflicting color names. This task elicits what is termed as the Stroop effect and is interpreted as an attentional incapacity or interference where irrelevant stimulus information often deteriorates performance. In this task, participants have to look at a list of color words (e.g. red, green), wherein each word is printed in a color different from the color of the word that spells it. For example the word red would be typed in orange, yellow in green, etc. After each participant is presented with the list, the participant must state the name of the ink color, ignoring the text. It took longer (110 secs) to complete this kind of list, compared to when the word spelling and the color of the letters were congruent (63 secs). In a study by Leung et al. (2000), using the conventional paradigm they found that performance on the Stroop task specifically activated the anterior cingulate, insula, premotor and inferior frontal regions, components of the executive attention system described above.

**Change blindness.**

Change blindness occurs when an individual fails to notice a change in a visual stimulus. The observer might not notice either a minute or large difference between two images that are otherwise identical. The main reasons why these changes go unnoticed by the individual include obstructions in the visual field, eye movements, location changes, or diminishing attention (Cavanaugh & Wurtz, 2004). Brain regions that have been designated as active during change blindness are the prefrontal lobe, fusiform face area, the pulvinar, the cerebellum, the inferior temporal gyrus, the parietal lobe and the frontal lobe (Beck et al., 2001). Change blindness is often demonstrated using the flicker paradigm, in which a blank screen is presented in the middle of an image and an altered form of that image might distract the observer's attention (Rensink, O'Regan, & Clark, 1997).

**Repetition blindness.**

When people attempt to report items that were presented in a rapidly displayed sequence of letters or words, commonly termed a rapid serial visual presentation (RSVP) display, they tend to make an error when the display includes an item that is repeated (Fagot & Pashler, 1995). This error is a failure to report the second occurrence of the repeated letter or word (Kanwisher, 1987). Kanwisher called this effect repetition blindness (RB), and suggests that it stems from a difficulty in perceiving the second occurrence. This phenomenon occurs even when there are as many as three intervening

words between the two repeated words, even when the appearance of the two might differ, for example – upper vs. lower cases. Repetition blindness has been demonstrated most efficiently when embedded words were repeated in sentences and presented in RSVP at the rate of 8 words/ sec, to be recalled verbatim (Kanwisher, 1987).

### **Odd ball paradigm.**

This technique uses streams of stimuli (usually auditory or visual) to assess the physiological or brain responses to unpredictable but recognizable events. The participant is asked to respond either by counting or by key press, to indicate detection of target stimuli that are hidden as rare events in a series of common stimuli (Squires, Squires, & Hillyard, 1975). This is incorporated into the current study (along with the P300, previously measured in oddball paradigm studies).

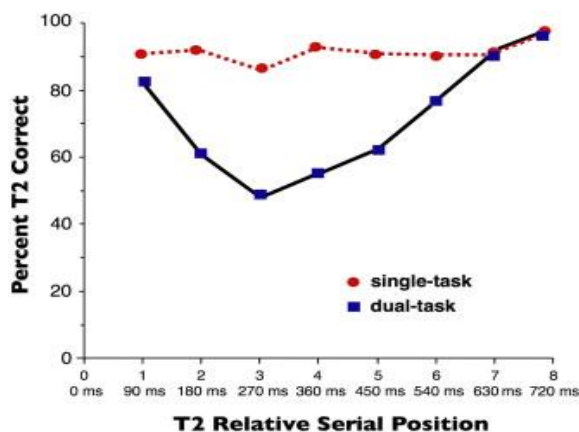
### **Pop-out effect**

The pop-out effect is driven by the fact that targets defined by attributes such as color or brightness are said to “pop-out” from a cluttered scene (Duncan & Humphreys, 1989). One study using this effect showed that luminance and color are not in themselves “pop-out” attributes for visual search, but can show a strong dependency on set-size, similar to that observed for other attributes like motion and orientation (Baldassi & Burr, 2004; Morgan et al., 1998).

### **Attentional Blink**

This paradigm is used in the current study and is presented in detail below.

When multiple targets occurring in close temporal proximity of each other must be identified, there is a frequent impairment of attention. Attentional blink (AB) is the failure to detect a second target occurring in a sequence of characters that are presented in a Rapid Serial Visual Presentation (RSVP). Participants often have difficulty reporting the second target (T2) when it appears 200-500ms after the onset of the first target (T1) and this is called attentional blink (AB) (Raymond, Shapiro, & Arnell, 1992). This impairment is thought to exist due to competition between the two (or more) targets for limited attentional resources (Raymond et. al, 1992; Slagter et al., 2007) that occurs when T2 is presented (refer to Figure 4). In terms of the present study, the focus is on attentional blink as a reflection of the limited capacity of attention. Chun (1997) suggested that AB is the inability to encode a target into working memory and as such is a function of central processing limitations. Keil and Heil (2009) state that limitations of selective attention in the human visual system take place due to spatial distribution of stimuli in the visual field, as well as due to their temporal proximity and density.



*Figure 4.* Attentional blink curve: Typical findings characterizing the results of an attentional blink experiment. Percent T2 correct responses are plotted on the Y axis, whereas the relative serial position and SOA values between T1 and T2 are plotted on the X axis. Results from the single-target (control) condition are plotted with circles and the results of the dual-target (experimental) condition are plotted with squares (Raymond, Shapiro, & Arnell, 1992).

### **General theories of AB.**

A number of theories have been suggested to account for the AB phenomenon. Of these, two important ones are the two stage model and the interference model. The key difference between the two stage and the interference models is that the former assumes the failure of T2 to reach working memory and the latter assumes that T2 enters working memory but is ultimately lost due to interference from T1 (Vogel, Luck & Shapiro, 1998). ERP studies have attempted to differentiate between these theoretical accounts of AB (Babiloni et al., 2006; Koivisto & Revonsuo, 2003; Pins & Ffytche, 2003; Sergent, Baillet, & Dehaene, 2005; Vogel et al., 1998; Wilenius-Emet, Revonsuo, & Ojanen,

2004) as the different paradigms used provide information about the depth of processing or variations in processing. Inaccurate reporting of T2 may result from a decrease in the availability of cognitive resources (Chun & Potter, 1995; Sessa et al., 2007) or limitations in attentional capacity (Vul, E., Nieuwenstein, M., & Kanwisher, N., 2008) as a consequence of encoding or selecting T1.

### **The two stage model.**

This model proposes two ‘processing stages’, the first of which analyzes features relevant to target detection, and the second of which involves full identification and consolidation of the target. Here, the assumption is that the first stage is short-lived but goes over all items of an RSVP task, but the second stage clearly exceeds the item’s stimulus duration used in RSVP and is limited in capacity. According to this model, subsequent items will only be processed beyond stage one if second stage item processing for the previous items is complete. Hence, the appearance of T2 while the second stage is still preoccupied with T1 delays stage two processing for T2. As this delay increases, the probability that T2 will not be consolidated becomes greater (Chun, & Potter, 1995).

### **The interference model.**

The interference model (Isaak, Shapiro & Martin, 1999) rests on the assumption that AB reflects competition among multiple RSVP items in a short-term buffer. T1 and T2 (along with the items immediately following them) are assumed to compete for limited processing resources initially engaged by T1 when the inter-target duration is less than approximately 500ms. Higher frequency of encoding of T1 over T2 results in successful

reporting of T1 and a greater probability that the item selected for T2 reporting will be incorrect. If the inter-target duration is greater than 500ms, it is implied that T2 processing is not subject to interference from T1.

### **Alternative models of AB.**

Some alternative theoretical views of AB have put forth non trade-off aspects during RSVP target identification (Di Lollo et al., 2005; Olivers & Nieuwenhuis, 2006). For example, research investigating the ‘lag-1 sparing’ effect shows that two or more targets can be reported with high accuracy if presented one immediately after the other in sequence, without intermittent distracter items present (Olivers & Nieuwenhuis, 2006). Additionally, additional AB tasks added to RSVP protocols employ resources but have been reported to reduce rather than increase AB impairment (Olivers & Nieuwenhuis, 2006), due to increased cognitive flexibility. In fact, it is also understood that AB is not entirely characterized by an attentional bottleneck, as many participants are able to identify both targets on at least a portion of the trials (e.g., Martens et al., 2006). It has also been suggested that the processing of T1 results in a transient loss of control over the perceptual “filter” used in selection of target items based on their features (Di Lollo et al., 2005). As this perceptual system is set to respond to target features, items that do not match the perceptual properties of the target will disturb the functioning of this symbolic “filter” and reduce sensitivity to targets that follow.

## **Studying Attentional Blink**

Studying the AB paradigm involves the use of RSVP. Its use has provided both behavioral (performance accuracy) and neurological (such as EEG) data.

### **RSVP.**

This consists of a stream of items of which one or two items are defined as targets. The second target (T2) is presented at different intervals or time lags in the millisecond range following the first target (T1) and in this way the entire presentation flashes before the viewer's eyes at typically 10 items per second. For example, a string of 15 grey letters flash rapidly before your eyes, including 2 green numbers called targets embedded anywhere in this string or sequence. The duration between the presentation (onset) of one character in the stream and the start of another is termed the "stimulus onset asynchrony" (SOA). For a description of the RSVP used in the present study please refer to figure 9.

### **Lag 1 sparing as a part of RSVP.**

Within the RSVP stream, each character has a serial position from 1-20 (assuming there are 20 characters in total). In addition, each position after that of T1 is designated as a "lag" position relative to T1. Thus, the character immediately after T1 is in lag position one (Lag 1). When T2 is presented at Lag 1, both targets are likely to be reported, which is called Lag 1 sparing (Nakatani et al., 2005). AB and Lag 1 sparing have been repeatedly observed using visual, auditory (Potter et al., 1998), and cross-modal stimuli (Soto-Faraco et al., 2002). AB requires attentional processing of T1 and capacity-limited processing/masking of T2 (Kawahara, Di Lollo, & Enns, 2001). Lag 1 sparing, on the

other hand, typically requires a constant spatial location of stimulus presentation and an absence of task switching between T1 and T2 (Di Lollo et al., 2005; Visser, Bischof, & Di Lollo, 1999). The proposed study will vary the position of T2, using Lag 1 as well as several other lag positions (see Methods section below).

Two experiments by Hommel and Akyürek (2005) investigated the mechanisms underlying the lag 1 sparing effect. Experiment 1 showed that requiring correct identification and order of targets at Lag 1 produces good performance on T2 but (relative to each other) bad performance on T1. Thus there is a tradeoff. Experiment 2 confirmed that participants frequently confuse target order at short lags, especially if the two targets are equally easy to discriminate. These results suggest that, if two targets appear in close succession, they compete for attentional resources and if the two competitors are of unequal strength, the more recognizable one is more likely to win and be reported at the expense of the other. If the two are equally recognizable, however, they will often be integrated into the same attentional episode. However this comes at a price, since it eliminates information about the targets' temporal order. On the other hand, in the absence of a lag 1 sparing effect, (Koivisto & Revonsou, 2007; Leber et al., 2009; Martens, Munneke et al., 2006) the normal AB effect categorized by frequent failure to recognize T2 appears when the targets are separated by a duration of 200-500ms

## **Attentional Blink Research**

Research on AB as an index of attentional capacity has provided behavioral, neuroanatomical & neurophysiological information that AB is found within visual and auditory modalities (Duncan, Martens, & Ward, 1997; Vachon & Tremblay, 2005; 2006), as well as between modalities (Arnell & Jenkins, 2004; Arnell & Jolicoeur, 1999; Arnell & Larson, 2002; Potter et al., 1998). However few studies have focused on the training aspect, more specifically whether AB can be reduced with colored stimuli or if auditory stimuli can do a better job.

### **Auditory AB.**

Even though it has been previously documented that some individuals (termed non-blinkers) do not show AB (Martens, Munneke et al., 2006) a study by Martens, Munneke & colleagues (2006), using the AB paradigm provides evidence that visual non-blinkers do show an auditory AB. In a study by Olivers and Van der Burg (2008) two targets were presented in RSVP with a synchronous sound, thereby enabling T2 to escape the AB, bringing performance back to the level of T1. Additionally, the sound improved identification of T1, with little evidence for a trade-off between T1 and T2. Further improvement was noticed if sounds coincided with distracters on 82% of trials, suggesting an automatic component. In fact, sounds that preceded targets had little or no effect on T2, suggesting that the enhancement was not due to alerting alone. These findings shed more light on audition-driven perceptual enhancement of single visual targets and have potential implications for AB theories. In another study by Vachon and

Tremblay (2005) using masking (T2 is flanked by a trailing item) to check whether masking plays a critical role in auditory AB like it does in visual AB. Results showed a reliable AB effect even when the item following T2 was replaced by silence. An experiment by Martens and colleagues (2009) revealed that when the difficulty in identifying visual targets is increased, nonblinkers continue to show little or no AB. This suggests that the presence of an AB in the auditory but not visual modality is not due to differences in task difficulty, as a similar pattern of results was found in other AB experiments.

#### **Visual AB and color-visual tasks.**

Several studies have investigated attention to color while attending to selective features, using behavioral as well as physiological measures like ERPs (e.g., Anllo-Vento et al., 1998; Egeth et al., 1984; Hillyard & Munte, 1984; Martin – Loeches et al., 1999). Ross and Jolicoeur (1999) used colored letters presented by RSVP. Two letters (T1 and T2) were targets that required (T1) or a delayed (T2) response. T1 was shown on half of the trials. The experimental condition required a discrimination between 2 letters (when T1 shown) or an indication of T1's absence (Task1). Experiment one involved detecting the presence of a unique color in the RSVP stream (for example green among alternating red and grey items). Experiment two required that the participant report the color of the first colored letter to appear in the RSVP stream, which had varied lag times between T1 and T2 (Task2). Results indicated that accuracy of color was poor at shorter lags and

improved for longer lags in both experiments, demonstrating an AB for chromatic information.

A study by Turatto and Galfano (2000) employed a serial search task and the pop-out effect. Although this is somewhat different from the regular AB paradigm, the goal was to infer whether attentional capture (likelihood and extent to which a stimulus or feature is attended to) could be affected by manipulating color, luminance and form of the stimulus. Results revealed that these physical properties impacted attentional capture.

### **Cross-Modal AB.**

With respect to cross-modal attentional blink, previous research has shown that responses to visual stimuli can be facilitated by an accompanying auditory stimulus, even when the auditory stimulus bears no information relevant to its visual pairmate (Hershenson 1962; Simon and Craft, 1970). Stein et al. (1996) suggests that the auditory signal enhances visual perception. They found that observers judge lights as being brighter when they are accompanied by a sound. In another study, Van der Burg et al., (2007) found that a person's attention is drawn to visual events that are hard to differentiate when these events are synchronized with a short beep.

Recent research suggests that cross-modal attentional blink may depend on the complexity of the stimuli (Van der Burg, et al., 2007). More specifically, an auditory T1 may interfere only with a visual T2 if both are processed at a semantic level. The reason for this is that semantic processors may take over from the different modalities. In the Van der Burg et al. (2007) study, no audiovisual attentional blink was found with T1s

that were specific to the auditory modality (i.e. different beeps). Most studies reported an attentional blink when T1 and T2 were separated by distracter elements (e.g. letters). However, Nieuwenstein and colleagues (2009) demonstrated an AB within the visual modality in the absence of distracters between T1 and T2 (separation by a blank interval).

An important issue that remains unclear is whether the AB observed in visual and auditory modalities reflects a common underlying processing limitation or whether there are distinct mechanisms that exist for visual and auditory AB. This latter idea is supported by studies showing different time courses in the processing deficits of visual and auditory targets. For visual targets the time course of AB is represented by a U-shaped pattern. The auditory AB generally shows a linear function, reflecting a progressive improvement in performance as a function of lag. Basically, as lag time increases, the incidence/frequency of AB is represented as a U-shaped function for visual stimuli, but might be linear for auditory stimuli (refer to figure 4). Shen and Mondor, (2006) have argued that the difference between a linear and a U-shaped curve occurs because the auditory system has better temporal resolution than the visual system. Hence the nearby targets are processed in sequence instead of simultaneously like in the visual modality. A study by Potter et al. (1998) compared T2 performance in the visual and auditory conditions, and found that only the visual condition showed the characteristic AB effect, although there was a net T2 deficit of similar average magnitude (across all lags) for both visual and auditory modalities. There was a highly significant interaction between group (experimental and control) and lag in the visual case, but not in the

auditory group. Differences in patterns of interference with visual and auditory targets occurred even though the two modalities were matched in difficulty (as measured by T1 detection performance). These results indicate that attention can be deployed differently when the targets are auditory than when they are visual and suggest that auditory attention has a lower AB occurrence rate. Support for an auditory AB was first reported by Duncan, Martens, and Ward (1997). In three experiments, Duncan et al., (1997) compared cases in which both targets were auditory, both were visual, or one was visual and the other auditory. In the within-modality conditions an AB of significant magnitude was found. However across modalities (i.e., when one target was visual and the other auditory) no AB was observed, suggesting that a major source of the attentional limitation characterized by AB could be modality-specific. Although these results have subsequently been replicated (Hein, Parr, & Duncan, 2006; Soto-Faraco et al., 2002), there are also reports of cross-modality AB effects with visual and auditory target combinations (e.g., Arnell & Jenkins, 2004; Arnell, & Jolicoeur 1999; Arnell & Larson, 2002; Jolicoeur 1999; Jolicoeur et. al 2002). Here target combinations refer to the synchrony or asynchrony among audio-visual events and their efficiency to capture attention. In the face of these varied results, the cross-modal AB effect is usually considered weaker and less stable than its within-modality counterpart (Arnell & Jenkins, 2004; Arnell & Larson., 2002; Hein et al., 2006; Potter et al. 1998; Soto-Faraco et al., 2002).

### **Neural Network Model of the AB phenomenon.**

Within the context of the neural circuitry models of attention presented previously, attempts have been made to represent such neural circuitry for AB. One such attempt by Bowman and Wyble (2007) represents the dynamics of temporal visual processing as embodied in the ST<sup>2</sup> (Simultaneous-Type-Serial-Token) model (refer to Figure 5), which is a connectionist model of temporal attention and working memory. With this model they proposed an explanation for the observed effect of AB (to be measured in the proposed study) on the temporal precision of transient attention. The fundamental principles of how the ST<sup>2</sup> model describes temporal attention and WM are elaborated below.

**Types & tokens:** The ST<sup>2</sup> model incorporates a types-tokens account (Chun, 1997; Kanwisher, 1987; Mozer, 1989) to describe the process of working memory encoding. *Types* refer to all feature-related properties associated with an item, such as visual features (e.g. its shape, color and the line segments comprising it). Types also include semantic attributes, such as a letter's position in the alphabet. A *token*, on the other hand, refers to episodic information. It pertains specifically to a particular occurrence of an item and stands for serial order of items. By creating a connection between a type and a token, an item is encoded into working memory. Thus the information stored in the tokens provides identification as well as temporal order of stimuli. During the retrieval process, token and type information are accessed.

### Layout of the model.

As illustrated in figure 5, the  $ST^2$  model is comprised of three parts. (Chennu et al., 2009).

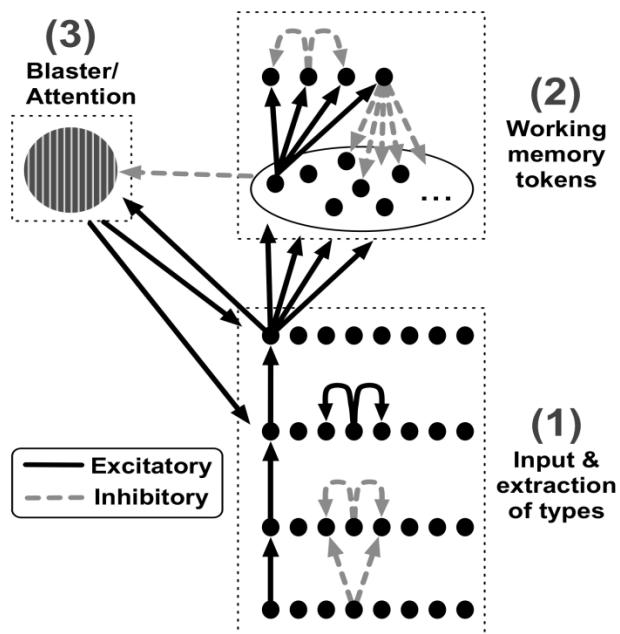


Figure 5: The  $ST^2$  model.

(1) Input & extraction of types in stage one. (2) Working memory tokens in stage two. (3) Temporal attention from the blaster (Chennu et al., 2009).

### Input and extraction of types.

In this initial stage, input “values” that simulate, for example, target letters and number distracters (such as would be used in an AB experiment), enter into the model at the lowest layer of stage one. As activation progresses forward, the layers that follow

represent “masking”: visual masking is the reduction or elimination of the visibility of a single brief ( $\leq 50$  ms) stimulus, called the ‘target’, which is then replaced by the presentation of a second brief stimulus, called the ‘mask’. At the highest layer of stage one, a task demand mechanism operates by selecting targets for encoding into working memory and suppresses the representations of distracters. Even though stimuli are presented serially during the AB task, processing within this stage may exceed presentation time of sequentially presented items. In the context of the model, these layers are considered to be parallel in nature (i.e. more than one node can be active at any one time).

#### **Working memory encoding.**

By connecting its type node in stage one to a working memory token in stage two, an item is coded into working memory. This process is called ‘tokenization’. At the end of a trial, if the type node of a target has obtained a valid connection to a token, then the target is said to be successfully ‘reported’ within the ST<sup>2</sup> model. Barriers between working memory tokens ensure that only one token is active at any one time. This imposes a serialization of working memory encoding as opposed to the parallel processing of the prior stage.

#### **Temporal attention from the blaster.**

Temporal attention is enforced by a mechanism called the ‘blaster’. It provides non-specific excitatory input to nodes in the later layers of stage one (input and extraction of types) in response to the detection of salient items (i.e., targets in the context of the

AB). Next, what is known as Transient Attentional Enhancement (TAE) received from the blaster, permits targets to become sufficiently active to initiate the tokenization process. During tokenization, the blaster remains suppressed until encoding of the target is done. This suppression prevents a second target from re-firing the blaster while the first one is being tokenized, thus preventing a fusion of the episodic representations of the two targets.

The ST<sup>2</sup> model suggests that working memory encoding involves a binding of the type of a stimulus (visual features and semantic attributes) and a token (an episodic representation specific to a particular occurrence of an item) (Kanwisher, 1987). Transient Attentional Enhancement (TAE) from the blaster emphasizes the type representation of a salient (i.e., task relevant) stimulus to help in its binding to a token. This TAE can potentially be an 'attentional gate' that can be temporarily deactivated to permit completion of one target's encoding before a second is initiated. Thus, the process of encoding T1 into working memory is triggered by TAE and TAE itself is suppressed until T1 encoding is complete. The duration for which TAE is unavailable varies from trial to trial depending on how long it takes to tokenize T1. Therefore, in an RSVP stream if T2 is presented 200–500 ms after T1 (characteristic of AB), its processing outcome depends on multiple factors. The salience of T2 will determine its dependence on TAE, as highly salient T2s can 'break-through' the AB and get encoded early (Shapiro et al, 1994). T2s that are not as strong cannot break through the AB (or overcome the suppression of TAE), and hence are indirectly influenced by T1 strength. Overall, the

variability in the temporal dynamics of T2's encoding process is influenced both by T1 and T2 strengths. Hence, this model proposes an increased variance in the time delay for targets seen during the AB. In connection with the  $ST^2$  model, AB can be seen as an artifact of the visual system, attempting to assign unique tokens to targets (Wyble, Bowman, & Nieuwenstein, 2009).

### **Neural Correlates of AB.**

Previous studies on AB have mostly focused on the P300 wave for visual stimuli, which has been recorded as typically maximal at medial and parietal sites ~400ms after the target. It has been proposed that the P300 reflects the updating of working memory (Donchin, & Coles, 1988). Typically, findings show that, during AB, the P300 component in response to T2 is suppressed (McArthur et al., 1999; Vogel & Luck, 2002). One example is that Vogel et al., (1998) showed a reduced P300 deflection or a reduction in amplitude of the P300 during AB.

In line with the resource allocation theory (lack of resources to process T2), many ERP studies (Kranzloch, Debener, Maye, & Engel, 2007; Martens, Elmallah et al., 2006; Martens, Munneke et al., 2006; Sergent, Baillet, & Dehaene, 2005; Sessa et al., 2007; Shapiro, Schmitz et al., 2006; Slagter et al., 2007) have indicated that the capacity to accurately identify T2 is related to the latency and/or amplitude of the T1-elicited P300, which is thought to be a brain-potential index of resource allocation (Wickens, Kramer, Vanasse, & Donchin, 1983). A delayed or larger T1-evoked P300 has been detected on trials in which T2 was missed (i.e., blink trials) compared to detected (i.e., no-blink trials)

(Sergent et al., 2005). These electrophysiological findings corroborate the claim that resource allocation to T1 processing clearly influences the processing capacity available for T2, and consequently, whether T2 will be perceived. Vogel and Luck (2002) also found that the P300 wave elicited by the target was delayed rather than suppressed when distracters following T2 were deleted, thereby eliminating the AB. These results are consistent with the 2-stage model, which states that the second stage is limited in capacity and that the target item cannot enter into this stage until the processing of the T2 is completed. The results from their study also suggest that during the period before this stage the target might be overwritten by the distracters that follow it. Hence, deleting the distracters following the second target enhanced performance and was accompanied by a delay in P300 latency. Findings from other studies using a similar paradigm but introducing targets from the same modality and from different modalities (i.e., one from the visual and one is from the auditory modality (Arnell 2006; Dell'Acqua et al., 2003; Pfitzer et al., 2008), suggest that the AB might not be modality-specific.

### **Training and Attentional Blink**

Recently, interest in “brain training” and its underlying mechanisms has gained popularity. Typically, such training involves improving cognitive functions which have previously been viewed as permanent or non-resistant to the effects of training. A topic that gained considerable interest in this area has been working memory (WM) training (Salminen et al., 2012). A study by Leber et al., (2009) utilized training to investigate long-term and short term abstract learning of an attentional set (selection or search strategy). In their study, participants were placed into 2 groups: singleton and feature. Observers in the singleton group searched for a target that on any given trial could be one of any five colors selected randomly, could be repeated, and was unpredictable to the participant. Observers in the feature group searched for a target of a consistent color on every trial which was embedded in a character stream of heterogeneously colored non targets (grey, blue, purple, etc.). In the training session, the variable ‘color assignment’ was used to indicate which color target the participants had to search for: red or green. During training, distracters were also present in four distracter conditions (all-grey, same colored singleton condition, different –colored singleton condition and no-distracter condition). The testing condition was conducted either after a 1-day delay, 1-week delay or immediately after training. The results showed that the training effect was not a result of perseveration (the tendency to continue or repeat an act or activity after the cessation of the original stimulus) but rather of long term abstract learning. Also, when training and testing were separated by one week, training effects were still observed and the learning

that took place from the training was more abstract (the singleton group transferred the abstract mode of searching for salience from training-to-test, rather than simply learning to search for a particular item) compared to feature specific learning. In another study, findings by Salminen and colleagues (2012) confirmed previous results that WM can be trained by showing that the training effects can be generalized to other tasks tapping into executive functions. In their study participants had to simultaneously perform a visual and an auditory (n-back) task, while the transfer tasks drew on WM updating, coordination of the multiple simultaneous tasks (i.e., dual-tasks) and sequential tasks (i.e., task switching), along with temporal distribution of attentional processing. The study culminated in assessment of reasoning abilities (using the Raven's advanced standard progressive matrices) and showed that participants significantly improved in a task switching situation and also in attentional processing. Another study by Slagter and colleagues, (2007) found that three months of intensive training in a certain type of meditation which reduces object processing (Lutz et al., 2008), successfully showed a reduction in attentional blink for participants who received meditation as compared to a control group (Slagter et al., 2007). Taken together, these results indicate potential benefits for attentional and memory processing resulting from training.

## **Proposed Study**

### **Brief review of central topics.**

Studies have questioned whether limitations of attention apply to modality-specific resources, a concern underlying fundamental brain function, and have investigated limitations in attentional capacity within auditory or visual domains. In the present study the targets (T1 and T2, in the training phase) are unique in color or are accompanied by a unique auditory stimulus. Here, “attention capture” is geared towards both targets in the RSVP sequence and will measure the P300 ERP during this sequence.

It is important to note that recent research shows that some individuals do not show an AB. This is substantiated by psycho-physiological evidence that target processing differences between “blinkers” and “non-blinkers” (Martens, Munneke, Smid, & Johnson, 2006). Electroencephalographic (EEG) activity for both groups was recorded during execution of a task in which two visually presented letters had to be detected in a sequential stream of digit distracters. Non-blinkers showed a shorter P300 latency (induced by identified targets and associated with the updating of working memory). This suggested that they are quicker to consolidate information than blinkers.

### **Link Between RSVP, AB and EEG**

#### **RSVP and AB.**

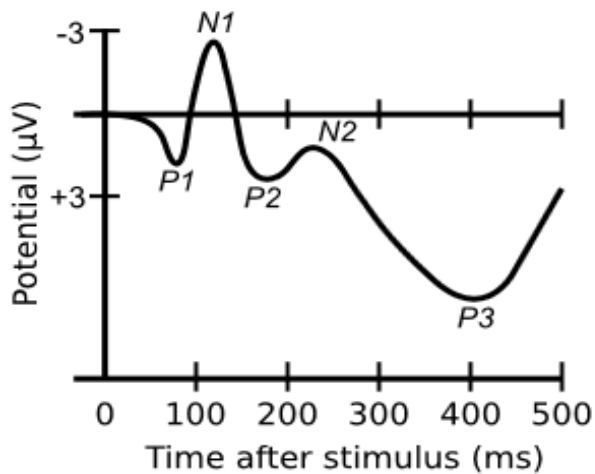
The RSVP consists of a series of characters (letters and numbers) typically presented at 100 -150 ms per character, of which two are defined as targets. The second

target (T2) is presented at different time lags following the first target (T1). In a dual task condition, in which participants attend to both targets, T2 detection performance is impaired when T2 is presented at 200-400 ms after T1. On the contrary, T2 detection rate is less impaired if T2 is presented at lag 1 (the lag sparing effect described above) or after a delay of approximately 500 ms or longer. However if only one of two target items is to be detected (also called a single task control condition), no attentional blink is observed. In this single task control condition, identification errors are generally found 22% of the time (Raymond et al., 1992). Hence the dual task condition is one requirement for AB to occur; another is masking (as described above) of targets. For T1, it has been shown that masking can occur using either integration or interruption. Integration occurs when the duration between target and mask is very short, i.e the two items are perceived as one, hence the target is difficult to report, just as when one word is written over another. Masking by interruption (separating T1 and T2 by an interval 200-500ms or longer) is crucial for the lag-dependent AB to occur (Enns et al., 2001; Kranczioch et al., 2003).

### **RSVP and the P300**

Measurement of the effects of RSVP components on the neural activity associated with attentional capacity (using an AB paradigm) is accomplished by recording specific neural events, such as the P300 (refer to figure 6). The P300 wave (refer to figure 6) is an event related potential (ERP) component that appears as a positive deflection in voltage with a latency or delay between stimulus and response of approximately 250 to 500ms

(Luck, 2005). This signal is typically measured most strongly by the electrodes recording from parietal sites (Luck, 2005). The presence, magnitude, topography and timing of this signal are often used as metrics of cognitive function, like attention. It is elicited in the process of decision making and is thought to reflect stimulus evaluation or categorization.



*Figure 6.* Waveform showing the P3 or the P300 component of ERP (positive deflection; plotted downward).

The reproducibility of this signal makes it a feasible option for psychological tests in both the clinic and laboratory (Polich, 2007). For the present study the P300 component for target items is of particular importance, since variations in the processing of different RSVP sequences are linked to measurable changes in latency and amplitude of the P300 (Luck, 2005).

### Goals and Hypotheses of the Present Study

Drawing on past results, the present study will compare the effects of color-visual and audio-visual training on: a) performance in an RSVP task (i.e. correct detection of T1 & T2) as a function of the different time lags; and b) the amplitude and latency of P300 in response to T1.

#### Definition of variables.

The independent variable is training; with 3 levels: (1.) Color-visual training: *red*, *green* and *blue* targets; (2.) Audio-visual training: 300 Hz, 400 Hz and 500 Hz sound frequencies; and (3.) No Training.

There are four dependent variables: (1.) percentage of correctly detected T1 and T2 (2.) performance as a function of lag (3.) amplitude, and (4.) latency of the P300.

TRAINING LEVELS		
COLOR VISUAL	AUDIO VISUAL	NO TRAINING
<i>N=20</i>	<i>N=20</i>	<i>N=20</i>
1) % of correctly identified T1 & T2	1) % of correctly identified T1 & T2	1) % of correctly identified T1 & T2
2) Performance as a function of lag	2) Performance as a function of lag	2) Performance as a function of lag
4) P300 Amplitude	4) P300 Amplitude	4) P300 Amplitude
5) P300 Latency	5) P300 Latency	5) P300 Latency

Figure 7. Design Matrix

Hypotheses:

1. Dual-trial post-test performance (percentage of correctly detected T1&T2) of the color visual training (with RSVP training) will be significantly better than performance in the audio visual training (with RSVP training); and the worst performance is expected in the control group (no RSVP/training).
2. Dual target trial performance (pre-test and post-test) will be the lowest for lag 3 compared with lag 1 and lag 6.
  - 2a. Different colors will produce different levels of AB during training.
  - 2b. Different frequencies will produce different levels of AB during training.
3. Dual-trial P300 amplitude and latency for T1 will decrease from pre-test to post-test. The greatest decrease will be in the color visual condition, 2<sup>nd</sup> greatest in the audio visual condition and the least in the control condition.

## Methods

### Participants

A total of 60 university students were recruited both via the Psychology Department's online SONA system, as well as from outside this participant pool. The students gave consent to participate in the study in return for credit toward fulfillment of a course research requirement. Through the pre-screening questionnaire it was ensured that all participants had normal or corrected-to-normal visual acuity and normal color vision, hearing and were not dyslexic. All participants were individually tested.

### Stimuli.

Stimuli were created and presented using Matlab (Mathworks, Natick, MA), running on a Mac-Book Pro laptop computer (Apple Inc. ®) with a 13-inch monitor (refresh rate of 60 Hz). Performance data was recorded via Matlab and the EEG data was recorded with the Biopac MP150 (©BIOPAC Systems, Inc.) system and Acqknowledge (AcqKnowledge ® 4) software package, running on a Macintosh computer (Apple Inc. ®) with a 27-inch monitor.

Visual stimuli were presented in RSVP format as an alpha-numeric stream of 20 characters consisting of letters from the English alphabet (excluding “B”, “O”, “I”, “Q”, “V,” and “S”) and numbers (excluding “0”, “1” and “8”) in default Helvetica text, (100 font). The viewing distance of 60 cm created a subtending angle of  $7.78^\circ$  by  $0.67^\circ$ . Each string contained either one target (T1; 20% of trials), both targets (T1 and T2; 60% of

trials) or none (20%) and the rest of the characters were considered “distractors”. T1 was always X, T2 was always a number (4 or 7), and the distractors were always letters. During RSVP presentation, each character was presented for a duration of 120ms with no time elapsed between characters. On T2-absent trials a letter was displayed in place of T2. The placement of T1 was varied across trials, i.e. it appeared as the 3<sup>rd</sup>, 4<sup>th</sup>, 5<sup>th</sup>, 6<sup>th</sup> or 7<sup>th</sup> character, in the string of 20 characters. The distance between the first (T1) and second (T2) targets (called the lag position) varied depending on lag positions relative to T1. Hence T2 was presented at lag 1, lag 3, or lag 6 (relative to T1). All trials were pseudo-random with each participant receiving each of the sequences and in the same order. This was done to preserve comparability of the EEG data as it is time-dependent, both within and across sequences. Participants were informed that they would have to indicate whether they saw an X, 4 or 7 in the character stream. They were not informed that an X would be present on all trials in training and that the other target would always be a number. The 30 T1 and T2 absent trials appeared only in Pre-test and Post-test.

In all phases except training (see below for description of phases), all strings of 20 characters were presented in black on a white background. During training, the targets for the color-visual condition were red, green or blue (n=20 each out of 150 total training trials). The colors were matched for luminance (perceived brightness; Red = 255, 0, 0; Green = 0, 255, 0; Blue = 0, 0, 255). The colors were randomly presented across trials and no single color was linked dominantly with AB- or non-AB-inducing lag positions. Similar precautions were taken for auditory stimuli.

During training for the audio visual condition, the targets were always black against a white background. With the onset of each T2, a simultaneous auditory stimulus (tones of 200 Hz, 400 Hz and 800 Hz; n=20 for each tone over 150 total trials; tone duration was 120 msec) was delivered via computer speakers. The tones accompanying both T1 and T2 were uniform across a trial and pseudo-random across the 150 trials. These arrangements were designed to prevent any learning, order or cueing effects. The no-training (control) condition was the same during post and pretest – an RSVP with all black items against a white background.

The MATLAB code developed for this thesis was developed by the author under the guidance of Dr. Leigh Ann Mrotek and may be obtained by e-mailing the author: [singhs70@uwosh.edu](mailto:singhs70@uwosh.edu)

## **Procedure**

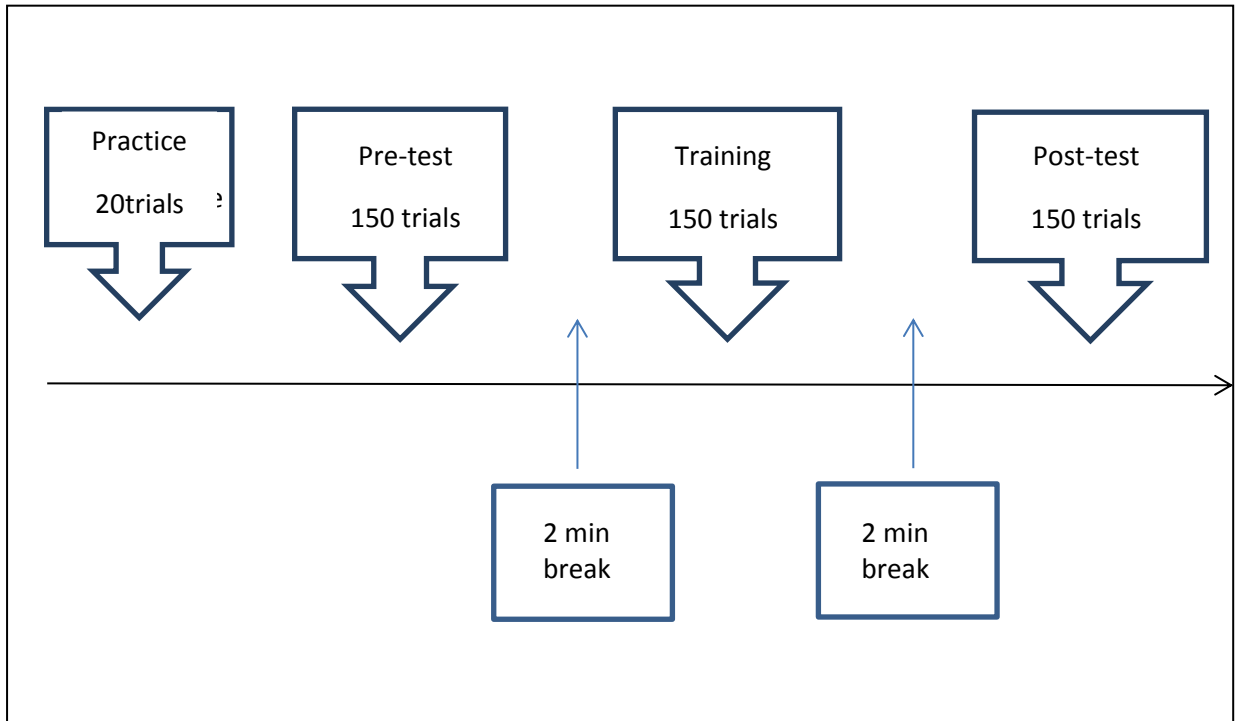
Upon arrival, each participant was greeted by the experimenter who led them to a chair and table near the entrance of the Perception laboratory (125 ft<sup>2</sup>), where they filled out the informed consent form. On completing the informed consent document, participant doubts or questions (if any) were addressed. The participant was asked to remove any remaining jewelry and was then comfortably seated in the chair used for data collection and facing the stimulus-presenting computer. The EEG and human physiology equipment necessary for the study were on a large table behind the participant. The participants were seated in this way so as to allow for minimal distraction and movement

after being connected to the EEG equipment. The experimenter sat a few feet away from the participant, and the screen on which the participant's online physiological responses were displayed was completely blocked from the participant's view. The experimenter then began with instructions about the study and provided a brief description of EEG procedures. After this, similar instructions appeared on the computer screen in written form. All stimuli were presented in the center of the computer screen, following a black fixation cross (500ms), which appeared only at the start of each trial. Participants were instructed to fixate on the cross and press the spacebar, after which the RSVP would commence.

**Verbal Instructions (generic).**

“You will now be presented with a string of characters on the computer screen in front of you, at the end of which you will be requested to answer the following two questions: 1) did you see the letter ‘X’? , and 2) did you see the number “4” or “7”? You are requested to make your response separately to both questions by pressing ‘1’ for yes and ‘0’ for no, on the keyboard. After making your response, hit enter/ return so that the computer registers your response. It is important that you make your response to each question as quickly as possible without compromising accuracy. This first set of trials are practice trials and will allow you to get acquainted with what to do during the experiment. Please do your best and let me know if you have any questions.”

There were four phases to the study (and a total of 470 trials): practice, pre-test, training and post-test.



*Figure 8.* Flowchart of phases.

### 1. **Practice.**

The Practice phase consisted of 20 trials which included practicing the key press and responding as quickly as possible as required in the remaining experimental portion (data from these 20 trials were not analyzed). The present study employed a dual task condition, instructions for which were to indicate whether they had seen an ‘X’ and also whether it was followed by the number ‘4’ or ‘7’ (See figure 9.) The question appeared in the center of the screen prompting an “unspeeded” response (untimed/ without a cut off time to respond). Responses were either ‘yes’ (1) or ‘no’ (0), to be made via keyboard press. No feedback was given regarding the accuracy of responses.

## **2. Pre-test.**

In the pre-test phase, the participant completed 150 trials (approximately 7.72 min total), of which only 60% contained both T1 and T2 (the same was true for the training and post-test sessions). At the end of the pre-test session, the participant was given a 2 min break (at this time they could stretch, relax or sit with their eyes closed).

## **3. Training.**

As before, participants were instructed to indicate, via key press, the presence or absence of target(s) embedded in the RSVP string. For the color-visual training both targets were colored (T1 & T2), in the audio-visual training each target was paired with an audio stimulus, and in the no-training condition, the targets were black against a white background. At the end of the training session the participant was given another 2 min break.

## **4. Post-test.**

In the post-test session the participants completed the last block of 150 trials. The stimuli were exactly the same as for the Pre-test, black against a white background. As before, the participant had to indicate the presence or absence of the target(s).

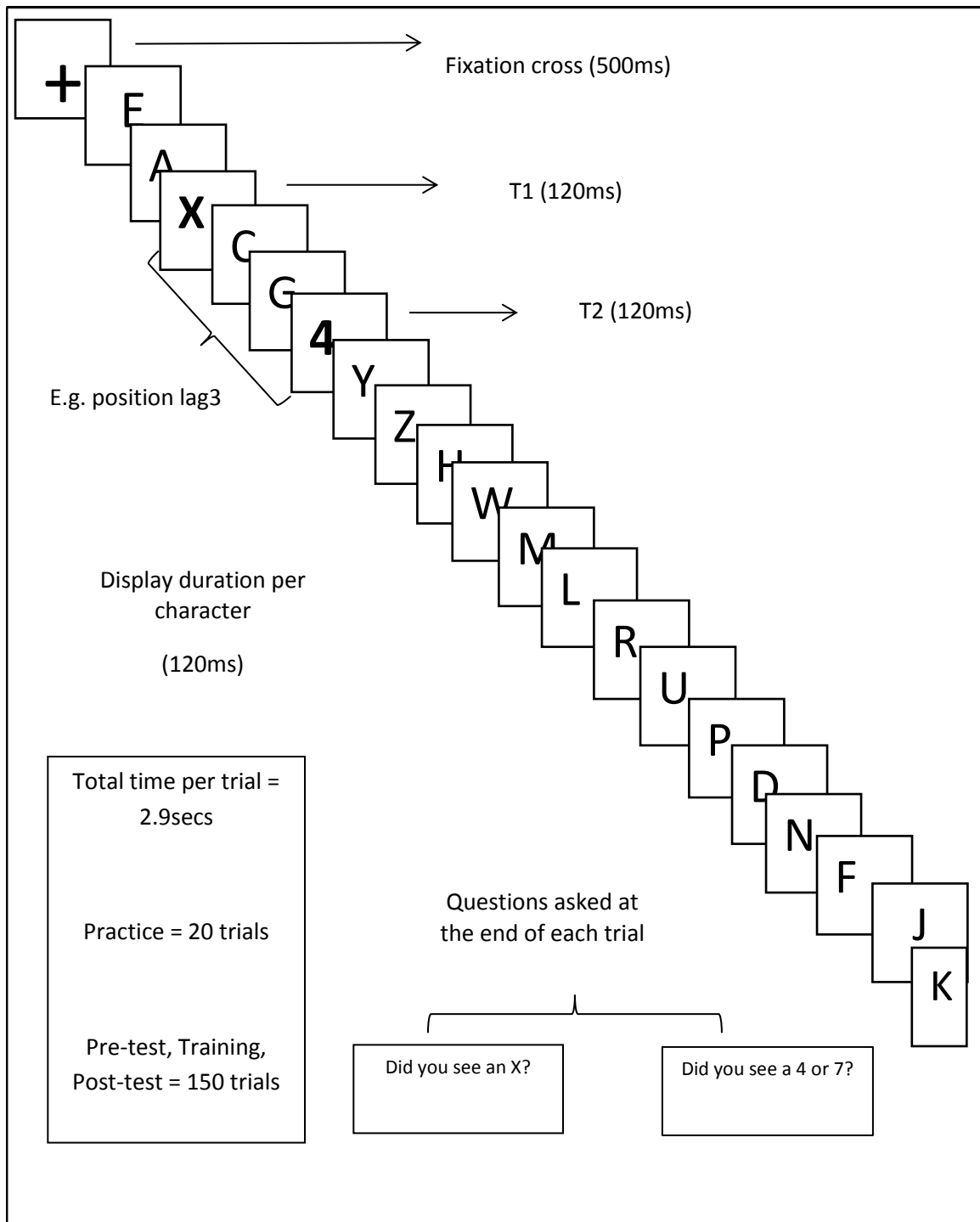


Figure 9. Basic Stimulus flowchart.

### **EEG apparatus & recording.**

Biopac MP150 (©BIOPAC Systems, Inc.) system and the Acqknowledge (AcqKnowledge ® 4) software package were used for electrophysiological recording. As participants had different head sizes, the experimenter measured the circumference of the skull from the nasion to the inion for fitting of the proper EEG cap (refer to figures 10 and 11). The EEG cap (Electro-Cap International, touch proof, CAP100C), with electrodes pre-positioned (stitched) in the international 10/20 montage (Jasper, 1958), was available in three sizes: small (50-54cm); medium (54-58cm) and large (58-62cm). The EEG cap was then placed on the participant's head and properly adjusted: after having anchored it down to a chest strap and holding it in place with two adhesive discs on the forehead, electrode CZ (see figure 11) was positioned at the junction of halfway between the ears and halfway between the nasion and inion (see figure 10).

The scalp under each electrode of interest (PZ, P3, and P4, CZ and ground) was then gently abraded with a blunt-end needle and each electrode was filled with Signa electrode gel (GEL101). Electrode CZ was the reference electrode, and the ground electrode was on the EEG cap itself (along the midline, anterior to CZ). Vertical eye movements (EOG) were recorded via 4mm electrodes one each above and below the right eye. The EEG and EOG signals were amplified with a band pass filter of 0.005-40Hz, at a sampling rate of 20kHz, and with a gain of 2500. Impedance of less than  $5K\Omega$  (Checktrode UFI model 1089ES; see figure 11) was required for each electrode before recording.

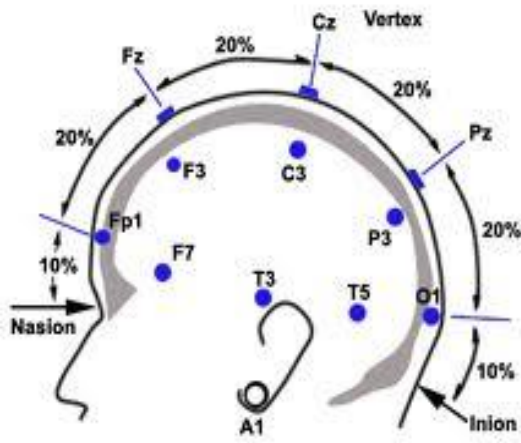


Figure 10. Nasion & Inion

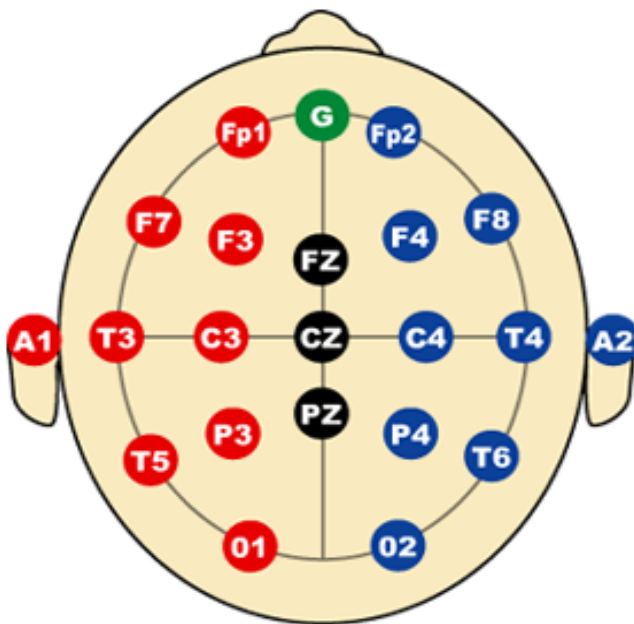


Figure 11. Electrodes of interest: Pz, P3, P4,

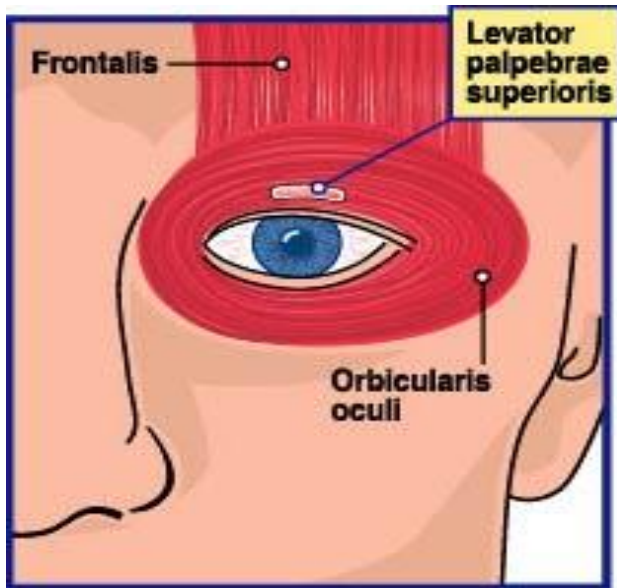


Figure 12. Eye and eye-lid muscles involved in blinking and other eye-movements, of importance in the measurement of EOG.



Figure 13. Checktrode box used to ensure proper operation of EEG equipment.

## **Results**

### **Screening of EEG Data**

Following data collection, EOG artifact removal was performed (using Acq EOG artifact removal tool). After this, the data were divided into epochs of approximately 6 secs (in relation to the onset of T1). The parameters for voltage peaks were set to 0.5 - 500 $\mu$ V. ERPs, relative to the onset of T2, from electrodes P3, P4 and Pz were analyzed.

On the basis of prior research and the nature of this study, the P300 time window was set at 250ms - 500ms after stimulus onset. The P300 will be quantified as the largest positive deflection during that epoch. Both P300 amplitude and latency data will be computed (P300 data are not presented here).

### **Statistical Analyses**

Pre-test and post-test values (overall and for the different lag positions) were obtained for each participant for the single and dual target conditions. This was done for target detection accuracy (behavioral data) as well as for the amplitude and latency of the P300 (physiological data). Data from one participant from the control group were identified as outlier data and excluded from the analyses. ANOVAs (except where pre-test or training is specified) were conducted on post-test data behavioral scores as a 1-way ANOVA of the pretest behavioral/performance data revealed no significant

differences between groups. Analyses of P300 data will be conducted on difference scores to take into account individual variability in pre-training EEG signals.

For behavioral data, performance (accuracy) levels for the single task condition were computed as a percentage of correctly detected T1 items in the post test. Dual task post-test performance was calculated as a percentage of trials in which both T1 and T2 were correctly identified.

To probe for evidence of attentional blink, a mixed 3 x 3 ANOVA was conducted for performance as a function of lag time across each training group for pre-test accuracy on dual trials. A similar 3 x 3 mixed ANOVA was run on post-test performance for dual target trials.

A 2 x 3 mixed ANOVA was performed using single and dual target performance on pre-test, training and post test scores as the within subjects factor and training groups as the between subjects factor.

Finally, four separate 1 x 3 repeated measures ANOVAs were conducted on single and dual task trials to investigate whether the colored stimuli (red, blue, green) or the audio frequencies (200Hz, 400Hz, 800Hz) had an effect on performance during training (between pre-test and post-test).

## Behavioral Performance

### Performance accuracy by trial type across groups

Although not hypothesized, it is essential that single target trials (baseline performance) should be easier to detect than dual target trials. Detection impairment in the latter stems from the need to allocate more resources to T2 while T1 is still being processed, which is reflective of AB. The descriptives and analysis below show performance by trial type (single vs. dual) and differences across training groups and experimental phases.

A 2 x 3 mixed ANOVA was run on single and dual target trial performance during the pre-test for all groups, with type of trial (single or dual target) as the within subjects factor and training group as the between subjects factor. A significant main effect was obtained for type of trial,  $F(1, 56) = 158.20, p < .01, \eta^2 = .74$ . There was no significant effect for training,  $F(2, 56) = .86, p > .05, \eta^2 = .03$ . There was no significant interaction between type of trial and training,  $F(2, 56) = 1.57, p = .22, \eta^2 = .05$ . (Refer to figure 20 below)

*Table 1. Means and standard errors of Single and Dual target trials at pre-test.*

Training group	T1 trials (single)			T1 & T2 trials (dual)	
	<i>N</i>	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>
Visual	20	77.14	3.75	44.14	4.97
Audio	20	72.14	3.75	44.79	4.97
Control	19	81.20	3.85	52.81	5.10
Total	59	76.83*	3.78	47.25	5.01

(\* $p < .001$ )

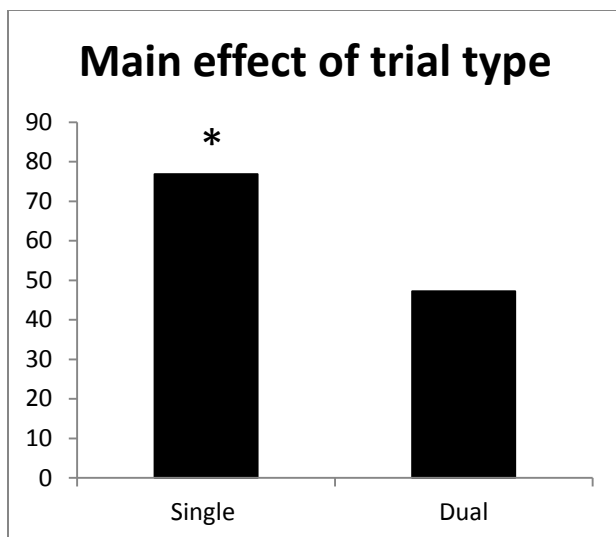
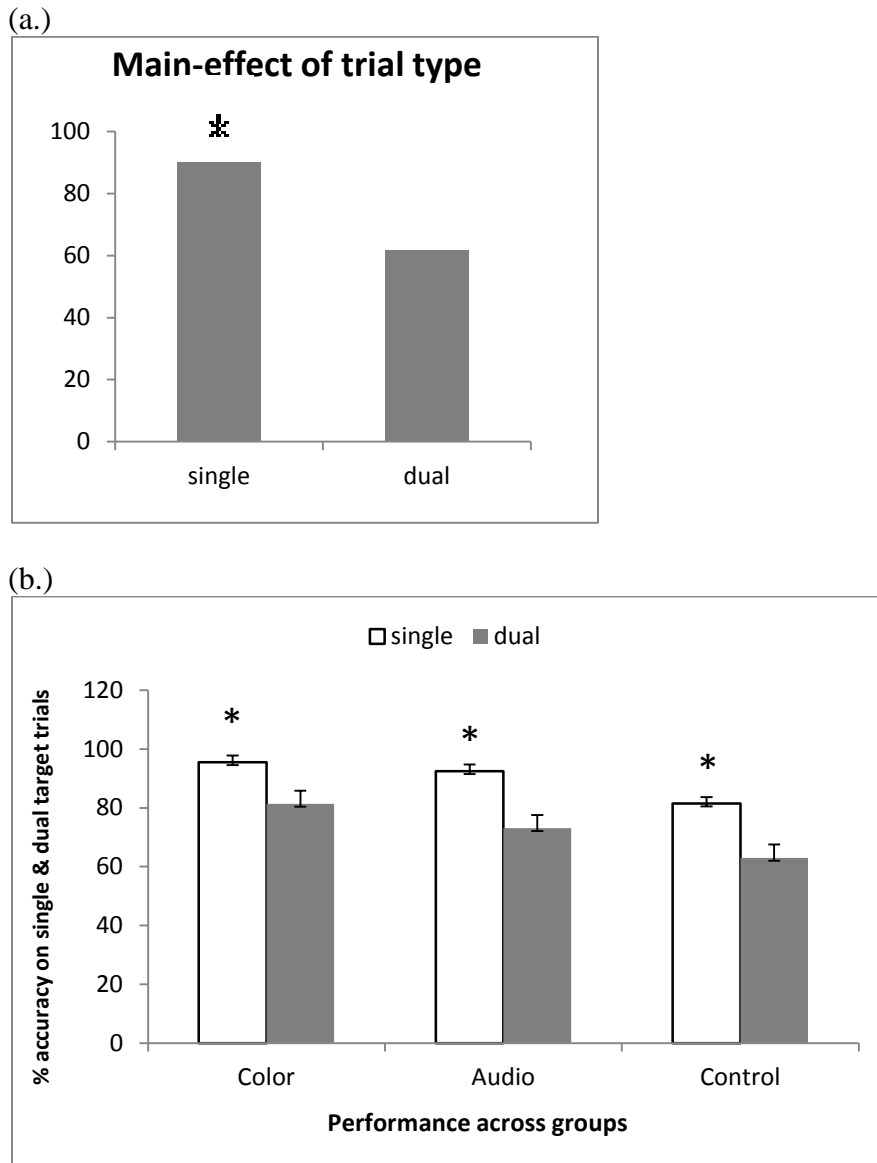


Figure 14. Graph showing main effect for trial type at pre-test; \* denotes significant performance increase for single trials.

A 2 x 3 mixed ANOVA was run on single and dual target trial performance during the training for all groups, with type of trial (single or dual target) as the within subjects factor and training group as the between subjects factor. There was a significant effect for type of trial (single or dual),  $F(1, 56) = 49.75, p < .01, \eta^2 = .47$ . There was no significant effect for training,  $F(2, 56) = 8.18, p = .001, \eta^2 = .23$ . There was no significant interaction between trial type and training group,  $F(1, 56) = .44, p > .05, \eta^2 = .01$ .

Table 2. Means and standard errors for single and dual target trials during training.

Training group	Single			Dual	
	<i>N</i>	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>
Visual	20	95.58	2.27	81.44	4.46
Audio	20	92.50	2.27	73.16	4.46
Control	19	81.49	2.23	62.98	4.58
Total	59	89.99*	2.26	61.64	4.50



*Figure 15.* Single and dual target performance for all groups in the training phase. (a.) Main effect for trial type; \* denotes significant performance increase for single trials. (b.) Training performance across groups by trial type; \*\*denotes significantly better performance for single trials. (significant at  $*p < .05$ ).

A 2 x 3 mixed ANOVA was run using single and dual target trial performance on post test scores as the within subjects factor and training groups as the between subjects

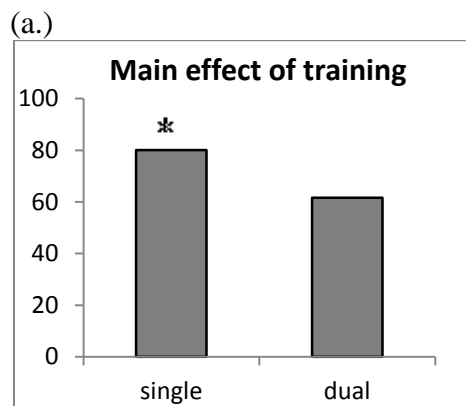
factor and resulted in no significant main effect for training type  $F(2, 56) = .60, p > .05, \eta^2 = .02$ . There was a significant main effect for type of trial, Greenhouse-Geisser  $F(1, 56) = 63.32, p < .001, \eta^2 = .53$ , such that post-test performance on single trials was significantly better than that on dual trials. There was no significant interaction between training and trial type,  $F(2, 56) = 1.81, p = .17, \eta^2 = .06$ .

Table 3 shows the means and standard error for post-test performance by condition on single and dual target trials. Figure 16 shows performance accuracy across training groups for single and dual target detection in the post-test.

*Table 3. Means and standard errors of Single and Dual target trials at post-test.*

Training group	T1 trials (single)			T1 & T2 trials (dual)	
	<i>N</i>	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>
Visual	20	79.82	3.35	58.91	4.91
Audio	20	80.36	4.06	67.99	4.47
Control	19	80.26	3.60	57.83	4.67
Total	59	80.15*	2.09	61.64	2.73

(\* $p < .001$ )



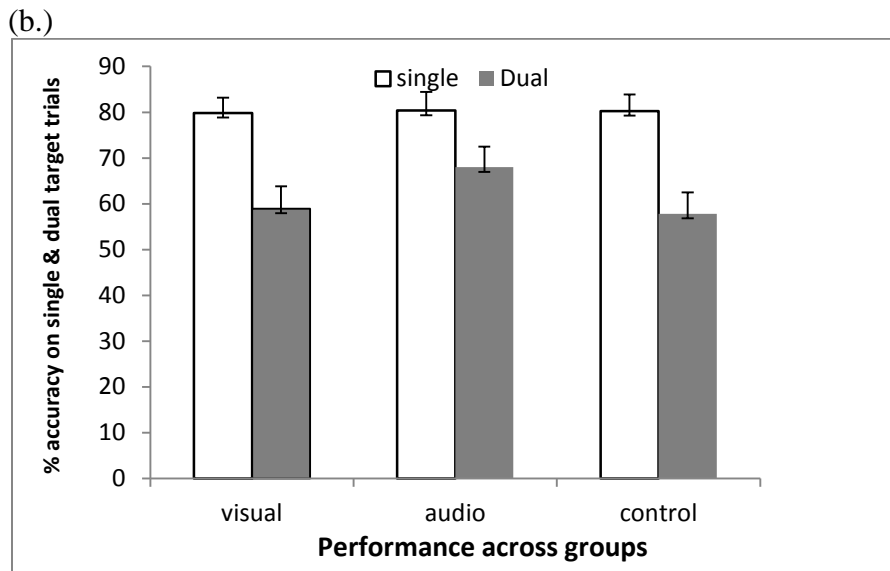
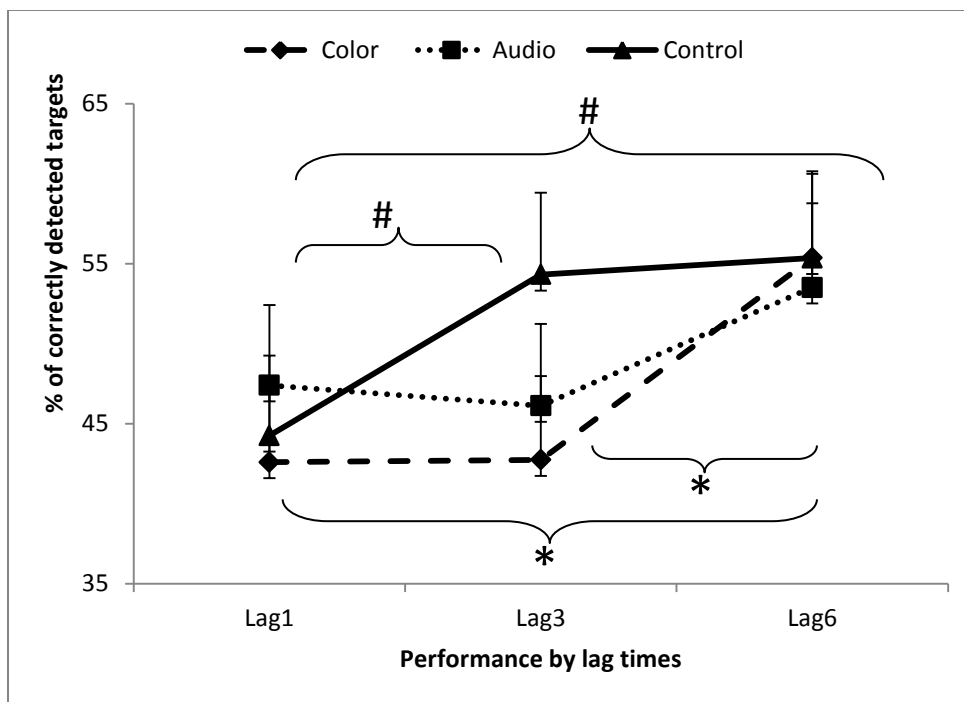


Figure 16. Graphs showing performance across training groups. (a.) Main effect of training; \* denotes significant performance increase for single trials. (b.) Post-test performance by type of trial for each training group; (significant at  $*p < .05$ )

### Performance by lag time.

The second set of hypotheses involved performance at each lag time for the different training groups. A 3 x 3 mixed ANOVA on pre-test scores using lag time performance on dual target trials as the dependent variable and lag times and training type as the independent variables revealed no significant main effect for training  $F(2, 56) = .21, p = .82, \eta^2 = .01$ . There was a significant main effect across lag times, Greenhouse-Geisser,  $F(1.72, 96.54) = 16.38, p < .001, \eta^2 = .23$ . Protected dependent t-tests for the performance scores on pre-test dual trials revealed no significant differences between performance at lag 1 ( $M = 44.75, SE = 2.95$ ) and lag 3 ( $M = 47.73, SE = 2.9$ ), ( $p > .05$ ). There was an increase in performance from lag 3 to lag 6 ( $M = 54.75, SE = 3.07$ ), ( $p < .001$ ) as well as a significant increase from lag 1 to lag 6 ( $p < .001$ ). There was a

significant interaction for lag time by training,  $F(3.45, 96.54) = 2.88, p < .05, \eta^2 = .09$ , however an effect size of .09 suggests low practical value. Three separate 1-way repeated measures ANOVAs (one for each training group) were run to test for simple effects of training at levels of lag time. A significant effect existed for the lag times in the color training group,  $F(1.6, 30.8) = 10.77, p = .001, \eta^2 = .36$ , but not for the audio training group,  $F(1.32, 25.07) = 2.99, p > .05, \eta^2 = .14$ . There was also a significant effect for the lag time performance in the control group,  $F(1.86, 33.46) = 8.96, p = .001, \eta^2 = .33$ . Post-hoc dependent t-tests indicated that performance in the color training group significantly increased from lag 1 to lag 6,  $t(19) = -3.66, p = .002$  as well as from lag 3 to lag 6  $t(19) = -3.55, p = .002$ . A different trend was observed in the control group, where performance increased significantly from lag 1 to lag 3,  $t(18) = -3.24, p = .005$ , and lag 1 to lag 6,  $t(18) = -4.50, p < .001$ . (Refer to figure 17)



*Figure 17.* Interaction for lag time by training for dual target trials in the pre-test; \*denotes significant differences across lag times 1 to 6 & 3 to 6 (color); # denotes significant differences across lag times 1 to 3 & 1 to 6 (control). (Significant at  $*p < .05$ )

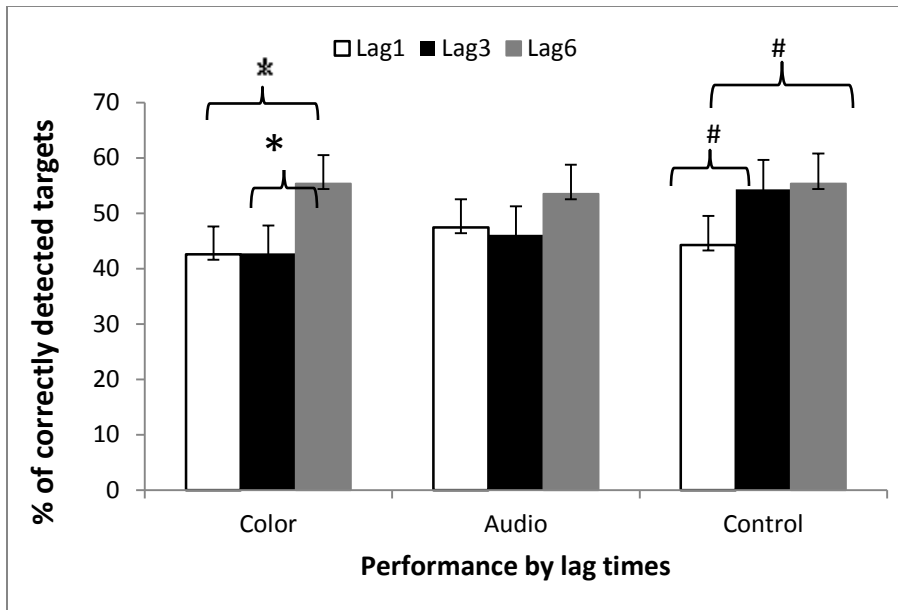
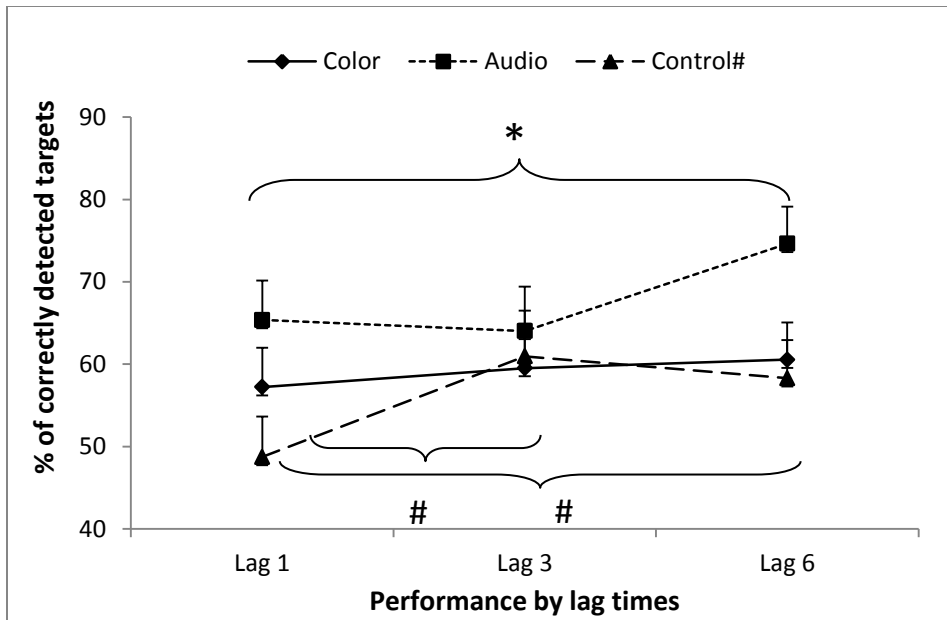


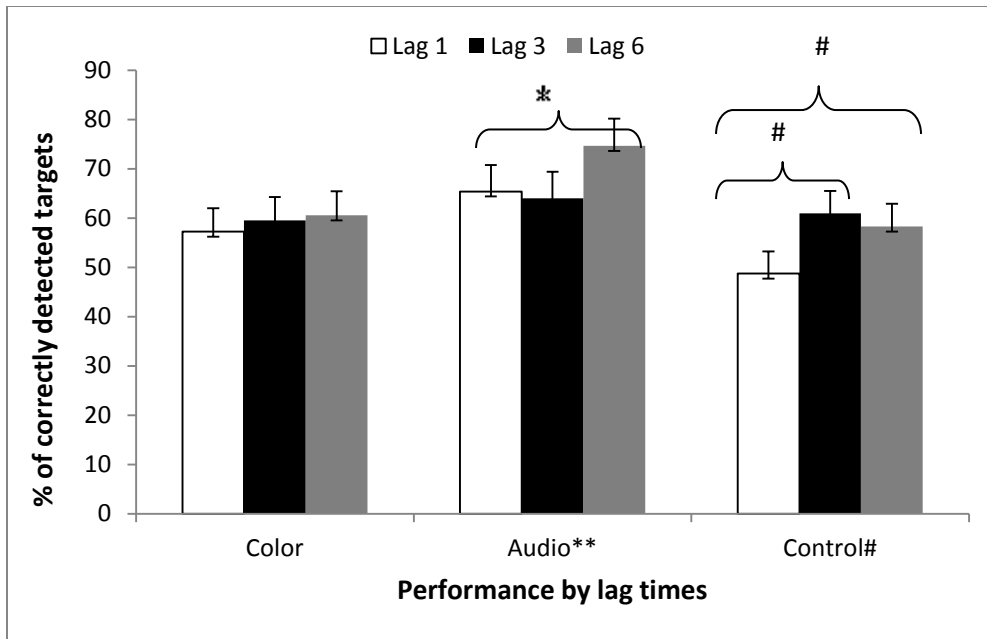
Figure 18. Performance accuracy by lag for dual targets in the pre-test; \* denotes significant increase from lag 1 to lag 6, and lag 3 to lag 6 (color); # denotes significant increase from lag 1 to lag 3 and lag 1 to lag 6 (control); (significant at  $*p < .05$ )

A second 3 x 3 mixed ANOVA was conducted on post-test performance accuracy, again using lag time performance on dual target trials as the dependent variable and lag times and training type as the independent variables revealed. Again, there was no significant main effect for training  $F(2, 56) = 1.86, p > .05$ , but the mean differences across training groups indicated that performance accuracy in the audio group was higher than the color-visual and the control group, with performance in the control group being the worst (see Table 3 for means and SE). There was a significant main effect for lag time, Greenhouse-Geisser correction  $F(1.47, 82.75) = 7.51, p < .05, \eta^2 = .12$ . Protected dependent t-tests for lag time performance indicated that performance increased significantly from lag 1 ( $M = 77.07, SE = 2.01$ ) to lag 3 ( $M = 82.60, SD = 1.78$ ), ( $p < .01$ ),

and from lag 1 to lag 6 ( $M = 82.83$ ,  $SD = 1.8$ ), ( $p < .001$ ) but not between 3 and 6 ( $p > .05$ ). There was also a significant interaction between training and lag times, Greenhouse-Geisser  $F(2.95, 82.75) = 3.26$ ,  $p < .05$ ,  $\eta^2 = .10$ . To follow up the significant interaction, simple main effects analyses were run with three separate 1-way repeated measures ANOVAs (one for each training group). No significant differences were found across lag time performance within the color training group, Greenhouse-Geisser,  $F(1.56, 29.72) = .79$ ,  $p > .05$ ,  $\eta^2 = .04$ . Performance differences across the three lag times were significant for the audio training group, Greenhouse-Geisser,  $F(1.21, 23.04) = 4.16$ ,  $p = .05$ ,  $\eta^2 = .18$ . The control group performance scores also demonstrated significant differences across lag times, Greenhouse-Geisser,  $F(1.57, 28.28) = 8.78$ ,  $p < .05$ ,  $\eta^2 = .33$ . Post hoc dependent t-tests indicated that in the audio group, performance at lag time increased significantly from lag 1 to lag time 6  $t(19) = -3.28$ ,  $p < .01$ . In the control group, performance improved from lag 1 to lag 3  $t(18) = -4.15$ ,  $p < .01$ , and also improved from lag 1 to lag 6  $t(18) = -4.05$ ,  $p < .01$ .



*Figure 19.* Interaction for training and lag times for dual trials at post-test. \*denotes significant differences across lag times 1 to 6 (audio); # denotes significant differences across lag times 1 to 3 & 1 to 6 (control); (significant at  $*p < .05$ )



*Figure 20.* Post-test performance accuracy across groups and lag times for dual trials. \* denotes significant increase from lag 1 and lag 6 (audio); # denotes significant increase from lag 1 to lag 3 and lag 1 to lag 6 (control); (significant at  $*p < .05$ )

### Colors and sounds.

The third set of hypotheses was an inquiry into whether any of the color-visual or audio-visual stimuli would produce any performance differences during the training phase.

Separate 1 x 3 within subjects ANOVAs were run on the performance during training for single and dual trials in the color-visual group to determine whether any one of the colored stimuli out of red, green or blue would have a significant effect on performance outcomes. There were no significant differences for single  $F(1.44, 27.33) = 1.93, p > .05, \eta^2 = .06$  or for dual target trials  $F(1.85, 35.16) = .84, p > .05, \eta^2 = .04$ .

Similarly, two 1 x 3 within subjects ANOVAs were performed on participants in the

audio-visual group,. No significant differences were found between the three sound frequencies, for single target trials  $F(1.78, 33.96) = .18, p > .05, \eta^2 = .1$  or for dual target trials  $F(1.67, 31.72) = .13, p > .05, \eta^2 = .01$ .

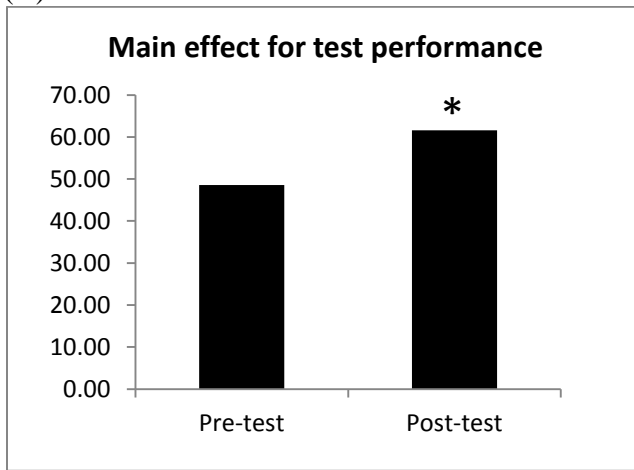
#### **Exploratory analyses: comparing pre-test and post-test.**

A 2 x 3 mixed ANOVA was run on dual target trial performance during pre-test and post-test with test performance as the within subjects factors and training type as the between subjects factor. Results revealed that there was a significant main effect for test performance, Greenhouse-Geisser correction,  $F(1, 56) = 30.26, p > .01, \eta^2 = .35$ . There was no significant effect for training,  $F(2, 56) = .62, p > .05, \eta^2 = .02$ . There was a significant interaction between test performance and training,  $F(2, 56) = 3.1, p = .05, \eta^2 = .10$ . To follow up the significant interaction, post hoc dependent t-tests indicated that performance significantly improved at post-test for the color-visual group,  $t(19) = -3.35, p < .01$ . Performance in the audio-visual group also increased significantly at post-test,  $t(18) = -4.85, p < .01$ . The control group did not show a significant change between pre-test and post-test,  $t(18) = -1.29, p > .05$ .

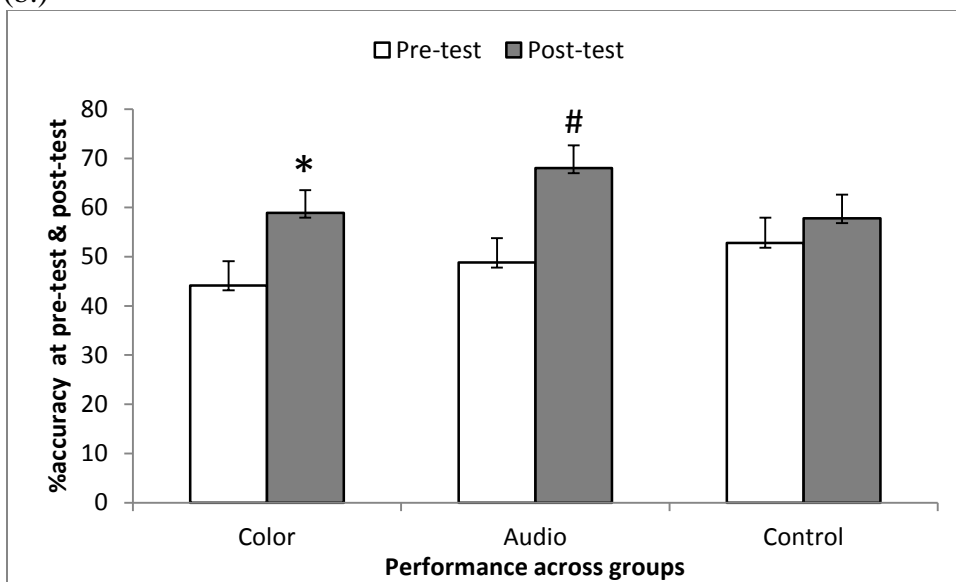
*Table 4. Means and standard errors at pre-test and post-test across training groups.*

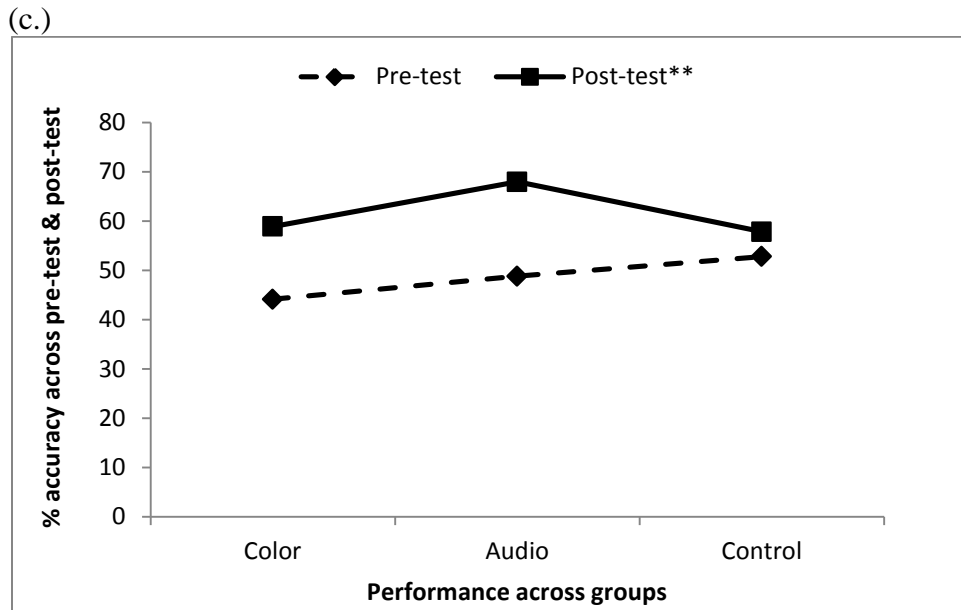
Training group	Pre-test			Post-test	
	<i>N</i>	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>
Visual	20	44.14	4.97	58.91	4.46
Audio	20	48.80	4.97	67.99	4.46
Control	19	52.81	5.10	57.83	4.58
Total	59	48.58	5.01	61.58	4.69

(a.)



(b.)





*Figure 21.* Pre-test and Post-test performance across groups for dual trials. (a.) Main effect of training; \* denotes significant performance increase in the post-test. (b.) Pre and post-test performance for each training group; \* denotes significant increase in post-test performance (color), # denotes significant increase in post-test performance (audio). (c.) Interaction for testing performance and training group; \* denotes a significant difference in post-test performance across groups; (significant at  $*p < .05$ ).

### **Exploratory analyses: by individual lag time.**

To further explore performance accuracy on dual target trials at pre-test and post-test, 2 x 3 repeated measures ANOVAs were run, one for each lag time.

A 2 x 3 mixed ANOVA was conducted first on dual target performance accuracy at lag 1, using pre-test and post-test performance (on dual target trials) as the within subject variables and training group as the between subjects variables. There was a significant main effect for experimental test phase (whether pre-test or post-test),  $F(1,56) = 20.77, p < .01, \eta^2 = .27$  but no significant effect was found across training groups,

$F(2,56) = 1.34, p > .05, \eta^2 = .04$ . There was also no significant interaction between test phase and training group,  $F(2,56) = 2.20, p > .05, \eta^2 = .07$ .

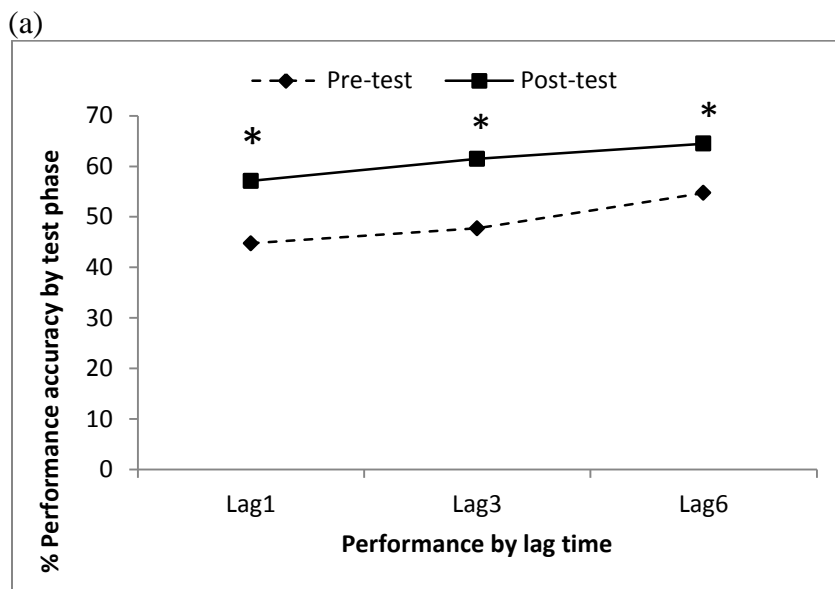
A 2 x 3 mixed ANOVA was then conducted on dual target performance accuracy at lag 3, using pre-test and post-test performance (on dual target trials) as the within subject variables and training group as the between subjects variables. There was a significant main effect for experimental test phase (whether pre-test or post-test),  $F(1,56) = 32.21, p < .01, \eta^2 = .37$  but no significant effect was found across training groups,  $F(2,56) = .45, p > .05, \eta^2 = .01$ . There was also no significant interaction between test phase and training group,  $F(2,56) = 2.15, p > .05, \eta^2 = .07$ .

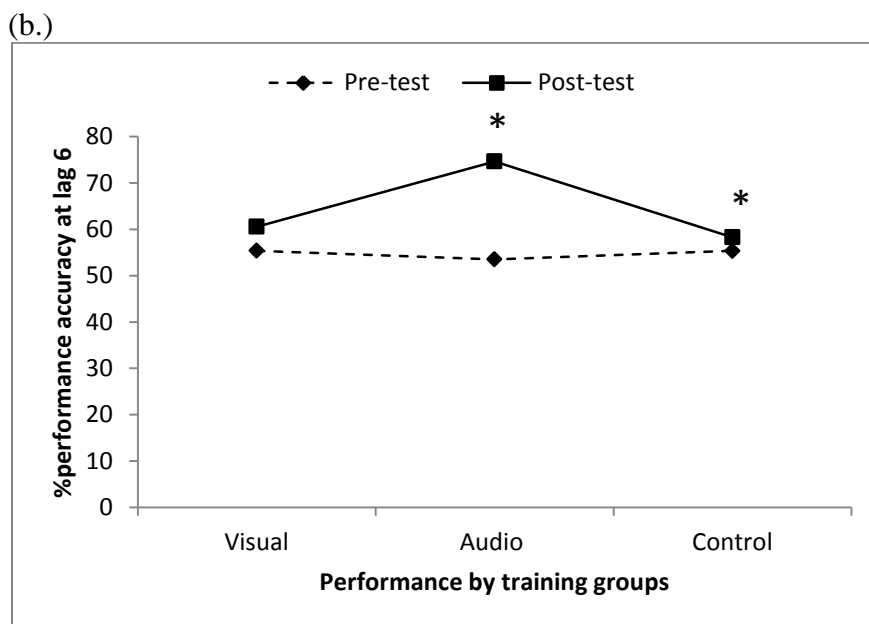
A 2 x 3 mixed ANOVA was finally conducted first on dual target performance accuracy at lag 6, using pre-test and post-test performance (on dual target trials) as the within subject variables and training group as the between subjects variables. There was a significant main effect for experimental test phase (whether pre-test or post-test),  $F(1,56) = 11.00, p < .01, \eta^2 = .16$  but no significant effect was found across training groups,  $F(2,56) = .43, p > .05, \eta^2 = .03$ . There was a significant interaction between test phase and training group,  $F(2,56) = 3.82, p < .05, \eta^2 = .12$ .

To follow up the significant interaction, post hoc dependent t-tests indicated that in the color group, performance at lag 6 did not significantly increase from pre-test to post test,  $t(19) = .90, p > .05$ . In the audio group, performance did significantly improve from pre-test to post-test,  $t(19) = -4.45, p < .01$ , and the control group did not show a significant increase in performance between pre-test and post-test,  $t(18) = -.63, p > .05$ .

*Table 5. Means and standard errors at pre-test and post-test across lag times.*

Lag times	Pre-test		Post-test	
	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>
Lag1	44.75	2.92	57.11	2.79
Lag3	47.73	2.97	61.50	3.14
Lag6	54.75	3.07	64.49	2.63
Total	49.08	2.99	61.03	2.85





*Figure 22.* Dual target trial test- phase performance per lag time across training groups. (a.) Dual target test-phase performance per lag time. \* denotes significant main effect for post-test performance (all lags). (b.) Interaction for lag time performance by training group at lag 6. \* denotes significant increase at post-test performance (Audio, Control).

## Discussion

The purpose of this study was to investigate if exposure to audio training, visual training or a control (no training) condition by way of an odd ball paradigm would lead to a reduction in AB. Each test phase (pre-test, training and post-test) was analyzed to identify any evidence of the AB effect or the potential counteracting of this effect by training. AB is an expected impairment in attention, involving failure to detect a second target, when presented at shorter lags (relative to a first target). The ideal AB curve demonstrates that performance on dual target trials is not impaired at lag 1 (when there are no intervening distracters between T1 and T2). The AB is then said to typically occur between ~100 to 500 ms (lags with one or more intervening distracters between T1 & T2), but recovers to the baseline level of accuracy or higher at longer lag intervals (Raymond et al., 1992)

### **Performance accuracy by trial type.**

The first set of analyses provides evidence for one of the necessary parameters for studies of AB: participants found it easier to correctly detect targets on single target trials compared to dual target trials across all groups and phases, irrespective of lag time. Performance accuracy on dual target trials was computed as the participant having correctly identified T2 when T1 was also correct. Several models have been developed to explain this difficulty in dual target performance accuracy. The two-stage model (Chun & Potter, 1995) contends that processing T1 interferes with processing of a second target,

T2, appearing within half a second. In stage 1, all stimuli are processed, involving comprehension of item features and meaning but not at a level that is worthy of/sufficient to report. In stage 2, stimuli are consolidated at a level that is adequate for response. By contrast, the central interference theory (Jolicoeur, 1998, 1999; Jolicoeur & Dell'Acqua, 1998) claims that a bottleneck occurs during working memory consolidation, a process requiring limited central (amodal) resources. As opposed to the two-stage model, the central interference theory stipulates that AB is not restricted to the visual modality (Chun & Potter, 1995), and thus may be more applicable to the relatively small audio AB found in the present study. Indeed, Vachon & Trambly, (2005) established functional characteristics of auditory AB that are similar to those typically associated with visual AB. They suggest that visual and auditory AB phenomena result from common mechanisms, probably central and amodal in nature. They also mention that potential constraints within each sensory system could modulate limitations on attention (e.g., Arnell & Duncan, 2002; Arnell & Larson, 2002). Haroush and colleagues, (2011) showed that during visual AB, auditory processing was not inhibited, as might be expected from sensory system overload.

A third explanation for the dual target processing difficulty (i.e. AB) can be found in the ST2 model, a connectionist model of temporal attention and working memory which encapsulates five main principles: (a) M. M. Chun and M. C. Potter's (1995) 2-stage model, (b) a Stage 1 salience filter, (c) N. G. Kanwisher's (1987, types (featural representation) and tokens (episodic context) distinction among items, (d) a transient

attentional enhancement, and (e) a mechanism for associating types with tokens called the binding pool. This model is often conceptualized with the salience filter as a bottleneck, restricting what passes through it. The ST2 model states that AB occurs because although Stage 2 is occupied encoding T1, T2 is decaying at Stage 1 and may have decayed completely by the time Stage 2 is disengaged from processing T1's information. More specifically, the blink occurs because the tokenization process (segmentation of items) is overloaded, in the sense that targets arrive so rapidly that T1 is still being tokenized when T2 arrives. As a result, the system forfeits tokenization of T2 in order to prevent it from interfering with the tokenization of T1. This could mean that the blink is an automatic mechanism to avoid any binding of T2 resulting from confusion, to a token that is in the process of being allocated to T1 (Bowman & Wyble, 2007). This would account for performance on single target trials being higher than that on dual target trials. With regards to lag time, performance is better at longer lags (600ms or more) as the tokenization is spread out over a longer time frame - targets arrive slowly (relative to shorter lags at 100- 500ms) and hence both targets are detected (on dual trials). Lag 1 sparing, though (see below), is not well-explained by this model.

### **Performance accuracy by training group.**

It was predicted that the performance of the color visual training group would be significantly better than performance in the audio and control groups. Performance for both the color and audio groups (but not control) increased significantly from pre-test to post-test, raising the possibility that the increase is due to training, but that few

differences exist between the effects of the different training modalities. Further, although the pre-test audio AB effect was small, this trend was not present in the post-test. This performance trend is not evident in the control group, which fits with their having received no training. The lack of change in the control group is evidence that simply providing exposure (practice) to the same set of trials thrice does not increase RSVP dual target performance.

### **Evidence of AB.**

#### *Performance as a function of lag time.*

After having established that dual target detection performance was worse than that of single target performance, and to find evidence of AB, it was necessary to tease apart performance as a function of lag times for dual trials. This was in line with the second set of hypotheses that predicted performance would be the worst at lag 3 and comparatively better at lag 1 and lag 6, and thus demonstrate the lag effect for AB. Evidence of lag 1 sparing in the present study is absent and although previous studies show varying results of lag 1 sparing evidence, impairment at lag 1 has been recorded in prior research (Dux, Wyble, Jolicoeur, & Dell'Acqua, (in press)). Pre-test performance was significantly affected by lag time but not training type, with performance at lag 3 decreasing slightly for the audio group compared to lags 1 and 6. For the color group, there was a climb in performance from lag 1 to lag 6, though little change from lag 1 to lag 3. By contrast, the control group improved from lag 1 to lag 3, but changed little from lag 3 to lag 6 (Refer to figures 14 & 16).

For post-test performance, the pattern for the control group was similar to that of its pre-test scores for all lag times, these consistent performance levels demonstrated that only having repeated exposure was not enough to improve performance. The audio group on the other hand improved their performance at lags 3 and 6 compared to lag 1 and overall compared to the pretest at all lag times. The color group showed no differences in performance by lag time but also improved overall at all lag times compared to pre-test performance. The overall improvement of the color and audio groups as compared to the control group is evidence of an effect of training on attentional performance, though potential differential effects of audio- vs. color-oriented training remain unclear. In addition, although the evidence for AB in the pre-test data is not compelling, the post-test data indicate not only an overall lack of AB but also a flattening out of the response curve in two of the three groups. Further, the color-trained group improves the most from pre- to post-test and shows smaller differences in performance by lag time in the post-test.

Another aspect of AB is lag 1 sparing, characterized by the fact that targets presented with no intervening distracter between T1 and T2 seem to escape the effect of AB. Although, this phenomenon is commonly noted in previous research, there are a variety of theories competing to provide an explanation: attentional gate, resource depletion, bottle neck, and the two-stage theory. Contributing to this debate is that stimulus duration, lag durations, number of lags and number of targets used vary across studies (Akyürek & Hommel, 2005; Visser & Enns, 2001). For example, Dell'Acqua et al. (2009) observed a drop in performance accuracy in sequential target report when T3

performance was dependent on T1 and T2 accuracy. Further, Dell'Acqua et al. (2012) found the target report was impaired when T1, T2 and T3 appeared sequentially, as opposed to when seven distractors separated the targets from one another. These findings possibly indicate that structural encoding limitations do influence target report in RSVP. Dux, Wyble, Jolicoeur, & Dell'Acqua, (in press) interpreted the above results as reflecting mutual interference between targets that appear in close proximity within the RSVP stream. Thus, depending on the time frame of lag 1 (present study: lag 1 = 120ms, lag 3 = 240ms) this could potentially be seen as a cost to lag 1 or a competitive exchange between T1 and T2 to both be encoded in WM and reproduced shortly after the RSVP (Dux et al., in press). The resource sharing hypothesis provides a good explanation of this cost to lag 1. It suggests that if the system allocates fewer resources to T1, more attention is available for T2, and hence T2 is more likely to be detected. If, however, too many resources are allocated to T1, T2 is more likely to be missed, which results in AB or performance impairment, as in the present study (Kranzloch et al., 2007). The study by Dux and colleagues was similar to the present study in terms of having no ISI. Participants were always exposed to 20 practice trials. One interesting finding in their study was that the AB effect was more prominent in experiments containing three as compared with only two targets in the RSVP stream. This could explain the current study's findings of a partial AB effect. The study by Dell'Acqua and colleagues, (2012) also explicitly mentioned in participant instructions that speed of responses were not important.

### **Colors and sounds.**

With the final set of hypotheses (general/ non-directional), the study attempted to disclose whether any of the different stimuli (the colors chosen in the color training group and the sound frequencies in the audio training group) could elicit better performance compared to others. This hypothesis was more general and non-directional in nature, For instance, red targets have been shown to stand out and improve detectability as compared to black targets (Dux & Marois, 2008). The present data, however, showed overlapping performance trends for the three colors and three sounds. This lack of difference might in part be the result of stimuli characteristics and the RSVP design. All three colors had equal luminescence, all three sounds were the same amplitude and timbre, and each stimulus was equally distributed across trials. It may be necessary to vary more stimulus features than just frequency in order to produce differential effects on post-training RSVP performance.

### **Performance by phase.**

As an exploratory step, performance accuracy on dual target trials at pre-test and post-test across training groups were conducted for each lag time. This was done to tease apart any differences in lag time performance effects. It was observed that performance at each lag time increased significantly at post-test, with the highest increase in performance at lag 3. This bolsters the claim that AB impairment existing at pre-test was potentially counteracted by post-test. As far as training group was concerned, the audio and control group, showed a significant performance increase at post-test for lag 6.

### **Current study vs. Other AB studies.**

It is important to note that in this experiment participants were not explicitly informed that they were going to receive training. One possible positive outcome of explicitly informing participants that training would be involved could be that participants might be more alert during training and the post-test. The impact of expectations about training effects on performance would be valuable to explore in future research.

In the present study, duration of the training phase (approximately 15 - 20 mins) could be considered short compared to other attention training studies. For example, in a study by Slagter and colleagues (2007), three months of intensive mental training resulted in a smaller attentional blink and reduced brain-resource allocation to the first target. However a study by Choi and colleagues (2012) used the color-salient training effect (red-targets) and found that just 1hr of specific attentional training can completely eliminate AB, and that this effect is robust enough to persist for a few months after training. This training, however, took place over two days, one training session per day. Leber and colleagues (2009) showed learning of an attentional set guided by a training phase that lasted for approximately 25 mins. Future studies would most likely benefit from training sessions that span a longer duration than in the present study. The basic design of the current study was akin to prior AB studies (Di Lollo et al., 2005; Hommel & Akyurek, 2005; Visser & Enns, 2001) but stands out in its endeavor to streamline attention on an RSVP task. Since this study was more concerned with the

effects of training, the design was more focused on performance accuracy rather than a speeded response (sometimes used in AB studies). A timed response might compel participants to guess while responding, due to the time constraint. Unspeeded responding relieves a person of any time-related pressure and instead allows them to allocate mental resources to target detection accuracy. Additionally, many AB studies have required a more stringent response criteria, i.e. identification of the target rather than merely detecting its presence (eg: reproducing the exact letter/ number target instead of just choosing a 'yes' or 'no' response) as well as remembering the temporal order of targets in a given sequence. The task in the current study's design was to simply detect two targets, at 3 lags - reproduction of the target was not required and neither was temporal order of targets. Perhaps this is one reason why these studies showed stronger evidence of AB than the current one. Another factor that is often taken into consideration in AB studies is the use of the inter stimulus interval (ISI) which was not a part of this study. While some AB studies have shown that ISIs of varying durations are sufficient to produce the AB effect (Di Lollo et al., 2005) other studies have shown that performance often decreases as ISI increases (Visser & Enns, 2001). The decision to not use ISI in the present study was based on concerns of fatigue leading to drops in performance in the latter portions of each phase as well as overall in the post-test, where it was hoped training would increase performance.

In light of the present study, a possible explanation for the lack of a strong AB effect could be individual differences in attentional capacity across participants. It is

possible that some of them would be characterized as “non-blinkers” (see below) as these individuals are used to task switching and parallel information processing. Although 5-10 % of all participants across studies do not show AB (i.e. are non-blinkers), studies on non-blinkers' AB are scant (Troche & Rammsayer, 2013). Willems and colleagues (2013) recently provided a mechanistic framework for such individual differences in selective attention. They suggest a distinctive ability of non-blinkers to accurately perceive targets presented in close temporal succession due to a relatively faster and more precise target selection process, compared to people who show a larger AB effect. Non-blinkers continue to show little or no AB when identification of targets is made more difficult by either increasing the overall rate of stimulus presentation (Martens, Munneke, et al. 2006) or specifically reducing the duration of the targets (Martens, Dun, Wyble, Potter, 2010; Martens et al., 2009; Martens, Korucuoglu et al., 2010). In addition, non-blinkers do not seem to differ in short-term memory capacity, working memory capacity, nor in general intelligence level (Martens, et al., 2009) Interestingly, EEG measurements have revealed differences in frontal and parietal brain activity, reflecting differences in target processing (Martens, Munneke et al., 2006). More specifically, increased target-related activity was found over the ventrolateral prefrontal cortex (assumed to play a role in a wide range of cognitive processes, such as the selection of non-spatial information), whereas blinkers showed more distractor-related prefrontal activity. Irrespective of the time interval between the targets, non-blinkers were also found to be quicker in consolidating target identity than blinkers, showing earlier peak latencies of the P3 ERP components—

associated with the updating of WM. It is unclear whether the weak AB effect in the present study was influenced by a certain percentage of non-blinkers in the sample. Until some clear cut- criteria are established to screen for non-blinkers before conducting an AB task on individuals, this remains a risk to demonstrating a strong AB effect.

Additionally, although they weren't considered outliers (descriptive data revealed no statistical outliers), there were a few participants who stated that they had been clinically diagnosed with attentional deficit disorder (ADD). There is little mention of this in previous studies and, although one might be prone to a diagnose-biased expectation of poorer performance on attention tasks, there was no evidence of this. It might be informative to compare those with attention deficits to controls in AB tasks as there may be implications for effective learning environments for those with ADD.

### **Conclusion & Future Directions**

Overall, the data demonstrate a partial AB. In addition, more research is needed to address the question of whether there are neurological or behavioral differences between non-blinkers and blinkers that perhaps might also be reflected in other cognitive tasks (Arnell, Howe, Joanisse, & Klein, 2006; Martens & Johnson, 2008), or whether individual differences in performance are due to the way non-blinkers approach a specifically designed RSVP task. Findings of an EEG study by Troche and Rammsayer (2013) suggest that the P300 latencies of non-blinker showed that they processed information faster than blinkers after the AB period but slower during the AB period.

Another interesting line of research would be to explore whether the expectation of improvement post-training has an impact on the actual post-test performance. Lastly, the duration of training might play an important role in training as well as learning effects for a certain task. Comparisons of performance at different training durations might help narrow down the ideal time period within which attentional focus can be obtained. This will help build on attentional sets that eventually guide visual search tasks or help suppress multi-modal AB.

In conclusion, all individuals encounter difficulties while acquiring information from multiple sources in their surroundings. These difficulties can be diminished with the help of visual or auditory aids, however these tools can only be developed when more efforts (such as the present study) are put into examining training paradigms or models that seek to explain limitations in attentional capacities. Given the results of the present study, it may be worthwhile to look more closely into the audio-visual aspect of training. It might be that engaging the auditory sense while the visual modality is already in use is more effective than using the pop-out effect to capture attention. For instance, in the real world robots and human-computer interfaces almost always have an auditory component for capturing a person's attention while communicating, such as alerting in case of an error, warning tones or even updates and reminders. This is all in tandem with visual information and this audio visual exposure is possibly more salient than different colors or lights that flash before our eyes but do not provide a sound. Auditory sounds, for

example, help to alert an individual in case of fatigue or drowsiness; and they also aid the visually challenged in their day to day activities.

APPENDIX A  
Informed Consent Form

### Informed consent form

You are invited to participate in a study conducted by the University of Wisconsin Oshkosh. We are studying the effects of visual or auditory training on brain wave patterns using an electroencephalogram (EEG). You were selected as a possible participant in this study because you met the guidelines required by this study.

If you decide to participate, the study should take 45 minutes to one hour.

Any information that is obtained with this study will remain confidential. The information you provide will be used for the completion of the study only. By signing the consent form you agree to provide us with information to enhance the progress of our study.

If you feel uncomfortable or unable to complete the study for other reasons at any point, you are free to withdraw your consent and to discontinue participation at any time without penalty. Also, research credit will still be given to you despite incomplete participation. We cannot guarantee that you will receive any direct benefits from this study. The Institutional Review Board (IRB) has reviewed and approved the present research to be conducted.

If you have any questions, please ask the experimenter. If you have any future questions please contact Dr. James Koch. Email: [kochj@uwosh.edu](mailto:kochj@uwosh.edu). Phone number: (920) 424-2303.

By providing your signature, you have decided to participate in the present study having read the information provided above. Please read all information prior to signing.

Printed Name	Signature	Date

**In addition**, please read the following information about the procedures in this study and provide your signature at the bottom.

A. For this experiment, the following conditions will be in place:

1. All data collected will be confidential and anonymous. No participants' names will appear in any subsequent presentation or publication involving any of this data. Data will be stored in a locked file cabinet in CF20, the office of Dr. Jim Koch.
2. I acknowledge that once I start the experiment, I can withdraw at any time without negative consequences,

and I acknowledge that I will not receive credit for research participation for only listening to the instructions.

3. During the experiment, any questions I have will be answered immediately and clearly.

4. Upon completion of or withdrawal from the experiment, I will be fully debriefed about the nature of the experiment.

5. I agree not to discuss the procedures, intent or results of this experiment with any person. All data will be available upon request at the completion of the entire experiment.

6. I have been informed and recognize that there are no known short- or long-term medical risks associated with participation in this experiment. 7. I agree to remove and keep possession of all jewelry or other items that might interfere with data collection. I agree that at no point in the experiment will any researcher be in possession of any of my personal items.

B. During this experiment, the following are necessary parts of the procedure:

1. wearing an EEG recording cap containing recording electrodes and attaching electrodes to near your right eye and applying electrode conductance gel underneath all electrodes.

2. if necessary, a slight abrading of any spot under the electrodes to enhance the signal; this is done by rubbing gently with a scrubbing sponge . Mild and temporary skin reactions to the conductive gel have been noted in a small percentage of participants in previous studies. There are no medical risks associated with this portion of the procedure.

3. making a temporary mark on your forehead with a washable marker

4. fitting yourself with a stability strap looped under the armpits and anchoring it to the EEG cap

5. a slight abrading of any spot under an EEG electrode to enhance the signal; this is done by inserting a blunt end syringe in the electrode hole, squeezing in some conducting gel, and wiggling the syringe back & forth in the electrode hole while the blunt end of the syringe is in contact with the skin. There are no medical risks associated with this portion of the procedure.

6. The entire experiment will take 45-60 minutes.

C. You will receive the following information/instructions during the study:

This study will focus on the effects of certain types of brain training while performing a visual or auditory task. This type of information is important when researching individual differences in perception of visual and auditory stimuli.

To start, you will be connected to a biomoitor used to collect physiological signals: electroencephalograms (EEG) and electrooculograms (EOG). Once hook up is complete, recording of EEG & EOG signals will start and continue until the end of the study.

You will be reading information on a computer screen, during and following which recordings will be taken. Please make sure that you complete all parts of the study to the best of your ability.

#### D. General Information

Your participation in this study is voluntary and you may decline further involvement at any time. You may also request that your data not be used and/or be destroyed.

Information on all participants is confidential and will be recorded and kept in an anonymous manner. At no time will your name or other identifying information be used in conjunction with your responses in this study. The information provided will also not be distributed and will remain in the sole custody of myself, the principal investigator.

Once the study is complete, we will be happy to give you the results. In the meantime, if you have any questions, please contact: James Koch, Ph.D., [kochj@uwosh.edu](mailto:kochj@uwosh.edu) or (920) 424-2303.

If you have a complaint about your treatment as a participant in this study, please call or write:

Chair, Institutional Review Board For Protection of Human Participants, c/o Grants Office,

UW Oshkosh, Oshkosh, WI 54901, (920) 424-1415; although the chairperson may ask for your name, all complaints are kept in confidence.

I acknowledge that I have read, understood and agreed to the procedures listed above. I am satisfied that I am proceeding with this experiment with full knowledge of the intentions and procedures involved. I understand that my participation in this study is strictly voluntary.

Printed Name

Signature

Date

\_\_\_\_\_

\_\_\_\_\_

APPENDIX B

Instructions to Participant

## **Instructions to participant**

### **Biomonitor Connection Instructions**

Prior to starting the experiment, you will be connected to a biomonitor used to collect physiological signals: electroencephalograms (EEG) and electrooculograms (EOG). Once connection is complete, recording of EEG & EOG signals will start and continue until the end of the study. Please sit here and remain as still as possible while I set up the connection.

### **For Practice trials**

“You will now be presented with a set of practice trials so that you familiarize yourself with the experimental task. These trials will comprise of a string of characters on the computer screen in front of you, at the end of which you will be requested to answer the following two questions: 1) did you see the letter ‘X’? , and 2) did you see the number “4” or “7”? You are requested to make your response to both questions separately by pressing the left arrow key on the keyboard to answer ‘yes’ and the right arrow key for ‘no’. It is important that you make your response to each question as quickly as possible, without sacrificing accuracy. Press 'space bar' to start a new trial. Please do your best and let me know if you have any questions.”

### **For Pre-test and Post test**

“You will now be presented with a string of characters on the computer screen in front of you, at the end of which you will be requested to answer the following two questions: 1) did you see the letter ‘X’? , and 2) did you see the number “4” or “7”? You are requested to make your response to both questions separately by pressing the left arrow key on the keyboard to answer ‘yes’ and the right arrow key for ‘no’. It is important that you make your response to each question as quickly as possible, without sacrificing accuracy. Press 'space bar' to start a new trial. Please do your best and let me know if you have any questions.”

### **For training**

“You will now start the training phase. In this phase you will again be presented with a string of characters on the computer screen in front of you, at the end of which you will be requested to answer the following two questions: 1) did you see the letter ‘X’? , and 2) did you see the number “4” or “7”?

The X and numbers will now be in a color other than black/ will be accompanied by an auditory signal. You are requested to make your response to both questions separately by pressing the left arrow key on the keyboard to answer ‘yes’ and the right arrow key for ‘no’. It is important that you make your response to each question as quickly as possible, without sacrificing accuracy. Press 'space bar' to start a new trial. Please do your best and let me know if you have any questions.”

APPENDIX C  
Debriefing Statement

### **Debriefing Statement**

Thank you for participating in this study. The purpose of this form is to provide you more in-depth information about this study. After reading it, any further questions you have will be answered.

This study was designed to compare color visual training and audio visual training in order to reduce the limitations to attentional capacity (attentional blink) via a rapid serial visual presentation, while recording EEG (brain wave patterns).

The scientific background for this study included similar studies demonstrating the P300 (in parietal region), an event related potential signal often associated with eliciting attentional capacity limitations or in this case the attentional blink. It is for this reason that we look at the brain activity in the parietal region. For this study we utilized the odd ball paradigm.

You were connected to a Biomonitor to provide specific physiological signals which are produced naturally by the nervous system's reactions to perceived stimuli, in this case the visual or auditory stimuli that were presented to you. There were two types of training and a control group that received no training (color-visual, audio-visual and control) and you were in the \_\_\_\_\_ group. The physiological signals collected are naturally-occurring EEG patterns, in this case event related potentials (ERPs) are time-locked to the event taking the waveform created reflects your responses. We recorded the accuracy of your responses as behavioral measures and the on-line EEG recording serves as our physiological measure, for this study.

The EOG data will be subtracted from the EEG data to control for artifacts in the EEG data produced by eye movements during reading.

No individual data will ever be presented or published. All data will be published as group data only. It is important to stress that you do not reveal the goal of this study to other potential participants, so that data remains original and uncontaminated.

If you have any concerns about this study, you may speak with Dr. Jim Koch at [kochj@uwosh.edu](mailto:kochj@uwosh.edu). He, as well the researcher involved, will be more than happy to talk with you about any concerns you may have.

Again, thank you very much for your participation. We value the time and energy you spent in this study and it is our hope that the data you have provided will help us to better understand human psychology.

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