

**Task-Dependent Oscillatory Brain Activity  
During Oculomotor Delayed Response Task**

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## Abstract

This study used three Oculomotor Delayed Response (ODR) tasks to investigate the unique cognitive demands during the delay period. Changes in alpha power were used to index cognitive efforts during the delay period. Continuous EEGs from 25 healthy young adults (18-34 years) were recorded using dense electrode array. The data was analyzed by 6-cycle Morlet wavelet decompositions in the frequency range of 2-30 Hz to create time frequency decompositions for four midline electrode sites. The 99% confidence intervals using the bootstrapped 20% trimmed mean of the 10 Hz frequency were used to examine the differences among conditions. Compared to two Memory conditions (Match and Non-Match), Control condition yielded significant differences in all frequencies over the entire trial period, suggesting a cognitive state difference. Compared to Match condition, the Non-Match condition had lower alpha activity during the delay period at each midline electrode site reflecting the higher cognitive effort required.

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## CHAPTER ONE: INTRODUCTION

Working memory (WM) is defined as the ability to retain, over a short time period, information that is no longer present in the environment in order to guide future behaviour (Gazzaley, Rissman, & D'Esposito, 2004). Baddeley (1992) defined WM as a multi-store cognitive system that temporarily stores and manipulates information to accomplish a goal in the very near term. With active maintenance and rehearsal, the information can be retained for longer periods of time (D'Esposito, 2007). Funahashi and Kubota (1994) highlight that the active storage process is a key feature of WM. Importantly, Funahashi (2006) describes that WM is an essential and basic component of other higher cognitive functions; thus the study of the neural mechanisms that support WM is important.

Although WM has been widely studied by researchers from different disciplines, the operational definition of WM and the general consensus regarding the mechanisms and processes that facilitate WM are often varied among researchers (Funahashi, 2006). Additionally, the distinction between WM and short-term memory (STM) is unclear (Miyake & Shah, 1999). Cowan (2008) asserts that WM and STM are not completely distinct from one another. He notes that WM has been "defined in three different, slightly discrepant ways: as short-term memory applied to cognitive tasks, as a multi-component system that holds and manipulates information in short-term memory, and as the use of attention to manage short-term memory" (p. 323). A key component differentiating WM from STM is that WM uses temporarily stored information to plan and carry out a specific goal and is mediated by attentional control. As noted by Funahashi and Kubota (1994), the active maintenance of information for a

brief period of time until the information is used in goal directed tasks, is a key feature that distinguishes WM from other types of memory. Fuster and Bressler (2012) purport that WM encompasses both retrospective memory codes (i.e. maintenance of past sensory events) and prospective planning that prepares for an upcoming action. They state that the prospective planning function distinguishes WM from other types of memory.

In the predominant models of WM there are two overarching approaches for the conceptualization of WM processes: The cognitive approach, and the biological/physiological approach. From the cognitive perspective, WM is defined as an independent, domain specific system with multiple components. This view was proposed by Baddeley and Hitch (1974) and was embraced by other cognitive psychologists such as Cowan (1988), and Ericsson and Kintsch (1995). In contrast to the domain specific specialized system models of WM, some neurophysiologists have proposed that WM is an emergent property of the brain that is distributed throughout the cortex (Fuster, 1995, 1997; Postle, 2006). This notion of WM argues against the localization of WM to specific brain areas but instead it asserts that WM in fact relies on the functional connectivity of widely distributed networks of cortical neurons (Fuster, 1997). This widespread connectivity during WM tasks has been observed via electrophysiological recordings (Fuster & Bressler, 2012).

Studies investigating the human cortical electrophysiological response during oculomotor delayed response tasks (ODR) reveal a persistent slow wave activity during the delay period (Bosch, Mecklinger, & Friederici, 2001; Rämä, Carlson, Kekoni, & Hämäläinen, 1995; Tekok-Kilic, Tays & Tkoch, 2011). This activity is

interpreted as an active maintenance of task relevant information in preparation for a response. Neural oscillations in different frequency bands have been shown to change with respect to WM demands (Bastiaansen, Posthuma, Groot, & de Geus, 2002; Klimesch, Schimke, & Schwaiger, 1994; Pesonen, Hämäläinen, & Krause, 2007; Roux & Uhlhaas, 2014). Although the functional significance of oscillations in various frequency bands is not clear (Başar, 2012), research on alpha band activity has led to the suggestion of a number of functions and characteristics: alpha oscillations may support the inhibition and suppression of irrelevant task information during WM tasks (Klimesch, 2012; Roux & Uhlhaas, 2014), alpha activity represents the 'idling' of the brain (MacLean, Arnell, & Cote, 2012), and it is related to attention (MacLean et al., 2012) and to changes in memory load (Gevins, Smith, McEvoy, & Yu, 1997; Jensen, Gelfand, Kounios, & Lisman, 2002; Pesonen et al., 2007)

Following these findings, the aim of this study was to investigate the neural activity during WM memory; specifically, the activity which reflects the participants' active maintenance of sensory information and preparation of a response in the delay period. The complex cognitive process in the delay period cannot be measured behaviorally because it involves the cognitive capacities of maintaining the sensory codes and response preparation in the brain. However, the use of electrophysiological methodology can allow for the cortical activity related to these cognitive capacities occurring during the delay period to be isolated and measured (Banich & Compton, 2011; Handy, 2005; Luck, 2005).

The current study utilizes electrophysiological methodology during three ODR tasks; one control condition and two WM conditions. More specifically, event-related

shifts in the power spectrum of the alpha frequency were used to investigate the task-dependent neural activity during the delay period. The ODR paradigm used in this study allows for isolating the cognitive activity related to the delay period from the cognitive activity associated with prior events such as the cue and subsequent events such as the response and feedback. Also, the three conditions of the ODR task (Control, Match, and Non-Match) required different cognitive demands during the delay period. Therefore differences in delay period activity between the conditions are expected to reflect the variation in cognitive processing.

## CHAPTER TWO: LITERATURE REVIEW

### Working Memory Models

**Cognitive approaches to working memory.** Traditionally, cognitive psychologists view STM as a limited capacity system which temporarily stores information (Atkinson & Shiffrin, 1968). WM was initially proposed as a subcomponent of STM but subsequently modeled as a unique system of memory (Atkinson & Shiffrin, 1968; Baddeley & Hitch, 1974). In the popular cognitive model proposed by Baddeley and Hitch (1974), WM is viewed as a multi-component dynamic system. This system is mediated by the Central Executive (CE), which controls attention and manages the information of two slave subsystems, the Phonological Loop (PL) and the Visuospatial Sketchpad (VSSP). The PL is primarily responsible for speech perception and the storage of verbal based information. The VSSP is responsible for the maintenance of visuospatial information (Baddeley, 1996; Baddeley & Hitch, 1974). Both of these systems possess an active storage mechanism, which involves rehearsal of information (Funahashi & Kubota, 1994). Baddeley (2000) noted that his original model proposed in 1974 did not account for all memory phenomenon, thus he later included an additional fourth component, the Episodic Buffer (EB). This component which is also controlled by the CE acts as a buffer to integrate information between the PL, VSSP and Long Term Memory (LTM) (Baddeley, 2000).

Although the model of WM proposed by Baddeley and Hitch (1974) and Baddeley (2000) has become the most well known cognitive model, there are a plethora of other cognitive approaches (see Miyake & Shah, 1999 for a comprehensive review). Miyake and Shah (1999) state that these cognitive models

demonstrate inconsistencies, and they lack overall consensus. For example Miyake and Shah (1999) note that one key theoretical issue that lacks consensus is whether WM is a unitary system or a domain specific system. However, there is some consistency within the cognitive model approaches. All cognitive models assert that there is a specialized system, specific to WM, and seek to localize this system and its subcomponents to specific brain areas (Miyake & Shah, 1999).

One criticism of Baddeley's model is that it does not account for non-visual or non-auditory experiences such as taste and touch (D'Esposito, 2007). Additionally, there have been substantial criticisms by neurophysiological researchers of the localization and fractionation of WM capacities by cognitive models. For example, Kotchoubey (2006) notes that the cognitive theoretical models have created a proliferation of brain mechanisms to explain each new phenomenon separately as its own entity.

This has led to an explosion in unique processing modules and processing stages to account for what are presumably innate and simple cognitive procedures. Kotchoubey (2006) argues for the merit of simplicity in understanding these cognitive processes and designates an alternative viewpoint as a "biological" approach. He suggests that theories proposed by cognitive psychologists place too much focus on deconstructing the cognitive processes into many subcomponents and that this preoccupation neglects the brain's main task which is "to ensure the organism's survival by optimal behavior adjustment to the environment" (Kotchoubey, 2006, p. 43). In addition, Postle (2006) asserts that understanding WM as a localized and specialized system lacks strong support in physiological research. Instead, he proposes

that WM functions through the recruitment of brain systems that are used in perceptual and sensory functions, which are coordinated through attentional systems. In physiological research, the notion of neural networks, i.e. networks of brain systems working in coordination rather than in isolation, has received substantial empirical support (D'Esposito, 2007; D'Esposito, Postle & Rypma, 2000; Fuster, 1997, 2009; Fuster & Bressler, 2012; Gazzaley et al., 2004; Kotchoubey, 2006; Postle, 2006). A number of physiological models have used the concept of neural networks as a foundational key in understanding the neural correlates of WM (Fuster, 2009; Fuster & Bressler, 2012; Postle, 2006).

**Physiological approaches to working memory.** Where the cognitive approach seeks to understand how an individual processes knowledge, a physiological approach puts biology at the centre of its theory. A review by D'Esposito (2007) of neurophysiological research concludes that there is a significant disagreement in reconciling the results of physiological research with tenets of the cognitive models of WM. In particular, the premise that WM is a localized and a specialized brain system has been challenged (Curtis, Rao, & D'Esposito, 2004; Fuster, 1997; Gazzaley et al., 2004). D'Esposito (2007) asserts that "from a neuroscience perspective, it is counterintuitive that all temporarily stored information during goal-directed behaviour requires specialized dedicated buffers. Clearly, there could not be a sufficient number of independent buffers to accommodate the infinite types of information." (p. 762).

Persistent activity in the prefrontal cortex (PFC) was first shown in monkey studies during the delay period paradigms (Fuster & Alexander, 1971). This PFC activity has been further replicated and although it has become the backbone of

empirical support for the localization of WM processes to the PFC (D'Esposito, 2007; Funahashi, 2006; Funahashi, Bruce, & Goldman-Rakic, 1993), further studies have indicated that other regions are also involved during WM tasks. These findings challenged the hypothesis that WM is localized to one area of the brain but rather support that it is part of a widely distributed network throughout the cortex (Curtis et al., 2004; Fiebach, Rissman, & D'Esposito, 2006; Ranganath, Cohen, Dam, & D'Esposito, 2004).

Curtis and his colleagues (2004) conducted a study using functional magnetic resonance imaging (fMRI) indicated that different brain regions were recruited during ODR tasks. The recruitment of these brain regions was found to vary depending upon whether the task required the temporary maintenance of retrospective (past sensory events) or prospective (planned, anticipated action plans) memory codes. Curtis et al.'s (2004) paradigm utilized two conditions: 1) Match: a task which allowed participants to use the temporarily displayed sensory information of a specific location to create and maintain a planned saccade to that same location. The participants' saccade response was postponed during a brief delay period in which no sensory information was present, and was later prompted by a response cue to initiate the saccade. This condition required the use of *prospective memory* codes as participants are able to create and maintain planned motor path using the sensory information provided. 2) Non-Match; a comparison condition in which the response saccade was not made to the initial location of a sensory stimulus but to a secondary unpredictable location. This condition required participants to retain the location of the initial sensory stimulus but did not allow for the creation of a prospective memory code, because the response

was to an unpredictable location. Therefore, this condition was utilizing a *retrospective memory* code. Curtis et al. (2004) found that delay-period activity was greater in the oculomotor regions (i.e. frontal eye fields and supplementary eye fields) for the Match condition, and that activity in the inferior frontal and posterior parietal regions was greater in the Non-Match condition. They argue that these results reflect that a number of brain regions are recruited during the maintenance of task relevant information and that these regions are dependent upon the type of information being retained (Curtis et al., 2004).

In line with the conceptualization that neural networks collaborate in WM processes, Fuster and Bressler (2012) assert that the interactions between posterior (perceptual) and frontal (executive) networks are fundamental in the WM processes. Numerous studies have supported this through results indicating the simultaneous activation of posterior and frontal regions during WM tasks (Curtis, Sun, Miller, & D'Esposito, 2005; Gazzaley et al., 2004; Jonides et al., 1993; Pollmann & von Cramon, 2000). For example, Pollman and von Cramer (2000) utilized fMRI to localize networks involved in an object recognition and visuospatial orienting task. Results demonstrated the concurrent activations of the PFC (in particular the FEF, pre-supplementary motor cortex and precentral gyri) with the posterior parietal cortex and the intraparietal sulcus. Additionally, Gazzaley et al.'s (2004) study of visual WM demonstrated further that the functional connectivity between the frontal regions (PFC and the premotor cortex) with the posterior regions (intraparietal sulcus and posterior parietal cortex).

Overall, with the growing support of research demonstrating multiple brain regions involved in WM, the neurophysiological models which use neural networks as a foundational tenet are becoming well accepted and physiologically supported conceptualization of WM (D'Esposito, 2007; Fuster, 1997, 2009; Postle, 2006).

**Our approach to working memory.** Gazzaley et al. (2004) notes that efforts to associate specific regions with different processes involved in WM has produced conflicting results. Due to the multiple cognitive processes that are simultaneously recruited during the delay period of WM, and the overlapping of the neural responses involved, isolating these cognitive processes has been a challenge (Fonaryonva, Dove, & Maguire, 2005). Additionally, neuroscientists have argued that the assumption of separate specialized mechanisms for each cognitive process in WM is counterintuitive to brain biology (D'Esposito, 2007, Fuster 1997; Kotchoubey, 2006). An alternative to this assignment of specific module has led to researchers identifying regions that make up larger neural networks.

In accordance with the recent developments in neurophysiological research, this study adopted a physiological approach to understanding WM as proposed by Fuster (1997, 2009), Fuster and Bressler (2012), and Postle (2006). According to this view, WM is conceptualized as a function of an interconnected neural network with frontal and parietal areas being particularly recruited.

## **Paradigm**

### **Delayed response tasks and oculomotor delayed response tasks.**

Delayed Response (DR) tasks have become the gold standard for investigating WM processes, as this type of task allows for the isolation of activity related to

sensory encoding, maintenance of prospective or retrospective codes, and motor execution (Curtis & D'Esposito, 2006). A DR task first requires the participant to encode sensory information from a cue, and second to maintain that information during a delay period in the absence of the stimulus (Srimal & Curtis, 2008). Finally there is a prompt for the participant to respond as instructed (i.e. to push a button or look to a certain location) to demonstrate that the information was successfully retained (Gazzaley et al., 2004). Researchers studying WM predominantly use DR task to isolate and describe the neural activity of these rapidly occurring cognitive processes (encoding, maintenance, response planning and execution).

Stemming from the methods of DR tasks, ODR tasks similarly involve presenting a stimulus, followed by a delay period and then a prompt for a response. However, specific to the ODR paradigm, the response is indicated by an oculomotor movement, a saccade, to indicate a response selection. For researching visuospatial WM, ODR paradigms are strong tools which allow for the isolation of neural activity related to visual processing, maintenance, and response separately (Brignani, Bortoletto, Miniussi, & Maioli, 2010; Goldman-Rakic, 1995). Saccades are the short, rapid eye movements between fixation points (Brignani, Maioli, Rossini, & Miniussi, 2007). These eye movements are generated in the brain stem but there is significant electrophysiological research indicating the cerebral cortex is involved in their control and preparation (Brignani et al., 2007).

Most often studied in ODR tasks is the delay period activity. This activity is hypothesized to reflect the cognitive processes of encoding and maintenance of

sensory information (Fuster & Alexander, 1971). Additionally, delay period activity, particularly the end of the delay period, has been proposed to reflect the preparation for an anticipated response (Constantinidis & Wang, 2004). The complex cognitive processes of the delay period cannot be measured behaviorally because they involve the internal cognitive capacities of maintaining the sensory codes and response preparation in the brain. Therefore, the ODR tasks allows for the isolation of neural activity during this period which in turn provides critical information about the cognitive processing that otherwise could not be effectively studied (Brignani et al., 2010).

### **Networks Involved in WM**

**Prefrontal cortex.** The Prefrontal cortex (PFC) is at the anterior part of the frontal lobes of the brain (Veqar Siddiqui et al., 2008). The PFC is thought to be involved in many higher order processes, such as executive functions, memory, language, intelligence, visual search and gaze control (Veqar Siddiqui et al., 2008). The PFC has three major functional subdivisions; the dorsolateral prefrontal cortex (DLPFC), orbitofrontal cortex (OFC), and ventromedial PFC (Veqar Siddiqui et al., 2008). The recruitment of the PFC in WM functions has been well established (Agam & Sekuler, 2007; Curtis & D'Esposito, 2003; D'Esposito, Postle, & Rypma, 2000; D'Esposito, 2007; Funahashi & Kubota, 1994; Funahashi, 2006; Gazzaley et al., 2004; Goldman-Rakic, 1995). The importance of the PFC in WM began with the initial observation of sustained activation in the prefrontal neurons during WM tasks in monkeys using single-unit recordings (Fuster & Alexander, 1971). Since these first findings, it has been proposed that the PFC is the medium for the temporary storage of information for the WM

system's storage buffers (Agam & Sekuler, 2007). Wilson, O'Scalaidhe, and Goldman-Rakic (1993) purport that the PFC contains separate processing systems for remembering what or where an object is. Funahashi (2006) proposed the DLPFC as the neural correlate for the maintenance of information for WM tasks in monkeys. Additionally Funahashi (2006) proposes that there are regional differences within the DLPFC such that the mid-DLPFC maintains visuospatial information and the mid-ventrolateral PFC maintains non-spatial visual information. However, this notion has been challenged by neuroimaging studies which fail to find support for the segregation of PFC areas by domain of the WM activity (Postle, 2006; Postle, Druzgal, D'Esposito, 2003).

Lesion studies have been used as primary support for the localization of memory to the PFC (Fuster, 2009). Lesion studies in monkeys have shown that unilateral lesions to the DLPFC lead to deficits in a visuospatial WM using a memory-guided saccade task when the visual stimulus was presented opposite to the hemisphere with the lesion (Funahashi et al., 1993). A visually-guided saccade task was also conducted which did not require retaining of stimulus information as was needed in the memory-guided saccade task. Monkeys with DLPFC lesions did not demonstrate deficits in the visually guided saccade task and therefore Funahashi et al., (1993) concluded that results of the WM deficits in the memory-guided task result from the failure to retain visual information and not due to sensory, perceptual, or motor abilities. Funahashi's (2006) analysis of delay period activity in monkeys indicated that DLPFC activity is a neural correlate of the mechanism for WM maintenance of

information. Funahashi (2006) noted PFC activity was persistent throughout the delay period of a WM task and that it was related to correct behavioural performances.

While it remains evident that there is involvement of the PFC in WM, overall the research has produced significant disagreement as to the PFC's level of contribution and overall purpose in WM processes (D'Esposito, 2007; Jonides et al., 1993). There are two conflicting views of the PFC's contribution to maintenance of information during WM tasks. First, in agreement with traditional cognitive models of WM, the PFC is viewed as the area of information storage for WM. Second, the PFC is only part of an expansive neural network involved in WM functions and has been proposed to mediate attentional control of the sensory reactivation and response planning processes (Agam & Sekuler, 2007; Curtis & D'Esposito, 2003; Fuster & Bressler, 2012). Postle (2006) proposes that sustained delay period activity in the PFC can be explained by many other potential functions in WM tasks. Some hypotheses include control of executive attention, maintenance of task goals, a response preparation and expectation of a reward.

The Frontal Eye Fields (FEF), located in the prefrontal cortex have also been indicated as a key area involved in WM (Brown et al., 2004). Curtis et al. (2004) found that the accuracy of the saccade in the Match condition was predicted by the activity level in the FEF. Similarly to Curtis et al. (2004), Connolly, Goodale, Goltz, and Munoz (2005) found evidence for the role of FEF activations in saccade initiation. In using fMRI measures and ODR tasks, Connolly et al. (2005) noted that the pre-target activity in the FEF predicted both the type of eye movement and the timing of the saccade. However in a study by Srimal and Curtis (2008), difference in the FEF activity during

the delay period was not found between a memory-guided saccade task and a similar memory task that utilized a button push response instead of a saccade. There was no saccade made in the second task therefore, Srimal and Curtis (2008) suggested that this lack of difference in persistent FEF activation during both delay periods is evidence that FEF activity does not represent the metrics for saccades. Overall, the contributions of the FEF to WM are still unclear (Brignani et al., 2010).

**Parietal cortex.** In addition to the activity in the PFC, other regions of the brain have also been reported to demonstrate activation during WM (Constantinidis & Wang, 2004). The parietal cortex (PC), in particular has also been indicated as another critical contributor to WM. It is hypothesized that prefrontal and parietal areas are working in collaboration during WM (Constantinidis & Wang, 2004; Fuster & Bressler, 2012). This has been substantiated by research indicating the concurrent PFC and PC activity during WM tasks (Curtis et al., 2005; Jonides et al., 1993; Pollmann & von Cramon, 2000). Fuster and Bressler (2012) note that the co-activation of cortical areas has been well substantiated in neuroimaging research. In their review, activation of the lateral PFC was reported in tandem with an area of the posterior cortex dependent upon the modality of sensory input. Specifically, concurrent with activation in the PFC, WM tasks in the visual domain typically includes activation in the inferotemporal and parastriate cortex; while WM in the auditory domain typically includes activation in the superior temporal cortex; and WM using the spatial domain typically includes activations in the posterior parietal cortex. This coordination between frontal and posterior regions in WM, across sensory modalities, corresponds to Fuster and

Bressler's (2012) 'cognit' model in which frontal PFC activation reflects executive functions and posterior activations reflect perceptual functioning.

### **Electroencephalography and Event-Related Potentials**

My research utilized electroencephalography (EEG) and event-related potentials (ERPs) to better understand the neural networks recruited in visual spatial WM. EEGs are the continuous recordings of the brain's electrical activity (Luck, 2005) that is related to sensory and cognitive processes (Quiroga, 1998). EEG measures the changes in voltage of the neuronal populations in the brain and this activity is recorded through the use of electrode sensors placed on the scalp of a participant (Banich & Compton, 2011). EEG activity therefore always reflects the summation of the synchronous activity of thousands or millions of neurons that have similar spatial orientation (mostly from pyramidal cells whose dendrites are perpendicular to the scalp) (Quiroga, 1998). If the cells do not have similar spatial orientation, their dipoles may not line up and will not create detectable waves (Luck, 2005; Teplan, 2002). Pyramidal neurons of the cortex are thought to produce the most EEG signal because they are well-aligned and fire together (Teplan, 2002). EEG reflects the electrical activity primarily from the cortex because activity from deep sources is more difficult to detect because the signal is weakened by the distance (Handy, 2005).

In utilizing EEGs, the study of event-related potentials (ERPs) has been of particular interest (Fonaryova et al., 2005). ERPs are the brain's evoked electrical responses to an event, such as an experimental stimulus. ERPs can be isolated within EEG recordings and play a key role in understanding the workings of the brain (Kotchoubey, 2006). By time-locking a particular event during an EEG recording

inferences can be made about the processes occurring in the brain that are related to the presented stimulus. For example, in an ODR task isolating activity in the delay period is thought to correspond to the maintenance of sensory information from the stimulus as well as the prospective planning of motor plans for the response (Brignani et al., 2010; Curtis et al., 2004).

The popularity of EEG methodology has in part arisen due to a number of key advantages over other data collection techniques (Fonaryova et al., 2005). The most notable advantage is that EEG methodology provides superior temporal resolution that allows for millisecond precision in terms of information regarding the brain's electrical activity (Bosch, et al., 2001; Kotchoubey, 2006). This exceptional temporal resolution makes EEG procedures very useful for studying basic physiological responses that occur in very quick timeframes as well as responses to very close, temporally spaced stimuli (Agam & Sekuler, 2007). While fMRI can obtain some of this information, it is much slower temporally and therefore only provides a summary of timed events (Kotchoubey, 2006). Although fMRI provides better-quality spatial information over EEG methods, when studying such short time windows during WM tasks, the rapidly occurring changes in the brain activity are best captured with EEG methods.

Another advantage of EEGs is that the data collection is significantly less expensive and less invasive than other neuroimaging methods such as fMRI (Luck, 2005). This makes the collection of this data far more accessible to researchers and allows for testing a greater number of subjects. Additionally, EEG may be better suited than fMRI for collecting data with young children as the electrode net placed on the scalp during EEG recordings may be less intimidating than the noise and appearance of

the fMRI machinery. Often the same experimental paradigm can be used with participants of all ages (Fonaryova et al., 2005).

A significant criticism and limitation to ERP methodology is the inability to adequately localize cortical activity (Banich & Compton, 2011; Luck, 2005). However, this limitation has been diminished by the development and use of techniques such as standardized low resolution electromagnetic tomography (sLORETA). Programs such as sLORETA, have allowed for significantly improved and reliable source localization (Brignani et al., 2010). However, caution is required when drawing spatial inferences from scalp recorded due to the polarity, spacing and direction of dipoles may result in activity that is disproportional (Luck, 2005). Additionally, EEGs only represent information recorded from the scalp and cannot adequately collect activity from deeper brain locations (Handy, 2005). Another challenge is that many trials are needed to consistently isolate ERPs via the process of averaging (Handy, 2005; Luck, 2005). Lastly, data can easily be affected by external and internal events that are not of interest such as eye blinks and fatigue (Quiroga, 1998). Therefore, well designed studies with good recording practices and many trials help to mediate the limitations of this methodology and enhance its benefits.

Due to the benefits of EEG methodology it has become a widely used resource for cognitive neuroscience research. With increased usage, a greater understanding and ability to characterize ERPs has occurred (Fonaryova et al., 2005). Research in the methodological practices of EEGs has allowed for a better understanding of how to isolate the events from noise, artifacts and other

physiological responses (Banich & Compton, 2011; Luck, 2005). Further the methods used to collect, preprocess and analyze the data has received immense scrutiny and subsequent development which has facilitated the attainment quality data.

**Components and slow waves.** The study of ERP components has been a key method of analysis for electrophysiological research (Delorme & Makeig, 2004; Quiroga, 1998; Samar, Bopardikar, Rao, & Swartz, 1999). An ERP component has been defined as “scalp –recorded neural activity that is generated in a given neuro-anatomical module when a specific computational operation is performed” (p. 22 Luck cited in Handy (ed), 2005). Thus components must arise from the same module and cognitive function. Traditionally components have been defined by their polarity, latency, amplitude and scalp distribution. Much of this analysis method is primarily done through visual inspection that can create issues of validity (Quiroga, 1998). Researchers using component analysis average many trials of ERP segmented data and seek to define particular prominent peaks, which are consistently seen and reproduced, to certain cognitive functions (Fonaryova et al., 2005). For example, the P3 or P300 component, is a pronounced positivity occurring over parietal areas approximately 300ms after stimulus onset (Fonaryova et al., 2005).

Unlike ERP components, which occur rapidly, lasting less than a second, slow waves (also called slow potentials) are long duration brain potentials that can last from 300ms to several seconds (Ruchkin, Johnson, Mahaffey, & Sutton, 1988). The amplitudes of slow waves have been shown to relate to task demands as well as the latency, polarity

and topography have been shown to vary as a function of task type (Ruchkin et al., 1988). For example, a study by Rämä, et al. (1995) utilizing EEG methodology and ODR tasks, found a prevalent slow wave delay period shift. Overall a trend of a more positive slow shift was seen in frontal site and a more negative shift in posterior locations. Additionally, there was a task related difference, as they collected EEG recordings from both a visually guided saccade task (Control condition) and a memory guided saccade task (WM condition). In the memory guided task the negative slow shift that was seen in the posterior sites was larger in magnitude than in the visually guided Control condition. Likewise, Bosch et al. (2001) notes that findings from ERP together with results of imaging studies show WM relies on the combined effort of frontal and parietal regions. In their study examining slow waves, Bosch et al. (2001) found collaborative relationships between frontal and parietal regions during a WM task. Their results indicated that negative parietal slow waves reflected spatial attention whereas a positive slow wave in the parietal occipital region indicated the retention of visual information, and a left frontal positive slow wave was generated by higher order frontal control processes which varied specific to information type. While studying components and slow waves have been traditional methods for examining neural activity, a paradigm shift in neuroscience now calls for the studying of oscillatory activity of the brain (Başar, 2012).

**Oscillatory activity during working memory.** Neurons do not function in isolation from one another, but rather through expansive networks of neuron assemblies (Fell & Axmacher, 2011). Oscillatory signals are the summation of large ensembles of neuronal activations oscillating in synchrony (Fuster & Bressler, 2012; Hanslmayr, Gross, Klimesch, & Shapiro, 2011; Medendorp et al., 2006). Oscillatory activity is

proposed to play a key role in neuronal processing (Medendorp et al., 2006). Fuster and Bressler (2012) assert that these oscillations during WM are products of the interactions between neural networks. EEG can measure this synchronized oscillatory activity of a large number of neurons (Fell & Axmacher, 2011). Studying of this activity has become a key conceptual and analytic tool for understanding cognitive processing of the brain (Başar, 2012).

Brain oscillations have been divided into frequency bands; Delta (0.5-3.5Hz), Theta (3.5- 7.5Hz), Alpha (7.5-12.5Hz), Beta (12.5-30Hz), and Gamma (30-60Hz) (Quiroga, 1998). However, these frequency bands are approximate thresholds, and researchers use slightly varying frequency band definitions with some researchers further classifying the bands into smaller ranges such as upper and lower alpha frequency bands (Klimesch et al., 1994). Klimesch et al. (1994) acknowledge individual variability in these frequency bands and they advocate for the use of individually determined bands in order to reduce error variance. These frequency bands have been shown to be related to different cognitive states and functions (Quiroga, 1998; Yeung, Bogacz, Holroyd, & Cohen, 2004). Research has demonstrated particular frequency dynamics in oscillatory activity within specific regions of the brain unique to the maintenance period of WM tasks (Medendorp et al., 2006). For example, oscillations in theta and gamma bands have been associated with brain activity related to memory maintenance, whereas alpha band activity has been proposed as both a reflection of inhibition of areas not required for WM and the "idling" of the brain (Medendorp et al., 2006).

Klimesch (1999) found that good performance in WM was related to increase in alpha level frequency and a decrease in theta level frequency power. Jensen et al. (2002) also similarly found that theta and alpha band oscillations modulate WM maintenance. Other researchers have found that increased beta and gamma frequency band amplitudes modulate WM maintenance (Jokisch & Jensen, 2007; Medendorp et al., 2007; Palva, Kulashekhar, Hämäläinen, & Palva, 2011). Palva et al. (2011) examined delay period activity during a visual WM task. Task performance was predicted by both early processing and late retention of stimulus activity during the delay period. Their results indicated that beta and gamma band oscillations reflect the maintenance of sensory information whereas alpha, beta and gamma oscillations were together related to attentional and executive processing (Palva et al., 2011).

**Alpha band activity.** Alpha band oscillations were the first frequency rhythm discovered by Berger in 1924 (Berger, 1929). The thalamus has been shown to be a key generator of alpha frequency and result from the interactions of excitatory and inhibitory neurons (Roux & Uhlhaas, 2014). Alpha oscillations are fundamental functions to the brain as they are the most common component in the human brain's electrical activity (Başar 2012; Klimesch, 1999). Overall, Başar (2012) purports that oscillations around 10 Hz are a fundamental area in neuroscience research.

There is significant conflict in research findings regarding the overall functionality of alpha band activity (Başar, 2012). Previous research has proposed this activity to reflect an "idling" of the cortex during a resting state (Pfurtscheller, Stancak, & Neuper, 1996). This notion has stemmed from studies examining

resting state brain activity with both open and closed eyes indicating greater alpha activity during when participants have their eyes closed versus eyes open (MacLean et al., 2012). Further research has demonstrated that alpha activity decreases with increased task difficulty (Gevins et al., 1997; Krause et al., 2000; Pesonen et al., 2007; Stipacek, Grabner, Neuper, Fink, & Neubauer, 2003). A study by Gevins et al. (1997) found that alpha decreased with increased task difficulty. Gevin's et al. (1997) propose that there is an inverse relationship between alpha and the cortical resources allocated to the task. Interestingly, they found that alpha activity increased with practice and they suggest that less cortical resources are needed with practice. In another study by Stipacek et al. (2003), increased desynchronization of alpha (less alpha than the baseline) was linearly related to increase in memory load. Pesonen et al. (2007) utilized an n-back visual memory task and similarly found as alpha was affected by task complexity and that the duration of alpha desynchronization increased with memory load.

However, the theory that alpha band activity reflects cortical "idling" has been challenged by research demonstrating that alpha activity and memory load are positively correlated. For example, Jensen et al. (2002) examined the effect of increased memory load during the retention period of a modified Sternberg task. Utilizing EEG recordings, their power spectral analysis demonstrated increase in amplitude in the frequency of 9-12 Hz (frequencies in the alpha band) as memory load demands increased. Additionally, Klimesch et al. (1999) found that alpha activations were higher during the retention of a supraspan (more than seven item) compared to a subspan (six or less items) memory list. These results contradict with

previous research which demonstrates a decrease in alpha activity with increase in task difficulty (Gevins et al., 1997; Krause et al., 2000; Pesonen et al., 2007 Stipacek et al., 2003).

Sustained alpha band activations during WM maintenance has been well reported but the functional interpretation for this activity has produced conflicting results (Roux & Uhlhaas, 2014). For example, evidence has suggested that alpha band activity reflects cortical communication and cognition (Roux & Uhlhaas, 2014). Another theory suggests that the alpha activity reflects the inhibition of task-irrelevant brain regions (Roux & Uhlhaas, 2014). In Başar's (2012) review of alpha literature, alpha activity was found not to be a unitary phenomenon. Başar states "[alpha] demonstrates considerable variation and changes, depending on age, mental state, the cognitive task being performed and the cerebral location from which the EEG signal is being recorded" (2012, p.2). Further research on this particular bandwidth activity is needed.

**Wavelet transform and time frequency analysis.** With the shift in neuroscience research towards examining oscillatory activity of the brain, new methods of analysis such as wavelet transform have demonstrated substantial improvements and valuable information to the field of electrophysiology over traditional analysis of ERP components (Quiroga, 1998; Samar et al., 1999). Analyzing ERPs through component analysis may be problematic as often these peak characteristics vary significantly (Samar et al., 1999). There is substantial inter-individual variability as well as inter-trial variability in the key parameters of ERP components; i.e. latency and amplitude (Fonaryonva et al., 2005). Task demands of an experimental condition may create overlap in components making it

difficult to decipher and isolate individual components (Fonaryova et al., 2005; Luck, 2005). As an alternative analysis method, wavelet transform has become more frequently utilized in studying ERPs. Wavelet transforms are methods for conducting time-frequency analysis (Quiroga, 1998). Time-frequency analyses provide valuable data for both temporal and frequency information of an EEG (Akin, 2002). The time evolution of dynamics in frequency patterns can be examined clearly with time-frequency analysis. ERPs contain many different frequencies and they are complex multi-component signals due to the overlapping of multiple simultaneous components (Samar et al., 1999). Wavelet transform provides a time-frequency analysis technique that aids in decomposing ERP frequency patterns into meaningful components (Samar, Swartz, & Mysore, 1995).

Changes in oscillatory patterns during an ERP can be examined using wavelet transform; therefore, wavelet transform can provide critical information about cognitive processes in the brain. Wavelet transform provides excellent joint time-frequency resolution (Quiroga, 1998; Samar et al., 1999). Unique to wavelet analysis is the flexible control over resolution with which ERPs can be localized in time, space and scale. This is of particular importance as the component and events that neuroscientist are studying are typically localized in time, space and scale (Samar et al., 1995). Control over resolution leads to increased power in statistical waveform analyses (Samar et al., 1999). This analysis method is argued to be well suited to the analysis of neuroelectric waveforms and an improved method for time-frequency analysis over other methods such as Fourier transforms (Akin, 2002; Samar et al., 1995). Wavelet transform can overcome the issue

of overlapping components that may be problematic for other analysis methods (Samar et al., 1999).

### **The Present Study**

**Purpose and the rationale.** In the light of this extensive research literature, the purpose of the present study is to investigate the brain dynamics during the delay period of three ODR tasks with variable cognitive demands. Differences in alpha power were used to index possible differences in cognitive efforts during delay periods. For this reason, the short delay period of a visuospatial WM task with three conditions (Match, Non-Match and Control) was studied using electrophysiological methodology. The cognitive activity during the delay period was partially controlled by manipulating the task requirements and response demands in each ODR conditions. Participants were exposed to the same visual stimuli as well as the same time constraints in all conditions and were required to make a similar response (the generation of a correct saccade). Importantly, different response strategies were required according to condition. Briefly, in the *Match condition*, the delay period requires the maintenance of both retrospective memory codes and a prospective motor plan to prepare for a correct saccade to the previously cued location. In the *Non-Match condition*, the delay period requires the maintenance of retrospective memory codes (i.e. the location of the visual stimulus) in order to inhibit a saccade to this location, and to make a saccade to a secondary, unplanned location. In the *Control condition* (also called visually guided saccade task), the delay period does not utilize WM. Instead it is a comparison condition for the automatic processes involved in matching a saccade to a cued position with no previous planning.

Previous research has indicated that changes in oscillatory patterns reflect cognitive processing (Jensen et al., 2002; Jokisch & Jensen, 2007; Klimesch, 1999, Medendorp et al., 2006; Palva et al., 2011; Pfurtscheller et al., 1996). Although results are equivocal, task difficulty and cognitive load was shown to modulate alpha activity (Gevins et al., 1997, Pesonen et al., 2007). Therefore, it was plausible to assume that the Non-Match condition in this study has a higher cognitive load as the participants have to remember the relevant information as well as make an effort to inhibit the prepotent response. This difference between Match and Non-match condition was expected to be reflected in alpha power observed during the entire delay period and is further expected to become more pronounced through the end of the delay period.

In this study I utilize different approaches to process (i.e. wavelet transform to analyze delay period oscillatory activity) and to statistically analyze (i.e. bootstrap technique) the data. The use of wavelet analysis to conduct time-frequency analyses allows for the examination of the entire trial period across a range of frequencies and allows for the concurrent retention of valuable temporal and frequency information that is unattainable with other methods (Akin, 2002; Quiroga, 1998; Samar et al., 1995; Samar et al, 1999). The bootstrapping method is a statistical procedure for robust estimation of a parameter of interest. This procedure does not rely on the Gaussian distribution and allows for approximating distributions that are needed for making statistical inferences and is well suited for the analyses of complex data (Wasserman & Bockenholt, 1989) such as the one used in this study. Recently bootstrap statistics have been adapted in EEG studies (Desjardins & Segalowitz, 2013; Rouseselet et al., 2008).

**Research questions and hypothesis.** Given that each ODR condition required different cognitive demands during the delay period, differences in neural activations are expected to reflect the variation in cognitive processing. For this study I asked two research questions and propose one hypothesis. The first question was related to the differences in brain dynamics during the delay period. The second research question was exploratory. It was related to the possible anterior posterior topographical differences of event-related spectral perturbations (ERSP) in alpha frequency range. This question was answered by visually inspecting time/frequency plots which illustrate significant differences in 2-30 Hz range.

***Research question one.*** Are there significant differences in the alpha frequency band during the delay period between three ODR conditions?

***Hypothesis.*** Overall, there will be significant differences in the delay period activity reflected in the alpha frequency band across three ODR conditions. Moreover, alpha power will be different in specific time windows (early delay and late delay).

***Research question two.*** Will the alpha frequency difference among conditions (Control versus WM, Match versus Non-Match) show a topographically distinct pattern (i.e. more frontal than parietal)?

## CHAPTER THREE: METHODOLOGY

### Participants

Data from 25 healthy young adults between 18 to 34 years of age (8 males,  $M = 24.25$  years; 17 females  $M = 20.35$  years) were collected as part of an ongoing developmental ERP study in the Developmental Neuroscience Laboratory in the Department of Child and Youth Studies at Brock University. Participants were verbally screened for any pre-existing health conditions that could impact the study and had normal to corrected vision (refer to Appendix B). They were briefed about the task and recording procedures. All participants gave written consent prior to their participation in the study (refer to Appendix A). The participants received a \$20.00 honorarium for their participation. This study's procedures have been approved by the Brock University Research Ethics Board (REB #10-211) (refer to Appendix D).

### Equipment and Software Used in Data Acquisition

**Electrophysiological recording.** Data were collected in a dimly lit, sound attenuated and electrically shielded room. A 128-channel NetStation EEG system (Electrical Geodesic Inc. Eugene, OR), with Net Amps 300 amplifier and HydroCel Geodesic Sensor Net were used to acquire electrophysiological data at a 500 Hz sampling rate. Data were filtered with a 0.1-100 Hz bandpass filter and vertex reference. Continuous EEGs were recorded and stored in NetStation. Channel impedances were monitored during the data acquisition and they were kept below 100k $\Omega$ .

**Eye tracking.** Infrared eye tracking was utilized to track the eye movements of the participants (Smart Eye Pro, Version 5.8). Two infrared cameras were positioned on either side of the computer monitor used to present the experimental task. Before data

acquisition eye tracking was calibrated for each individual participant, and participants were instructed to maintain proper positioning to ensure optimal tracking. During data acquisition, experimenters monitored the eye tracking on a computer outside the testing room.

### **Oculomotor Delayed Response Tasks**

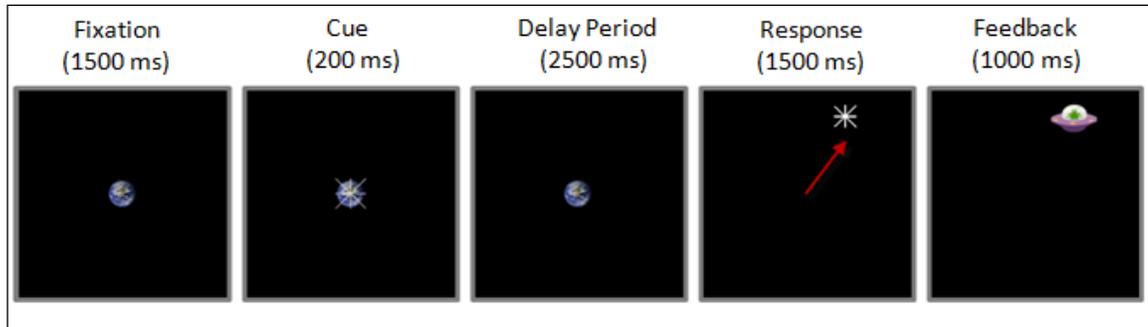
The three ODR tasks (from here on will be called as conditions) were developed using E-Prime Version 2.0 software (Psychological Software Tools, 2004). The conditions were displayed on a 19" Dell computer monitor. The stimuli were presented on a black background. The ODR conditions were designed as a game called the "Garbage Aliens Game". The major goal of this game was to protect the planet Earth from the aliens who were trying to dump their garbage on Earth. In each ODR task, an image of the planet Earth was presented at the center of the monitor. In one of eight positions (360 degrees) surrounding the planet an alien in a spaceship would appear. The participants could "block" the aliens from dumping their garbage if they looked in the location that the aliens would appear.

Participants completed three conditions; Control, Match and Non-Match. Each of these conditions has a total of 64 trials with a break after 32 trials. Total running time per condition was approximately eight minutes. The order in which these conditions were completed was counterbalanced. All three conditions had the same overall goal which was to stop the space aliens from dumping their garbage onto planet Earth, but the method to achieve this goal varied by condition. The Control condition is a visually-guided saccade paradigm in which the participants look to a cued location. The Match condition is a memory- guided saccade paradigm

in which the participants must remember the location of a previously cued location and direct their gaze to that location. The Non-Match condition is a variation of an anti-saccade task in which participants must remember the location of the initial cue, and inhibit a saccade to the initial location so that they may look to a secondary cue position when prompted to respond.

Although the different conditions facilitated different cognitive processes, the conditions all utilized the same visual stimuli and methods of response. Each of these conditions required the participants to maintain their gaze on a central fixation mark and make a saccade to a location. Participants were told try not to blink from the moment of the cue presentation to the saccade response. All three conditions had five phases: Fixation (1500 ms), Cue (200 ms), Delay Period (2500 ms), Response (1500ms), and Feedback (1000 ms). After each trial there was a 1000 ms inter-trial interval. A detailed explanation of the on-screen visual display and participant's instructions is provided for each condition below.

**Control condition.** During this condition participants were not required to remember any location. Participants were told to direct their gaze to the location of a star that appeared in one of the eight possible locations surrounding planet Earth. The appearance of the star indicates to the participant that an alien would soon appear there. By making a guided saccade to this location the participant was informed that their gaze would block the aliens from dumping their garbage (Figure 1).



*Figure 1: Control Condition Timeline.* Participants fixate on the Earth until it disappears and participants make a guided saccade to the star. The red arrow (not actually present on the screen during experiment) shows where participants would make their saccade.

*Fixation Phase* – The participant is instructed to fixate on an image of the planet Earth which is located in the centre of the screen on a black background.

*Cue Phase* – A star flashes on top of the Earth to warn the participant that the alien is about to appear in one of the eight locations surrounding the Earth.

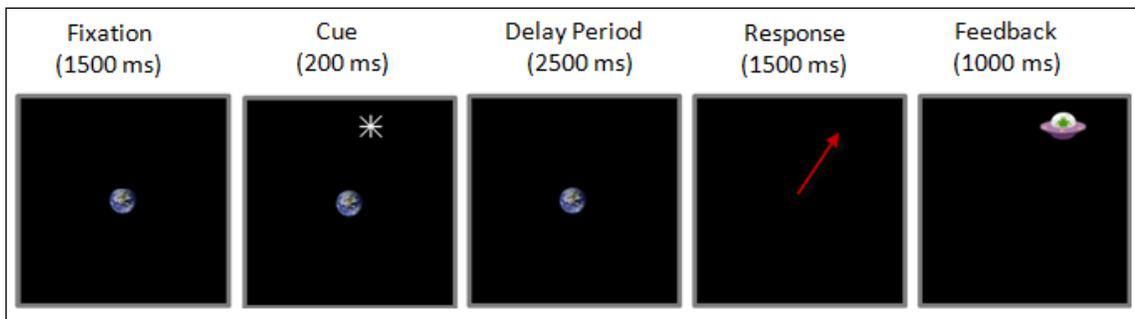
*Delay Period* – The participant must remain fixated on the image of planet Earth waiting for the alien to appear.

*Response* – The planet Earth disappears from the screen and a star appears in one of the 8 possible locations. The participant must look to that location, as the star is an indicator that an alien will be appearing in that location to dump its garbage on Earth.

*Feedback* – The star disappears and the alien appears in that location indicating that the alien was coming from that location to dump its garbage. The participant looks at the alien.

**Match condition.** During this condition participants were required to remember the location of where a star flashes which indicated the location in which an alien would appear to dump its garbage. In this condition participants make a memory-guided saccade

(Figure 2). Participants are able to use the stimulus information (location) to make a pre-saccadic motor plan during the delay period to the location that the aliens will appear. In contrast to the Control condition where WM was not involved, in the Match condition participants must utilize WM capacities to remember where the star flashed.



*Figure 2.* Match Condition Timeline. Participants fixate on the Earth until it disappears and participants make a saccade to the star's location. The red arrow (not actually present on the screen during experiment) shows where participants would make their saccade.

*Fixation Phase* - The participant is instructed to fixate on an image of the planet Earth which is located in the centre of the screen on a black background.

*Cue Phase* - A star flashes in one of the eight possible locations around the Earth. Participants must remain fixated on the image of Earth.

*Delay Period* - The participant remains fixated on the image of Earth.

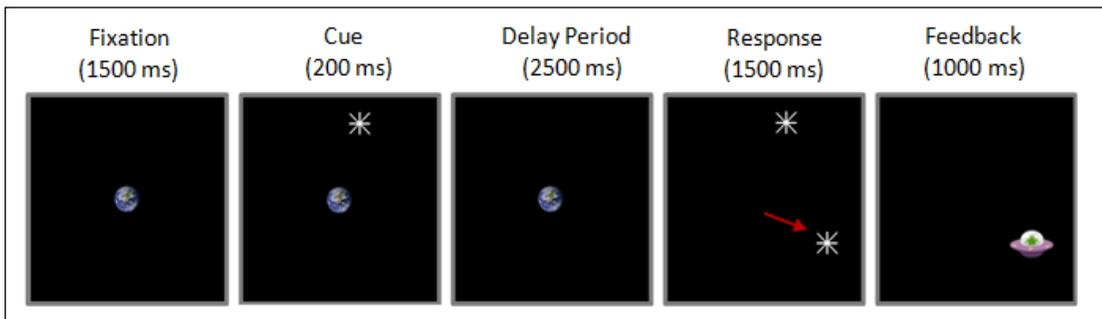
*Response* - The image of Earth disappears which cues the participant to look in the blank space in which the star previously appeared.

*Feedback* - The alien appears in the location that the star flashed to indicate to the participant if they were looking in the correct location.

**Non-Match condition.** During this condition participants must remember a location where they must *not* look. Participants were told that the aliens are playing a

trick and the location in which the first star appears is not the actual location that the alien will eventually attack; rather, this initial location is a decoy. After being cued to the decoy location, participants are shown both the initial decoy star and a secondary star. The location of this second star is the true location that the aliens will appear and is the correct location that participants must make their saccade to in order to stop the aliens (Figure 3).

In this condition, participants are not able to make a pre-saccadic motor plan as they could in the Match condition. Instead, participants must remember the location of the first star so they can inhibit themselves from looking at it and look towards the location of the secondary star when both stars appear on the screen. This condition places the greatest cognitive demand on the participant as they must both retain sensory information as well as inhibit a response to look towards the initial decoy star.



*Figure 3.* Non-Match Condition Timeline. Participants fixate on the Earth until it disappears and participants make a guided saccade to the secondary star. The red arrow (not actually present on the screen during experiment) shows where participants would make their saccade.

*Fixation Phase* - The participant is instructed to fixate on an image of the planet Earth which is located in the centre of the screen on a black background.

*Cue Phase* - A star flashes in one of the eight possible locations around the Earth. Participants must remain fixated on the image of Earth. This is the trick star that the participant must remember the location in order to inhibit looking at this location.

*Delay Period* - The participant remains fixated on the image of Earth.

*Response* - The Earth disappears from the screen. Two stars appear in two of the 8 possible locations. The first star appears in the same location and the new star appears in another location. Participants must look to the location of the new star as that is the true location that the alien will appear.

*Feedback* - The stars disappear from the screen and the alien appears in the location of the second, new star.

### **Data Collection Procedures**

Prior to participant's arrival, equipment was checked to ensure good working order and all materials necessary for data collection was gathered and prepared. The eye tracking system was calibrated by the researcher and re-calibrated when the participant arrived.

Upon arrival, participants were guided by the researcher through the types of equipment that were used in data collection, and the requirements of the experimental conditions were outlined. This was to ensure that the participants felt comfortable with the equipment and the procedures. After, participants were briefed and had any questions they might have answered. The participants signed an informed consent prior to testing. The participants' heads were measured to determine the appropriate net size. The net then was soaked in a potassium chloride and baby shampoo solution. This solution was used to ensure the conductance of the electrical activity from the scalp to

the sensors. After soaking, the net was placed on the participants' head and adjusted to ensure that all electrodes are in the correct position and are touching the scalp.

Participants were taken to a sound attenuated testing room that was dimly lit. This testing room is designed to eliminate external electrical interference that may affect the measurement of the electrical activity in the brain. Here the participants sat in an upright position on a chair approximately 45-55 cm from the Dell computer screen that the task will be displayed on. The net was then connected to the Net Amps 300 amplifier. The eye tracking was re-calibrated to the participant's specifications. Participants were instructed to maintain their position and minimize their movement throughout the recordings. Channel impedances were checked before beginning each condition and kept below 100 k $\Omega$ . Prior to each condition participants were read the task instructions and guided through an on-screen example of the task by the researcher. The participants had the opportunity to ask for clarification and complete five practice trials which were not recorded as data.

Once the participant fully understood the instructions the researcher left the testing room and the task was initiated through an external computer used for data collection. During the data recording, the researcher continuously monitored the data acquisition and eye tracking from the external data collection computers. At the half way point in each condition participants were prompted to take a break. During this break participants remained in the room but were allowed to rest their eyes or move if needed. Any adjustments to the equipment as well as impedance check were done during this time. When ready to resume, participants informed the researcher who started the second half of the condition. Upon completion of all three conditions,

participants were debriefed about the study and given the opportunity to ask questions (refer to Appendix C). At the end of the study each participant was given a \$20.00 honorarium.

### **Preprocessing of Data**

Preprocessing of EEG data was completed through Matlab (Mathworks, 2007b) using functions in the open source toolbox EEGLab Version 12 (Delorme & Makeig, 2004). Automated artifact removal was performed on the Shared Hierarchical Academic Research Computing Network (SHARCNet). Much of the preprocessing methods used were completed through automated scripts which utilizes statistical measures for artifact rejection. Previous methods of preprocessing use subjective decisions for determining whether to reject portions of messy data through visual inspection. The current method, allows for data to be preprocessed with consistency across participants. The preprocessing steps performed are outlined below.

First the participant's data files for each condition were concatenated to create one large continuous EEG file for each participant. Then this file was submitted to SHARCNet to complete a number of automated preprocessing scripts, the steps of these scripts are outlined further. First, automatic removal of break intervals was completed. Second, EEG signals were filtered from 2 Hz to 30 Hz. The data was re-referenced to an average interpolated electrode. This rereferencing procedure, interpolated 19 electrodes based on the standard 10-20 system, these 19 interpolated channels were then averaged together and subtracted from each of the 128 electrode sites. The continuous data were windowed into 50% overlapping 600 ms windows.

In order to identify poor channels, the maximum correlation coefficient  $r$  of each channel was calculated with its nearest three neighbours. For each time window, the channels which had  $r$  values that were greater than three standard deviations from the 10% trimmed mean were flagged. The channels that were flagged more than 10% of the time were considered to be contaminated with noise and were rejected. To identify bridged electrodes, the means and the standard deviations of the maximum  $r$  values for every channel was calculated across the time windows. The channels mean  $r$  value was divided by its standard deviation to create a composite score. This score represented a bridged electrode's high and relatively invariable correlation to its neighbour. When the composite score was above eight standard deviations from the 25% trimmed mean of the composite score across channels, the channels were rejected. Once bad channels were removed from the data, the data was again re-referenced to the average interpolated channel.

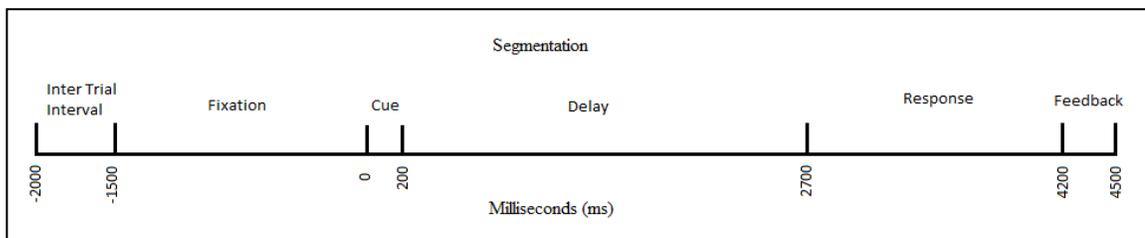
Next, time periods of noisy data were flagged for rejection. This was completed by calculating the maximum nearest neighbour correlation coefficient for each time window. When  $r$  was greater than three standard deviations from the 10% trimmed mean it was flagged, and if more than 10% of channels were flagged the time window was rejected.

Data was joined to a continuous form and discontinuities were marked as boundaries. Any continuous period shorter than 2 seconds was rejected. Continuous time intervals were then detrended before they were submitted to Infomax ICA with an N-1 channel PCA reduction.

After the first Independent Component Analysis (ICA), an ICA time pruning procedure was conducted. The ICA time-course activations were used to further rejection periods of time by calculating the standard deviations of each independent component activation and calculating the 99% confidence interval of each independent component across the time windows. The flagging and rejection criteria that was utilized for the channels was also employed for the independent component activations. The remaining data was resubmitted to a second ICA. The second ICA typically produces a more stable decomposition (Desjardin & Segalowitz, 2013). An ICA examines EEG signals and categorizes them as subcomponents. These subcomponents represent a pattern in the signals that is statistically independent from other signal fluctuations or other components. These subcomponents may represent patterns of cortical activity or artifacts such as eye movements and muscle movements. These independent components (IC) were used to identify and reject data that is non-cortical in nature. This was a manual procedure in which ICs for each participant were examined and data that appeared to resemble biological artifacts were flagged for rejection. The biological artifacts that were identified and rejected were eye blinks, lateral eye movements, electromyogram (EMG), and electrocardiogram (ECG). These artifacts display particular characteristics that are easily identifiable and provide reliable means for identification. Lastly, IC weights were applied back to the initial continuous 1 to 30 Hz filtered data with the period removed that were flagged during the ICA time pruning procedure.

**Segmentation.** Upon completion of all preprocessing and rejection of unviable data all remaining trials were time-locked to the onset of the Cue. The period of -2000 ms to 0 ms relative to the cue onset was used as the baseline. Post cue a time period of 4500

ms was used. A large time window was used to provide a better resolution for the Morlet wavelet analysis (Figure 4).



*Figure 4.* Segmentation of Data. Timeline of the data segmentation and the corresponding events.

### Data Analysis

Data analyses were conducted in EEGLab Version 12 (Delorme & Makeig, 2004). The bootstrapped group statistic was utilized to calculate the 99% confidence intervals of the 10 Hz frequency and the time-frequency decompositions.

**Bootstrapped grouped statistic.** The data was analyzed by the bootstrapping methods defined by Wasserman and Bockenholt (1989) and Wilcox (2005). Bootstrapping is a statistical procedure for robust estimation of a parameter of interest. This procedure does not rely on the Gaussian distribution and allows for approximating distributions that are needed for making statistical inferences (Wasserman & Bockenholt, 1989). Because parameters of a distribution are not often known, this method estimates the parameters from the data and uses these values as the true parameters (Wasserman & Bockholt, 1989). Estimating to a sample distribution is done by creating a number of surrogate sets of data (Wilcox, 2005). These surrogate sets contain the same number of data points from the original data set but the data points are obtained through random resampling with replacement from the original full data set (Wilcox, 2005).

In this research, I utilized the bootstrapping procedures similar to those employed by Desjardins and Segalowitz (2013) and Rousselet et al. (2008). More specifically, the differences between event-related spectral perturbations (ERSP) were examined using a percentile bootstrap technique averaged across individuals. Instead of full means, 20% trimmed means were used for this analysis. A trimmed mean is best suited for accurately representing electrophysiological data due to the nature of extreme values inherent in EEG data (Desjardins & Segalowitz, 2013). Additionally Wilcox (2005) notes that the trimmed mean can control the probability of type I error.

For the bootstrap analyses, grand average ERSPs for each condition (Match, Non-Match and Control) were created by collapsing all participants' trials within each condition. Each grand average was resampled with replacement until 1,000 bootstrap (surrogate) samples were obtained. Twenty percent trimmed means were calculated for each surrogate sample independently for all three conditions within four electrode sites (Fz, Cz, Pz, Oz). Surrogate ERSPs were averaged for each condition. Surrogate averages were used to create the difference waveforms which were obtained based on subtracting one condition from another.

In order to test the hypotheses two contrasts were examined: first, Control condition minus two memory conditions collapsed, and second, Match minus Non-Match conditions. The 99% confidence intervals were obtained for every point in the bootstrapped difference waveforms. These confidence intervals were produced from the standard error of the trimmed mean. The periods that does not include zero were considered significant ( $p < .01$ ). Confidence intervals were calculated for the 10 Hz frequency activity. Overlays of the 10 Hz frequency activity in the two contrasts were

examined. The 10 Hz frequency was chosen due to its centrality in the alpha band from 8-12 Hz, as well as its presence in the current literature demonstrating the 10 Hz range to be of importance (Başar, 2012). Alpha band oscillations are the dominant frequency of the brain with the mean frequency at approximately at 10 Hz (Klimesch, 2012). Research has reported the alpha frequency band as a key contributor and frequency of interest in WM ODR conditions (Jensen et al., 2002). Additionally, in our initial examination of the complete frequency range from 3 to 30 Hz, significant differences across conditions were found in this range providing further support for interest in the 10 Hz frequency.

**Time frequency analyses for 2-30 Hz oscillations.** To examine the EPSPs, 6-cycle Morlet wavelet decompositions were performed in the frequency range of 2 to 30 Hz in 1 Hz steps over the entire period of the trials. Time-frequency decompositions were performed for the midline electrode sites (Fz, Cz, Pz and Oz) and the results were visualized in time-frequency-power plots (see Figure 5). These time-frequency decompositions utilized the 1,000 bootstrapped differences of the  $z$  scores. Additionally, these decompositions were colour masked at 99% confidence intervals such that burst of red colour represent statistically significant difference ( $p < .01$ ).

## CHAPTER FOUR: RESULTS

### Overview of the Analyses

To answer this study's two research questions, two contrasts were analyzed: Control versus Working Memory conditions (Match and Non-Match collapsed), and Match versus Non-Match. The bootstrapped differences of these two comparisons were calculated with a 1000 surrogate resample using the 20% trimmed mean on four electrode sites (Fz, Cz, Pz, and Oz). Time frequency decompositions of the 99% confidence intervals were examined across all frequencies between 2 to 30 Hz and specifically examining the 10 Hz frequency.

The results of these contrasts are illustrated in Figure 5 for each midline electrode site (Fz, Cz, Pz and Oz) within 3 cluster figures (a, b, c). Each figure includes a baseline to compare with the delay period activity. Figure 5 (a) depicts the overlay of surrogate grand average ERSPs in 10 Hz alpha power for two contrast of interest for visual purposes, Figure 5 (b) plots the results of percentile bootstrap confidence intervals in 10 Hz. Figure 5 (c) shows the results of time frequency decomposition where red bursts show the time/frequency of the significant differences between the waveforms.

The results of these analyses are outlined below in relation to this study's research questions and hypothesis.

### Research Question One

Are there significant differences in the alpha frequency band during the delay period between the three ODR conditions?

**Hypothesis one.** Overall, there will be significant differences in the delay period activity reflected in the alpha frequency band across the three ODR conditions.

Moreover, alpha power will be different in specific time windows (early delay and late delay). This hypothesis is tested by two contrasts.

***Contrast one - control versus working memory conditions (match and non-match).*** Visual examination of alpha power difference at 10 Hz (Figure 5a), suggested that there was greater 10 Hz (alpha) activity in Control condition compared to the WM conditions during the entire delay period in each midline electrode site. Figure 3b demonstrates that this difference in 10 Hz frequency was significant at 99% confidence intervals throughout the delay period. However, examination of the entire trial period from 2-30Hz indicated that there were significant differences in all frequencies over the entire temporal period (Figure 5c) including the baseline. This shows the activation of cortex manifested with a large frequency range (including alpha) throughout the Control condition compared to the WM conditions that is not specific to delay period. Delay period activity differences did not show specific temporal differentiation (i.e. early versus late delay) as expected in the second part of the first hypothesis.

***Contrast two - match versus non-match.*** Visual examination of alpha power difference at 10 Hz (Figure 5a), suggested that there was greater alpha activity in Match condition compared Non-Match condition during the delay period and this was observed at each midline electrode site (Fz, Cz, Pz, Oz). In examining specifically the 10 Hz frequency, the 99% confidence intervals of the 1000 bootstrapped trimmed mean differences showed significant activity in the delay period (Figure 5b) compared to baseline. Results of this contrast also indicated that the significant differences were specific to the delay period and clustered in the late delay (Figure 5c) supporting the first hypothesis for Match and the Non-Match difference.

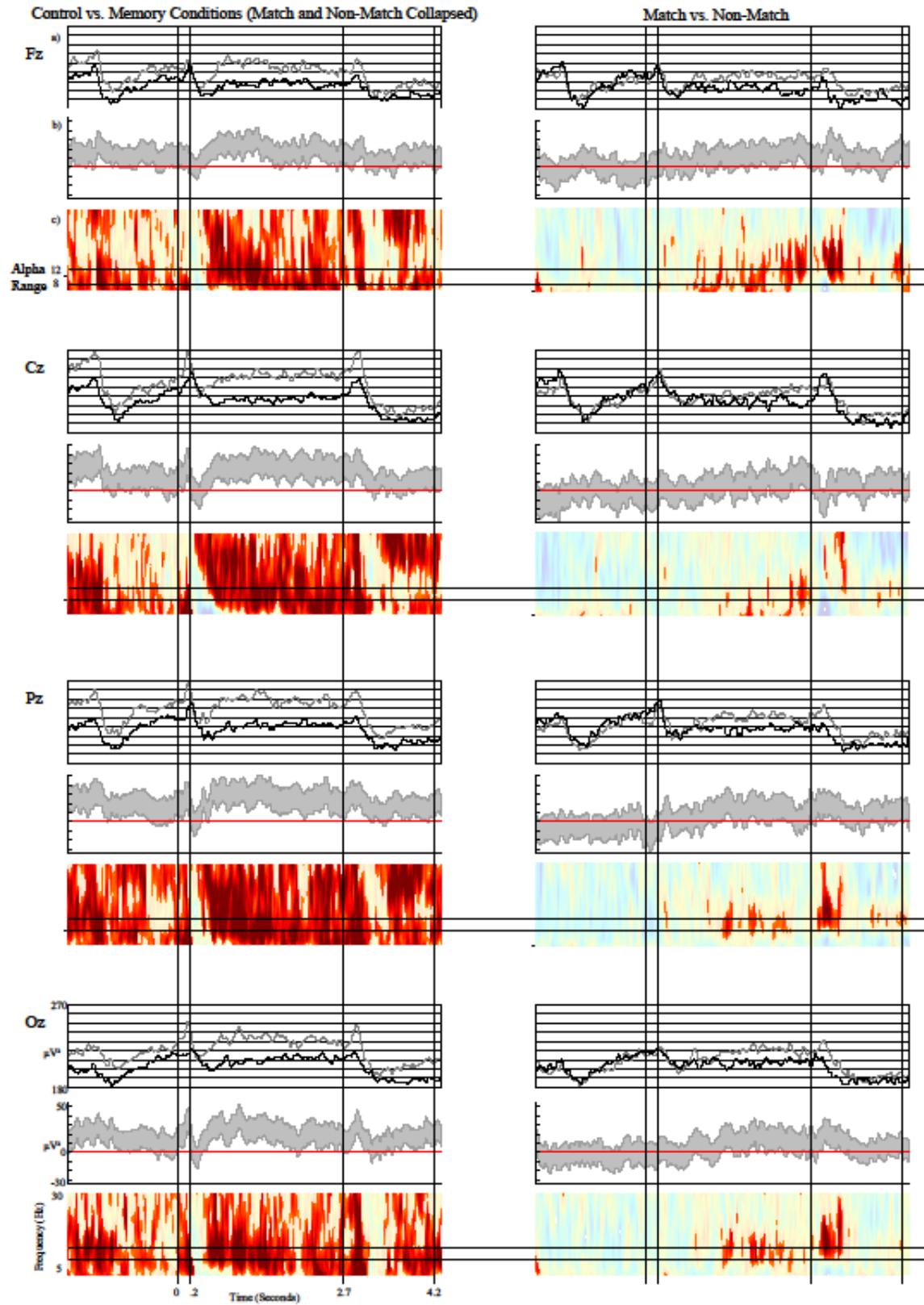
In examining the trajectory in alpha power between the Match and Non-Match conditions (Figure 5a), the Match and Non-Match conditions maintain a relatively similar trajectory of alpha power until the late delay period in which a divergence is seen. At approximately 800 ms in Fz and 1250 ms in Cz, Pz, and Oz sites alpha power in the Match condition increases however, the trajectory of alpha power in the Non-Match condition maintains the same level.

### **Research Question Two**

Will the alpha frequency difference among conditions (Control versus WM, Match versus Non-Match) show a topographically distinct pattern (i.e. more frontal than parietal)?

This question was examined by visually inspecting the significant alpha band differences illustrated in Figure 5 (c) for each midline electrode site (Fz, Cz, Pz, Oz). The visual illustration of the first comparison (Control versus WM conditions) suggested that the difference in alpha activity was not likely to localize onto frontal-parietal axis as the difference between conditions are similar in each midline site (Figure 5a-c for Fz, Cz, Pz, Oz). On the other hand the Non-Match versus Match alpha power difference during the late delay was more pronounced in frontal midline (Figure 5a \_Fz) compared to central (Figure 5a \_Cz), parietal (Figure 5a \_Pz) and occipital (Figure 5a \_Oz) midline electrodes. Although at Fz, significant differences in ERSPs are observed in alpha range (8-12 Hz), significant differences in frequency activations also extended into the low beta range (13-18 Hz). These differences began at approximately 800ms and extended to the remainder of the delay period when the onset of the response occurred at 2700ms. A visual inspection of significant alpha power difference showed that the significant difference started later in

delay period at parietal and occipital midlines, beginning at approximately 1250ms and ending around 2400ms. Significant differences were found across 8-16 Hz range (alpha to low beta). The interpretation of the time/frequency plots created from bootstrapped difference waveforms between the two WM conditions, suggested that the ERSP (not only alpha but possibly beta) are most likely localized in anterior sites.



*Figure 5 (a-c). Left Column – Control (Grey) versus WM Conditions Collapsed (Black), Right Column – Match (Grey) versus Non-Match (Black).*

*Trial timeline: Onset of the Cue=0s; End of the Cue=.2s; Delay period= .2s to 2.7s; Response onset= 2.7s; Feedback=4.2s*

- a) Overlay of conditions in the 10 Hz frequency band during complete time period of the trials (averaged across all artifact free trials from all participants).
- b) Confidence intervals at 99% for the bootstrapped differences conditions in the 10 Hz frequency band. The grey area represents the 99% confidence interval of the 1,000 bootstrapped difference waves. The red line is placed at zero. Where the confidence interval does not include zero the waveforms are considered to be significantly different from one another.
- c) Time –frequency decomposition from 2 to 30 Hz. 99% confidence interval of the 1,000 bootstrapped differences of z scores was calculated. Where the colour is not masked (orange to red) waveforms are considered to be significantly different from one another.

## CHAPTER FIVE: DISCUSSION

This study used three ODR tasks to manipulate and investigate the unique cognitive demands of each task. Results of this study revealed significant differences in the delay period activity, indexed by alpha frequency band, across three ODR tasks. First, delay period alpha was significantly larger in Control condition compared to WM conditions. Although this result may seem to support lower cognitive load due to less demanding feature of the Control task, it is more likely that Control condition created a different brain state which probably confounded the comparisons across conditions. This result was unexpected but points to an important methodological issue for examining and analyzing ERP/ERSP data.

Second, between the two WM conditions, delay period alpha was larger in Match compared to Non-Match. This difference, which was specific to the delay period, was observed particularly during the late delay, prior to the response (saccade generation). Anterior –posterior topographical distribution of alpha power difference was examined visually. Visual inspection suggested that the significant difference between conditions was localized more anteriorly (i.e. Fz, compared to other midline electrode sites).

These two findings and their methodological implications are further discussed .

### **Alpha Frequency Differences Among Conditions**

According to Fuster and Bressler's (2012) perception/action cycle there is a cyclical relationship between the environment and the perception/action processes in the cerebral cortex. In this cycle, information from the environment is perceived and this information is used to output an action into the environment. The delay period of these tasks provide a critical tool in measuring cortical activity related to the perception and action planning of

this cycle. In the delay period of the Match condition, participants maintain both sensory codes (retrospective) and actions codes (prospective) whereas in the Non-Match condition only sensory codes are maintained. The differences in the delay period activity could likely reflect the prospective action codes that prepare for the response. Fuster and Bressler (2012) purport that the retrospective and prospective functions of WM are embodied in networks of cortical neuronal assemblies. Previous research utilizing a very similar paradigm (i.e. Match/Non-Match), found differential activations during the maintenance period of these tasks (Curtis et al., 2004). In the Match condition, oculomotor areas were more active and in the Non-Match, the posterior parietal cortex and inferior frontal cortex were more active. Curtis et al. (2004) suggest that different nodes of the WM network are active during representation of different codes, prospective and retrospective. Curtis et al. (2004) utilized fMRI methodology and did not examine oscillatory activity as in the present study. However, their results indicating variation in sustained activity of different cortical regions during the delay period supporting the findings of this thesis. Put together with our results, activity in different regions seen through fMRI and the significant difference of alpha activity provide evidence that different cognitive functions are occurring during the delay period.

Results of this study clearly demonstrated 10 Hz (alpha) frequency power differences between two WM conditions, Match and Non-Match during the delay period. These conditions required different cognitive demands during the delay period. The Non-Match condition can be presumed to be more effortful as it required the additional component of preparation for inhibition. Başar (2012) asserts that alpha is not unitary in its functionality, but rather changes as a function of age, mental state, cognitive task, and

location of the EEG signal recording. The results of this study speak to this variation in alpha activity as this study's results indicate alpha activity varies as a function of task demand.

The research on alpha band activity has produced conflicting results in terms of the functionality of alpha frequency (Başar, 2012). This study did not propose to answer questions relating to the functionality of alpha but rather use differences in alpha power as an index of different cognitive demands during the delay period. During the delay period participants were required to engage different cognitive processes in order to successfully complete the task. These differences were found cortically in the 10 Hz frequency power.

While the literature on function of alpha band is equivocal, results of this study may be reconciled with previous literature on changes to cognitive load. Several studies found a negative correlation between alpha activity and the effort required for the tasks (Gevins et al., 1997; Krause et al., 2000; Pesonen et al., 2007; Stipacek et al., 2003). The Non-Match condition of this study presumably required more cognitive effort and demanded more cognitive resources than the Match condition. Therefore, the result of less power in the 10 Hz frequency during Non-Match is supported by the findings that decrease in alpha band activity reflects increases in cognitive load (Gevins et al., 1997; Krause et al., 2000; Pesonen et al., 2007; Stipacek et al., 2003). Pesonen et al. (2007) found that as memory load increased alpha activity decreased. This decrease in alpha activity was also sustained for longer periods as the memory load was increased.

Another explanation offered for alpha suggests that alpha is an index of the orientation of attention (Hanslmayr et al., 2011; MacLean et al., 2012). It is proposed that larger alpha is indicative of an internally oriented attention state (MacLean et al., 2012). In

this case, attention is oriented at internally generated information, such as memories. On the other hand, smaller alpha indicates an externally oriented attentional state (MacLean et al., 2012). Specifically, attention is directed to incoming, externally generated information. Support for this has been found in attentional blink studies by MacLean et al. (2012) and Hanslmayr et al., (2011). The results of the present investigation supports attentional allocation model of alpha activity. In the Match condition participants may be in a state of internally oriented attention as they have sufficient information about the cued location (memory item) needed to generate the saccade. In the Non-Match condition, attention may be focused externally as participants are waiting for additional information to successfully generate a saccade. Although participants in the Non-Match condition must retain some information internally (the location of the first star to which they will inhibit a saccade), the overall goal of the task, which is to make a saccade to an unknown location, likely becomes the primary attentional focus.

According to the model, the demands of Match and Non-Match conditions require different orientations of attention (i.e. internal versus external). The results of the analysis (Contrast two, Match versus Non-Match) support the conceptualization of alpha as an index of attention orientation. Specifically, internally oriented state (Match condition) demonstrated larger alpha whereas the externally oriented state (Non-Match condition) demonstrated smaller alpha. Additional explanations, however, are indicated in the research. MacLean et al. (2012) found larger attentional blink magnitudes in individuals who had greater alpha while at rest. They proposed that greater alpha could be conceptualized as a state of readiness. This hypothesis may also help to explain the results of greater alpha in the Match condition of this study. In the Match condition participants

may exhibit a state of readiness given that the location to which they must generate a saccade is known.

It is challenging to reconcile the results of the present study with the existing research findings of the effects of memory load on alpha activation because in memory load studies the number of items to be recalled is manipulated (Jensen et al., 2002; Gevins et al., 1997; Pesonen, et al., 2007). However, in this study, the cognitive load is manipulated without changing the memory load in WM (i.e. only one item is retained in both conditions). Specifically, the Non-Match condition requires more attention allocation and vigilance as the participants must be ready to respond to an unknown location while remembering the previous location (two goals). On the other hand, in the Match condition participants know where the stimulus will appear, and maintain this information in WM; thus in Match condition the participants can presumably be fully prepared to make their saccade when cued (one goal). Therefore, the Non-Match can also be considered more difficult. Decrease alpha power in Non-Match is related to increase in cognitive demands in this condition.

### **Frontal and Parietal Activity during Working Memory**

A functional network of the PFC and PC, were found to be simultaneously recruited during WM (Curtis & D'Esposito, 2003, Koch et al. 2005, Fuster & Bressler, 2012; Sarnthein, Petsche, Rappelsberger, Shaw, & von Stein, 1998). Results from Koch et al. (2005) study evidenced parallel processing in frontal-parietal regions during the delay phase of a spatial WM task. Fuster and Bressler (2012) assert that WM is dependent upon the frontal (executive) and posterior (perceptual) cortices. They propose activations of

expansive and overlapping cortical networks (which they termed 'cognits') that serve as a mechanism to bridge information necessary for prospective use.

Results of the present study indicate that compared to Non-Match condition, Match condition had significantly larger 10 Hz activity during the delay period in both frontal and parietal scalp sites. This increase in 10 Hz frequency was similar in both frontal and parietal locations in the Match condition suggesting that both frontal and parietal areas were recruiting the same 10 Hz activity (Figure 5). In the Non-Match condition, activity in the 10 Hz frequency was also similar in both frontal and parietal regions (although it had less power than the Match in both conditions) (Figure 5). The similar recruitment of 10 Hz frequency at frontal and parietal locations may suggest the synchronization of alpha frequency activity in the PFC and PC during WM conditions (Koch et al., 2005). In line with Fuster and Bressler's (2012) perception/action cycle, increased alpha power in the Match condition may indicate frontal-parietal coordination of the perceptual and executive functions necessary for prospective planning, where such prospective planning cannot be completed in the Non-Match condition.

### **State Differences**

The *Control* condition was carefully designed to mimic the events and visual stimuli of the two WM conditions. The Control was a visually-guided saccade task so participants were not required to do anything during the delay period, whereas in the WM condition participants must retain task relevant information. Therefore, it was presumed that the Control condition would provide a strong comparison for observing differences in neural activity related to non-WM cognitive demands (Control) versus WM cognitive demands (Match and Non-Match conditions). The analysis revealed that

throughout the entire Control condition there were significantly different frequency activations across a wide spectrum of frequencies (2-30 Hz) in all four electrodes (Fz, Cz, Pz, and Oz) when compared to the WM conditions. These differences were not specific to the delay period but sustained through the entire duration of the trial suggesting that the Control condition demonstrated a task-evoked cognitive state difference. Therefore, it was not possible to make inferences based only on the delay period differences between the Control and the WM conditions.

Results of this comparison were unexpected. However, upon reflection it is understandable that participants may be in a different cognitive state due to the repetitive and automated nature of the Control condition. Previous research has examined the task-evoked states of participants by examining the resting state connectivity both pre and post task (Gordon, Breeden, Bean, & Vaidya, 2014). The findings indicated that resting state connectivity post-task was significantly different from pre-task. Therefore, they conclude that a task can effectively change resting state connectivity after completing a task. Given that Gordon et al. (2014) demonstrated that a task can evoke a cognitive state differences lasting into the rest period post-task, it is reasonable to hypothesize that in the present study the Control condition evoked a cognitive state difference during the task. The 64 trials of the Control condition were blocked together such that participants would perform these trials consecutively (with a small break in the middle of the task, typically two to three minutes in duration, dependent upon the participant's readiness to proceed). I propose that due to the repetitive nature of the Control condition, participants became very complacent and did not require a significant amount of cognitive resources to complete the task. As participants were required to complete this task for 64

consecutive trials, it is likely that the task became almost automatic. This may have changed the mindset of the participants as participants did not need to utilize the cognitive resources as they would with the WM conditions. These suggestions may be in part supported by the results of Contrast One, as it was found that the Control condition had significantly larger alpha activity throughout the entire time period. Previous research has proposed that alpha band activity reflects the "idling" of the brain (Başar, 2012). A well documented literature on resting state alpha has shown that alpha increases when eyes are closed versus open, and it is proposed that more cortical resources are being utilized when the eyes are open versus closed (MacLean et al., 2012). Additionally, studies have shown that alpha decreases as tasks become more difficult (Gevins, et al., 1997; Krause et al., 2000; Pesonen et al., 2007). Therefore, in line with this research, the results of this study suggest that the increased alpha activity observed in the Control condition reflects the limited task demands on the brain and is a product of automated processing.

Given that differences in cortical activity between the Control condition and the WM conditions were not unique to the delay period or a clustered frequency range, results of this contrast could not appropriately answer the research questions of this study. Overall, the Control condition of this study may have invoked a state effect in the participants as demonstrated by the substantial differences across the entire trial period and a wide range of frequencies from 2-30 Hz. Although inferences about delay period differences could not be made, results of this comparison did demonstrate noteworthy results. In line with research on alpha activity, the increased alpha power is proposed to reflect the more basic nature of this condition (Başar, 2012; MacLean et al., 2012;

Pesonen et al., 2007). Although not appropriate for this study, this type of manipulation can be beneficial for other studies which wish to manipulate the state of the participant.

### **Methodological Implications**

The results of this study demonstrate evidence in support of examining and analyzing data in its entirety. Results of the analysis can shed some light on the potentially problematic practice of a priori analysis in which areas of interest are predefined and solely examined. In the case of our data, the common practice of pre-defining specific time periods of interest such as the delay period may have led to inaccurate support for the hypothesis. By only examining a limited time point of interest, mainly the delay period, the results may have been inaccurately representing the overall neural activity of the brain. When the entire trial period was analyzed it was found that in the Control condition the participants were in a cognitive state distinct from the other two conditions. This resulted in finding significant differences across the entire temporal period, that otherwise would not have been found if only the delay period was studied.

In ERP research defining and analyzing specific time ranges, or frequencies of interest is a common practice for analysis. However, researchers are moving away from this approach, in part because a substantial portion of the EEG recording is effectively ignored; thus much information about cognitive processing is lost. Methods such as time-frequency analysis are providing better alternatives for analysis (Pesonen et al., 2007). Pesonen et al. (2007) note this method allows for more detailed observations of oscillatory activity, as it includes time, frequency and power measures.

Given that blocking many of the trials of the same task together resulted in a state-affect, researchers must be aware of this methodological implication when creating their

paradigms. The consecutive ordering trials for tedious tasks such as in our Control condition may unintentionally create a state-affect in their participants and thus such Control tasks may not be suitable for comparison. This may be overcome by randomizing the order of individual trials for all conditions such that trials of the same condition are not consecutively presented.

Additionally, the use of bootstrapped statistics in EEG data has been receiving strong support from researchers (Desjardin & Segalowitz, 2013; Di Nocera & Ferlazzo, 2000; Rousselet, Husk, Bennet, & Sekuler, 2008). Di Nocera and Ferlazzo (2000) propose this method for within-subjects ERP studies. They assert that reliability of data is problematic when it relies on some method of estimation such as averaging. Di Nocera and Ferlazzo (2000) tested the bootstrap method to compare against conventional methods (ANOVA using grand averages) and found that the results of the ERP data displayed two different patterns. The bootstrap method did confirm the results of the ANOVA however it also demonstrated that the significant differences were not reliable for all subjects, as there was substantial inter-subject variability. Di Nocera and Ferlazzo (2000), propose that when bootstrapping is used with conventional analysis, it provides more accurate interpretation of the data.

### **Possible Limitations**

It should remain clear that this study does not address the question of the overall functionality of alpha activity. Rather, alpha activity was used as an index to examine differences in delay period activity which reflect different cognitive demands of the tasks. The function of alpha varies by a number of factors and this study can

only provide some insight into how alpha changes with respect to changes in task demands (Başar, 2012).

Due to processing and data analysis methods, theta and gamma frequency bands cannot be adequately investigated. For this study, alpha was chosen to be a focus for analysis and therefore beta frequency differences were not analyzed. This is a possible limitation, as previous research has found that frequency activations may work in synchrony, thus when one frequency band increases another decreases (Bastiaansen et al., 2002; Klimesch, Doppelmayr, Schwaiger, Auiger, & Winkler, 1999). Additionally, in this study only four midline scalp locations were examined.

### **Future Directions**

A further examination of the state affect found in this study may provide important practical knowledge and implications for researchers when constructing their paradigms. As this study is part of ongoing research in the Developmental Neuroscience Laboratory, these findings may demonstrate the need for a restructuring of the paradigm conditions. The *Control* condition did not provide a comparable control to the WM conditions, thus in the future Control condition should be modified. One possible solution is present conditions in a mixed-randomized order. Additionally, future research may benefit from the collection of behavioural measures such as reaction times and response accuracy. It would also be beneficial to administer to the participant a strategy questionnaire related to their performance during the different ODRs as well as their perception of task difficulty. Finally, future analyses of this data should use more scalp locations to include lateral electrodes both anteriorly and posteriorly.

Başar states that a "profound understanding of alpha activity can only be achieved by examining observations in the maturing brain, evolving brains, emotional brain and pathologic brains" (2012, p.2). Given the successful results of the analysis methods used, these methods should be replicated on data collected from the youth and children involved in the broader research study. This may provide valuable information from a developmental perspective as to the fundamental role of alpha activity and WM capacities.

Sternman et al. (1996) notes that EEG responses can involve both suppression and enhancement of various frequencies, thus, future research should examine the relationship between frequency bands. Pesonen et al. (2007) found that there was a complex interaction between frequency activations in alpha, theta, and beta ranges as memory load changed. Oscillations in theta, beta, and gamma bands may be of particular interest as previous research has reported their involvement in WM (Bastiaansen et al., 2002; Jensen et al., 2002; Klimesch et al., 1994; Palva et al., 2011; Pesonen et al., 2007; Roux & Uhlhaas, 2014). Further processing or additional analysis methods may be able to address these additional frequency bands more effectively.

Frontal and parietal areas of the brain have been noted as areas critical to WM function (Fuster & Bressler, 2012). Specifically, studies have noted an increased activity in these regions during WM, which has led to the theory that they are integral to WM (Fuster & Bressler, 2012; Klingberg, Forssberg, & Westerberg, 2002). As such, future research should analyze the coherence between the neural networks involved in WM.

The paradigm of this study was designed to be very simple so that inferences could be made about the most primary cognitive capacities occurring during the delay periods of these tasks. The simplicity of the paradigm also buffered against confounds typical in paradigms with complex task designs or instructions. This paradigm provided a strong foundation for analyzing and interpreting these basic functions. With this foundation, future studies should manipulate the task instructions to change the cognitive demands in various (i.e. more items to recall) ODR tasks.

### **Conclusion**

In conclusion, differences in neural activity which are proposed to reflect the response preparation aspect of WM, were found in this study. Specifically, differences in 10 Hz activity were found in the delay period when comparing Match to Non-Match conditions, with the Match condition demonstrating higher 10 Hz frequency power in all four electrodes (Fz, Cz, Pz, and Oz) compared to the Non-Match condition. These results are in line with traditional theories of alpha that purport that increased alpha activity reflects more basic processing. This interpretation of the alpha's function is substantiated by studies by Gevins et al. (1997) and Pesonen et al. (2007) which found that alpha power decreased as task difficulty increased. However, theories suggesting alpha differences reflect the degree of attention orientation, or level of readiness can also aid in the interpretation of this study's results (Hanslmayr et al., 2011; MacLean et al., 2012). This conception of alpha function resonates particularly well with the results found in this study as the critical difference of between the two WM conditions is degree of readiness to respond and the orientation of attention. The Match condition allowed for a high degree of readiness prior to the response and attention was oriented towards internal

information. The Non-Match condition did not facilitate complete readiness to respond and attention was oriented towards to incoming external information. Differences in alpha activity in the 10 Hz frequency likely reflect this degree of readiness to respond and to the orientation of attention to internal or external stimulus in WM tasks.

Finally, the results of this study shed light on an important methodological issue when analyzing EEG data. The methods used in this analysis proved to be critical to attaining an accurate understanding of the overall cortical activity during a task. Without utilizing a method such as time-frequency analysis, which examines a large time window and wide frequency spectrum, the results of this study may have been interpreted inaccurately. Task-evoked cognitive state differences are a methodological implication that researchers should remain aware of. Researchers should be cautious about interpreting their results when the data was not examined in its entirety.

## REFERENCES

- Agam, Y., & Sekuler, R. (2007). Interactions between working memory and visual perception: An ERP/EEG study. *NeuroImage*, 36, 933-942.
- Akin, M. (2002). Comparison of wavelet transform and FFT methods in the analysis of EEG signals. *Journal of Medical Systems*, 26(3), 241-247.
- Atkinson, R. C., & Shiffrin, R. M. (1968). Human Memory: A Proposed System and its Control Processes. In K. W. Spence, & J. T. Spence (Eds.) *The psychology of learning and motivation: Advances in research and theory* (Vol. 2, pp. 89-195). New York: Academic Press.
- Baddeley, A. (1992). Working memory. *Science*, 255(5044), 556-559.
- Baddeley, A. (1996). The fractionation of working memory. *Proceedings of the National Academy of Sciences*, 93, 13468-13472.
- Baddeley, A. (2000). The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences*, 4(11), 417-423.
- Baddeley, A., & Hitch, G. (1974). *Working memory*. In G. H. Bower (Ed.), *The psychology of learning and motivation: Advances in research and theory* (Vol. 8, pp. 47-89). New York: Academic Press.
- Banich, M.T., & Compton, R. J. (2011). *Cognitive Neuroscience (Third Edition)*. Belmont, CA: Wadsworth, Cengage Learning.
- Başar, E. (2012). A review of alpha activity in integrative brain function: Fundamental physiology, sensory coding, cognition and pathology. *International Journal of Psychophysiology*, 86, 1-24.

- Bastiaansen, M., Posthuma, D., Groot, P., & de Geus, E. (2002). Event-related alpha and theta responses in a visuo-spatial working memory task. *Clinical Neuroscience, 113*, 1882-1893.
- Berger, H., 1929. Über das Elektrenkephalogramm des Menschen. I. Bericht. *Archiv für Psychiatrie und Nervenkrankheiten, 87*, 527–570.
- Brignani, D., Bortoletto, M., Miniussi, C., & Maioli, C. (2010). The when and where of spatial storage in memory guided saccades. *NeuroImage, 52*, 1611-1620.
- Brignani, D., Maioli, C., Rossini, P.M., & Miniussi, C. (2007). Event-related power modulations of brain activity preceding visually guided saccades. *Brain Research, 1136*, 122-131.
- Bosch, V., Mecklinger, A., & Friederici, A. D. (2001). Slow cortical potentials during retention of object, spatial, and verbal information. *Cognitive Brain Research, 10*, 219-237.
- Brown, M. R. G., DeSouza, J. F. X., Goltz, H. C., Ford, K., Menon, R. S., Goodale, M. A., & Everling, S. (2004). Comparison of memory- and visually guided saccades using event-related fMRI. *Journal of Neurophysiology, 91*, 873-889.
- Connolly, J. D., Goodale, M. A., Goltz, H. C., & Munoz, D. P. (2005). fMRI activation in the human frontal eye field is correlated with saccadic reaction time. *Journal of Neurophysiology, 94*, 605-611.
- Constantinidis, C., & Wang, X. (2004). A neural circuit basis for spatial working memory. *The Neuroscientist, 10*(6), 553-565.

- Cowan, N. (1988). Evolving conceptions of memory storage, selective attention, and their mutual constraints within the human information processing system. *Psychological Bulletin*, 104, 163-191.
- Cowan, N. (2008). What are the differences between long-term, short-term, and working memory? *Progress in Brain Research*, 169, 323-338.
- Curtis, C. E., Sun, F. T., Miller, L. M., & D'Esposito, M. (2005). Coherence between fMRI time-series distinguishes two spatial working memory networks. *Neuroimage* 26(1), 177–183.
- Curtis, C. E., & D'Esposito, M. (2003). Persistent activity in the prefrontal cortex during working memory. *Trends in Cognitive Sciences*, 7(9), 415-423.
- Curtis, C. E., & D'Esposito, M. (2006). Selection and maintenance of saccade goals in the human frontal eye fields. *Journal of Neurophysiology*, 95, 3923-3927.
- Curtis, C. E., Rao, V. Y., & D'Esposito, M. (2004). Maintenance of spatial and motor codes during oculomotor delayed response task. *The Journal of Neuroscience*, 24(16), 3944-3952.
- Desjardins, J. A., & Segalowitz, S. J. (2013). Deconstructing the early visual electrocortical responses to face and house stimuli. *Journal of Vision*, 13(5) 1–18.
- Delorme, A., & Makeig, S. (2004). EEGLAB: An open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of Neuroscience Methods*, 134, 9-21.

- D'Esposito, M. (2007). From cognitive to neural models of working memory. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 362, 761-772.
- D'Esposito, M., Postle, B. R., & Rypma, B. (2000). Prefrontal cortical contributions to working memory: Evidence from event-related fMRI studies. *Experimental Brain Research*, 133, 3-11.
- Di Nocera, F., & Ferlazzo, F. (2000). Resampling approach to statistical inference: Bootstrapping from event-related potentials data. *Behavior Research Methods, Instruments & Computers*, 32(1), 111-119.
- Ericsson, K. A., & Kintsch, W. (1995). "Long-term working memory." *Psychological Review*, 102, 211-245.
- Fiebach, C. J., Rissman, J., & D'Esposito, M. (2006). Modulation of inferotemporal cortex activation during verbal working memory maintenance. *Neuron*, 51, 251-261.
- Fell, J., & Axmacher, N. (2011). The role of phase synchronization in working memory processes. *Nature Reviews: Neuroscience*, 12, 105-118.
- Fonaryonva Key, A. P., Dove, G. O., & Maguire, M. J. (2005) Linking brainwaves to the brain: An ERP primer. *Developmental Neuropsychology*, 27(2), 183-215.
- Funahashi, S. (2006). Prefrontal cortex and working memory processes. *Neuroscience*, 139, 251-261.

- Funahashi, S., Bruce, C. J., and Goldman-Rakic, P. S. (1993). Dorsolateral prefrontal lesions and oculomotor delayed-reponse performance: Evidence for mnemonic "scotomas". *Journal of Neuroscience*, *13*, 1479-1497.
- Funahashi, S., & Kubota, K. (1994). Working memory and prefrontal cortex. *Neuroscience Research*, *21*, 1-11.
- Fuster, J. M. (1995). *Memory in the Cerebral Cortex*. Cambridge, MA: MIT Press.
- Fuster, J.M. (1997). Network memory. *Trends in Neuroscience*, *20*, 451-459.
- Fuster, J. M. (2009). Cortex and memory: Emergence of a new paradigm. *Journal of Cognitive Neuroscience*, *21*(11), 2047-2072.
- Fuster, J. M., & Alexander, G. E. (1971). Neuron activity related to short-term memory. *Science*, *173*(3997), 652-654.
- Fuster, J. M., & Bressler, S. L. (2012). Cognit activation: A mechanism enabling temporal integration in working memory. *Trends in Cognitive Neuroscience*, *16*(4), 207-218.
- Gazzaley, A., Rissman, J., & D'Esposito, M. (2004). Functional connectivity during working memory maintenance. *Cognitive, Affective, & Behavioral Neuroscience*, *4*(4), 580-599.
- Gevins, A., Smith, M., McEvoy, L., & Yu, D. (1997). High-resolution EEG mapping of cortical activation related to working memory: Effects of task difficulty, type of processing, and practice. *Cerebral Cortex*, *7*(4), 374-385.
- Goldman-Rakic, P. S. (1995). Cellular basis of working memory. *Neuron*, *14*, 477-485.

- Gordon, E., Breeden, A., Bean, S., & Vaidya, C. (2014). Working memory-related changes in functional connectivity persist beyond task disengagement. *Human Brain Mapping, 35*(3), 1004-1017.
- Handy, T. C. (2005). *Event Related Potentials: A Methods Handbook*. Cambridge, MA: MIT Press.
- Hanslmayr, S., Gross, J., Klimesch, W., & Shapiro, K. (2011). The role of alpha oscillations in temporal attention. *Brain Research Reviews, 67*, 331-343.
- Jensen, O., Gelfand, J., Kounios, J., & Lisman, J. E. (2002). Oscillations in the alpha band (9-12 Hz) increase with memory load during retention in a short term memory task. *Cerebral Cortex, 12*, 877-882.
- Jokisch, D., & Jensen, O. (2007). Modulation of gamma and alpha activity during a working memory task engaging the dorsal or ventral Stream. *The Journal of Neuroscience, 27*(12), 3244-3251.
- Jonides, J., Smith, E. E., Koeppe, R. A., Awh, E., Minoshima, S., & Mintun, M.A. (1993). Spatial working memory in humans as revealed by PET. *Nature 363*, 623-625.
- Klimesch, W. (1999). EEG alpha and theta oscillations reflect cognitive and memory performance: A review and analysis. *Brain Research Reviews, 29*, 169-195.
- Klimesch, W. (2012). Alpha-band oscillations, attention, and controlled access to stored information. *Trends in Cognitive Sciences, 16*(12), 606-617.
- Klimesch, W., Doppelmayr, M., Schwaiger, J., Auinger, P., & Winkler, T. (1999). 'Paradoxical' alpha synchronization in memory task. *Brain Research. Cognitive Brain Research, 7*, 493-501.

- Klimesch, W., Schimke, H., & Schwaiger, J. (1994). Episodic and semantic memory: An analysis in the EEG theta and alpha bands. *Electroencephalography and Clinical Neurophysiology*, *91*, 428-441.
- Klingberg, T., Forssberg, H., & Westerberg, H. (2002). Increased brain activity in frontal and parietal cortex underlies the development of visuospatial working memory capacity during childhood. *Journal of Cognitive Neuroscience*, *14*(1), 1-10.
- Kotchoubey, B. (2006). Event-related potentials, cognition, and behavior: A biological approach. *Neuroscience and Behavioural Reviews*, *30*, 42-65.
- Krause, C., Sillanmäki, L., Koivisto, M., Saarela, C., Häggvist, A., Laine, M., & Hämäläinen, H. (2000). The effects of memory load on event-related EEG desynchronization and synchronization. *Clinical Neurophysiology*, *111*(11), 2071-2078.
- Luck, S. (2005). An introduction to the event-related potential technique: The MIT Press, Cambridge MA.
- MacLean, M., Arnell, K., & Cote, K. (2012). Resting EEG in alpha and beta bands predict individual differences in attentional blink magnitude. *Brain and Cognition*, *78*, 218-229.
- Medendorp, W. P., Kramer, G., Jensen, O., Oostenveld, R., Schoffelen, J., & Fries, P. (2006). Oscillatory activity in human parietal and occipital cortex shows hemispheric lateralization and memory effects in a delayed double-step saccade task. *Cerebral Cortex Advance Access*, 1-11.

- Miyake, A. & Shah, P. (Eds) (1999). Models of working memory: Mechanism of active maintenance and executive Control. Cambridge, UK: Cambridge University Press.
- Palva, S., Kulashekhar, S., Hämäläinen, M., & Palva, J. M. (2011). Localization of cortical phase and amplitude dynamics during visual working memory encoding and retention. *The Journal of Neuroscience*, *31*(13), 5013-5025.
- Pesonen, M., Hämäläinen, H., & Krause, C. (2007). Brain oscillatory 4-30 Hz responses during a visual n-back memory task with varying memory load. *Brain Research*, *1138*, 171-177.
- Pfurtscheller G., Stancak A., Jr., Neuper C. (1996). Event-related synchronization (ERS) in the alpha band - An electrophysiological correlate of cortical idling: A review. *International Journal of Psychophysiology*, *24*, 39-46.
- Pollmann, S., & von Cramon, D. Y. (2000). Object working memory and visuospatial processing: functional neuroanatomy analyzed by event-related fMRI. *Experimental Brain Research*, *133*, 12-22.
- Postle, B. R. (2006). Working memory as an emergent property of the mind and brain. *Neuroscience*, *139*, 23-38.
- Postle, B. R., Druzgal, T. J., & D'Esposito, M. (2003). Seeking the neural substrates of visual working memory storage. *Cortex*, *39*, 927-946.
- Quiroga, Q. Q. (1998). Quantitative analysis of EEG signals: Time-frequency methods and chaos theory. Doctoral Dissertation from Institute of Physiology, Medical University Lubeck..

- Rämä, P., Carlson, S., Kekoni, J., & Hämäläinen, H. (1995). A spatial oculomotor memory-task performance produces a task-related slow shift in human electroencephalography. *Electroencephalography and Clinical Neurophysiology*, *94*, 371-380.
- Ranganath, C., Cohen, M. X., Dam, C., D'Esposito, M. (2004). Inferior temporal, prefrontal, and hippocampal contributions to visual working memory maintenance and associative memory recall. *Journal of Neuroscience*, *24*, 3917-3925.
- Rousselet, G. A., Husk, J. S., Bennett, P. J., & Sekuler, A. B. (2008). Time course and robustness of ERP object and face differences. *Journal of Vision*, *8*(12), 1-18.
- Roux, F. & Uhlhasas, P. (2014). Working memory and neural oscillations: Alpha-gamma versus theta-gamma codes for distinct WM information? *Trends in Cognitive Sciences*, *18*(1), 16-25.
- Ruchkin, D., Johnson, R., Mahaffey, D., & Sutton, S. (1988). Toward a functional categorization of slow waves. *The Society for Psychophysiological Research*, *25*(3), 339-353.
- Samar, V. J., Bopardikar, A., Rao, R., & Swartz, K. (1999). Wavelet analysis of neuroelectric waveforms: A conceptual tutorial. *Brain and Language*, *66*, 7-60.
- Samar, V. J., Swartz, K. P., & Mysore, R. R. (1995). Multiresolution analysis of event-related potentials by wavelet decomposition. *Brain and Cognition*, *27*, 398-438.
- Sarnthein, J., Petsche, H., Rappelsberger, P., Shaw, G. L., & von Stein, A. (1998).

- Synchronization between prefrontal and posterior association cortex during human working memory. *Proceedings of the National Academy of Science USA*, 95, 7092-7096.
- Srimal, R., & Curtis, C. E. (2008). Persistent neural activity during the maintenance of spatial position in working memory. *Neuroimage*, 1(39), 455-468.
- Stipacek, A., Grabner, R., Neuper, C., Fink, A., & Neubauer, A. (2003). Sensitivity of human EEG alpha band desynchronization to different working memory components and increasing levels of memory load. *Neuroscience Letters*, 353(3), 193-196.
- Teplan, M. (2002). Fundamentals of EEG measurement. *Measurement Science Review*, 2(2), 1- 11.
- Tekok-Kilic, A., Tays, W. J., & Tkach, R. (2011). Activational patterns of the frontal-parietal networks during oculomotor delayed response tasks: An event-related potential study. *Psychophysiology*, 48 (Suppl.1), S97.
- Veqar Siddiqui, S., Chatterjee, U., Kumar, D., Siddiqui, A., & Goyal, N. (2008). Neuropsychology of prefrontal cortex. *Indian Journal of Psychiatry*, 50(2), 202-208.
- Wilcox, R. R. (2005). Introduction to robust estimation and hypothesis testing (2nd ed.). San Diego, CA: Academic Press.
- Wilson F., O'Scalaidhe, S. P., Goldman-Rakic, P. S. (1993). Dissociation of object and spatial processing domains in primate prefrontal cortex. *Science*, 260, 1955-1958.

Yeung, N., Bogacz, R., Holroyd, C., & Cohen, J. (2004). Detection of synchronized oscillations in the electroencephalogram: An evaluation of methods.

*Psychophysiology*, 41, 822-832.

## Appendix A

Developmental Neuroscience Laboratory  
 Department of Child and Youth Studies  
 Brock University

CONSENT FORM    Date: \_\_\_\_\_

TITLE OF STUDY: Visual-spatial working memory: What does saccade-related brain activity tell us?

### **Principal Investigator**

Dr. Ayda Tekok-Kilic  
 Developmental Neuroscience Lab  
 Department of Child and Youth Studies  
 Brock University  
 (905) 688-5550 ext. 3937  
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### **Research Assistant**

William Tays  
 Developmental Neuroscience Lab  
 Brock University  
 (905) 688-5550 ext. 3347

Dear Participant:

This form provides you with the information you will need to make an informed decision about whether or not you would like to participate in our study on working memory development. Please read it over carefully and if you have any questions, you are welcome to phone the research coordinator, William Tays (905) 688-5550 ext. 3347 or, or myself (Dr A. Tekok-Kilic) at ext. 3937 for clarification.

The goal of this study is to investigate brain function while participants take part in game-like computer tasks. We believe that this study will lead to a richer understanding of the brain mechanisms underlying the functionality of working memory processes and its development.

### **WHAT IS INVOLVED**

The study will take place at the Developmental Neuroscience Lab. You will be asked to come to the lab for a 2 hour session. All of the tasks and procedures will be explained to you and we will review this letter with you so you have a full understanding of what is involved before we begin.

A soft, elasticized sensor cap is placed on the head to record naturally-occurring brain activity while you engage in a series of game-like computer tasks. The tasks do not involve motor responding (such as pressing a key) but they involve directing eye gaze to specific locations cued by visual stimuli on a computer screen. Eye gaze is measured by analyzing real-time images taken from two digital cameras attached to the computer monitor. These cameras do not store the images they measure. They only record digitized landmarks that represent your eyes and face. It will take about 30 minutes for all of the set-up we require, during which time you can relax or ask us questions. There will be three 15 minute computer tasks presented sequentially during the study. Including extra time for breaks, the entire session is expected to take 2hours and there will be a \$20.00 honorarium for volunteering your time.

### **POTENTIAL RISKS AND BENEFITS**

There are no risks involved in this study. Benefits include introducing participants to research. The techniques and procedures will be fully explained to you and you will be free to ask questions throughout. Most participants find it interesting to see their brain waves and eye tracking on the

computer screen. As well, young people often feel good about taking part in a project that could increase our scientific understanding of the factors that influence brain development.

#### CONFIDENTIALITY

All information gathered is kept completely confidential. Names are replaced with code numbers and it is these code numbers that are entered into our data base along with the physiological information. They will be stored in a restricted-access laboratory, only researchers working on this project will have access to these data and all records of the information will be destroyed when no longer required. You would never be identified in any way when the data are published in academic journals or presented at scientific conferences.

#### PARTICIPATION IS VOLUNTARY

Participation in this study is entirely voluntary. You may refrain from participating in any component of this study. As well, you may decide to withdraw from this study at any time without penalty even after signing this form.

#### SECONDARY USE OF THE DATA

The present investigation is designed as a pilot project and therefore the results will be preliminary. The researchers may decide to re-analyze the data in the future. This is considered as "secondary data analyses" and will only be conducted if you give your consent.

#### CONTACT INFORMATION

If you have any questions about this study or if you would like further information, please contact the project coordinator, Carleigh Sanderson (contact information above). This study has received ethics clearance from the Research Ethics Board of Brock University (#10-211). If you have any comments or concerns about the rights of a research participant, please contact the Research Ethics Office at 905-688-5550, Ext. 3035.

Thank you for considering this project. If you would like to participate, please return a signed copy to the lab in the envelope provided but keep the extra copy for your records.

#### CONSENT

I agree to participate in the study described above. I have made this decision based on the information provided above and have had the opportunity to receive any further details and understand that I am welcome to ask any further questions in the future. I also understand that I can withdraw this consent at any time without penalty even after signing this form.

Participant's Name: \_\_\_\_\_

Signature: \_\_\_\_\_

Date: \_\_\_\_\_

I also agree on the secondary use of the data collected for this research by the researchers in future research.

Participant's Signature: \_\_\_\_\_

This participant received research participation hours ( ) or an honorarium ( ).

## Appendix B

**TELEPHONE SCRIPT – For Undergraduate Volunteers**

Name \_\_\_\_\_ Phone \_\_\_\_\_

Thank you for calling. My name is \_\_\_\_\_. Let me first tell you about the study. We are interested in how the brain supports performance on tasks requiring attention and memory. We are studying brain and cognitive development as humans grow and change from young children into adults.

We would like you to come to the Developmental Neuroscience Lab at Brock University for a single 2 hour session. During this session, you will complete 3 versions of a computerized memory task in the form of a game while we use EEG to monitor your naturally occurring brain response and visual sensors to monitor the direction of your eye movements.

Of course, we will explain all procedures to you fully when you arrive at the lab before you begin. But I can answer any general question you might have right now (give any practical or technical information required). If you think you might be interested, can I ask you a few health-related questions to see if the study would be appropriate for you. Is this alright? This and all other information is kept strictly confidential.

1. What is your birth date? \_\_\_\_\_ Approx years of education? \_\_\_\_\_  
Right or left-handed? \_\_\_\_\_
2. Do you have any visual problems? \_\_\_\_\_ Yes No
4. Do you have any major health conditions? \_\_\_\_\_ Yes No
6. Do you have any conditions that could affect nervous system function? Yes No  
(e.g., multiple sclerosis, epilepsy, fibromyalgia?)
7. Do you have diabetes, hypoglycaemia, lupus, chronic fatigue syndrome? Yes No
8. Have you ever had any serious psychiatric difficulties? Yes No  
(e.g. diagnosed ADD, clinical depression \_\_\_\_, other? \_\_\_\_\_)
9. Have you ever had a head injury or concussion? If yes: \_\_\_\_\_ Yes No

*If serious visual problems, or serious physical, neural or mental condition say.....*

Having \_\_\_\_\_ could affect the physiological responses that we will be measuring so I'm afraid that this study won't be appropriate for you. However, if you are still interested, we could send you some information about the outcome of the study when it's ready. Also, there may be other studies coming up where \_\_\_\_\_ would not be an issue. If you like, I can put your name on a list and we could contact you about participating at another time.

*If health screening is passed say:* That all seems fine. However, since we will be collecting EEG, there are a couple of other things I have to ask: Do you use non-permanent hair dye? \_\_\_\_ Is your

hair extremely thick? \_\_\_\_\_ In corn rolls? \_\_\_\_\_ Dreadlocks? \_\_\_\_\_ Anything else that might make fitting a tightly fitting cap difficult?

Would it be alright for you to not wear makeup (or remove any makeup) the day you come for the study?

*If they meet criteria and are willing to participate ...*

O Take contact info, arrange an appointment, and describe how to get to the lab.

O If they wear contacts, suggest wearing glasses that day instead.

O Remind them that this is entirely voluntary and that they are free to withdraw at any time if they wish.

O Tell them that we can email or call to give a reminder prior to their visit.

O THANK THEM!

***Contact Information:***

***Appointment Date:***

## Appendix C

### Developmental Neuroscience Lab, Brock University Feedback Form

#### **Project Title: Visual spatial working memory: What does saccade-related brain activity tell us?**

Dear Participant,

Thank you for taking part in this study. Without the help of volunteers like you, this research would not be possible.

As you know we measured EEG and monitored your eye-movements while you completed very simple computer games that required you to maintain specific spatial locations in mind. Holding or manipulating information in your mind over a short period of time is referred to as “working memory” and is fundamental to both basic and complex thinking in human beings. In this study, we are specifically interested in how children and young adults are able to hold spatial information in working memory and use that knowledge to properly guide the eyes to the locations required in our computer game.

The working memory functions you needed to use in this study are supported by various regions of the brain including the dorsolateral prefrontal cortex and frontal eye fields (both in the front of the brain) as well as the inferior parietal lobule (located about several centimetres behind and above your ears). Understanding how these different areas support the storage of spatial information and are used to guide the movement of your eyes is of great interest to cognitive neuroscientists. By recording brain responses in children of various ages, we can chart the development of the different neural structures involved in spatial working memory and the control eye movements. This information can also be used to identify and understand abnormal developmental trajectories in spatial working memory as well how damage to the brain (from head injuries or disease) can be expected to impact mental skills and behaviour.

As you are aware from the consent form, all of your data will be kept strictly confidential and when the data is presented, you will not be identified in any way.

If you would like to learn more about the results of this study, feel free to contact the principle investigator (see below). However, please be advised that it takes several months to complete data collection and then to process the data and perform necessary analyses. Thus, preliminary results are not likely to be ready before the summer of 2011.

If you have any issues that you would like to discuss regarding your involvement in this study, you may contact the Brock Research Ethics Board through the Research Office at 905-688-5550, Ext: 3035, File # 10-211.

Thank you again for taking part in this study. Your help was very much appreciated.

*Principle Investigator:*

*Dr. Ayda Tekok-Kilic*

*atekokkilic@brocku.ca*

*Lab Phone: 905-688-5550, Ext: 3347 Office Phone: 905-688-5550, Ext: 3937*

