Neural Correlates of Rote Memory: Auditory Interference and Working Memory Capacity Effect Quranic Recall in Children and Young Adults Using Electroencephalography

By

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A thesis submitted to the Faculty of Graduate and Postdoctoral Affairs in partial fulfillment of the requirements for the degree of

Master of Science

in

Neuroscience

Carleton University

Ottawa, Ontario

Abstract

The study in question investigated the neural activation patterns in children and young adults who have previously memorized text from the holy Quran of the Islamic religion without understanding the Arabic language. The Quran Recognition Task (QRT) was developed to test long term memory recall and working memory capacity during electroencephalography (EEG) recording. The study examined the effect of auditory interference as a means of distraction, manipulating the processes underlying recall and recognition. 16 subjects (Aged 8-27 years) participated in the study. Auditory interference was proven to significantly affect the accuracy rate for both groups (F (1, 14) = 12.34, p<.05). Significant differences in brain activation patterns and in the appearance of select event related potentials (Early sustained potentials, P300 and N400) were observed across distraction conditions, across different periods in the task presentation and between groups. Children exhibited more global activation, showing their need for more neural resources and working memory capacity to successfully complete the task while the brain activation patterns for adults depicted decreased amplitudes in the waveforms overall. The results illustrated the major differences between groups in the cognitive strategies used to complete the task. This study suggests developmental differences in the cognitive and neural approaches in retaining and recalling rote memory in a specific cultural context.

Acknowledgements

In the Name of Allah, the Most Gracious, the Most Merciful.

I would first like to praise God for the opportunity to complete this project and work with the blessed Quran. “And We have certainly made the Qur'an easy for remembrance, so is there any who will remember?” Surah 54:17 illustrates the very idea that was the driving force of this project.

The prophet Muhammad (Peace and blessing be upon him) has said:

" لاَيَشْكُرُ اللهَ مَنْ لاَيَشْكُرُ النَّاسَ "

“He who does not thank people is not thankful to Allah.”

This project would forever remain just an idea without the support and encouragement of my Supervisor Dr. Amedeo D’Anguilli. My preliminary meetings with him gave me the inspiration and motivation to work on this amazing project. His guidance and patience has been instrumental to my success. Thank you, for taking the crazy idea of a 3rd year undergraduate student seriously.

I extend my gratitude to the members of my thesis advisory committee Dr. Shawn Haley and Dr. Patrice Smith. Your considerable knowledge and your valuable feedback on my prospectus allowed me to think beyond the constraints of my understanding about my thesis. Thank you to my internal examiner Dr. Zeba Crook; your ingenious insight, thorough feedback and passion toward the subject was extremely encouraging. Also, your sense of humour is well appreciated (semicolons will always be scary). I am grateful to Dr. Mike Hildebrand, the chair of my thesis defence, for being so forthcoming and helpful. I am honoured someone as sincere and passionate about Neuroscience is on my committee.

I would like to thank Dr. Kim Hellemans and Diane Trenouth for their continuous support and encouragement. Kim, thank you for being an amazing mentor over the past few years. I sincerely enjoyed my time and learned valuable skills as your teacher's assistant as well as your student. You fully embody what it means to be a teacher. Also, I can watch your snapchat stories now. Thank you, Diane, for being a phenomenal graduate administrator. It means the world me that I always have the option to go see you in your office and feel a lot better when I come out. Thank you for your patience and belief in me.

I would like to thank Vicki Boman for being an amazing source of help and support. Thank you for making me realize the pleasures of life. You are a wonderful uplifting spirit. I would also like to sincerely thank Laura Brawn, my Learning Strategist. I am very happy to have met you this last semester. Thank you for always believing in me and encouraging me. You most definitely have been crucial to my success.

I would like to thank my NICER lab members: Jeremy Grant, Nina Hedayati, Christina Ou and Matt Buchannan. Jeremy, you are honestly the coolest person I've met in this degree (And I met a lot of cool people; it's the juggling obviously). You have been an inspiring role model of hard work. Nina, thank you for being a great friend and office buddy. Let's climb the CN tower. Thank you, Christina for being the most amazing and supportive friend one could ask for. Thanks for the early morning breakfasts. Thank you, Matt for always being accessible and welcoming. You're on to big things (future rapstar).

I would like to thank Julius Spring for his work on this project. We made a great team and it was my greatest pleasure being your mentor. I am also grateful for the support of Patricia Van Roon, Kylie Schibli, Korey MacDougal and Mason MacDonald.

A special thanks to all the sponsors for the project including the Saudi Arabia Embassy, Abu Hurairah Center, Ottawa Islamic School and the Islamic Society of Sandy Hill for their involvement and support for the project.

I would also like to thank my friends, in no particular order, Samantha Santoni, Hebo Ahmed, Fatimah Mirza, Aisha Hersi, Subin Park, Lindsay Hyland, Sherine ElSharnouby, Eliza Alim, Libby Madge and Bhawandeep Sekhon. You are all greatly appreciated. I would also like to thank my Seerah Sisters; classes with you guys got me through the tough times. A special shout out to my team at Amarah Media and Design. We got an amazing future ahead!

I would like to thank my family members and all my six brothers and sisters: Sahra, Abdullahi, Zaynab, Fowzia, Abdulrahman and Zakaria. I love you all. I would like to thank my cousin Susan Soufi for the continuous encouragement and for being a great role model. I am thankful for my aunt Anisa Soufi for her phenomenal care and good will. Shoutout to my family members in Hargeisa and Wajaale in Somalia, who have always been rooting for me.

I am truly blessed by having the best friends anyone could ask for. Shukri Ahmed, without your presence, I could not have made it this far. Thank you for always having my back. Zaynab Omer, you are a selfless individual and I am proud to be your big sister. Thank you for helping me every step of the way. Maryan Hersi, you are my day one; ride or die. Thank you for all your pep talks and encouragement through the years.

Last but not least, I extend my utmost gratitude to my Hooyo and Aabo, my beautiful parents. Everything that I have ever accomplished is due to their dedication to everything about me whether it is as mundane as the food I eat and the warmth of my clothes. You two are my biggest fans and I beyond blessed to call you both my parents. I love you forever and always. This thesis is dedicated to you.

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1 Chapter: Introduction

1.1 Memorization of the Holy Quran

Memory drives the mechanisms behind our everyday actions. Whether it is remembering the name of a new colleague, recalling your friend's address or preparing for a thesis defense, memory is an essential factor in daily functioning. From specific personal anecdotes to broad shared histories, memory can also be regarded as a major feature of identity. Holy texts, for example, include recounted stories from the past to form a collective identity for a particular religious group. A unique practice from one of such Holy Scriptures includes the full memorization of the Quran: the holy text of the Islamic religion. Quran memorization is a unique practice followed by millions worldwide (Iqbal, 2012). Successful commitment of the text to memory requires a coordination of memory processes and executive functions. Working memory, and the phonological loop subcomponent in particular, is an executive function imperative to Quran memorization (Omer *et al.,* 2015). Auditory interference disrupts verbal working memory capacity needed to retain Quranic scripture. On the other hand, a population of Muslims follows this practice without comprehending the language of the Quran, which adds an added dimension of complexity in understanding the mechanisms underlying this practice (Saleem, 2015). The following will explore the basics of Quran memorization, implicated memory systems, and auditory interference as a working memory disruptor in literature.

1.1.1 What is the Quran? Visual and Aural Mediums

The Quran is the religious scripture of the Islamic religion and can be approached through visual (calligraphic art), textual (reading) and aural (oral recitation or citation) mediums. The text in the *kitab* (book) spans 604 pages divided into thirty *juz* (sections) and 114 *surahs*

(chapters) (Ali, 2000). Since its inception to the prophet Muhammad multiple centuries ago, Muslims boast the existence of one unedited version of the text. Its primary written form is in classical Arabic or *Fus'ha* (Gade, 2010). Muslims begin the journey of memorization by studying the orthography of classical Arabic in order to facilitate the reading of the written text.

The most distinctive feature of the Quran is its original medium: sound. The main mode of transmission of the text was oral recitation as opposed to written script. Muslims believe that the verses were primarily recited out loud and memorized decades before it was transcribed into a written book (As-Said, 1975). The word Quran itself is derived from the Arabic root word "*qara'a*" which means to recite, translating as 'The Recitation' (Rane, 2010). The text encompasses rhyme and prose to convey what Muslims believe to be its 'divine' message, which introduces a melodic feature to the recitation. The sound of the recitation of the Quran cannot be categorized as music due to the lack of musical elements such as timbre, harmony and color (Nelson, 1985). On the other hand, the Quran is characterized as having "musical touches", a "melodic quality" and a "uniqueness of sound" (Nelson, 1985; As-Said, 1975). The Quran's melodic qualities are facilitated by the rules of recitation, referred to as *Tajwid*, through specificities such as the moments to breathe and the length of sounds for each letter (Gade, 2010).

1.1.2 Cultural Phenomenon: Memory and Learning

Islamic theological sources maintain that in order to preserve the authenticity of the holy text and to establish an intimate connection to what they believed to be the words of God, early Muslims would memorize the entire Quran in order to create a "linkage across time" through passing it on to the next generation (As-Said, 1975). The memorization of the Quran, including

recitation and rote memorization, remains a widespread practice for Muslims worldwide. Concurrently, the Quran is the most memorized book in history, an estimated number of 75 million of 2.5 billion Muslims around the world currently have the Arabic text fully memorized (Iqbal, 2012). The practice is so common that the memorization of the Quran is a prerequisite to gain acceptance in some Islamic based colleges (Saleh and Sadiq, 2012).

The primary mode of memorizing the classical Arabic text requires dedicated hours of rote memorization, either through reciting the text orally or listening to the recited text (Rafiq, 2014). The latter requires either a Quran teacher or professionally recorded recitations of the text. The study of the Quran usually occur in *Madrassas, Katabib* and *Pesantren* or Quran-based schools (Hassan and Zailaini, 2013; Saleh and Sadiq, 2012). In some countries, *Madrassas* preside over traditional secular education (Wagner, 1978). Children typically begin to learn the orthography of the Arabic language at 4 or 5 years of age and finish memorization five to ten years later (Gade, 2010). In order to retain the verses, the Quran is consistently revisited in a practicing Muslim's life: daily through prayers and annually during the month of Ramadan (Nelson, 1985).

Though the Quran is transcribed in the classical Arabic language, non-Arabic speaking Muslims memorize the text along with Arabic speakers. This poses a unique dynamic: memorization of text in a language without comprehension (Boyle, 2006; Rafiq, 2014; Saleem, 2015). Non-Arabic speaking Muslims learn the Quran in Arabic within households that are not fluent in Arabic. Non-Arabic speaking Muslims primarily read and memorize the text without the help of semantic knowledge and then learn the meaning through translation (Sardar, 2011). The ethnic tribe of Banjar, for example, resides in Indonesia and follows the Muslim faith (Rafiq 2014). Despite not speaking the traditional language of the Quran, Arabic, the Banjars still

practice the act of memorizing the Quran. This non-Arabic speaking community memorizes the book using traditional methods such as oral and aural techniques. A study examining Quran memorization in Islamic schools in three Muslim majority countries (Yemen, Nigeria and Morocco), found that generally students from all three countries could not translate the text that they spent hours memorizing (Boyle, 2006).

Non-Arabic speakers can still memorize the scripture without the visual aid of the physical book and relying only on auditory information (Saleem, 2015). A study including eight participants (three blind and five with sight) who had previous experience with memorizing the Quran without comprehension were interviewed around five categories: preparation questions, basic information about the memorization of the Quran, mistakes during memorization and recall, memorization tactics, and unique features of the text (Saleem, 2015). The techniques between blind and seeing memorizers differed in the amount of time spent orally repeating the text. Blind memorizers would further associate the words with cues such as the tone, voice, pitch of the teacher compared to memorizers with sight who have access to visual cues from the Arabic text (Saleem, 2015**).** This study further reiterates the importance of auditory based learning in the Quran whereas students without sight can efficiently memorize the text without comprehension as well. Other than specific religious based practices that employ the memorization of holy text, such as the memorization of the holy Torah in Judaism and Latin hymns in Christianity, the memorization of the Quran without semantics is heavily polarized from several other practices around the world that are somewhat similar including memorizing songs in another language (Jaffee, 2001). This is primarily due to the binding sense of religious obligation fueled by the inherent belief that the sacred text is the word of God. The next section will address the motivations driving this feat of memory.

1.1.3 Motivation behind the Practice

This book is regarded as a source of guidance for both everyday affairs and to the proposed afterlife in Islam (Gade, 2010). The completion of the memorization of the book is seen as a high virtue, so much so that those who achieve this accomplishment are given the esteemed title *Hafidh*, or protector of the Quran. The 'divine' verses of God in the Islamic religion are the most important words to a Muslim. The motivation for this feat of memory also stems from the many virtues that are associated with the practice. In a saying of the prophet Muhammad, it is said that the best of you is he who learns the Qur'an and teaches it (Bukhari, 1980). As well as, "Whoever recites one word from the Book of Allah (God) will be rewarded for a good deed and ten more like it" (Al-Tirmidhi, 2007). The text is recited during the Muslim's five daily prayers, during major life events such as a funeral or a marriage and acts a guide for everyday affairs. The Quran contains political, judicial, social, and religious themes to influence the lifelong decisions of a Muslim. Therefore, the Quran is an essential part of the life of a Muslim, a source of virtue, and a guide to day-to-day life. Motivation alone does not drive successful completion of memorizing the text: individual differences in the efficiency of memory processes play a significant role. In the next section, the key basic systems associated with long-term auditory memory retention will be addressed.

1.2 Memory Processes Implicated in Quran Memorization

Memory, in a general sense, refers to the processing, storage and retrieval of information of the mind (Atkinson & Shiffrin, 1968). The Atkinson-Shiffrin Model, also referred to as the Multi-Store Model, divides memory into three storage categories: sensory memory, short-term

and long-term memory. The brain stores information through first either attending or disregarding environmental stimuli (sensory memory), then retaining memories for a limited time through attention (short term memory) and keeping memories after repeated rehearsal (long term) (Baddeley and Hitch, 1974; Atkinson & Shiffrin, 1968). Long term memories are stored until retrieved during short term memory maintenance or deleted due to lack of recall (Anderson *et al.,* 1994). Memory retrieval is divided into recall and recognition: recall is thought to be accessed through a specific "search process" while recognition is accessed in a more global fashion (Gillund and Shiffrin, 1984; Unsworth, 2016).

Working memory, a component of short term memory, refers to an executive function that holds, processes and manipulates information from either short-term memory or long term memory for a limited time (Engle, 2002). The most widely accepted model for working memory was developed by Baddeley and Hitch (1974). This working memory model includes four components: the visuospatial sketchpad, central executive, phonological loop and the episodic buffer (Baddeley, 2003). Working memory involves a limited amount of resource that differs among individuals and is referred to as working memory capacity or load (Engle, 2001). Various studies have demonstrated that working memory capacity is imperative to higher order functions including comprehension, attention, reasoning, and fluid intelligence (Kane and Engle, 2002; Unsworth, 2016). Performance on working memory tasks are closely related to performance on other cognitive tasks (Daneman and Carpenter, 1980; Case *et al.,* 1982). A study by Daneman and Carpenter, employed the reading span task, in which participants were asked to recall the last word of a sentence they had previously read out loud (1980). Performance on this working memory task correlated with the reading comprehension scores suggesting the link between

comprehension and working memory capacity. Counting span and operation spans are also used to predict working memory capacity (Turner and Engle, 1989; Case *et al.,* 1982).

In regards to Quran memorization, the auditory or visual sensory information from the physical book and/or the recitation is transferred into short term memory. After prolonged active rehearsal, the information is moved into long term memory for future recall. The primary method of Quranic studies is rote memorization, where constant textual repetition ensures sub-permanent retention (Marton *et al.,* 1997; Gonzalez *et al.,* 2008). Though all the components of working memory play a role in Quran retention, the phonological loop is of distinct interest as an auditory-based domain. The phonological loop consists of the phonological store and the articulatory rehearsal system which account for speech processing and holding auditory information respectively (Baddeley, 2003). Studies on the phonological loop have discovered different factors that govern verbal memory, including the phonological similarity effect, word length effect, and articulatory suppression (Papagno *et al.,* 1991; Zoccolotti *et al.,* 2005). The phonological similarity effect refers to the difficulty of remembering word strings that are similar sounding over phonologically unrelated words (Baddeley, 2003). The difficulty of remembering words that are longer in length as compared to remembering shorter words demonstrates the rehearsal component of the phonological loop and is referred to as the word length effect (Baddeley *et al.,* 1975). Articulatory suppression refers to the interference of unrelated speech during memory rehearsal (Vallar and Baddeley, 1982). All three factors play a role in non-Arabic comprehending memorizers (articulatory suppression will be further discussed in chapter 3). As the Quran employs poetic tools such as rhyming and alliteration, phonological similarity increases the difficulty during the memorization process of the Arabic language in the non-Arab speaking population (Saleem, 2015). The word length effect applies to the general rule of longer

verses as the chapters decrease in the Quran; longer verses will require increased rehearsal strategies. Both factors require increased working memory capacity for more efficient memorization.

All factors are based on studies using native languages with added semantic information which does not apply to the present study. Quran memorization without semantic information requires more effort and more rehearsal (Saleem 2015). The most similar research studies that do not employ semantic information include tests using verbal non-words and foreign language studies (Gathercole, 1995; Masoura and Gathercole, 1999). Active rehearsal of random verbal non-words activates the phonological loop (Hulme *et al.,* 1991; Gathercole, 1995; Jarvis and Gathercole, 2003). Gathercole's (1995) study involving the active repetition of non-words in children demonstrated increased verbal memory capacity when *prior lexical knowledge* (which presumes categorization) of the language exists in long term memory. Additionally, foreign language studies showcase increased level of success when prior exposure of the new language exists (Masoura and Gathercole, 1999; Van den Noort *et al.,* 2006). Also, young children learning language will use the phonological loop decreasingly as the knowledge for the language deepens (Gathercole and Baddeley, 1989). This suggests that increased *lexical familiarity* and perceptual categorization of the constructs of the Arabic language in non-Arabic speakers will allow for more efficient memorization, rehearsal, and recall.

1.3 Auditory Interference: Disruptions to Recognition and Recall

Competing sensory information can be used to cause disruptions on attention to working memory tasks including visual or auditory interference (Banbury *et al.,* 2001; Clapp *et al.,* 2009). Interference refers to a stimulus that is presented in order to distract or disrupt attention at a

particular task (Clapp *et al.,* 2009). Memory span tasks including interference have shown impairments to performance (Postle *et al.,* 2005; Morgan, 1917). A larger working memory capacity indicates better resistance against interference (Kane and Engle, 2003). An experiment that tested the working memory capacity and attention control using the Stroop task showed that those with higher working memory capacity performed better on this task (Kane and Engle, 2003). Differences in the interference medium lead to differences in the level of memory disruption (Duff and Lasky, 1995). Duff and Lasky examined the effects of cross-modal interference on a short memory task (1995). The task consisted of the serial recall of two ten-word lists with two types of presentation (visual and auditory) and three forms of interference (visual, auditory and control). Auditory interference had the biggest impairment on performance compared to the control and visual interference conditions (Duff and Lasky, 1995). Auditory interference using unrelated verbal speech causes distinct disruptions to working memory span due to articulatory suppression using the phonological loop (Richardson and Baddeley, 1995; Hanley and Bakopoulou, 2003). Therefore, in regards to Quran memorization, interference should lead to impaired recall. Auditory interference in particular will disrupt phonological processes and disrupt momentary rehearsal as long term auditory retrieval.

1.4 Electroencephalography and Working Memory Capacity: ERP Signatures

1.4.1 P300 and Memory

Event related potentials (ERP) are the measurements of electrical brain activity in response to a specific stimulus. Breakthroughs in the field of electrical brain imaging techniques have led to the classification of ERPs through the amplitude and latency of occurrence. The P300 is a positive potential that occurs 300ms after the stimulus. It is associated with an information-

processing cascade and attentional processes (Polich, 2012). The amplitude of the P300 corresponds to the amount of general neural areas that are being used; the higher the amplitude the more neuronal resources are summoned for the particular task. The P300 has two recognized components: p300a (p3a) and p300b (p3b). The P3a is associated with either attending or ignoring a novel stimulus while the P3b is associated with actively attending any type of stimulus (Andreassi, 2007).

The P300 in terms of memory and the encoding of memory, has been largely investigated. Short term memory storage in visual and auditory domains elicit the P300 potential (Ruchkin *et al.,* 1990; Martin-Loeches *et al.,* 1997). Existing research has also identified the link between the strength of memories, the latency and amplitude of the P300 (Johnson *et al.,* 1985). A study by Johnson *et al.,* found that recognized words elicited higher amplitudes and shorter latencies than unrecognizable words (1985).

1.4.2 N400 and Semantic Processing

The ERP response N400 is largely associated with semantic processing of language. This waveform will give more insight on the semantic qualities of the Quran. The first appearance of this electrophysiological response was associated with incorrect semantic substitutions in sentences (Lau *et al.,* 2008). The N400 can be described as a large negative peak that appears 400ms after the visual or aural presentation of a stimulus, usually a word. If the word is a semantically incorrect fit to a sentence or part of an incongruent word pair, the N400 peak is higher than that of an appropriate use of a word (Rugg, 1985). The N400 has been linked to long term memory processes that retrieve the semantic representations of words (Federmeier, 2003). Also, tasks examining the phonological loop such as employing the phonological similarity

effects are shown to elicit a N400 potential (Martin-Loeches *et al.,* 1997). All in all, the N400 is a crucial ERP signature in studies that encompass working memory and language.

1.5 Present Study: Hypotheses

The focus of the present study is the working memory mechanism implicated in Quran memorization in non-Arabic speaking children and young adults. Quran memorization requires a coordination of memory processes including the phonological loop. In this study, the auditory component implicated in the Islamic practice will be the point of focus. Auditory interference will be used to disrupt verbal memory capacity and long term recall as a result. Also the word length effect and phonological similarity effect will be examined through the comparison of two different *juz* that vary in verse length and the use of rhyming words respectively.

The Quran Recognition Task was created modeling Daneman and Carpenter's Listening Span Task (1980). The task is hypothesized to test verbal working memory capacity during recognition and recall of long terms stores of Quranic verses. I hypothesize that the interference condition and increased difficulty through the separate *juz* will influence the performance of both children and young adults in the Quran Recognition Task differently. Young adults should show ERP correlates of more semantic processing and increased working memory load due to enhanced lexical knowledge of the Arabic language while children should show less semantic processing and decreased working memory capacity during the same task. I also hypothesize increased difficulty in the overall task for both groups due to the word length effect and phonological similarity effect as non-Arabic speakers.

In terms of ERP correlates, I hypothesize the appearance of the P300 in both groups due to its role in information processing and memory. The N400 specifically should be observed in

the adult group due to increased lexical knowledge of classical Arabic. Overall activations in the interference condition should have higher amplitudes compared to the noninterference condition.

The Quran remains an integral aspect to the life a practicing Muslim. Research on this widespread cultural phenomenon will provide new insight on learning and memory. This research project addresses the memory-based mechanisms associated with Quran memorization through the use of a neuroimaging technique.

2 Chapter: Methods and Design

2.1 Participants

Twenty participants, nine young adults between the ages of 18 and 27 (M = 21.6) and eleven children between the ages of 8 and 13 (M=10), were recruited from the public and Quran *Madrasas* respectively. There was a general equal representation of gender in the participants in the task which included 9 females and 11 males. Four participants were unable to complete the study: one due to scalp sensitivity and three due to equipment malfunction. All subjects had basic history of previous Quran memorization and have memorized the equivalent of at least two *juz* (or two sections). All participants were right-handed, fluent in English, brought up in Canada and were capable of orthographic knowledge of the Classical Arabic language. All participants were not raised in a fluent Arabic household and could not translate Arabic prose. The young adults and parents of the children consented to the study and completed questionnaires pertaining to previous Quran history, the Edinburgh Handedness Inventory and their general background. The children were required to sign a Child Assent Form, consenting to participate in the study. All participants had normal hearing abilities which were tested through an auditory stimulus test. The participants were given $40 for their involvement as well as refreshments and transportation

fees. The Carleton University Ethics Board had approved the experimental procedure. Characteristics of prior Quranic history in both age groups is summarized in Table 1.

Table 1

Means and standard deviations of Prior Quran History Questionnaire Characteristics for Children and Adults

Variable	*M*	*SD*
Average age (years)		
Children	*10.00**	*1.67*
Adults	*21.62**	*3.83*
Average age of beginning studies (years)		
Children	*5.61*	*0.87*
Adults	*7.34*	*4.54*
Average juz memorized (juz)		
Children	*12.76*	*12.98*
Adults	*8.38*	*10.02*
Average length of time studying (years)		
Children	*4.00**	*2*
Adults	*14.16**	*3.08*
Average hours memorizing per week (hours)		
Children	*9.18***	*4.81*
Adults	*6.47 ***	*10.64*
Primary method of memorization		
Children	*3 Audio / 6 Audiovisual***	
Adults	*6 Audio / 1 Audiovisual***	

**significant*
*** Marginally significant*

2.2 Experimental Design

The task included 80 verses from the Quran that were binaurally presented using inserted foam earplugs at 40db in two conditions: auditory-only or auditory-interference. Both these conditions contained easy and hard levels. Half of the 80 verses were taken from *Juz Tabarak* (29th section of the Quran) which was considered to be the hard level while the other half of the verses were taken from *Juz 'Amma* (30th section of the Quran) which was considered the easy level. The hard level sentences were presented first in order to control for any fatigue effect followed by the easy level. There were two distraction conditions included in the study: interference and non-interference. The experiment consisted of four blocks for each of the distraction and difficulty levels. The Quran Recognition Task (QRT) consisted of partially incomplete verses of the Quran (the ending word was omitted). Four sounds of typically rhyming Arabic words were presented along with visual numbers on a computer screen. The participant listened to the incomplete Quran verse; following a 1-second blank screen she/he had to fill in the missing word by making a choice corresponding to the appropriate number in a numbered keyboard. A static noise overlaid on the Quran verses (interference) was used as a tool to induce heightened neural processing of the brain areas for the mechanism behind the Quran (Belin *et al.,* 1999).

All the auditory sentences were recorded by a student trained in a high level of *Tajweed* (elocution) to ensure perfect pronunciation in a sound attenuated facility at Carleton University. The experiment was programmed through the use of Presentation version 6 software.

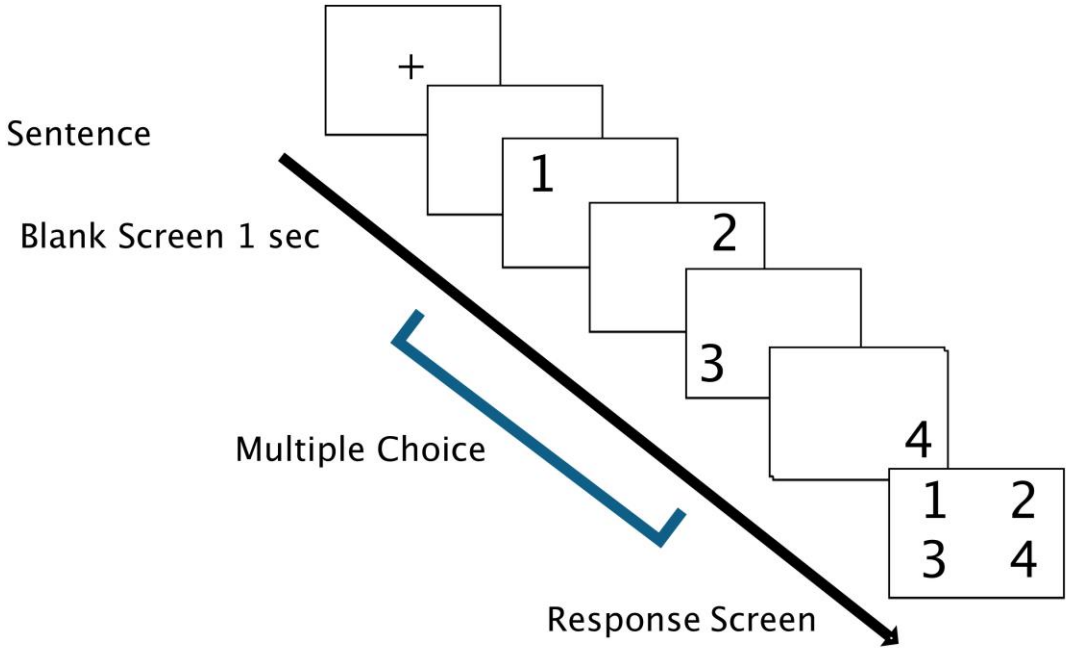


Figure 1. Schema depicting the visual and auditory stimuli presentation of one trial.

2.3 Procedure

2.3.1. ERP

ERPs were recorded from the participant during the sentence task. The frontal, central, parietal, and occipital electrode sites were recorded. The region of interest (ROI) were the 12 electrode sites of interest (ESI) waveforms (Figure 3). By use of an elastic cap comprising of 32 locations, the EEG recordings were obtained from electrodes on the scalp using the International 10–20 system (actiCAP, Brain Products GnbH, Munich, Germany) amplified (0.5 to 500 Hz sampled up to 2000 Hz) and referenced to Cz with AFz ground (Figure 2). The channel configuration included: Frontal, Fronto-central, Fronto-temporal, Central, Parieto-central,

Parietal, Temporal, Temporo-parietal, Occipital. A channel was placed manually at the location LO2. To ensure uniform voltage strength, all impedances were kept under 5 kOhms.

After the primary EEG capping procedure on the participant, the EEG data was collected using the Brainvision system, which includes the Actichamp Amplifier and Powerpack. The EEG data concurrently with the auditory working memory task was recorded using the Brain Vision system (actiCAP, Brain Products GnbH, Munich, Germany); Task and stimuli were presented through Presentation software (Version 16.3, build 12.20.12, Neurobehavioral Systems Inc., Berkley, USA). The electrical information was received using a parallel port through a 25-pin connector to a 9-pin connector to the Brainvision system then to the Acquisition computer.

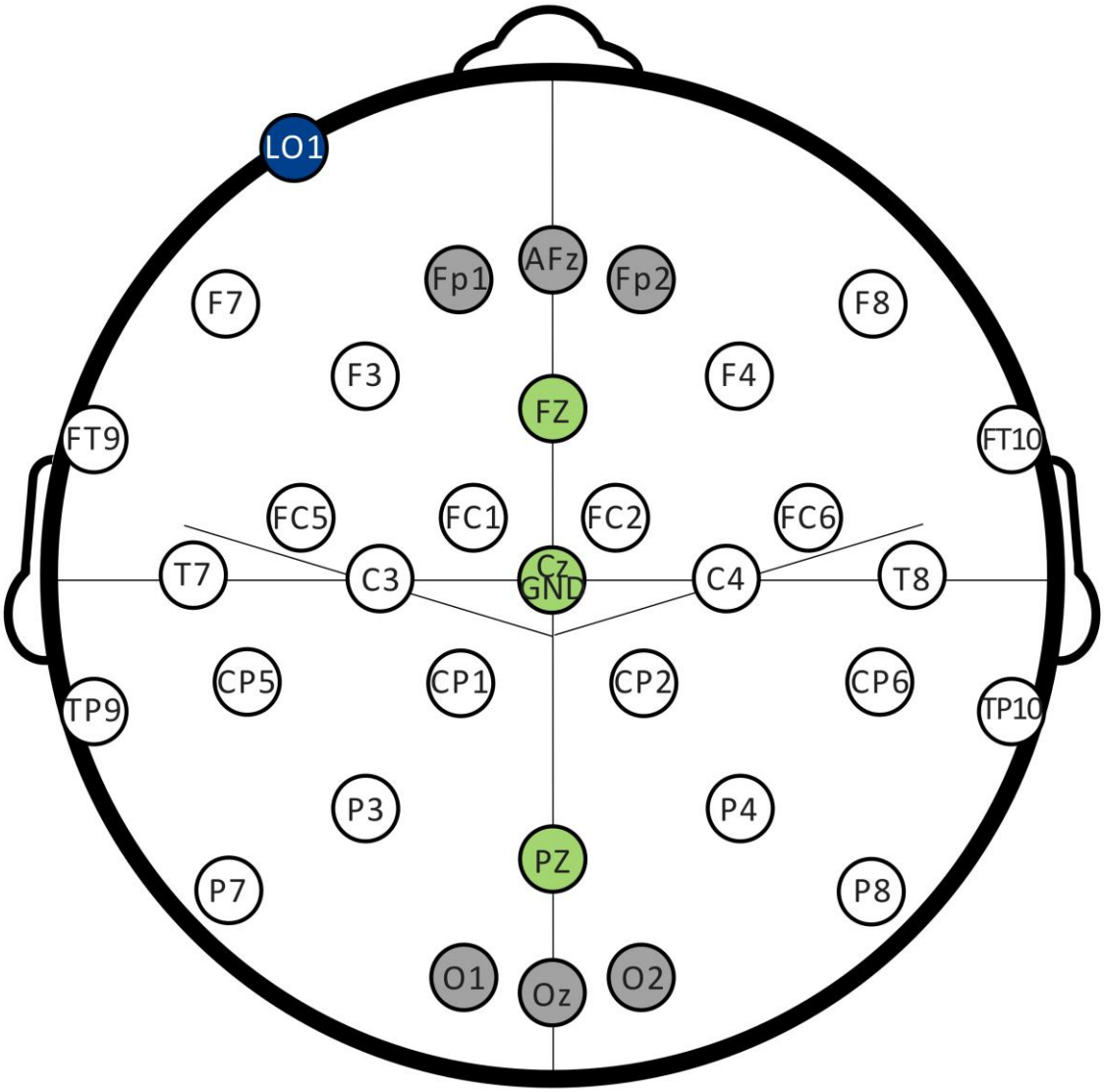


Figure 2: Schematic of configuration map of a 32-channel EEG cap placement based on the international 10-20 system. Location of electrodes are represented by circles.

Electrodes are labeled by their anatomical location on the scalp: Lateral Ocular (LO), Frontal Pole (FP), Frontal (F), Frontocentral (FC), Frontotemporal (FT), Temporal (T), Central (C), Centroparietal (CP), Parietal (P) and Temporoparietal (TP) and Occipital (O). Odd-numbered electrodes are on the left hemisphere and even-numbered electrodes are on the right hemisphere.

Green electrodes numbered ‘Z’ run down the center line (midline). Grey electrodes indicate unused electrodes. Blue electrodes indicate unused and interpolated electrodes.

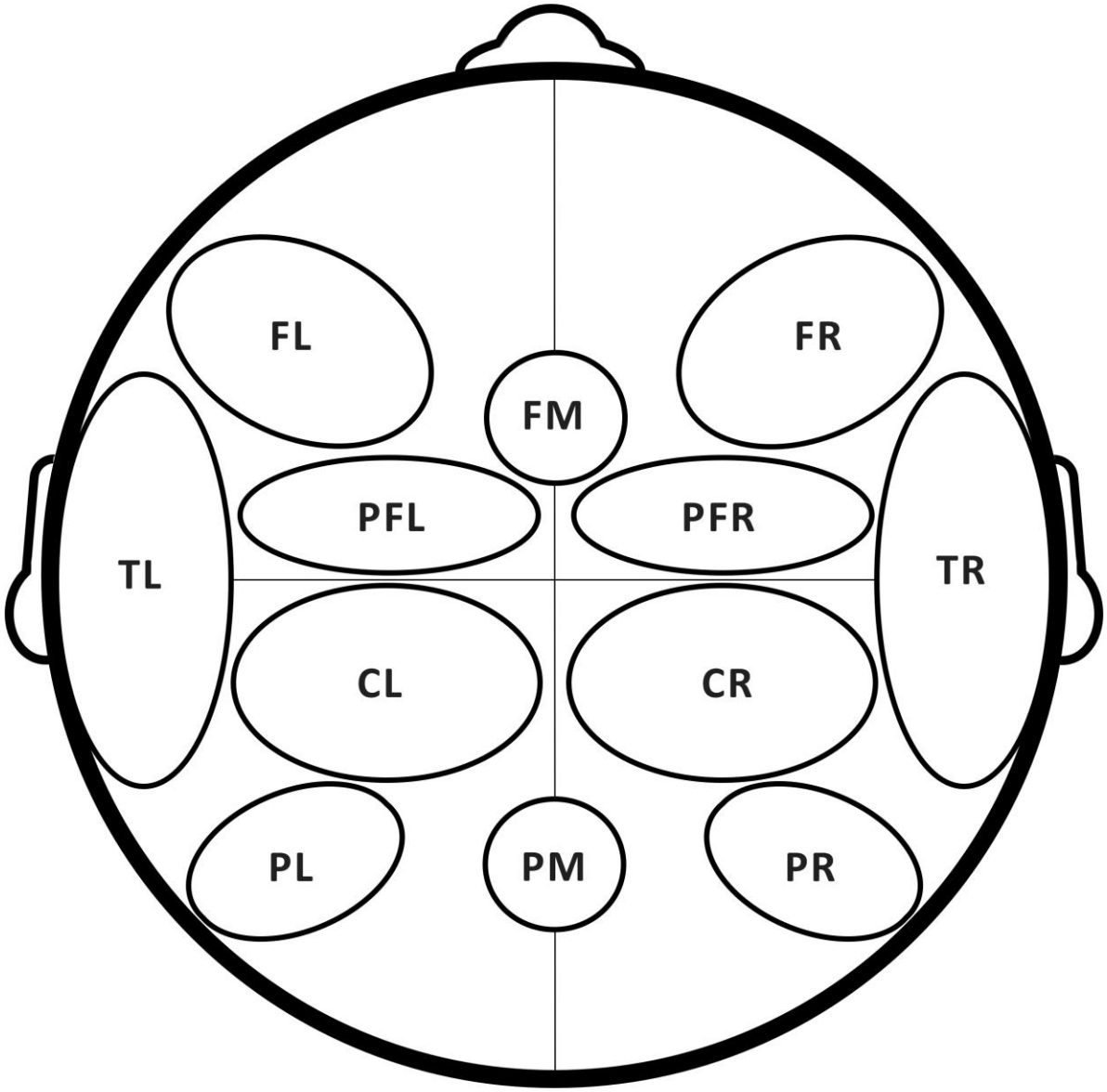


Figure 3. Modified configuration of the 32-channel electrode placement averaged into 12 electrode sites of interest (ESIs). Nomenclature for the 12 ESIs are as follows: Frontal Left (FL), Frontal Midline (FM), Frontal Right (FR), Temporal Left (TL), Temporal Right (TR), Prefrontal Left (PFL), Prefrontal Right (PFR), Central Left (CL), Central Right (CR), Parietal Left (PL),

Parietal Midline (PM) and Parietal Right (PR). Individual electrodes used to average each ESI are as listed: FL (P7 & P3), FM (FZ), FR (F4 & F8), TL (FT9, T7 & TP9), TR (FT10, T8 & TP10), PFL (FC5 & FC1), PFR (FC2 & FC6), PL (P7 & P3), PM (PZ) and PR (P4 & P8).

2.3.2 Experiment

The auditory stimuli were presented through the GSI 61 Clinical Audiometer using inserted foam earplugs at 40db for adults and 20db for children. After two practice trials, the participants were instructed to complete the missing word after listening to the Quranic verse and the multiple-choice options. Four sounds of typically rhyming Arabic words will be presented along with visual numbers on a computer screen. The participant was then required to make a choice corresponding to the appropriate number after a 1 second blank screen with a numbered keyboard. Each of the four blocks consisted of twenty sentences divided into five trials, each ascending trial including more sentences and increasing in length and difficulty.

2.4 Questionnaires

2.4.1. General Questionnaire

The general questionnaire was used to gather background information on each participant including occupation, current health status, family background, ethnic background, and socioeconomic status. This information gathered may provide an explanation in the case of any unique representations in the data. The parent/guardian answered the questionnaire on behalf of the child.

2.4.2 Edinburgh Handedness Inventory

The left hemisphere is implicated in language-based processing: differences in hemispheric processing will be a source of confound in the experiment (Sperry, Gazzaniga, and Bogen, 1969). As a result, only right-handed individuals were recruited for this experiment using the handedness inventory as a screening method. At least 80% handedness allowed right-handedness to be determined.

2.4.3. Prior Quran History Questionnaire

This questionnaire is designed to provide background information of any features associated with prior Quran study such as the methods used in order to retain verses. This is due to the individual difference in Quran memorization level between each of the participants. As there are 30 sections and 114 chapters that make up the Quran, participants were asked the about the current chapter of memorization, the frequency of practice and primary medium of memorization.

2.5 Data Analysis

2.5.1. Behavioral Data

The behavioral data of accuracy and reaction time were statistically assessed using SPSS statistical software to test the overall effects of the experimental conditions. Averaged ERP data was inputted in SPSS as microvolts using the standard binning technique (Ratcliff, 1979). The technique also named vincentization simplifies population distribution into quantiles. Each 1200ms epoch, or division in time, including a -200ms pre stimulus and 1000ms post stimulus window, was divided into 25ms bins. Each bin (48 per ESI) was then averaged to create one value which corresponded to one quantile. All ERP statistical tests were run using binned data.

2.5.2. EEG Data

Brain Electrical Source Analysis software (BESA, GmbH Freihamer Str. 18 82166 Gräfelfing, Germany) was used to analyze collected EEG waves and remove artifacts including blinks, horizontal and vertical eye movements. An artifact file calibrated to match the individual biological characteristics was created. The filter used to clean the data was set to a slope of 12dB/octave and a high cutoff of 20. The lateral ocular dropdown electrode (LO1) was interpolated to minimize muscular effects. The main events analyzed during the ERP recording or triggers included the beginning of the Quranic verse, the end of the verse, correct and incorrect trials. The accepted triggers had a cutoff of 75% in each block. The software was also used to average EEG data and output grand waves for each condition. BESA was also used to output the analyzed activity of the channels to SPSS.

Of the 32-channel configuration, 12 electrode sites of interest (ESI) were created (Figure 3). The occipital channels were removed due to the unclear visual instructions indicating the use of a cross hair. The frontal pole channels were omitted due to the enhanced degree of artifact integration.

Chapter 3: Results

3.1 Behavioural Data Findings: Prior Quranic History, accuracy and Reaction Time

The children and adults significantly differed in the years memorizing the Quran F (1, 14) = 59.7, $p<.05$. The amount of text memorized did not significantly differ between groups F (1, 14) = 0.56, $p=0.47$. The hours spent practicing the Quran was not significant between groups F (1, 14) = 0.44, $p=0.52$.

The overall performance of participants on the Quran Recognition Task was fairly good. The average score from all participants was 74.6%. The lowest overall score was 47.5% (SD = 5.26) while the highest score was 92.5% (SD = 1). The children performed better than the adults overall at 78.3% (SD = 1.74) accuracy rate where the adults had 70.9% (SD = 2.42) accuracy.

The accuracy data was analyzed using a mixed model repeated measures ANOVA. The two age groups (children, adults) were compared using a 2 (distraction; interference and non-interference) x 2 (difficulty; easy and hard) design. The use of interference as a distraction was found to significantly affect performance within groups, F (1, 14) = 12.34, $p<.05$. There were no significant differences between groups for either distraction and difficulty. All the reaction times for each level were found to be insignificant including interference in children (M=1070.61, SD = 526.26) and in adults (M=682.68, SD=245.94).

In order to counteract the ceiling effect, the winsorization technique was used to transform the data through the elimination of possible outliers. A significant difference between non-interference and interference distraction conditions was found in each group F (1, 14) = 7.44, $p<.05$ showing that both the first interference condition (M= 12.52, SD= 4.38) and second interference condition (M= 14.75, SD= 4.85) had a significant effect on scores. The level of difficulty had a significant effect within groups, F (1, 14) = 4.68, $p<.05$.

3.2 ERP Patterns

Correlations between each electrode (FM, FL, FR, PFL, PFR, CR, CL, TR, TL, PM, PR and PL) and each of the four triggers (beginning of sentence, end of sentence, correct and incorrect responses) were performed to indicate if the link between the response and sentence

event is significant. A binomial test was performed revealing the significance cut-off for correct responses to be p = 0.0015 and p =0.84 for incorrect responses. Incorrect responses for every electrode were shown to not be significantly linked in the sentence event ERPs while four electrodes for the correct responses were significantly linked to either sentence events (PFL, CR and PR for the end of sentence and PR for beginning of sentence as well).

Table 2

Pearson correlation r values between sentence events and responses

	Correct		Incorrect	
Electrode	Beginning of sentence	End of sentence	Beginning of sentence	End of sentence
FM	0.21	-0.06	0.17	-0.21
FR	-0.13	0.15	-0.44	0.65
FL	0.07	0.11	0.25	-0.64
PFL	0.12	0.27*	-0.04	0.33
PFR	-0.15	-0.12	0.12	0.09
CR	-0.11	0.29*	-0.08	0.29
CL	-0.01	0.17	-0.33	0.53
TR	0.13	0.03	-0.05	0.12
TL	-0.09	-0.19	-0.06	-0.08
PM	0.02	0.03	-0.35	0.58
PR	-0.28*	0.29*	-0.28	0.42
PL	0.04	-0.15	-0.27	0.50

**Denotes significance*

A mixed model four-way ANOVA contrasts testing interactions among 3 within subject factors including condition (interference; non-interference), trigger (beginning of sentence, end of sentence), electrode (12 electrode sites of interest), with groups (children; adults) as the only between-subject factor. Greenhouse-Geisser was used as a correction. The main effects were all significant: condition F (1, 47) = 184.5; MSE = 73.2, p<.05, trigger F (1, 47) = 123.14; MSE = 29.44, p<.05 and electrodes F (1, 47) = 33.2, MSE = 27.9, p<.05. Two three-way interactions were significant between Condition*Electrode*Age (F (1, 47) =4.96; MSE = 23.2, p<.05)) and Condition*Interference*Electrode (F (1, 47) =27.8; MSE = 53.9, p<.05). The only four-way interaction Condition*Interference*Electrode*Age was significant (F (1, 47) =26.87; MSE = 13.86, p<.05)).

3.2.1 Analysis of Mean Amplitude Differences

Amplitude threshold relative to the 12 electrode sites of interest (ESI) were averaged for each group at the beginning and end of the sentence. A single epoch contained the grand average over 48 intervals of 25ms. Averages were computed using two methods of appraisals: focused ANOVA t-contrasts and the "microvolt measuring stick" method at three different p-values (p = 0.05, 0.01, 0.001). The focused t-contrasts between the paired binned mean amplitudes (with the factors Condition × Trigger × Electrode) yielded an MSE_{within} = 182.17. "Microvolt measuring stick" sizes which were used as effect size thresholds between the absolute amplitude differences and were calculated using the following equation (D'Angiulli *et al.,* 2015):

$$Abs\ amp\ diff_{\mu V} = |M_{ERP}\lambda_i| = t_{crit} \cdot \left(\sqrt{\mathrm{MSE}_{\mathrm{within}} \cdot \left(\sum \frac{\lambda_i^2}{n_i}\right)}\right)$$

Where, i denotes each bin interval, the predicted mean difference between pairs of same time-interval bin microvolt values is represented by M_{ERP}, the contrasted weight is represented

by λ_i. t_{crit} is represented by the critical t-value and MSE_{within} represents the t-contrasts error factor. Three t_{crit} values (2.01, 2.86 and 3.51) were used to yield three microvolt measuring sticks represented by three colors seen in Figure 4. The effect size threshold was at 0.05 ($t_{crit}(47)$ = 2.01, two-tailed), at 0.01 ($t_{crit}(47)$ = 2.86, two-tailed) and at 0.001 ($t_{crit}(47)$ = 3.51, two-tailed). Inputting the t_{crit} values and MSE_{within} = 182.17 into the absolute amplitude differences equation yielded 0.81 μV (blue, p = 0.05), 1.4 μV (red, p = 0.01) and 1.7 μV (green, p = 0.001) microvolt measuring stick sizes. These stick sizes remained the same for analysis only of the beginning and end of sentence waveforms. However, analyses of the differences between interference and non-interference waveforms in each group employs a different MSE_{within} value (MSE_{within} = 158.44) but the same three t_{crit} values. The absolute amplitude difference equation generated stick sizes 0.75 μV (blue, p = 0.05), 1.07 μV (red, p = 0.01) and 1.3 μV (green, p = 0.001) for analysis of the difference waveforms.

In addition, the latency expressed by ERPs are examined over three potentials: 1) early sustained potential (0 to 299ms) 2) P300 waveform (300 to 599ms); and 3) N400 waveform (400 to 699ms).

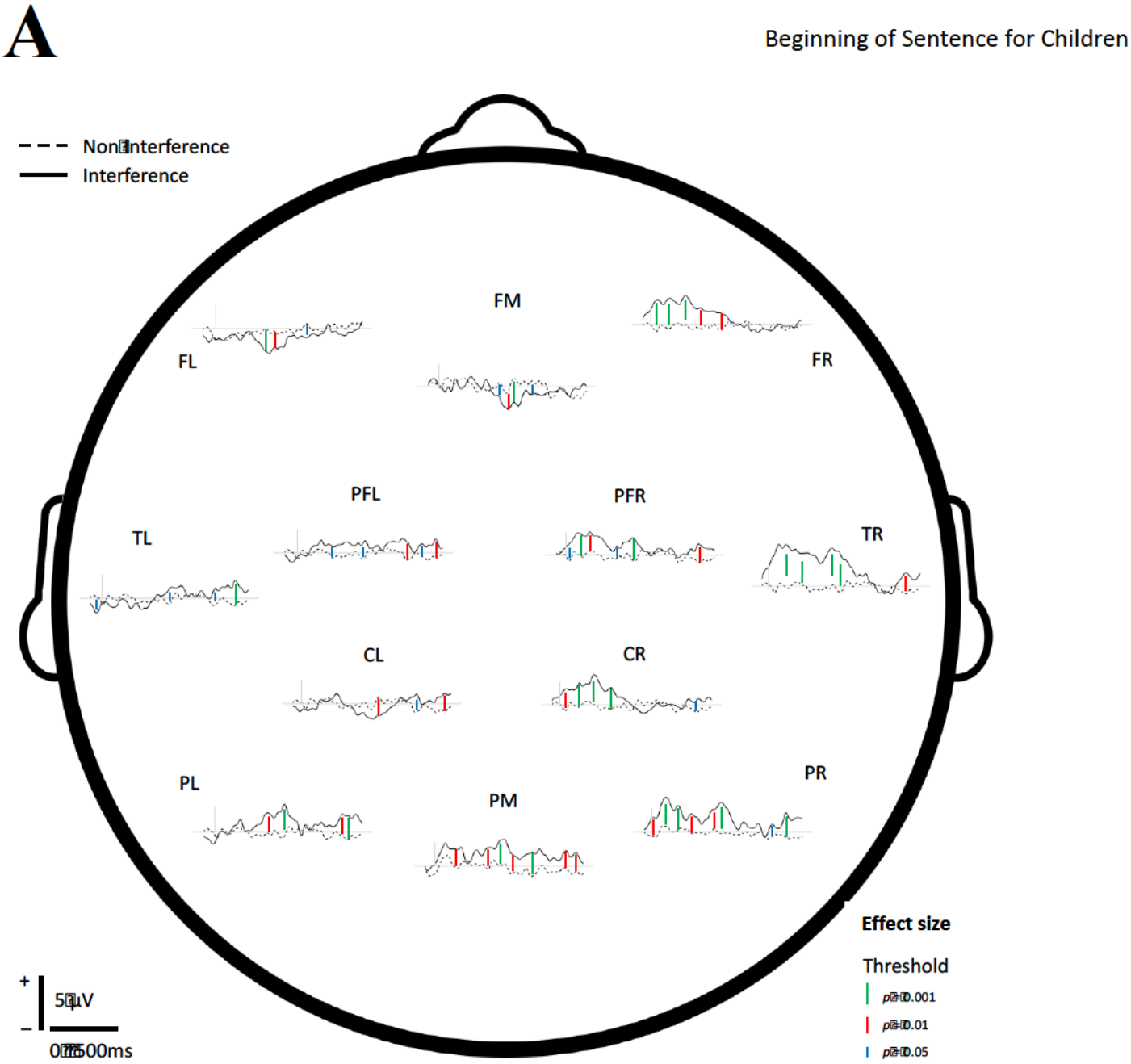
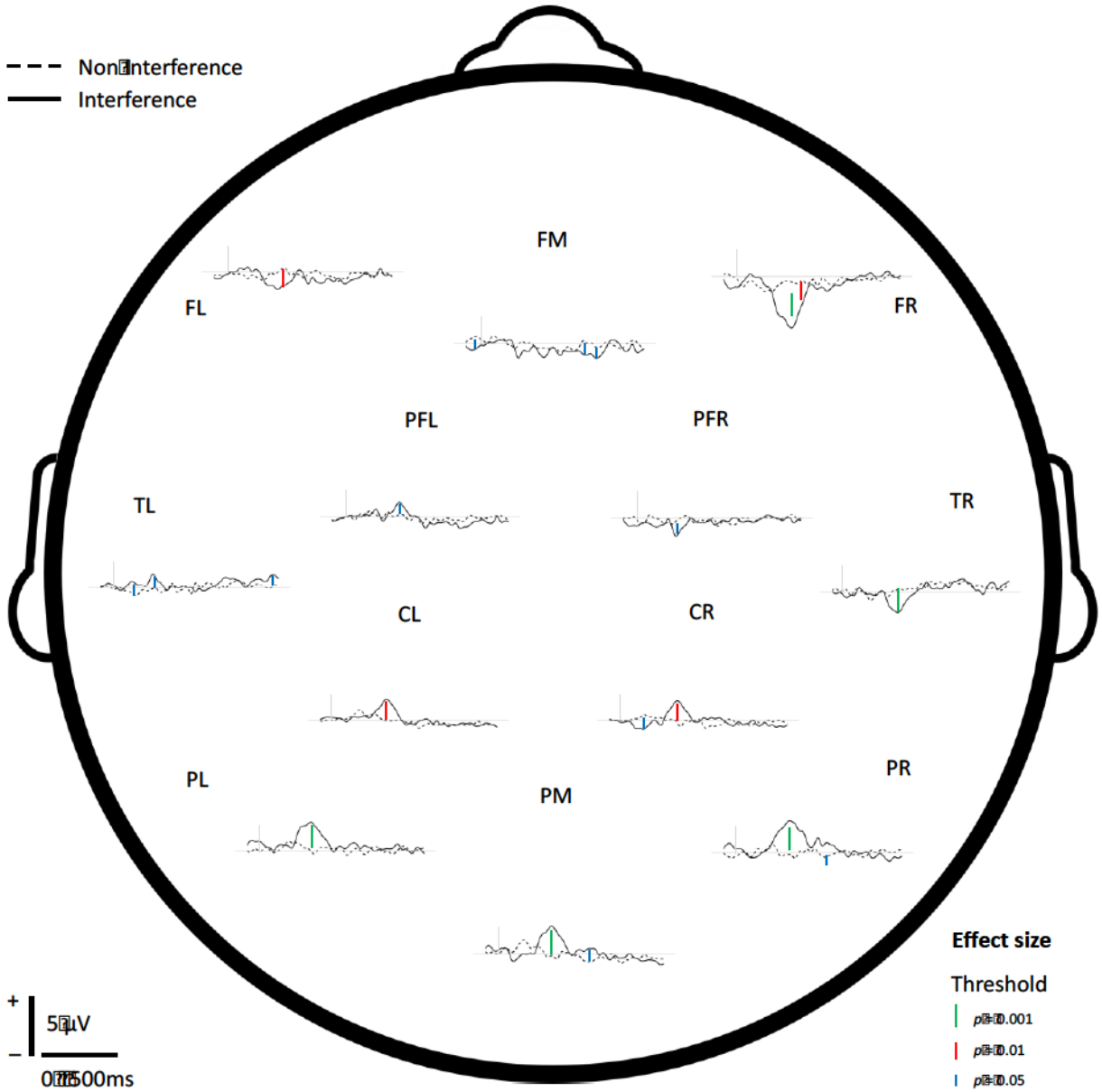


Figure 4. Schematic of the modified configuration map of a 32-channel EEG cap placement based on the international 10-20 system was used. This modified configuration averages the 32-channel placements into 12 electrode sites of interest (ESIs). The overall scale for the map was 5µV (for horizontal measurements) and 500ms (for vertical measurements). ERPs are displayed

as amplitude differences between interference (bold line) and non-interference conditions (dotted-line) for the Quran Recognition Task (QRT). Averages of these amplitudes were computed for both children and adult groups during the beginning and end of the sentence. Effect size thresholds for three different *p* values and were created using a "microvolt measuring stick" ($p = 0.05$ as blue; $p = 0.01$ as red; $p = 0.001$ as green). External stimulus introduced at vertical grey line (i.e., 0ms for the epoch). Horizontal grey line represents 0 μV. Total ERP averages were tallied for the following groups: (**A**) Beginning of sentence for children; (**B**) Beginning of sentence for adults; (**C**) End of sentence for children; (**D**) End of sentence for adults. Differences in interference and non-interference amplitudes are also represented for (**E**) the beginning of the sentence and (**F**) the end of the sentence.

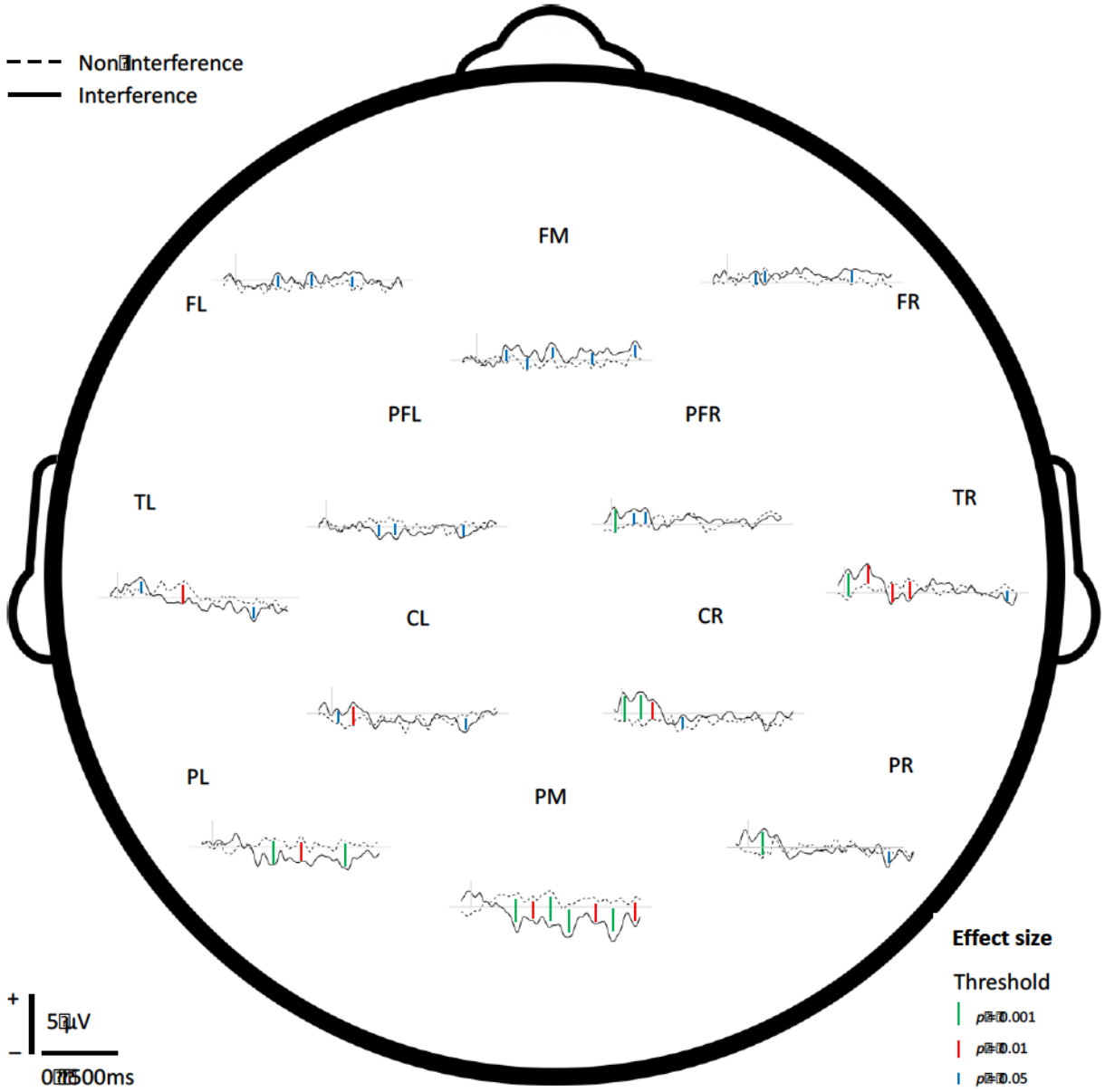
B

Beginning of Sentence for Adults

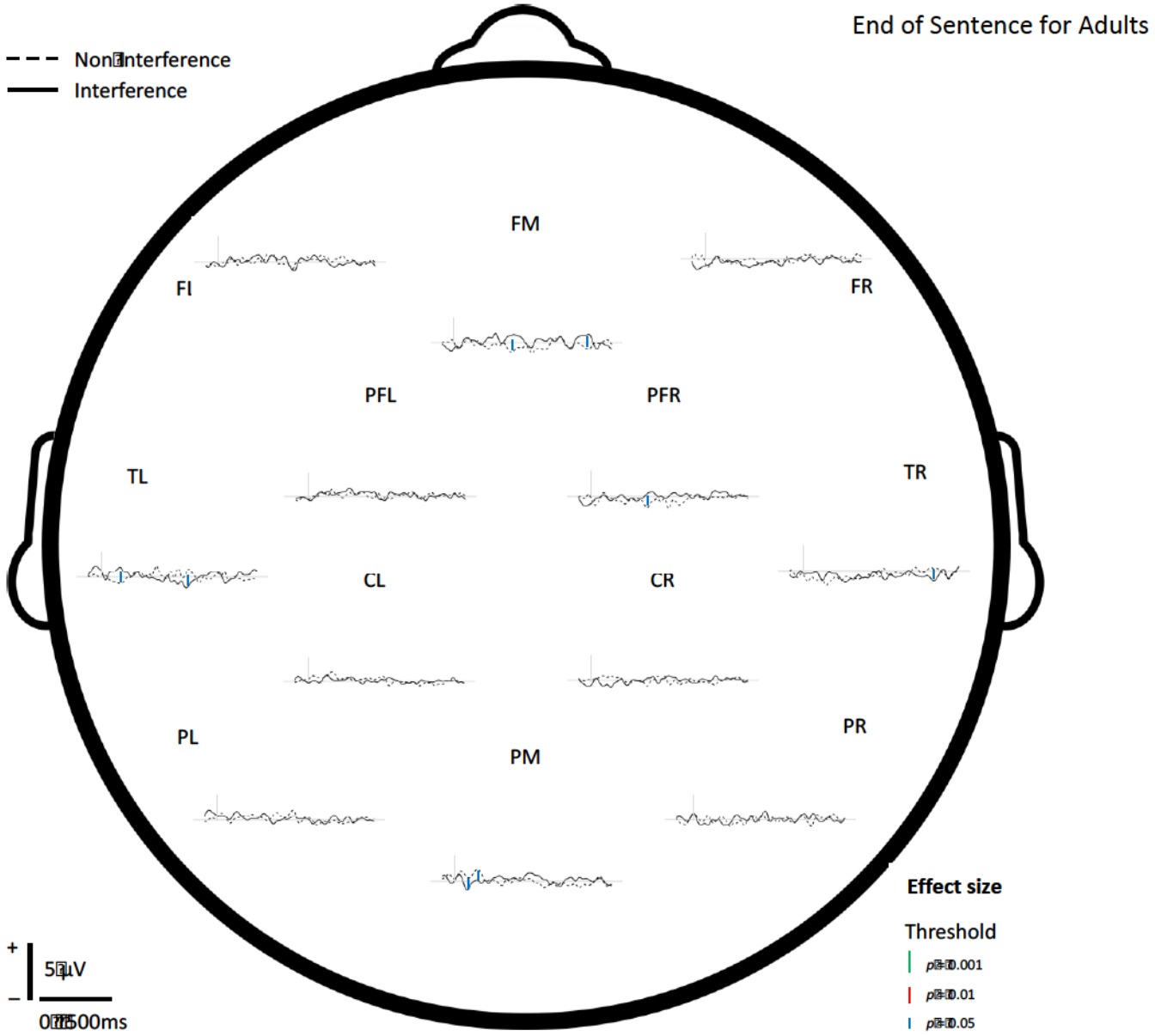


C

End of Sentence for Children

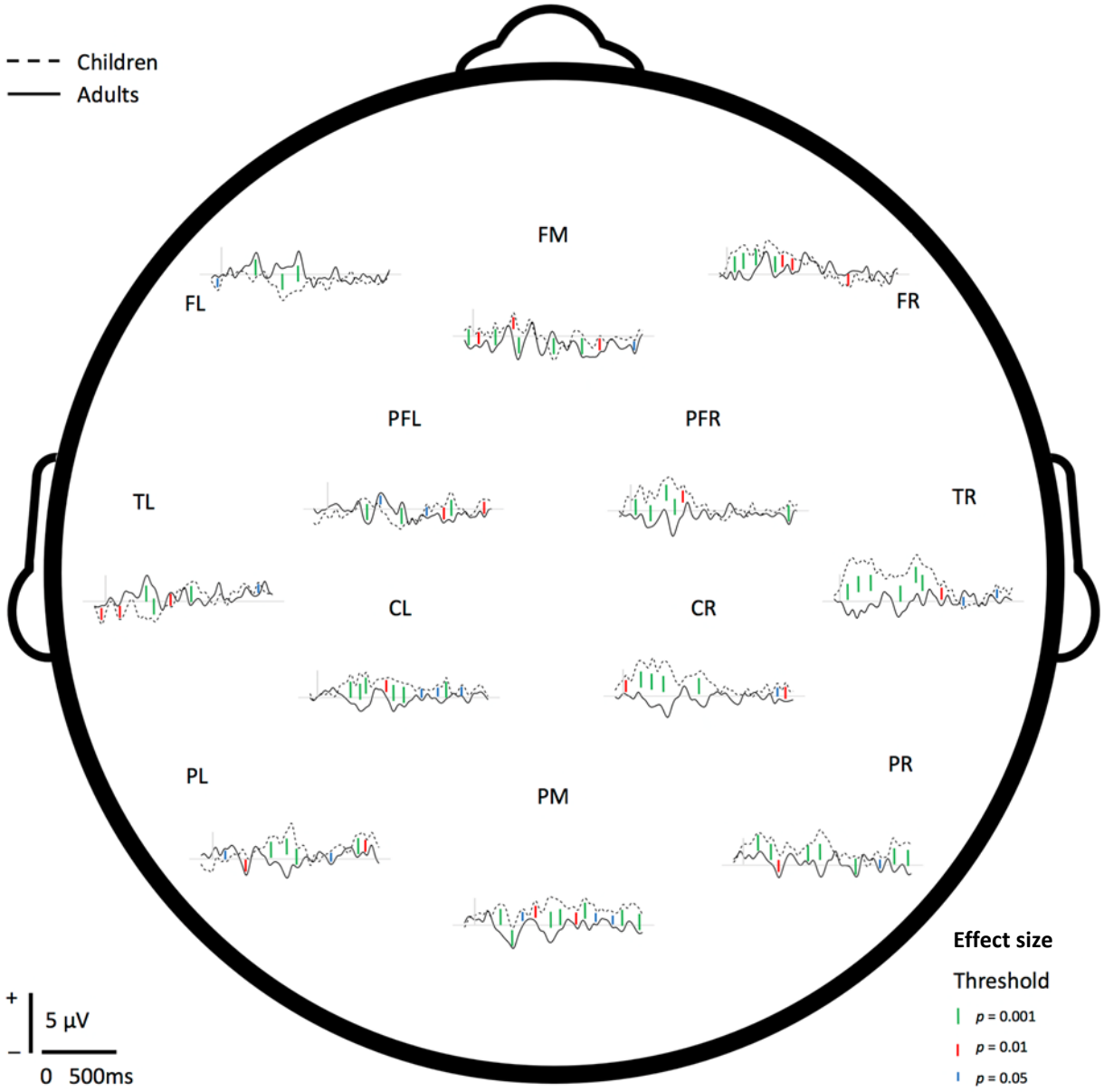


D


End of Sentence for Adults
Non-Interference
Interference
FM
FI
FR
PFL
PFR
TL
TR
CL
CR
PL
PR
PM
Effect size
Threshold
p=0.001
p=0.01
p=0.05
+
−
5µV
0-500ms

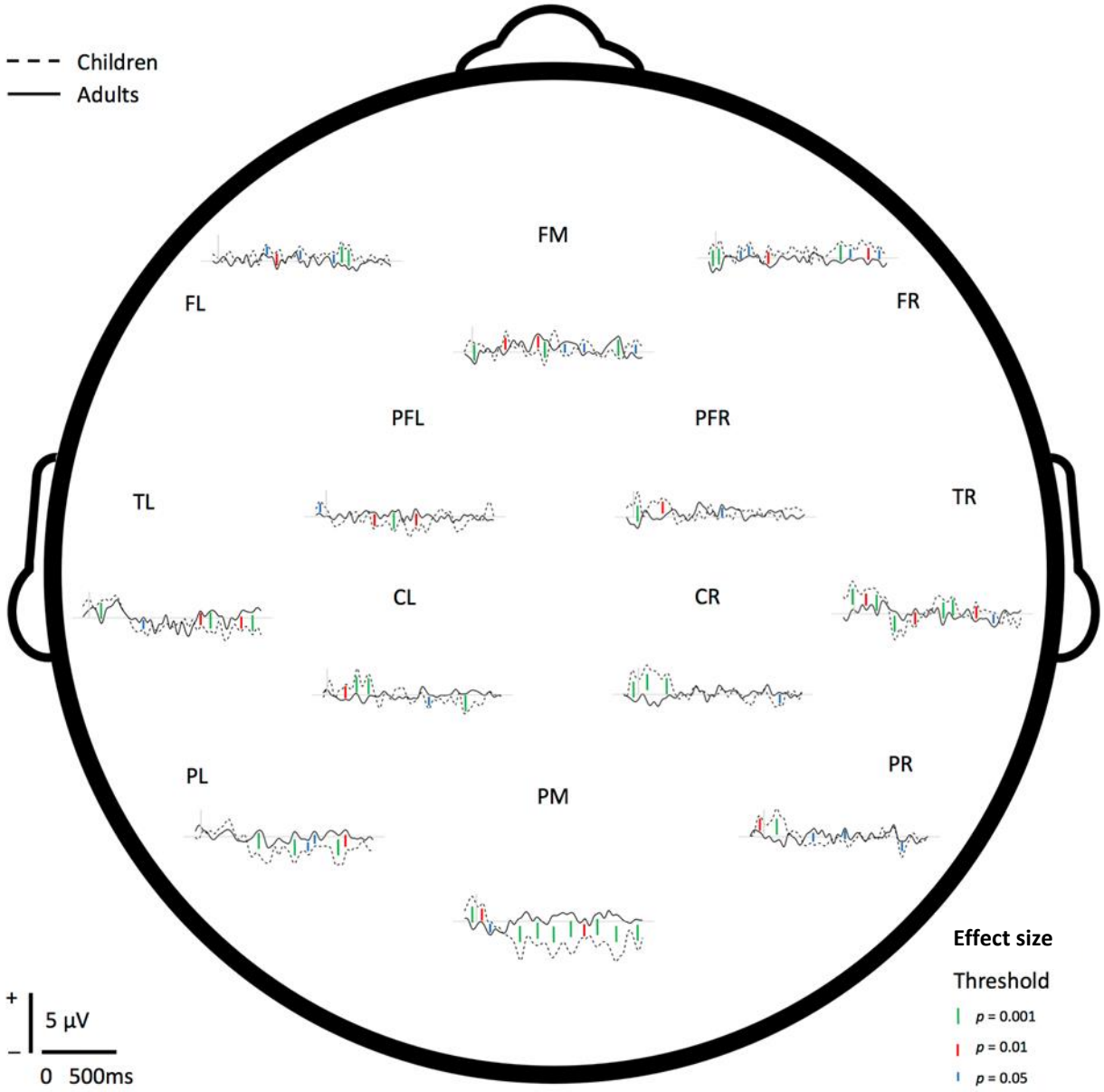
E

Condition differences at the beginning of sentence



F

Condition differences at the end of sentence



3.2.2 Overall ERP Patterns

Overall major global activation was observed in the children for both sentence events compared to the adults (Figure 4a; d). Interference revealed higher amplitudes versus non-interference which elicited reduced, flat waveforms in all conditions (Figure 4a; d).
Brain activity maps for the beginning of the sentence elicited more overall activation in both children and adults compared to the end of the sentence (Figure 4). Polarity differences between sentence events are exhibited in the parietal areas, frontal and temporal areas primarily in children (PM, PL, PR, TR and FM) (Figure 4a; c). There were three observed waveforms in the interference condition that were deemed relevant to the nature of the study: Early sustained potentials, P300 and N400.

3.2.2.1 Analysis of Early Sustained Potential (0-299ms)

Major significant positive peaks, P100 and P200, were evident around the presentation of the stimulus for both the beginning and end of the sentence in the interference condition for children (Figure 4a; 4c) suggesting the existence of an early sustained potential (ESP). The beginning of the sentence during interference elicited major ESPs in the right areas including the pre-frontal, temporal, frontal, central and parietal–right areas in children. The end of the Quranic verse with interference produced significant yet smaller waveforms in the same right areas excluding the frontal area in children. In contrast, there were no major significant ESPs observed in the adult waveform map in both the beginning and end of sentence for either distraction conditions. The only exception is the observation of N200 for the central right area in the beginning of the sentence in adults (Figure 4b).

3.2.2.2 Analysis of P300 waveform (300-599ms)

In children, significant P300 amplitudes differences between interference and non-interference waveforms in the beginning of the sentence were observed in the right areas including prefrontal and temporal areas (Figure 4a). The adults exhibited a clear significant P300 potential in seven electrode sites of interest including central and parietal areas for the beginning of the sentence (Figure 4b). Both maps representing the end of the sentence in each depicted the absence of the P300 waveform.

3.2.2.3 Analysis of N400 waveform (400-699ms)

The N400 was observed primarily in the frontal, prefrontal and temporal areas in adults (FR, FL, PFR and TR) while children exhibited the N400 in only one frontal electrode site (FM) in the beginning of the sentence (Figure 4a; b). In the end of the sentence, the adults do not show any N400 activations the children on the other hand show reduced deflections in the parietal and temporal right area (Figure 4 c; d).

4 Chapter: Discussion

In the case of the Quran, a number of variables need to be considered. Firstly, the existence of the orthographical knowledge of the Arabic language in both groups without the addition of full semantic knowledge suggests that the cognitive strategies used are completely different than the typical rote memorization of a story or a sentence. In hindsight, increased semantic knowledge would allow for the use of a different cognitive mechanism as seen in studies using native languages as a stimulus. This hypothesis is proven through both observed behavioral and ERP patterns. Also, another variable to be considered is that the memorization of

the Quran is primarily practiced verbally and through auditory means. The auditory memory based processes in addition to the visual elements of the Arabic text introduce another level of complexity of cognitive processing and are reflected in the observed results.

To begin with, auditory interference magnifies brain activity due to heightened sensory information and this validates the use of auditory interference as a probe. Seeing as much, both behavioral and ERP results should show significance with the use of auditory interference. The addition of the auditory interference condition proved effective as a distraction method for both groups, $F(1, 14) = 12.34$, $p<.05$, confirming existing literature on the subject (Postle *et al.,* 2005). This was further proven in the significant differences seen in ERP amplitudes between distraction conditions across events in both age groups (Figure 4). Altogether, the results confirm the use of the interference condition as a probe as a means to amplify the neural correlates of rote memory and the working memory mechanism implicated in the Quran Recognition Task.

The major differences in ERP activation between children and young adults suggests key differences in cognitive based strategies in successfully completing the task. Global activation seen in the children group suggests that they are using pattern matching to recognize and recall the verse (Figure 4a; c). In children, the observation of ESPs in both maps (Figure 4c) demonstrated that they continue to repeat the sensory stimulus, or "word", while simultaneously attempting to conjure the visual aspect of the word from their memory (Goldinger, 1998). This proves that children largely depend on auditory and visual methods to aid with memory recall (Table 1). Matching the features of a sound pattern to a previously encountered verse stored in memory requires the rehearsal of the presented sound by means of the phonological loop (Buchsbaum *et al.,* 2005). In other words, children hold and manipulate "echoes" of the stimulus using working memory capacity. In contrast, the adults are thought to be using a higher order

cognitive means of categorizing and organizing the presented information after recognition familiarity (Wagner and Gabrieli, 1998). The adults showed subdued global activation (Figure 4d) in comparison to children and this can be explained by their method of systematically recognizing and recalling the verse. In lay terms, adults are exerting less effort to make the correct response. Also, key differences in brain activity between the two groups are also attributed to developmental differences. Children use generally more occipital/parietal or bottom-up based processing compared to adults, which use top-bottom processing (Açık *et al*, 2010). This is reflected in the data as children show increased parietal activity compared to the adults group (Figure 4). For accuracy, both groups achieved similar results, showcasing the effectiveness of each method. Despite the results, children did perform better and the explanation may be due to the supplementary recalled sensory information not available to adults and the recency of the memorized text (Table 1). In other words, children utilize various brain areas and pathways to match the sound of the verse to past episodic memories or existing visual representations of the text. The process evidently utilized a large portion of working memory load, especially in the phonological store in children. This mechanism for episodic memories could also be working in addition to pattern matching and word rehearsal in children. On the other hand, adults used fewer neuronal resources and less working memory load using a different cognitive strategy while achieving similar scoring results.

Differences in polarities are primarily observed between the beginning of the verse and the end of the verse in children (Figure 4a; c). The change from positive to negative waves may be due to an attempt to inhibit resources in the brain after recognizing the verse. Perhaps children are suppressing the irrelevant auditory and visual information recalled when attempting to correctly conjure the verse. Also, changes in ERP polarity are related to changes in selective

attention (Michie *et al.,* 1990). It can be said that children are selectively attentive during positive polarities and not paying attention during negative polarities. Adults displayed minimal polarity changes between the beginning and end of the verse due to their efficient systematic method of recognition and recall strategy at the presentation of the stimulus.

The appearance of the three ERPs of interest, ESPs, P300 and N400, in select areas in the brain represent the origins of the key neural resources used in rote memory recall. The sensory association cortices lie in the right parietal-central areas and demonstrate the recall of sensory based memories in the auditory and visual domain (Haenschel *et al.,* 2005; Michie *et al.,* 1990). Therefore, these activated areas seen in children (Figure 4a; c) reinforce my aforementioned theory that children are holding auditory and visual information as well as working memory. This is consistent with the nature of the memorization of the Quran wherein both visual information from the physical text and auditory information from the recitation of the text are used to memorize the text (Saleem, 2015). Consistent with the hypothesis, the appearance of P300 in areas such as the central, prefrontal and parietal-right in both groups suggests the involvement of the sensory association cortices and working memory (Burton *et al.,* 2005). The P300 in the prefrontal left area seen in both groups suggests its role is implicated in decision making processes governing the parietal and central areas (Philiastides *et al.,* 2006). The prefrontal left area may suggest the involvement of Broca's area, implicated in speech production, which can be imagined in this case (McGuire *et al*, 1996). The prefrontal cortex also acts as the link between the production of imagery, long term memory retrieval and complex planning (Halpern & Zatorre, 1999; Esposito *et al*, 1995). The N400 was observed in the adult group referred to the supplementary semantic information available to adults compared to children as hypothesized. The notion of a lexical framework of the Arabic language available to

adults (from years of exposure to the language) is supported by the appearance of N400 potentials seen in Figure 4b and 4d (Federmeier, 2003). Interestingly, the children also exhibited N400 potentials in the temporal and right areas as well which suggests the beginning stages of building a lexical framework of the classical Arabic language (Figure 4a; c). This also may be due to the existence of a memory trace of the sound or an engram of the stimulus consistent with studies on the phonological loop (Gathercole, 1995).

To add, activation of right temporal and parietal areas in the beginning of the verse may also be due to the melodic characteristics of the Quran. A study using fMRI pertaining to the perception, imagery and memory of familiar tunes concluded that the perception of a melody was highly associated with the imagination processes of remembering a melody (Herholz *et al.,* 2012). The auditory imagery component of Zatorre's study corresponded to the role of an additional processing network which included the prefrontal cortex, intraparietal sulcus and the cerebellum (Herholz *et al.,* 2012). In addition, the right temporal lobe was shown to be associated with perception and imagery behind the processing of a melody (Zatorre and Halpern, 1999). Zatorre's findings on remembering a melody coincide with the most activated electrode sites in my study.

In addition, the working memory model developed by Baddeley and Hitch can be applied to this unique cultural practice (1974). The children are heavily relying on the visuospatial sketchpad, episodic buffer (linking to episodic memories related to learning the text) while the adults have built a pathway using the phonological loop and the lexical framework of the Arabic language (Figure 5).

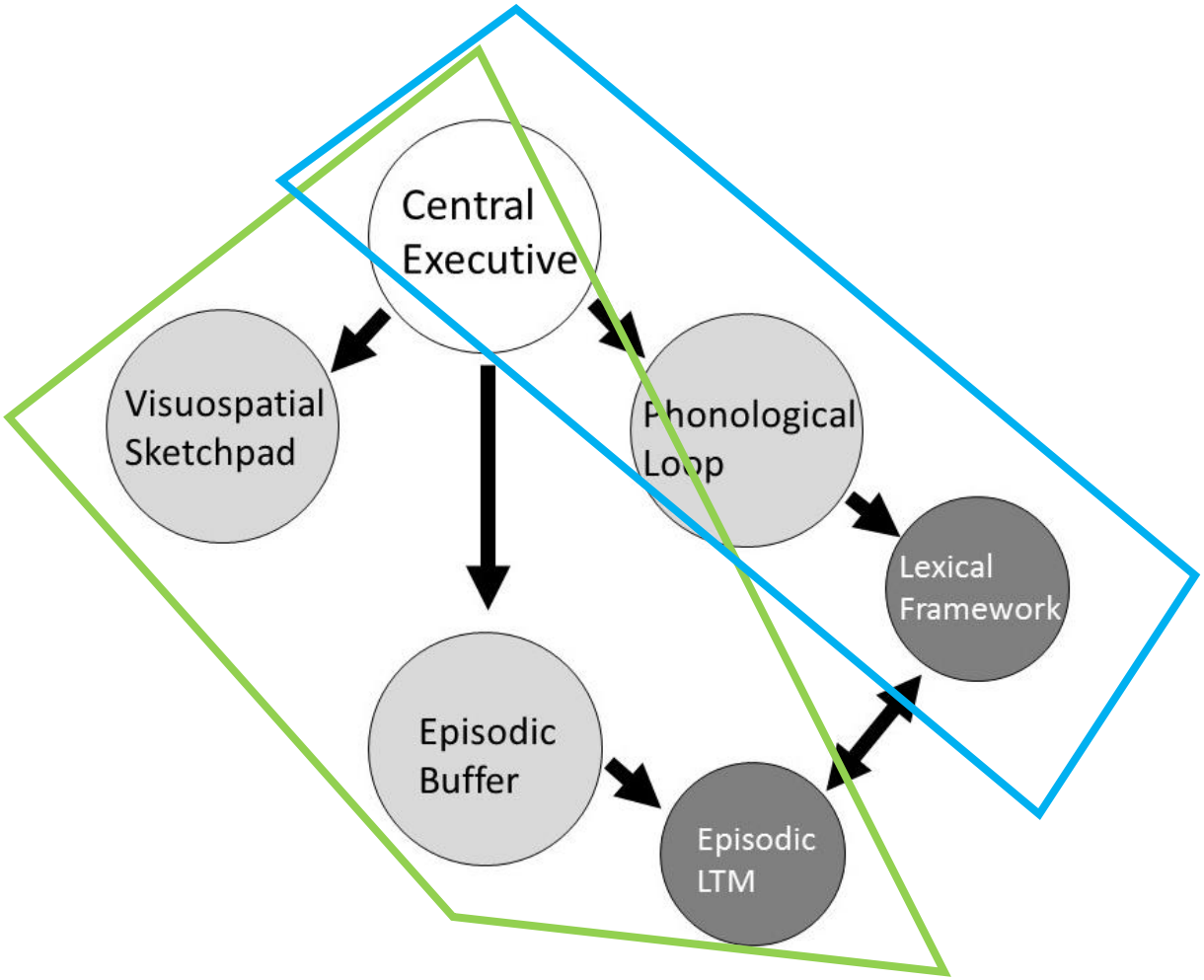


Figure 5. Modified version of the updated Baddeley and Hitch's working memory model specific to non-Arabic speaking children (green box) and adults (blue box) during auditory interference.

In conclusion, the availability of a lexical framework of the Arabic language built over years of contact with the Quran, suggests that the cognitive strategy used by adults was refined over years. On the other hand, children employed the greater activation of global sites in order to find a match to an existing memory while rehearsing sensory information and holding a memory trace. To compare, the adults used a more efficient faster method while the children over loaded their working memory capacity. The observation of ESPs, P300 and N400 potentials provided insight to the key areas found to be implicated in the study; prefrontal left, frontal, parietal and temporal right areas. Changes in polarity as seen in children may be due to inhibition of memory and changes in selective attention. Furthermore, the melodic features of the Quran may explain the activation of certain electrode sites. Limitations in this study include the small population size which may account for the insignificance of certain behavioral factors including reaction time. Also, the high variability between the amount of text memorized amongst participants may have created a confound in the study.

Future research exploring cognitive and neural mechanisms behind the Quran can illuminate differences in cognitive skills such as verbal memory skills with people who have not memorized the text. Also, a longitudinal study illustrating the change in the auditory recall strategy from children to adults will further shed light on the neural correlates of rote memory. A cross examination of melodic verses in the Quran and singing *a capella* will explore the similarities and differences between the two auditory mediums. All in all, research on the Quran will allow for unique and new insights on memory, music and language.

All in all, long term Quranic recall in populations without fluency of the classical Arabic language is seen to require more than basic surface recognition and recall. Against Saleem, we find that rote memory, as seen in children, is far more complex from the perspective of brain

activation than one could think of based on the fact that rote memory is seen as a basic and lower-level cognitive activity (2015). Paradoxically, the adults who are using lexical, semantical and categorization processes seem to require a more segregated activation, suggesting a developmental specialization, and therefore show a “simpler” pattern of activation. This study employed the Quran as model to study learning and memory in a cultural context which includes complex ecological factors such as specialized cognitive strategies in two age groups. This study suggests that Quran memorization developmentally may lead to the understanding of certain semantic regularities of the Arabic language even without explicit formal instruction.

Appendices

Appendix A

A.1 Informed Consent

Carleton UNIVERSITY
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Informed Consent Form

Experiment Title: Working memory mechanism behind Koran memorization using auditory interference in children

Faculty Sponsor: Dr. Amedeo D'Angiulli,
Department of
Neuroscience Carleton
University
2202A Dunton Tower
(613) 520-2600 x 2954

The purpose of this informed consent form is to ensure that you understand both the purpose of the study and the nature of your participation. The informed consent must provide you with enough information so that you have the opportunity to determine whether you wish to participate in the study. Please ask the researcher to clarify any concerns that you may have after reading this form.

Research Personnel:
In addition to the Faculty Sponsor named above, the following people are involved in this research and may be contacted at any time should you require further information about this study:

Principal Investigator: Faisa Omer (faisaomer@cmail.carleton.ca)

Purpose:
This study examines how the working memory mechanism behind Koran memorization using auditory interference comparing Arabic-comprehending and non-comprehending children.

Task:
At the start of the session, the participant will complete some visual acuity tasks to measure how well you can see with both eyes at near and far points and a color blindness test. The parent/guardian will be asked to complete a general/health questionnaire, a prior Koran history questionnaire and a handedness inventory. Participants must achieve certain scores on these tasks to continue. If the scores show that the participant is not a candidate to participate, the participant will be excused from the rest of the experiment. The participant will then complete sentence recall tasks across three conditions (Auditory only, Auditory interference and Control) in two languages (Arabic and English).

The brain activity recordings that we take are similar to those of routine clinical electroencephalography (EEG). To record the brain responses, electrodes are placed on your scalp and around the eyes. The electrodes on the scalp are kept in place with an elastic cap that fits over your head like a bathing cap. The ones around the eyes will be kept in place with double-sided

washers and some medical tape. The skin beneath the electrodes is rubbed slightly with a prep pad or Nu-Prep, which contain pumice, to remove any dirt or oil before the electrodes are connected to the skin with a double-sided washer. When the electrodes are taken off, any residue can be removed with water. The skin under the electrodes may be slightly red for a little while after the recording but this soon returns to normal.

Informed Consent: Event-related potentials study 2

The recording session will last approximately one hour. The recording session has two blocks, separated by a rest period. During each block we will measure brain activity while you read short sentences and answer questions about words presented on a computer screen or through an auditory device. Across each block there are three conditions, which are composed of a study and test phase.

When you have completed the two blocks, you will receive information about the experiment and given the opportunity to ask any questions and provide feedback to the researcher. You will also be allowed another rest break for up to 10 minutes.

Duration & Locale:

The experiment will take place in the NICER Laboratory located in the Loeb building of the Neuroscience Department at Carleton University. You will only need to come on one occasion to the laboratory. The whole session will take about 2-3 hours.

Potential Risks/Discomfort:

There are no known risks with the procedure. The electrodes for the EEG recordings can be mildly uncomfortable (the skin is rubbed slightly with pumice to remove any dirt or oils that can interfere with the measurements) and the experiment may seem a bit dull because of the repetitive measurements. If, however, you should feel uncomfortable at any time and wish to end your participation in the experiment, please notify the researcher and the session will be discontinued.

Anonymity/Confidentiality:

Your name appears only on this consent form. All other records are identified by an arbitrary identification number, making them anonymous. The consent forms are kept in a locked file cabinet accessible only to project personnel. After all the data have been collected, the consent forms will after which they will be destroyed in accordance with the policies set by Library and Archives Canada. Any personal information collected about you during this study will be kept anonymous be stored in a locked file cabinet at the National Research Council of Canada for seven (7) years, and strictly confidential, and will only be used for the purposes of this research. In any publications or presentations that derive from this research, you will not be referred to in any way that will allow your identification. Furthermore, all data gathered from this experiment will only be made accessible to the researchers involved with this study and to duly authorized authorities at Carleton University.

Right to Withdraw:

Your participation in this experiment is completely voluntary. You can withdraw your consent and stop participation in this experimental study at any time and for any reason. Such withdrawal from the study will not prejudice in anyway your treatment at Carleton University. If there is anything with which you are uncomfortable providing information, you have the right to omit these items without affecting your participation in the study.

The results of these experiments will not provide any direct benefit to you. However, these results may help us in further understanding the working memory mechanism.

Approval:

This study has been approved by and received clearance from the Carleton University Research Ethics Committee (reference #11-xxx).
For additional information, please contact Dr. Amedeo D'Anguilli at (613) 520-2600 ext 2954.

Should you have any ethical concerns regarding this study then please contact: **Dr. Andy Adler, (Research Ethics Chair, Carleton University Ethics Board).**

Should you have any other concerns about this study then please contact Dr. John Stead (Department Chair, Department of Neuroscience 327 LSRB, 613 520-2600 x8774).

Consent:

I have been provided with a description of the experimental procedures and any possible risks or benefits that might be associated with these procedures. I have been told that confidentiality will be maintained.

I have also been given an opportunity to ask questions concerning these procedures and any questions that I have asked have been adequately answered. I shall be given a copy of this informed consent.

I have been told that I can withdraw my consent and stop my participation in this experimental study at any time and for any reason. Such withdrawal from the study will not prejudice, in any way, my treatment at Carleton.

I understand the information that I have been provided and I voluntarily consent to participate in this experimental study.

Participant's Name _____

Parent/
Guardian's Name _____

Signature _____ Date_____

Researcher's Name _____

Signature _____ Date_____

A.2 General and Health Questionnaire

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GENERAL:

The purpose of the following set of questions is to collect demographic information about various aspects of your life. Although some of the questions may seem unrelated to the present study (e.g. weight, height, religion, etc...) these factors may be important determinants of your health and well-being.

1. What is your child's age? _____ years
2. Child's gender: Male/Female
3. How many years of education does your child have? _____ years
4. Is your child in a daycare program? Yes/No If yes, for how long have they attended the program? _____
5. What is your occupation or study now? _____
6. How many hours of sleep did your child have last night? _____hours
7. Does your child wear glasses or contact lenses? Yes / No
   If yes, please describe the problem(s): _____
   or circle one of the options below:
   near-sightedness far-sightedness astigmatism color blindness
8. Do you wear glasses or contact lenses? Yes / No
   If yes, please describe the problem(s): _____
   or circle one of the options below:
   near-sightedness far-sightedness astigmatism color blindness
9. Is your child on any kind of medication? Yes / No
   If yes, what is the medication/dosage? _____
   _____
10. Have you had or do you currently have any health related (i.e., medical) illnesses or physical conditions? Please select the one that best applies to you.
    _____ No, I don't
    _____ Yes, I did but I no longer do

_____ Yes, I do

If YES, please specify illness/condition you had/have _____

If YES, please specify treatment received or currently receiving

_____

11. Is your child currently under any psychiatric or neurological treatment? Yes / No If yes, please describe the problem(s): _____

_____

12. Are you currently under any psychiatric or neurological treatment? Yes / No

If yes, please describe the problem(s)_____

_____

_____

_____

13. What is your citizenship status?

_____ Canadian citizen

_____ Landed immigrant Since what year?_____ Country of origin

_____ Student visa Since what year?_____ Country of origin

_____ Temporary visa Since what year?_____ Country of origin

_____ Refugee Since what year?_____ Country of origin

18. What is your first language? _____

If your first language is not English, how long have you been fluent in reading, writing and comprehension of the English language?

19. What is your ethnic/racial background? Please select the one that best applies to you.

____Asian (e.g., Chinese, Japanese, Korean)

____South Asian (e.g., East Indian, Pakistani, Punjabi, Sri Lankan)

____South East Asian (e.g., Cambodian, Indonesian, Laotian)

____Arab/West Asian (e.g., Armenian, Egyptian, Iranian, Lebanese, Moroccan)

____Black (e.g., African, Haitian, Jamaican, Somali)

____Latin American/Hispanic

____Aboriginal

____White/Euro-Caucasian

____Other (please specify): _____

20. What is your religious affiliation? Please select the one that best applies to you.

____None—Atheist (e.g., belief that there is NO God)

____None—Agnostic (e.g., belief that the existence of God cannot be known)

____Protestant (e.g., United, Anglican, Baptist, Presbyterian, Lutheran, Pentecostal, Mennonite, "Christian")

____Catholic (e.g., Roman Catholic, Ukrainian Catholic)

____Jewish

____Muslim

____Buddhist

____Hindu

____Sikh

____Bahá'í

____Other (please specify):_____

21. What is your current living arrangement? Please select the one that best applies to you.

_____ Living alone

_____ Living with friends

_____ Living with roommates

_____ Living with parents

_____ Living with spouse/significant other

_____ Living with spouse/significant other and young children (13 years and younger)

_____ Living with spouse/significant other and older children (13 years and older) alone

_____ Living with young children (13 years and younger)

_____ Living alone with older children (13 years and older)

_____ Other (please specify) _____

22. What is your current relationship status? Please select the one that best applies to you.

_____ Single, and not seeing anyone

_____ Going out with someone

_____ In a serious dating relationship

_____ Have recently broken up ..... Please specify how many weeks ago you broke up

_____ Living with an intimate other

_____ Engaged

_____ Married

_____Separated/Divorced ..... Please specify how many months ago you separated

_____ Widowed

23. Is your current (or most recent) partner:

Male _____ OR Female _____?

24. Please provide your current height: _____ (ft) OR _____ (metres)

Please provide your current weight: _____ (lb) OR _____ (kg)

25. What level of education have you completed?

_____ 8 years or less of elementary school

_____ some high school but no diploma

_____ a high school diploma or equivalent

_____ 1 to 3 years of college/university (including study at a technical college or CEGEP)

_____ an undergraduate university degree

_____ a master's degree

_____ a doctoral degree

_____ a professional degree [medicine (M.D.), dentistry (D.D.S.), law, or other similar degrees]

26. In your opinion, how would you describe your health?

_____Poor

_____Fair

_____Good

_____Very good

_____Excellent

27. Are you on any of the following medications (please check all that apply)?

Anti-inflammatories (please specify) _____

Anti-depressants (please specify) _____

Anti-anxieties (please specify) _____

Allergy medication (please specify) _____

Other prescription drugs (please specify) ___

A.3 Edinburgh Handedness Inventory

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EDINBURGH HANDEDNESS INVENTORY

Experiment Code: **Participant Number:** **Date:**

Gender: **Male** **Female** **(circle one)**

Please circle your preferences in the use of hands in the following activities. If you are really indifferent, select "**Either**". Where the preference is so strong that you would never try to use the other hand select "**No**". Some of the activities require both hands. In these cases the part of the task, or object, for which hand preference is wanted is indicated in brackets. Please try to answer all the questions, and only leave a blank if you have no experience at all of the object or task.

When:	**Which hand do you prefer?**			**Do you ever use the other hand?**	
Writing:	L	R	Either	Yes	No
Drawing:	L	R	Either	Yes	No
Throwing:	L	R	Either	Yes	No
Using Scissors:	L	R	Either	Yes	No
Using a Toothbrush:	L	R	Either	Yes	No
Using a Knife (without fork):	L	R	Either	Yes	No
Using a Spoon:	L	R	Either	Yes	No
Using a Broom (upper hand):	L	R	Either	Yes	No
Striking a Match:	L	R	Either	Yes	No
Opening a Box (lid):	L	R	Either	Yes	No
Which foot do you kick with?	L	R	Either	Yes	No
Which eye do you use when only using one?	L	R	Either	Yes	No

Are any of the following family members left-handed? (check all that apply)

Father	
Mother	
Sister	
Brother	
Children	

Adapted from: Oldfield, R.C. (1971). The assessment and analysis of handedness: The
Edinburgh inventory. Neuropsychologia, **9**:97-113.

A.4 Quran Prior History Questionnaire

1. Does your child understand Arabic? If yes, to what extent?

2. Does your child memorize or learn to read the Koran proficiently?

3. How many Juz has your child memorized previously? What surah is she/he currently studying?

4. If your child primarily learns to read the Koran proficiently without memorization, how many Juz can your child read proficiently?

5. Has your child previously memorized Juz ‘Amma?

6. How many hours does your child practice reading/memorizing the Koran a week?

7. What method primarily does your child use to read/memorize the Koran?

8. At what age did your child start memorizing the Quran?

A.5 Child Assent Form

Carleton UNIVERSITY
Canada's Capital University

Child Assent Form

Experiment Title: Working memory mechanism behind Koran memorization using auditory interference in children
Principal Investigator: Faisa Omer (faisaomer@cmail.carleton.ca)

We want to tell you about a research study we are doing. A research study is a way to learn more about something. We would like to find out more about what part of your brain memorizing the Quran uses compared to English. You are being asked to join the study because you memorized Juz 'Amma before.

If you agree to join this study, you will be asked to come to the lab once for almost 2 hours and wear an EEG cap that reads your brain waves. You will be asked to remember some verses from the Holy Quran and some English words while wearing the cap. Wearing the cap doesn't hurt at all and if you feel tired you can take a break anytime you want. If you get hungry there will be some juice and snacks. Mom or Dad will be close by the whole time.

This study will help us learn more about kids that memorize the Quran who don't understand it and those who do understand it.

You do not have to join this study. It is up to you. You can say okay now and change your mind later. All you have to do is tell us you want to stop. No one will be mad at you if you don't want to be in the study or if you join the study and change your mind later and stop.

Before you say **yes or no** to being in this study, we will answer any questions you have. If you join the study, you can ask questions at any time. Just tell the researcher that you have a question.

If you have any questions about this study please feel free to contact Faisa Omer at (613) 712-0220.

Would you like to be in this research study?

_____ Yes, I will be in this research study. _____ No, I don't want to do this.

_____	_____	_____
Child's name	Signature of the child	Date
_____	_____	_____
Person obtaining assent	Signature	Date

A.6 Quran Recognition Task

Includes trial number, Koranic verses list in Arabic and chapter/verse numbers. The recall word is the last word in each verse.

Auditory Only

Trial 1

1. 112:1

قُلْ هُوَ ٱللَّهُ أَحَدٌ ﴿١﴾

2. 108:3

إِنَّ شَانِئَكَ هُوَ ٱلْأَبْتَرُ ﴿٣﴾

Trial 2

1. 101:6

فَأَمَّا مَن ثَقُلَتْ مَوَٰزِينُهُۥ ﴿٦﴾

2. 98:2

رَسُولٌ مِّنَ ٱللَّهِ يَتْلُوا۟ صُحُفًا مُّطَهَّرَةً ﴿٢﴾

3. 100:7

وَإِنَّهُۥ عَلَىٰ ذَٰلِكَ لَشَهِيدٌ ﴿٧﴾

Trial 3

1. 93:5

وَلَسَوْفَ يُعْطِيكَ رَبُّكَ فَتَرْضَىٰٓ ﴿٥﴾

2. 88:7

لَّا يُسْمِنُ وَلَا يُغْنِى مِن جُوعٍ ﴿٧﴾

3. 87:18

إِنَّ هَٰذَا لَفِى ٱلصُّحُفِ ٱلْأُولَىٰ ﴿١٨﴾

4. 87:9

فَذَكِّرْ إِن نَّفَعَتِ ٱلذِّكْرَىٰ ﴿٩﴾

Trial 4

1. 85:7

وَهُمْ عَلَىٰ مَا يَفْعَلُونَ بِٱلْمُؤْمِنِينَ شُهُودٌ ﴿٧﴾

2. 86:7

يَخْرُجُ مِنۢ بَيْنِ ٱلصُّلْبِ وَٱلتَّرَآئِبِ ﴿٧﴾

3. 84:7

فَأَمَّا مَنْ أُوتِىَ كِتَٰبَهُۥ بِيَمِينِهِۦ ﴿٧﴾

4. 83:13

إِذَا تُتْلَىٰ عَلَيْهِ ءَايَٰتُنَا قَالَ أَسَٰطِيرُ ٱلْأَوَّلِينَ ﴿١٣﴾

5. 82:6

يَٰٓأَيُّهَا ٱلْإِنسَٰنُ مَا غَرَّكَ بِرَبِّكَ ٱلْكَرِيمِ ﴿٦﴾

Trial 5

1. 78:39

ذَٰلِكَ ٱلْيَوْمُ ٱلْحَقُّ ۖ فَمَن شَآءَ ٱتَّخَذَ إِلَىٰ رَبِّهِۦ مَـَٔابًا ﴿٣٩﴾

2. 79:40

وَأَمَّا مَنْ خَافَ مَقَامَ رَبِّهِۦ وَنَهَى ٱلنَّفْسَ عَنِ ٱلْهَوَىٰ ﴿٤٠﴾

3. 78:37

رَّبِّ ٱلسَّمَٰوَٰتِ وَٱلْأَرْضِ وَمَا بَيْنَهُمَا ٱلرَّحْمَٰنِ ۖ لَا يَمْلِكُونَ مِنْهُ خِطَابًا ﴿٣٧﴾

4. 78:14

وَأَنزَلْنَا مِنَ ٱلْمُعْصِرَٰتِ مَآءً ثَجَّاجًا ﴿١٤﴾

5. 79:10

يَقُولُونَ أَءِنَّا لَمَرْدُودُونَ فِي ٱلْحَافِرَةِ ﴿١٠﴾

6. 82:19

يَوْمَ لَا تَمْلِكُ نَفْسٌ لِّنَفْسٍ شَيْـًٔا ۖ وَٱلْأَمْرُ يَوْمَئِذٍ لِّلَّهِ ﴿١٩﴾

Auditory Interference

Trial 1

1. 105:1

أَلَمْ تَرَ كَيْفَ فَعَلَ رَبُّكَ بِأَصْحَٰبِ ٱلْفِيلِ ﴿١﴾

2. 111:5

فِي جِيدِهَا حَبْلٌ مِّن مَّسَدٍ ﴿٥﴾

Trial 2

1. 103:2

إِنَّ ٱلْإِنسَٰنَ لَفِي خُسْرٍ ﴿٢﴾

2. 100:11

إِنَّ رَبَّهُم بِهِمْ يَوْمَئِذٍ لَّخَبِيرٌۢ ﴿١١﴾

3. 113:4

وَمِن شَرِّ ٱلنَّفَّٰثَٰتِ فِي ٱلْعُقَدِ ﴿٤﴾

Trial 3

1. 91:8

فَأَلْهَمَهَا فُجُورَهَا وَتَقْوَىٰهَا ﴿٨﴾

2. 97:2

وَمَآ أَدْرَىٰكَ مَا لَيْلَةُ ٱلْقَدْرِ ﴿٢﴾

3. 99:2

وَأَخْرَجَتِ ٱلْأَرْضُ أَثْقَالَهَا ﴿٢﴾

4. 78:11

وَجَعَلْنَا ٱلنَّهَارَ مَعَاشًا ﴿١١﴾

Trial 4

1. 99:6

يَوْمَئِذٍ يَصْدُرُ ٱلنَّاسُ أَشْتَاتًا لِّيُرَوْا۟ أَعْمَـٰلَهُمْ ﴿٦﴾

2. 98:1

لَمْ يَكُنِ ٱلَّذِينَ كَفَرُوا۟ مِنْ أَهْلِ ٱلْكِتَـٰبِ وَٱلْمُشْرِكِينَ مُنفَكِّينَ حَتَّىٰ
تَأْتِيَهُمُ ٱلْبَيِّنَةُ ﴿١﴾

3. 90:17

ثُمَّ كَانَ مِنَ ٱلَّذِينَ ءَامَنُوا۟ وَتَوَاصَوْا۟ بِٱلصَّبْرِ وَتَوَاصَوْا۟ بِٱلْمَرْحَمَةِ ﴿١٧﴾

4. 85:8

وَمَا نَقَمُوا۟ مِنْهُمْ إِلَّآ أَن يُؤْمِنُوا۟ بِٱللَّهِ ٱلْعَزِيزِ ٱلْحَمِيدِ ﴿٨﴾

5. 79:46

كَأَنَّهُمْ يَوْمَ يَرَوْنَهَا لَمْ يَلْبَثُوٓا۟ إِلَّا عَشِيَّةً أَوْ ضُحَىٰهَا ﴿٤٦﴾

Trial 5

1. 83:34

فَٱلْيَوْمَ ٱلَّذِينَ ءَامَنُوا۟ مِنَ ٱلْكُفَّارِ يَضْحَكُونَ ﴿٣٤﴾

2. 89:23

وَجِاْىٓءَ يَوْمَئِذٍۭ بِجَهَنَّمَ ۚ يَوْمَئِذٍ يَتَذَكَّرُ ٱلْإِنسَـٰنُ وَأَنَّىٰ لَهُ
ٱلذِّكْرَىٰ ﴿٢٣﴾

3. 83:26

خِتَٰمُهُۥ مِسۡكٞۚ وَفِي ذَٰلِكَ فَلۡيَتَنَافَسِ ٱلۡمُتَنَٰفِسُونَ ٢٦

4. 85:11

إِنَّ ٱلَّذِينَ ءَامَنُواْ وَعَمِلُواْ ٱلصَّٰلِحَٰتِ لَهُمۡ جَنَّٰتٞ تَجۡرِي مِن تَحۡتِهَا
ٱلۡأَنۡهَٰرُۚ ذَٰلِكَ ٱلۡفَوۡزُ ٱلۡكَبِيرُ ١١

5. 78:40

إِنَّآ أَنذَرۡنَٰكُمۡ عَذَابٗا قَرِيبٗا يَوۡمَ يَنظُرُ ٱلۡمَرۡءُ مَا قَدَّمَتۡ يَدَاهُ وَيَقُولُ
ٱلۡكَافِرُ يَٰلَيۡتَنِي كُنتُ تُرَٰبَۢا ٤٠

6. 78:38

يَوۡمَ يَقُومُ ٱلرُّوحُ وَٱلۡمَلَٰٓئِكَةُ صَفّٗاۖ لَّا يَتَكَلَّمُونَ إِلَّا مَنۡ أَذِنَ لَهُ ٱلرَّحۡمَٰنُ
وَقَالَ صَوَابٗا ٣٨

Control

Trial 1

1.114:4

مِن شَرِّ ٱلۡوَسۡوَاسِ ٱلۡخَنَّاسِ ٤

2. 107:5

ٱلَّذِي يُوَسۡوِسُ فِي صُدُورِ ٱلنَّاسِ ٥

Trial 2

1. 96:5

عَلَّمَ ٱلۡإِنسَٰنَ مَا لَمۡ يَعۡلَمۡ ٥

2. 100:3

فَٱلْمُغِيرَٰتِ صُبْحًا ﴿٣﴾

3. 102:4

ثُمَّ كَلَّا سَوْفَ تَعْلَمُونَ ﴿٤﴾

Trial 3

1. 97: 5

سَلَٰمٌ هِىَ حَتَّىٰ مَطْلَعِ ٱلْفَجْرِ ﴿٥﴾

2. 93:4

وَلَلْءَاخِرَةُ خَيْرٌ لَّكَ مِنَ ٱلْأُولَىٰ ﴿٤﴾

3. 95:5

ثُمَّ رَدَدْنَٰهُ أَسْفَلَ سَٰفِلِينَ ﴿٥﴾

4.91:11

كَذَّبَتْ ثَمُودُ بِطَغْوَىٰهَآ ﴿١١﴾

Trial 4

1. 84:8

فَسَوْفَ يُحَاسَبُ حِسَابًا يَسِيرًا ﴿٨﴾

2. 89:16

وَأَمَّآ إِذَا مَا ٱبْتَلَىٰهُ فَقَدَرَ عَلَيْهِ رِزْقَهُۥ فَيَقُولُ رَبِّىٓ أَهَٰنَنِ ﴿١٦﴾

3. 90:19

وَٱلَّذِينَ كَفَرُوا۟ بِـَٔايَٰتِنَا هُمْ أَصْحَٰبُ ٱلْمَشْـَٔمَةِ ﴿١٩﴾

4. 83:32

وَإِذَا رَأَوْهُمْ قَالُوٓاْ إِنَّ هَٰٓؤُلَآءِ لَضَآلُّونَ ﴿٣٢﴾

5. 88:17

أَفَلَا يَنظُرُونَ إِلَى ٱلْإِبِلِ كَيْفَ خُلِقَتْ ﴿١٧﴾

Trial 5

1. 83:29

إِنَّ ٱلَّذِينَ أَجْرَمُواْ كَانُواْ مِنَ ٱلَّذِينَ ءَامَنُواْ يَضْحَكُونَ ﴿٢٩﴾

2. 81:29

وَمَا تَشَآءُونَ إِلَّآ أَن يَشَآءَ ٱللَّهُ رَبُّ ٱلْعَٰلَمِينَ ﴿٢٩﴾

3. 85:10

إِنَّ ٱلَّذِينَ فَتَنُواْ ٱلْمُؤْمِنِينَ وَٱلْمُؤْمِنَٰتِ ثُمَّ لَمْ يَتُوبُواْ فَلَهُمْ عَذَابُ جَهَنَّمَ
وَلَهُمْ عَذَابُ ٱلْحَرِيقِ ﴿١٠﴾

4. 84:21

وَإِذَا قُرِئَ عَلَيْهِمُ ٱلْقُرْءَانُ لَا يَسْجُدُونَ ۩ ﴿٢١﴾

5. 84:25

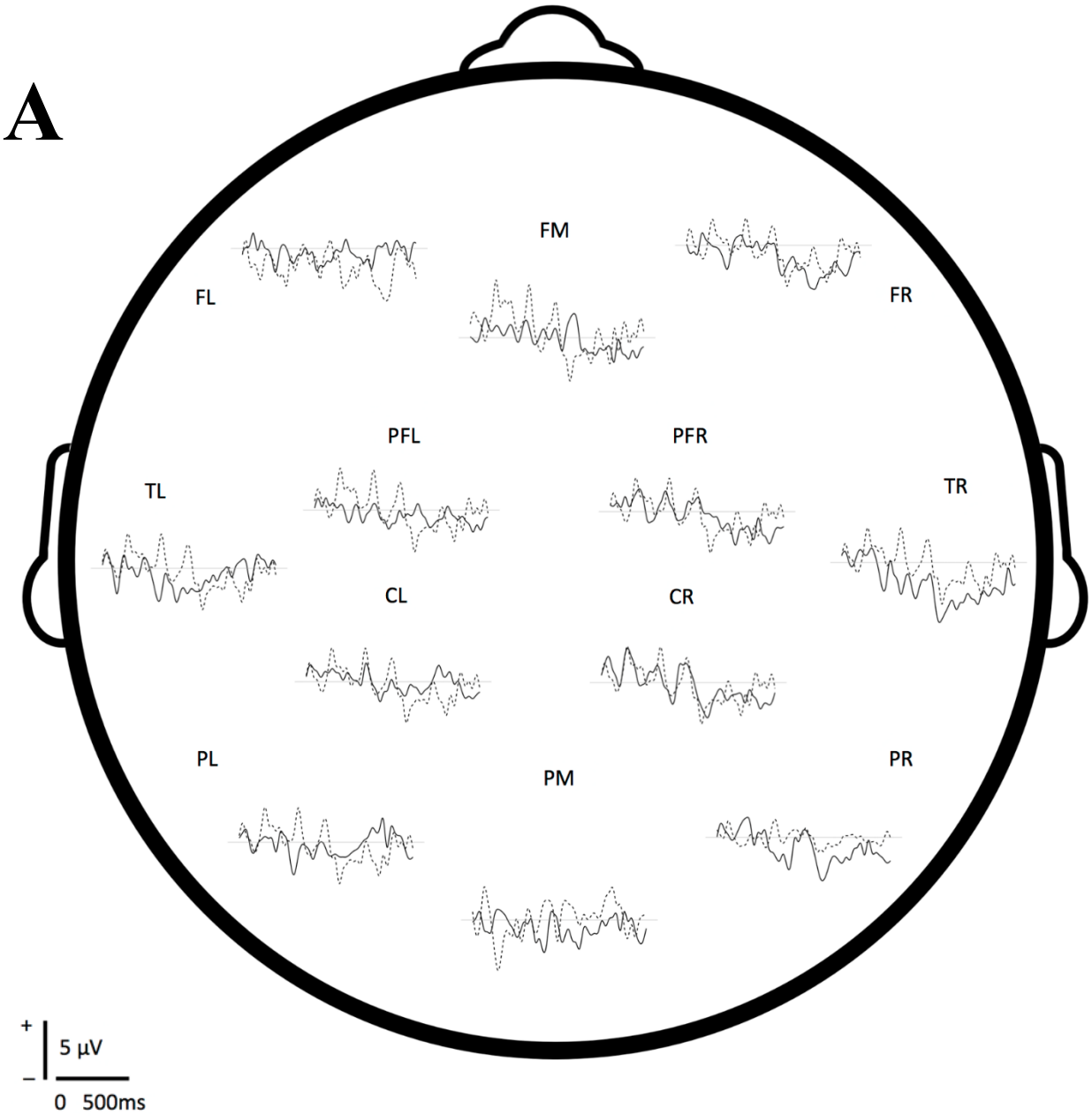
إِلَّا ٱلَّذِينَ ءَامَنُواْ وَعَمِلُواْ ٱلصَّٰلِحَٰتِ لَهُمْ أَجْرٌ غَيْرُ مَمْنُونٍۭ ﴿٢٥﴾

6. 84:6

يَٰٓأَيُّهَا ٱلْإِنسَٰنُ إِنَّكَ كَادِحٌ إِلَىٰ رَبِّكَ كَدْحًا فَمُلَٰقِيهِ ﴿٦﴾

Appendix B

B1 Correct and Incorrect Binned Headmaps



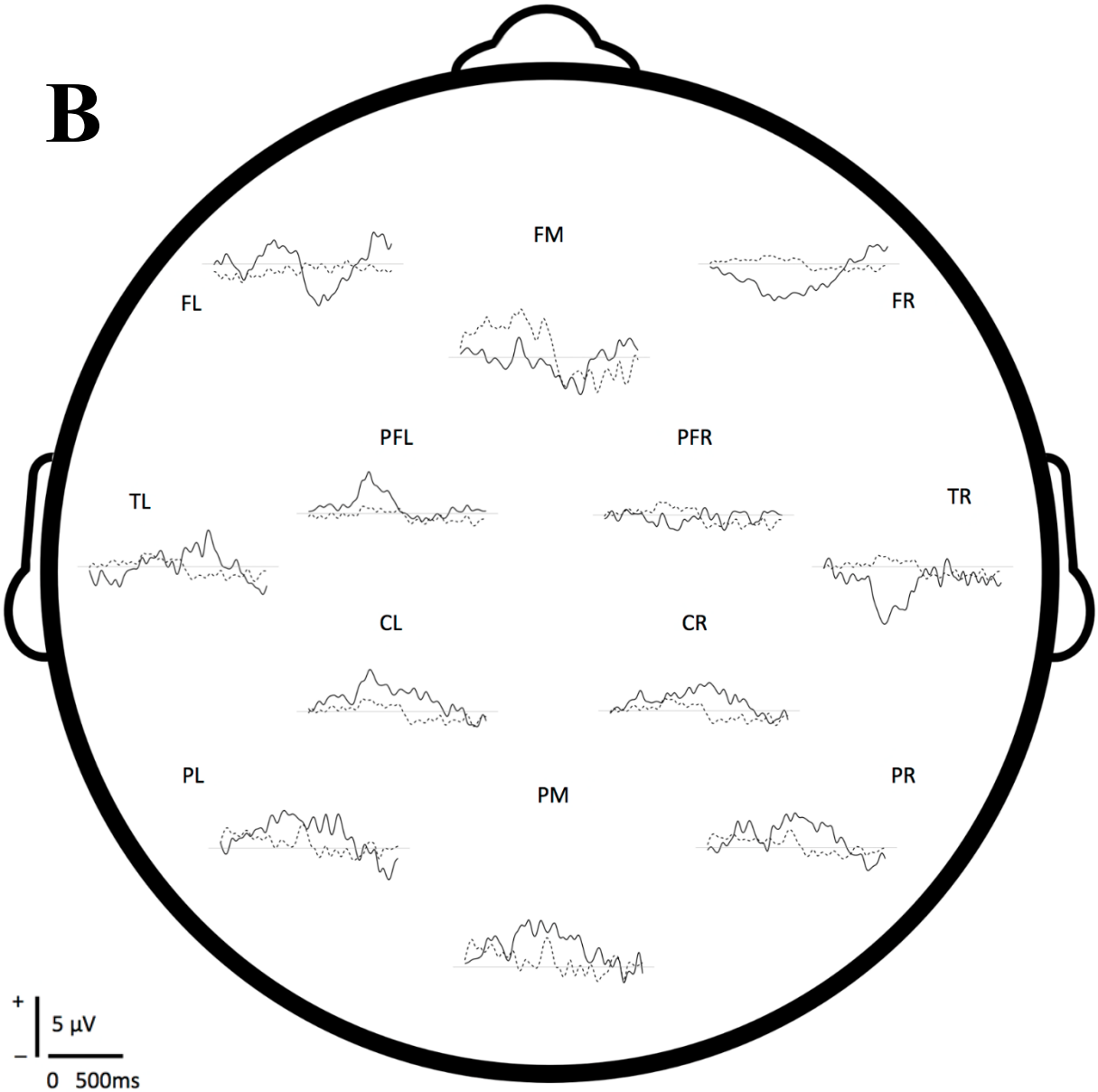
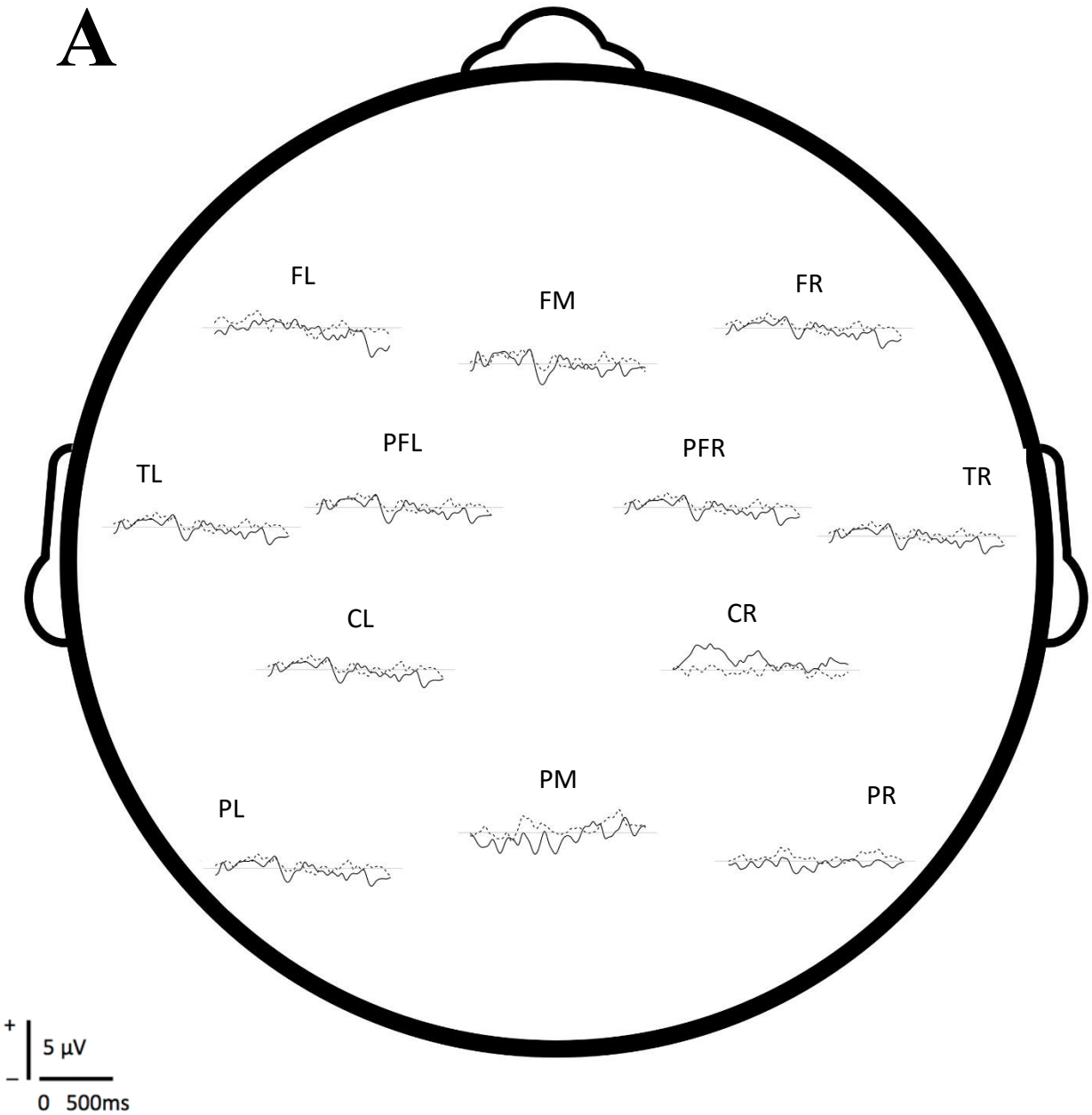


Figure S1: Schematic of the modified configuration map of a 32-channel EEG cap placement based on the international 10-20 system was used. This modified configuration averages the 32-channel placements into 12 electrode sites of interest (ESIs). The overall scale for the map was 5µV (for horizontal measurements) and 500ms (for vertical measurements). ERPs are displayed as amplitude differences between interference (bold line) and non-interference conditions (dotted-line) for the Quran Recognition Task (QRT). External stimulus introduced at vertical

grey line (i.e., 0ms for the epoch). Horizontal grey line represents 0 μV. Total ERP averages were tallied for incorrect responses for both groups: (**A**) Children (**B**) Adult.


A
FL
FM
FR
PFL
PFR
TL
TR
CL
CR
PL
PM
PR
+
5 µV
–
0 500ms

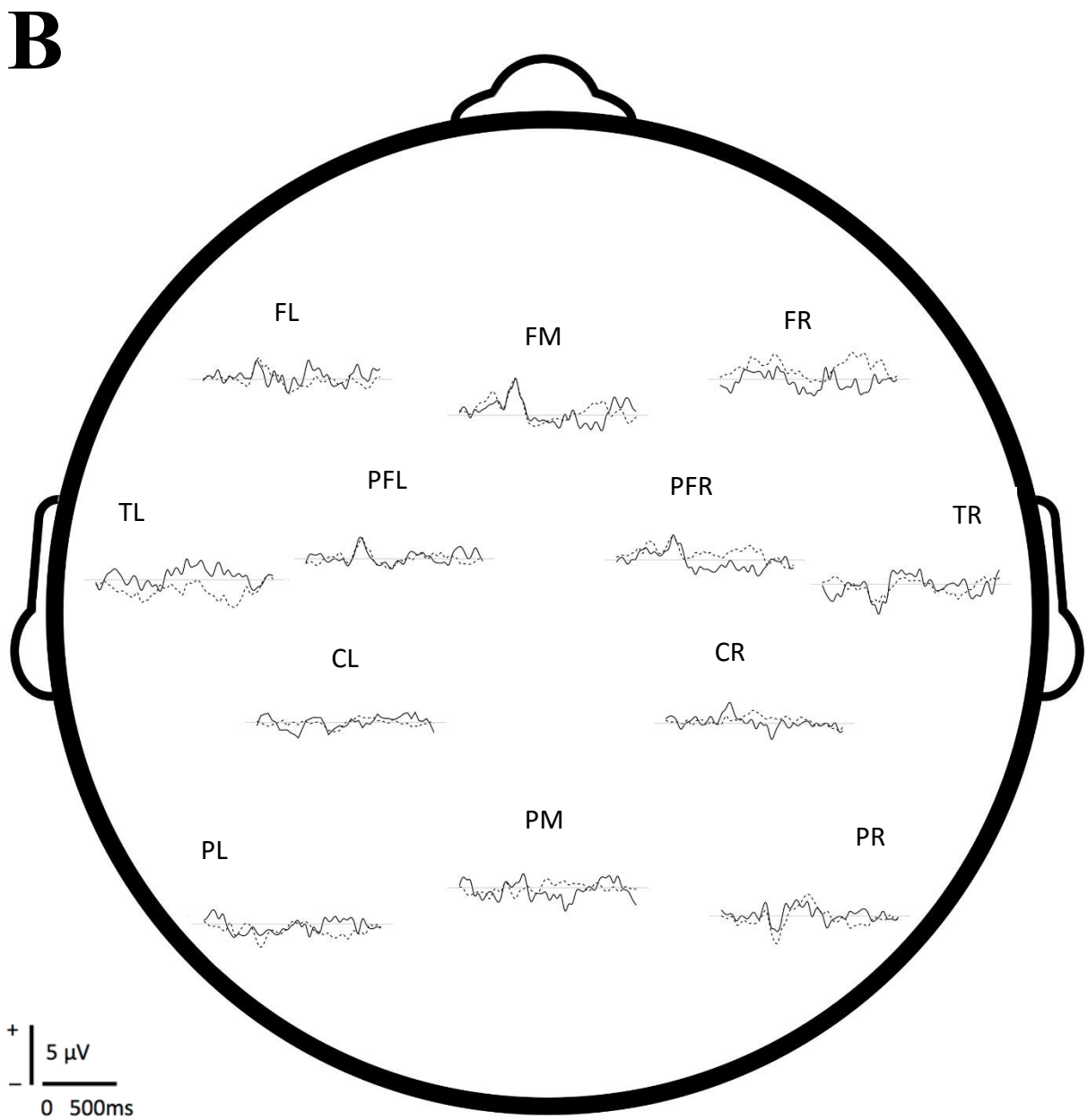
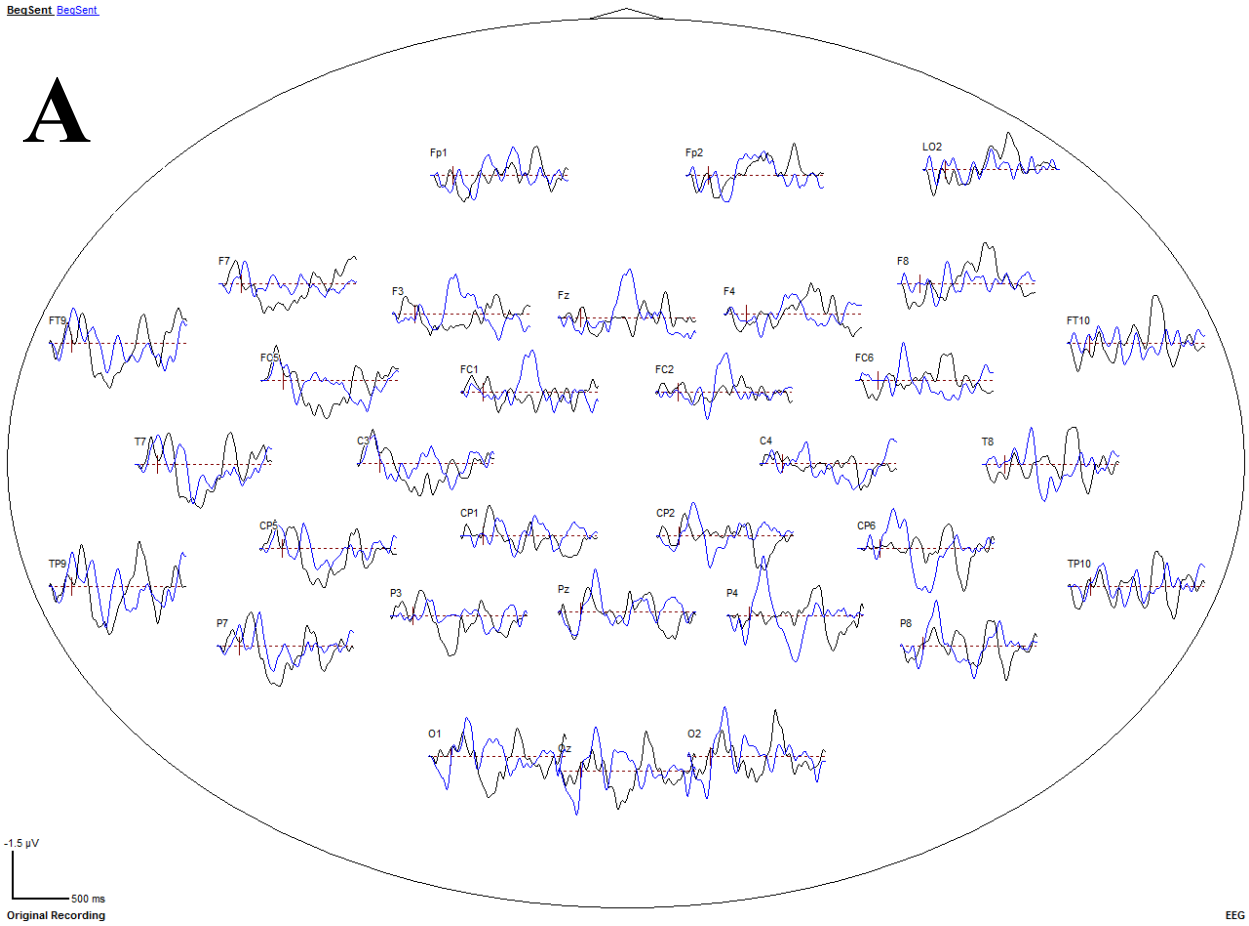
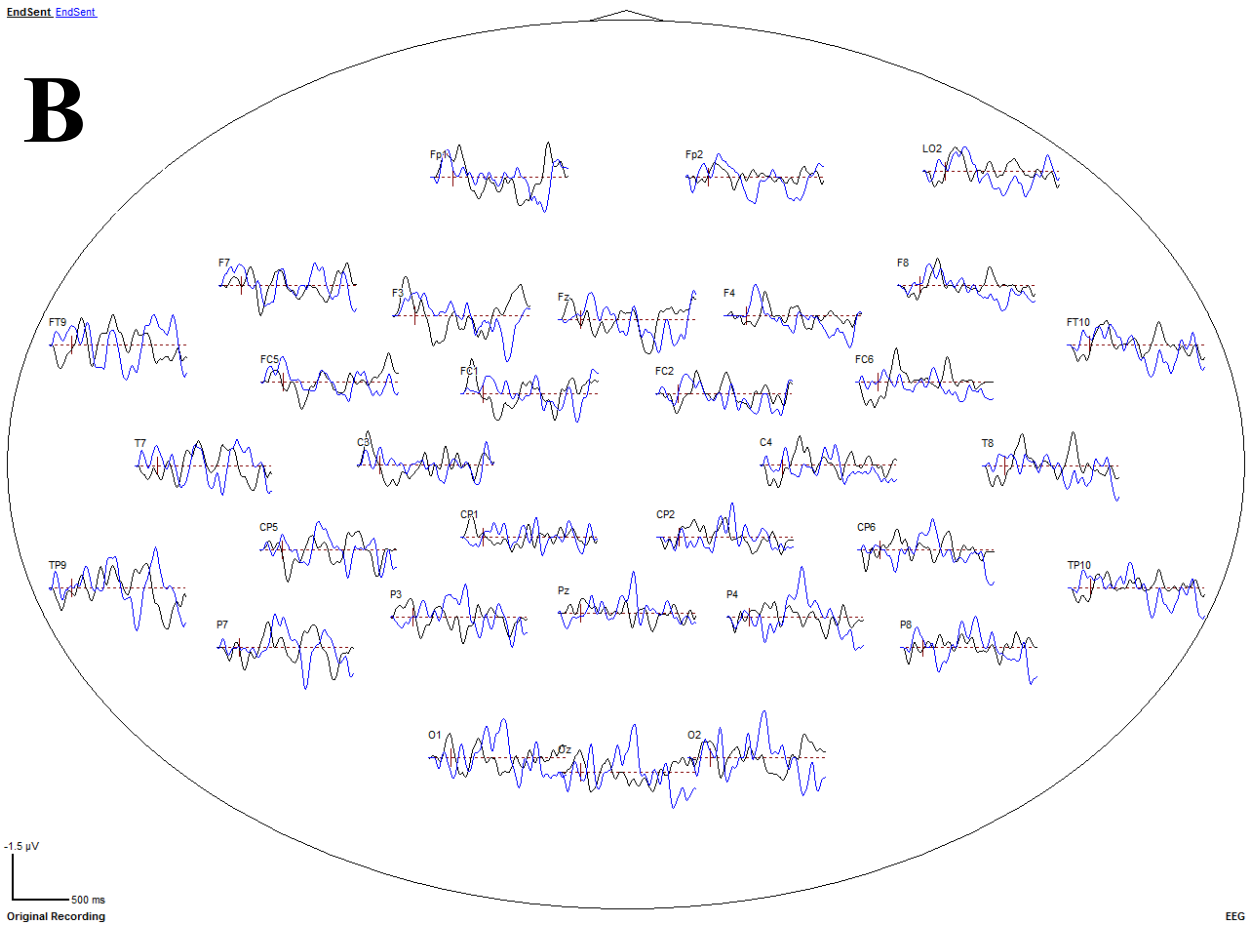


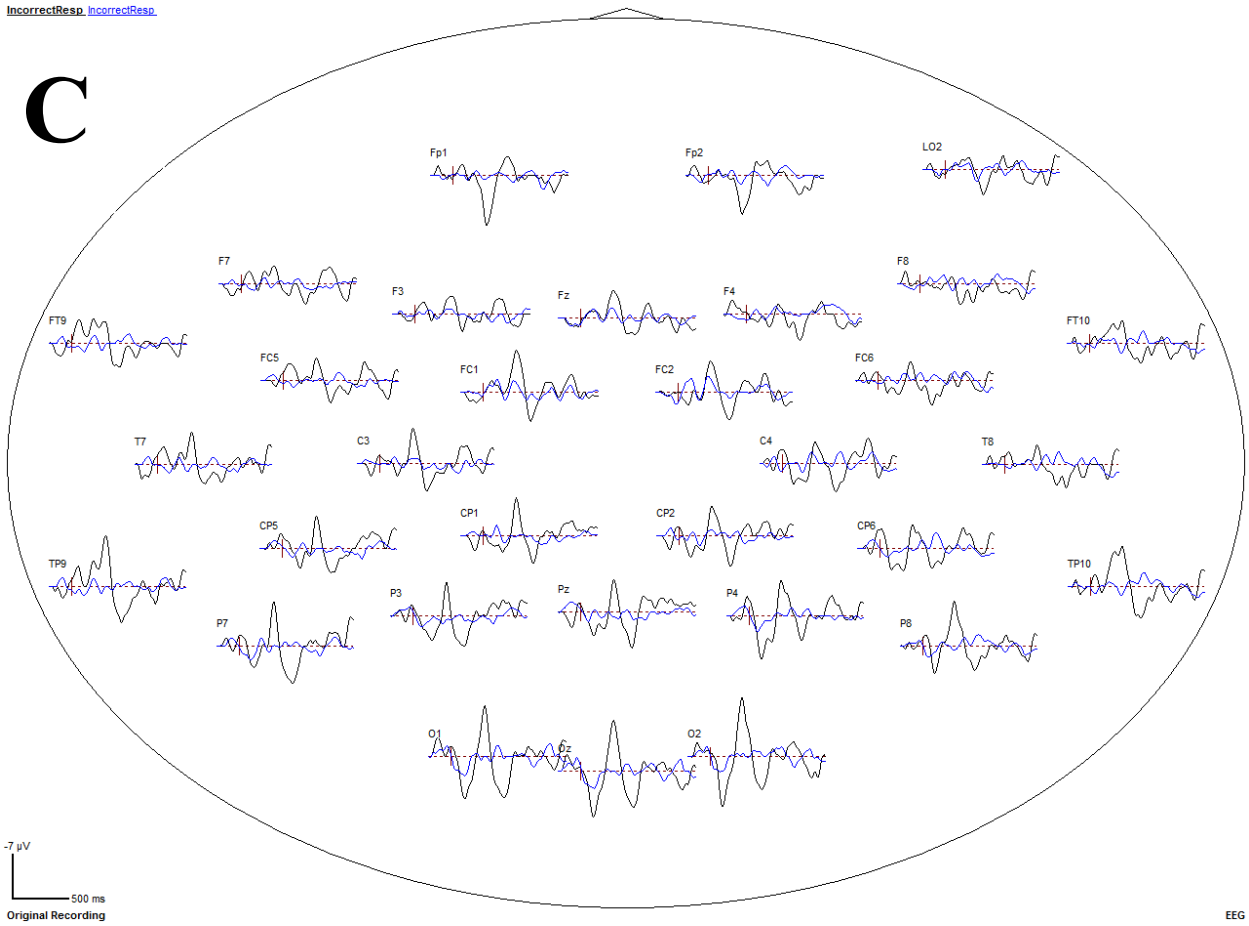
Figure S2: Schematic of the modified configuration map of a 32-channel EEG cap placement based on the international 10-20 system was used. This modified configuration averages the 32-channel placements into 12 electrode sites of interest (ESIs). The overall scale for the map was 5µV (for horizontal measurements) and 500ms (for vertical measurements). ERPs are displayed

as amplitude differences between interference (bold line) and non-interference conditions (dotted-line) for the Quran Recognition Task (QRT). External stimulus introduced at vertical grey line (i.e., 0ms for the epoch). Horizontal grey line represents 0 μV. Total ERP averages were tallied for correct responses for both groups: (**A**) Children (**B**) Adult.

B2 Raw BESA Headmaps




EndSent EndSent
B
Fp1
Fp2
LO2
F7
F3
Fz
F4
F8
FT9
FT10
FC5
FC1
FC2
FC6
T7
C3
C4
T8
CP5
CP1
CP2
CP6
TP9
TP10
P7
P3
Pz
P4
P8
O1
Oz
O2
-1.5 µV
500 ms
Original Recording
EEG


IncorrectResp IncorrectResp
C
Fp1
Fp2
LO2
F7
F3
Fz
F4
F8
FT9
FT10
FC5
FC1
FC2
FC6
T7
C3
C4
T8
CP5
CP1
CP2
CP6
TP9
TP10
P7
P3
Pz
P4
P8
O1
Oz
O2
-7 µV
500 ms
Original Recording
EEG

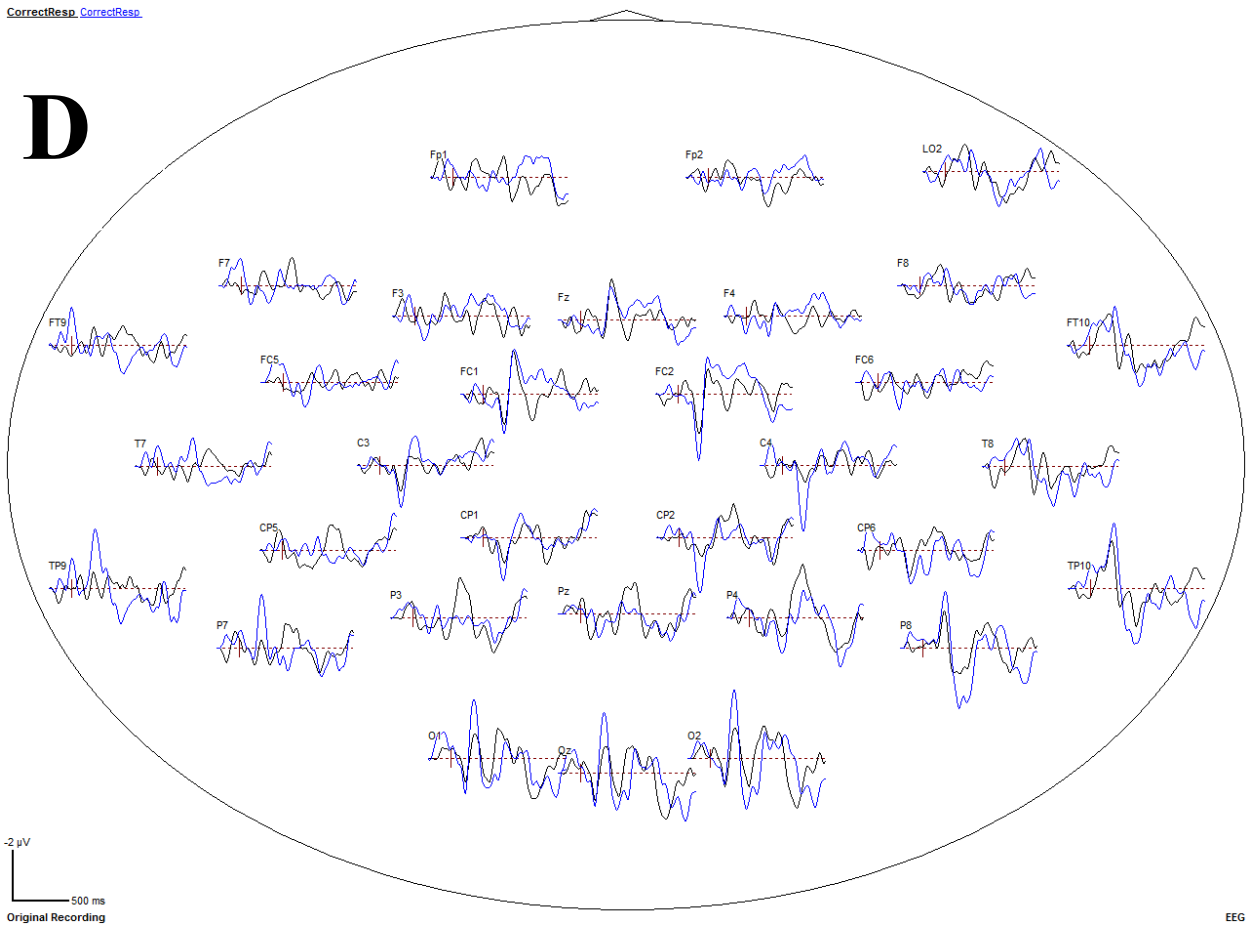
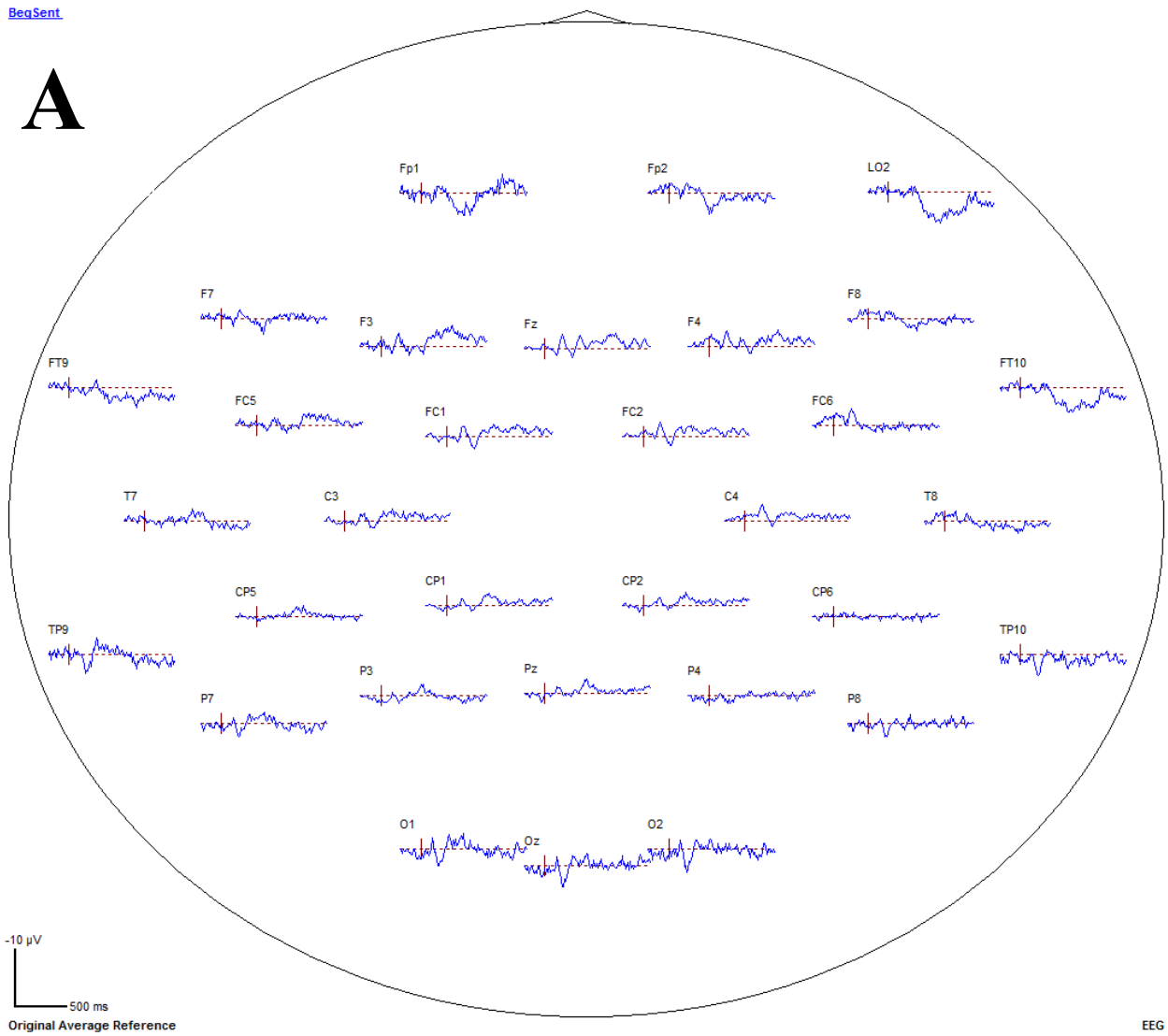
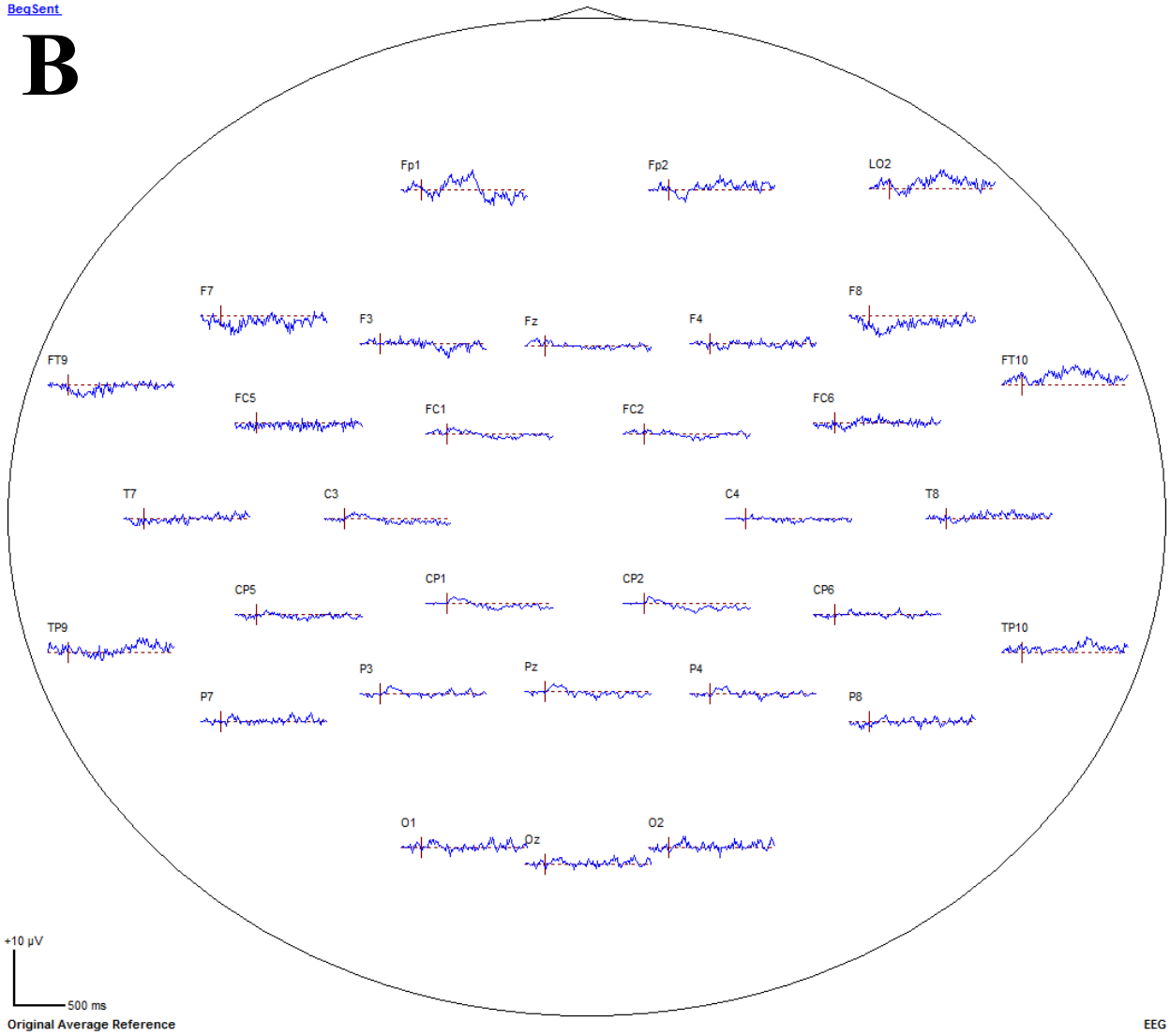


Figure S3: Raw BESA headmaps for children at the (**A**) Beginning of sentence (**B**) End of sentence (**C**) Incorrect response and (**D**) Correct response for interference (Blue line) non-interference (Black line) using a scale of -2µv and 500ms.


BegSent
A
Fp1
Fp2
LO2
F7
F3
Fz
F4
F8
FT9
FT10
FC5
FC1
FC2
FC6
T7
C3
C4
T8
CP5
CP1
CP2
CP6
TP9
TP10
P7
P3
Pz
P4
P8
O1
Oz
O2
-10 µV
500 ms
Original Average Reference
EEG

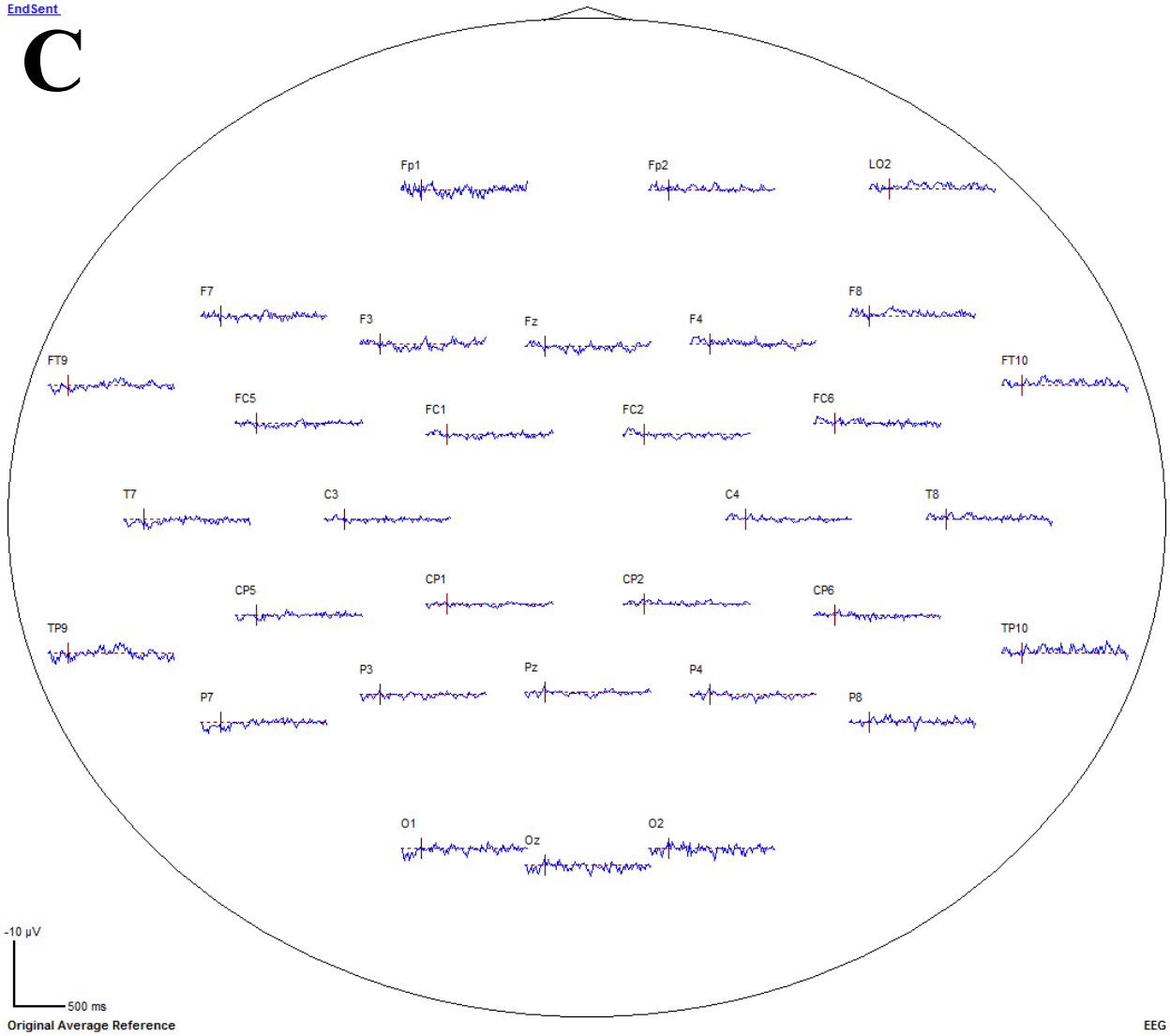
BegSent

B


Fp1
Fp2
LO2
F7
F3
Fz
F4
F8
FT9
FT10
FC5
FC1
FC2
FC6
T7
C3
C4
T8
CP5
CP1
CP2
CP6
TP9
TP10
P7
P3
Pz
P4
P8
O1
Oz
O2
+10 µV
500 ms
Original Average Reference
EEG

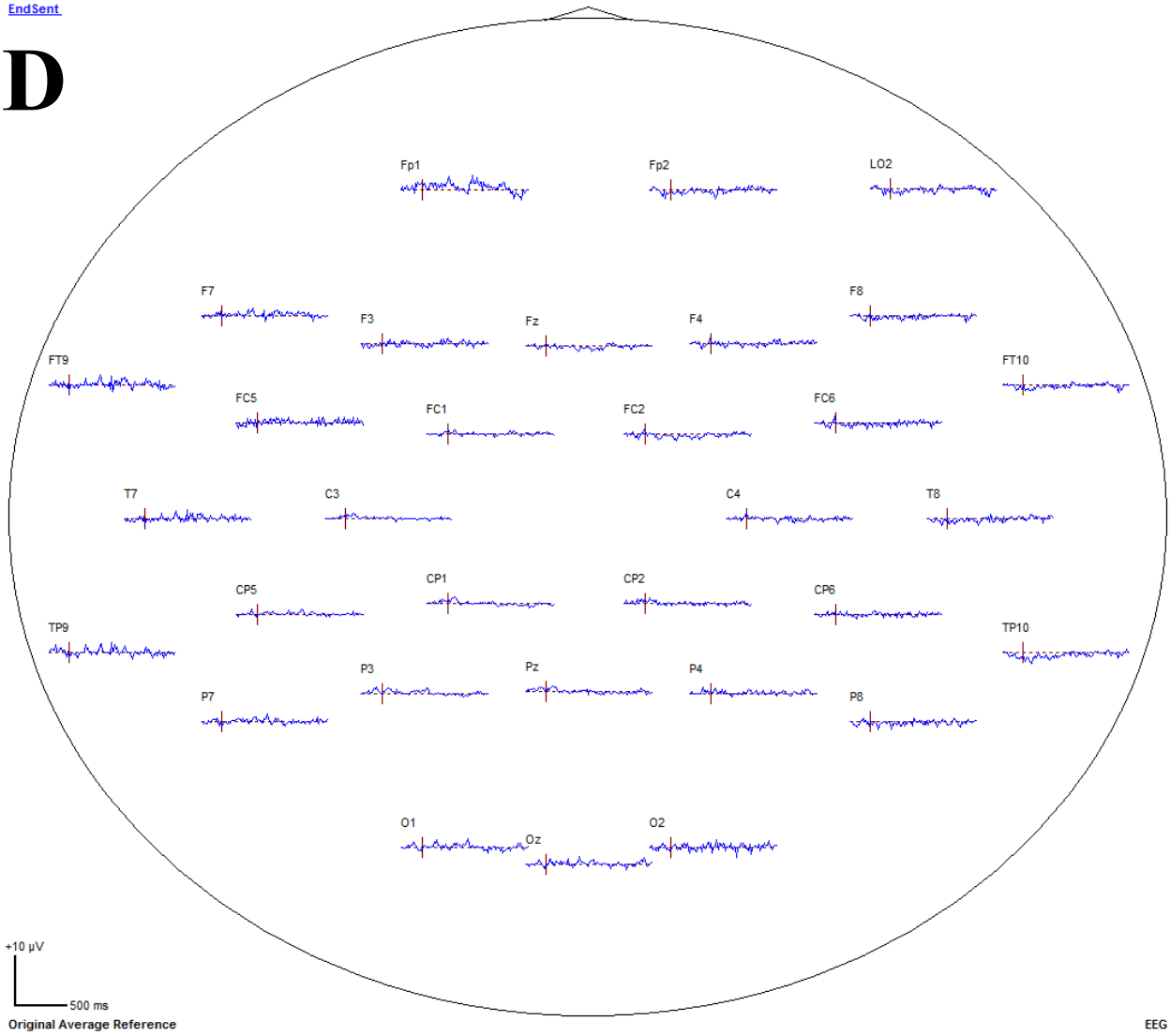
EndSent

C


Fp1
Fp2
LO2
F7
F3
Fz
F4
F8
FT9
FT10
FC5
FC1
FC2
FC6
T7
C3
C4
T8
CP5
CP1
CP2
CP6
TP9
TP10
P7
P3
Pz
P4
P8
O1
Oz
O2
-10 µV
500 ms
Original Average Reference
EEG

EndSent

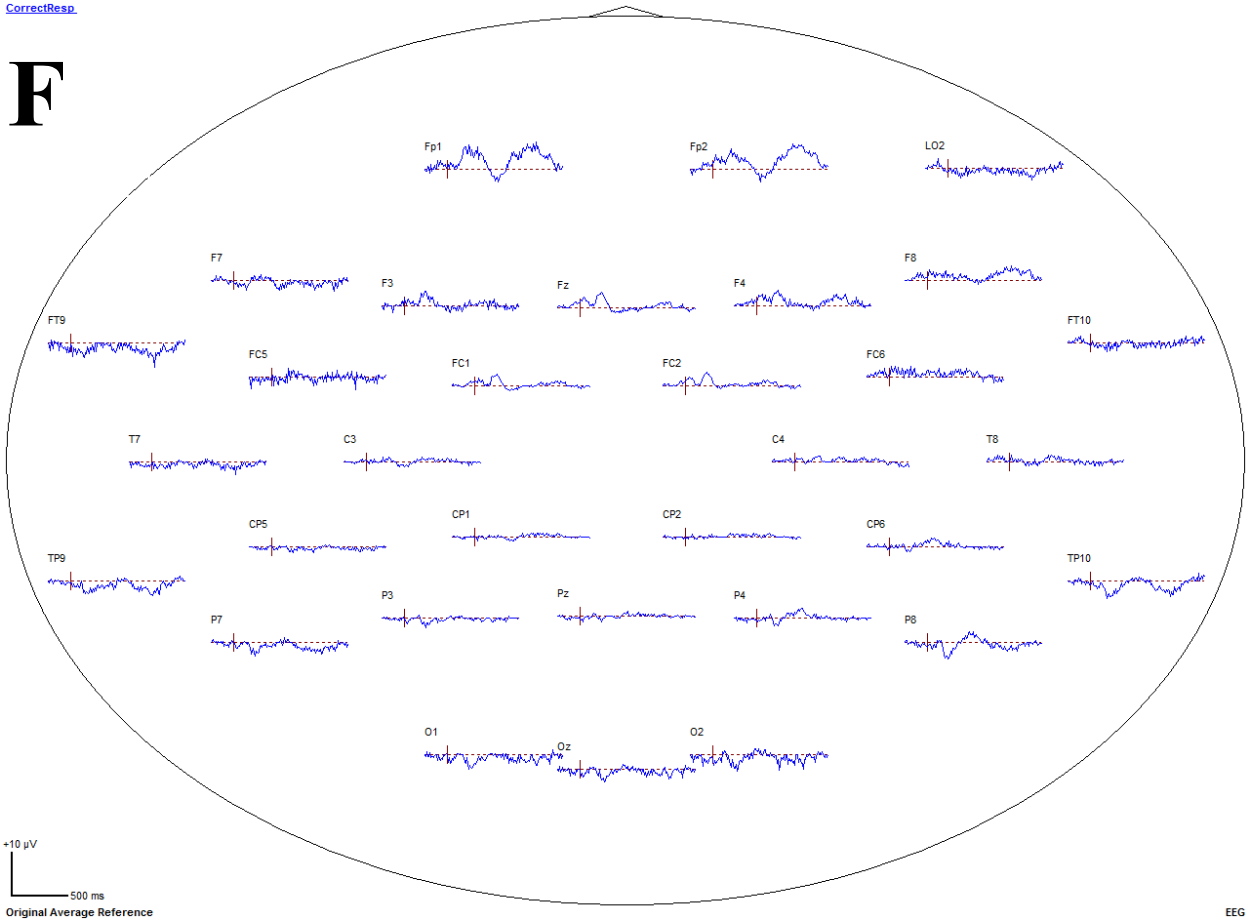
D


Fp1
Fp2
LO2
F7
F3
Fz
F4
F8
FT9
FT10
FC5
FC1
FC2
FC6
T7
C3
C4
T8
CP5
CP1
CP2
CP6
TP9
TP10
P7
P3
Pz
P4
P8
O1
Oz
O2
+10 µV
500 ms
Original Average Reference
EEG

CorrectResp

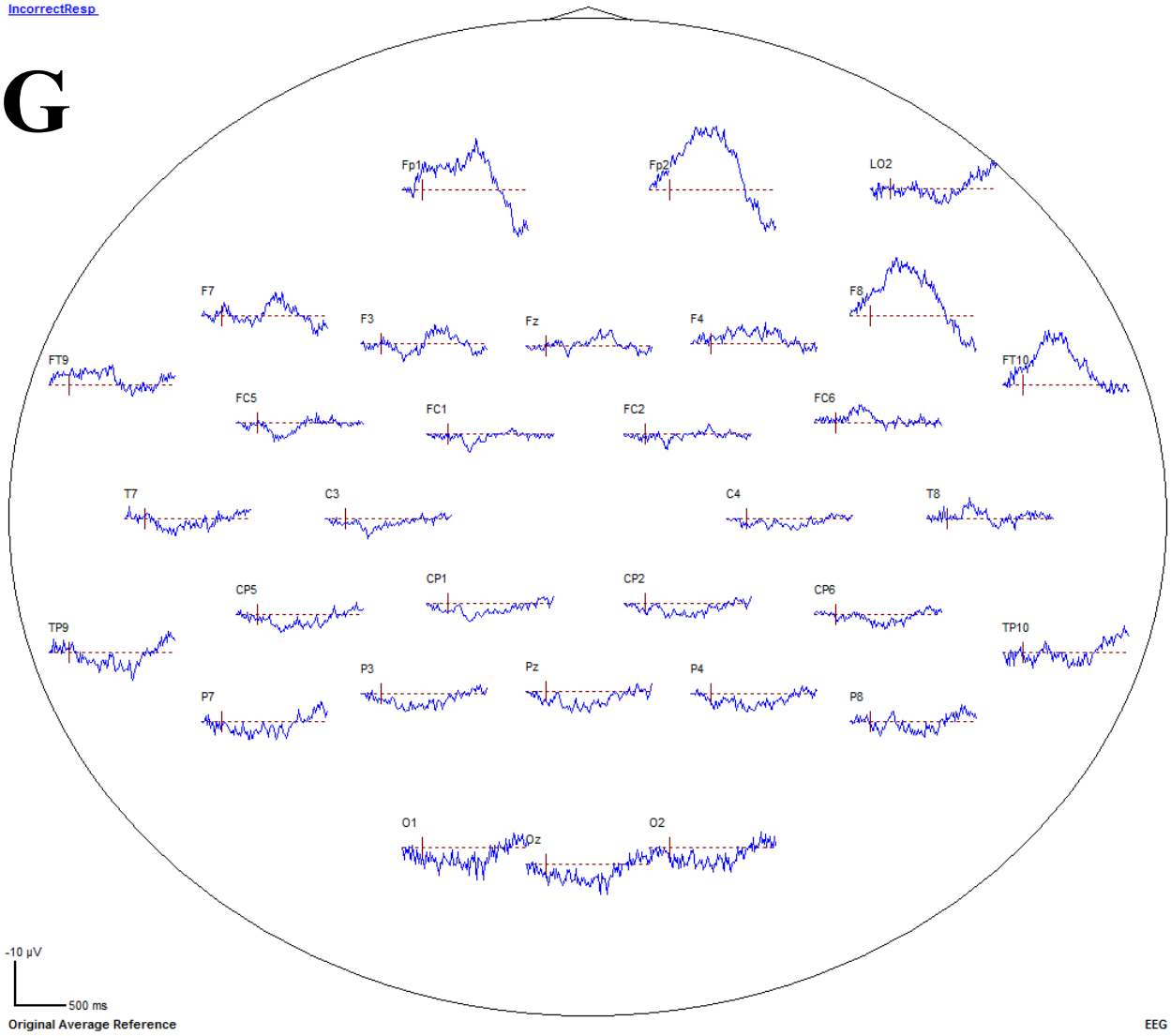
CorrectResp

F



IncorrectResp

G



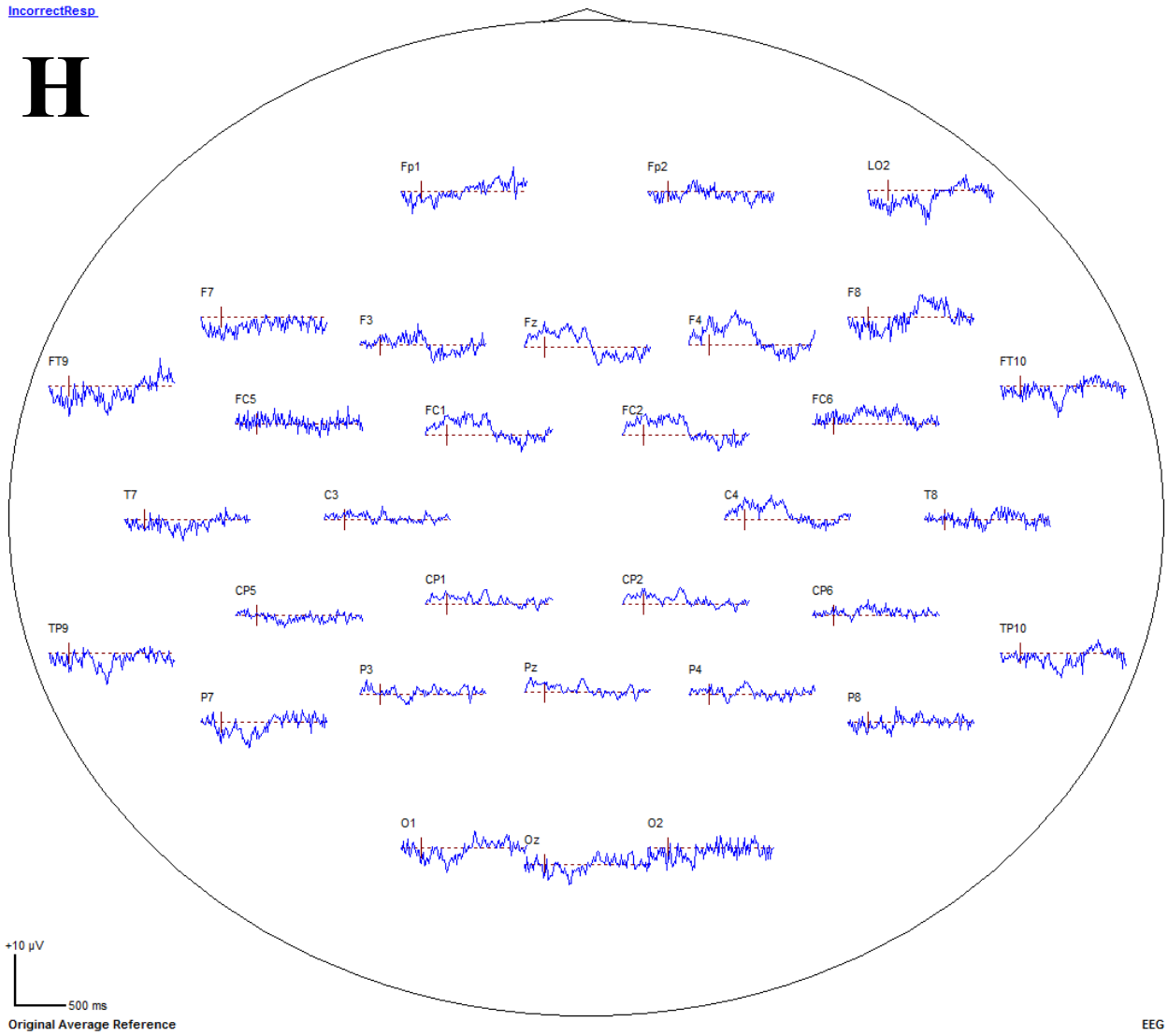


Figure S3: Raw BESA headmaps for adults at the (**A**) Beginning of sentence interference (**B**) Beginning of sentence non-interference (**C**) End of sentence interference (**D**) End of sentence non-interference (**E**) Correct response interference (**F**) Correct response non-interference (**G**) Incorrect response interference (**H**) Incorrect response non-interference using a scale of 10µv and 500ms.

References

Açık, A., Sarwary, A., Schultze-Kraft, R., Onat, S., & König, P. (2010). Developmental changes in natural viewing behavior: bottom-up and top-down differences between children, young adults and older adults. *Frontiers in psychology*, *1*, 207.

Ali, A.Y. (2000). *The Holy Qur'an: Arabic Text with an English Translation and Commentary.* Hertfordshire, UK: Wordsworth Editions.

Al-Tirmidhi, A. E. (2007). Jami At-Tirmidhi. *Trans. Abu Khaliyl. Riyadh, Saudi Arabia: Darussalam*.

Anderson, M. C., Bjork, R. A., & Bjork, E. L. (1994). Remembering can cause forgetting: retrieval dynamics in long-term memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *20*(5), 1063.

Andreassi, J. L. (2013). *Psychophysiology: Human behavior & physiological response*. Psychology Press.

As-Said, L. (1975). *The Recited Koran: a History of the First Recorded Version*. Princeton, NJ: The Darwin Press.

Atkinson, R. C., & Shiffrin, R. M. (1968). Human memory: A proposed system and its control processes. *Psychology of learning and motivation*, *2*, 89-195.

Baddeley, A. (2003). Working memory: looking back and looking forward. *Nature reviews neuroscience*, *4*(10), 829-839.

Baddeley, A. (2003). Working memory and language: An overview. *Journal of communication disorders*, *36*(3), 189-208.

Baddeley, A. D., & Hitch, G. (1974). Working memory. *Psychology of learning and motivation*, *8*, 47-89.

Baddeley, A. D., Thomson, N., & Buchanan, M. (1975). Word length and the structure of short-term memory. *Journal of verbal learning and verbal behavior*, *14*(6), 575-589.

Banbury, S. P., Macken, W. J., Tremblay, S., & Jones, D. M. (2001). Auditory distraction and short-term memory: Phenomena and practical implications. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *43*(1), 12-29.

Boyle, H. N. (2006). Memorization and learning in Islamic schools. *Comparative Education Review*, *50*(3), 478-495.

Buchsbaum, B. R., Olsen, R. K., Koch, P., & Berman, K. F. (2005). Human dorsal and ventral auditory streams subserve rehearsal-based and echoic processes during verbal working memory. *Neuron*, *48*(4), 687-697.

Bukhari, I. A. (1980). Sahih al-Bukhari Hadith. *Trans. Dr. Muhammad Muhsin Khan. Beirut, Lebanon: Dar al-Arabia*.

Burton, M. W., LoCasto, P. C., Krebs-Noble, D., & Gullapalli, R. P. (2005). A systematic investigation of the functional neuroanatomy of auditory and visual phonological processing. *Neuroimage*, *26*(3), 647-661.

Case, R., Kurland, D. M., & Goldberg, J. (1982). Operational efficiency and the growth of short-term memory span. *Journal of experimental child psychology*, *33*(3), 386-404.

Clapp, W. C., Rubens, M. T., & Gazzaley, A. (2009). Mechanisms of working memory disruption by external interference. *Cerebral Cortex*, bhp150.

D'Angiulli, A., Griffiths, G., & Marmolejo-Ramos, F. (2015). Neural correlates of visualizations of concrete and abstract words in preschool children: a developmental embodied approach. *Frontiers in psychology*, *6*.

Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal of verbal learning and verbal behavior*, *19*(4), 450-466.

Duff, S. L., & Lasky, D. I. (1995). Effects of same and cross-modal interference on recall of word lists. *Perceptual and motor skills*, *80*(2), 587-591.

Engle, R. W. (2001). What is working memory capacity? *The nature of remembering: Essays in honor of Robert G. Crowder*, 297-314.

Engle, R. W. (2002). Working memory capacity as executive attention. *Current directions in psychological science*, *11*(1), 19-23.

Esposito, M. D., Detre, J. A., Alsop, D. C., & Shin, R. K. (1995). The neural basis of the central executive system of working memory. *Nature*, *378*(6554), 279.

Federmeier, K. D., Van Petten, C., Schwartz, T. J., & Kutas, M. (2003). Sounds, words, sentences: age-related changes across levels of language processing. *Psychology and aging*, *18*(4), 858.

Gade, A. M. (2010). *The Qur'an: An Introduction.* Oxford, UK: Oneworld Publications.

Gathercole, S. E. (1995). Is nonword repetition a test of phonological memory or long-term knowledge? It all depends on the nonwords. *Memory & Cognition*, *23*(1), 83-94.

Gathercole, S. E., & Baddeley, A. D. (1989). Evaluation of the role of phonological STM in the development of vocabulary in children: A longitudinal study. *Journal of memory and language*, *28*(2), 200-213.

Gillund, G., & Shiffrin, R. M. (1984). A retrieval model for both recognition and recall. *Psychological review*, *91*(1), 1.

Goldinger, S. D. (1998). Echoes of echoes? An episodic theory of lexical access. *Psychological review*, *105*(2), 251.

González, H. L., Palencia, A. P., Umaña, L. A., & Galindo, L. (2008). Mediated learning experience and concept maps: a pedagogical tool for achieving meaningful learning in medical physiology students. *Advances in physiology education*, *32*(4), 312-316.

Haenschel, C., Vernon, D. J., Dwivedi, P., Gruzelier, J. H., & Baldeweg, T. (2005). Event-related brain potential correlates of human auditory sensory memory-trace formation. *Journal of Neuroscience*, *25*(45), 10494-10501.

Halpern, A. R., & Zatorre, R. J. (1999). When that tune runs through your head: a PET investigation of auditory imagery for familiar melodies. *Cerebral Cortex*, *9*(7), 697-704.

Hanley, J. R., & Bakopoulou, E. (2003). Irrelevant speech, articulatory suppression, and phonological similarity: A test of the phonological loop model and the feature model. *Psychonomic Bulletin & Review*, *10*(2), 435-444.

Hassan, S. S. B., & Zailaini, M. A. B. (2013). Khatam Al-Quran in Islamic Education Curriculum in Malaysia. *Procedia-Social and Behavioral Sciences*, *103*, 558-566.

Herholz, S. C., Halpern, A. R., & Zatorre, R. J. (2012). Neuronal correlates of perception, imagery, and memory for familiar tunes. *Journal of cognitive neuroscience*, *24*(6), 1382-1397.

Hulme, C., Maughan, S., & Brown, G. D. (1991). Memory for familiar and unfamiliar words: Evidence for a long-term memory contribution to short-term memory span. *Journal of memory and language*, *30*(6), 685-701.

Iqbal, M. (2012). *Integrated encyclopedia of the Quran.* Sherwood Park: Al Qalam Publishing.

Jaffee, M. S. (2001). *Torah in the mouth: writing and oral tradition in Palestinian Judaism 200 BCE-400 CE*. Oxford University Press.

Jarvis, H. L., & Gathercole, S. E. (2003). Verbal and non-verbal working memory and achievements on national curriculum tests at 11 and 14 years of age. *Educational and Child Psychology*, *20*(3), 123-140.

Johnson, R., Pfefferbaum, A., & Kopell, B. S. (1985). P300 and long-term memory: Latency predicts recognition performance. *Psychophysiology*, *22*(5), 497-507.

Kane, M. J., & Engle, R. W. (2002). The role of prefrontal cortex in working-memory capacity, executive attention, and general fluid intelligence: An individual-differences perspective. *Psychonomic bulletin & review*, *9*(4), 637-671.

Kane, M. J., & Engle, R. W. (2003). Working-memory capacity and the control of attention: the contributions of goal neglect, response competition, and task set to Stroop interference. *Journal of experimental psychology: General*, *132*(1), 47.

Lau, E. F., Phillips, C., & Poeppel, D. (2008). A cortical network for semantics :(de) constructing the N400. *Nature Reviews Neuroscience*, *9*(12), 920-933.

Martín-Loeches, M., Schweinberger, S. R., & Sommer, W. (1997). The phonological loop model of working memory: An ERP study of irrelevant speech and phonological similarity effects. *Memory & Cognition*, *25*(4), 471-483.

Marton, F., Watkins, D., & Tang, C. (1997). Discontinuities and continuities in the experience of learning: An interview study of high-school students in Hong Kong. *Learning and instruction*, *7*(1), 21-48.

Masoura, E. V., & Gathercole, S. E. (1999). Phonological short-term memory and foreign language learning. *International Journal of Psychology*, *34*(5-6), 383-388.

McGuire, P. K., Silbersweig, D. A., Murray, R. M., David, A. S., Frackowiak, R. S. J., & Frith, C. D. (1996). Functional anatomy of inner speech and auditory verbal imagery. *Psychological medicine*, *26*(01), 29-38.

Michie, P. T., Bearpark, H. M., Crawford, J. M., & Glue, L. C. (1990). The nature of selective attention effects on auditory event-related potentials. *Biological psychology*, *30*(3), 219-250.

Morgan, J.B. (1917) The Effect of Sound Distraction upon Memory. *Am J Psychol* 28, 191-208.

Nelson, K. (1985). *The Art of Reciting the Qur'an.* Austin, TX: University of Texas Press.

Omer, F., Van Roon, P., D'Angiulli, A. (September, 2015) EEG Correlates Working Memory Mechanism and Auditory Imagery Underlying Quran Memorization in Arabic in Non-Comprehending Children Using Auditory Interference. Poster presented at the NeuroDevNet Brain Development conference Ottawa, Ontario, Canada.

Papagno, C., Valentine, T., & Baddeley, A. (1991). Phonological short-term memory and foreign-language vocabulary learning. *Journal of Memory and Language*, *30*(3), 331-347.

Philiastides, M. G., Ratcliff, R., & Sajda, P. (2006). Neural representation of task difficulty and decision making during perceptual categorization: a timing diagram. *Journal of Neuroscience*, *26*(35), 8965-8975.

Polich, J. (2012). Neuropsychology of P300. *Oxford handbook of event-related potential components*, 159-188.

Polich, J. (1986). Normal variation of P300 from auditory stimuli. *Electroencephalography and Clinical Neurophysiology/Evoked Potentials Section*, *65*(3), 236-240.

Postle, B. R., D'Esposito, M., & Corkin, S. (2005). Effects of verbal and nonverbal interference on spatial and object visual working memory. *Memory & cognition*, *33*(2), 203-212.

Rafiq, A. (2014). *The Reception of the Qur'an in Indonesia: A Case Study of the Place of the Qur'an in a Non-Arabic Speaking Community*. Temple University.

Rane, H. (2010). Islam and Contemporary Civilisation: Evolving Ideas, Transforming Relations. Carlton, VIC: Melbourne University Press.

Ratcliff, R. (1979). Group reaction time distributions and an analysis of distribution statistics. *Psychological bulletin*, *86*(3), 446.

Ruchkin, D. S., Johnson, R., Canoune, H., & Ritter, W. (1990). Short-term memory storage and retention: An event-related brain potential study. *Electroencephalography and clinical Neurophysiology*, *76*(5), 419-439.

Rugg, M. D. (1985). The Effects of Semantic Priming and Word Repetition on Event-Related Potentials. *Psychophysiology*, *22*(6), 642-647.

Saleem, A. (2015). *Does memorization without comprehension result in language learning?* (Doctoral dissertation, Cardiff University).

Saleh, A. G., & Sadiq, H. (2012). The influence of denominational affiliations on the information seeking behavior of the Ulama in Borno State, Nigeria. *Annals of Library and Information Studies (ALIS)*, *59*(2), 79-89.

Sardar, Z. (2011). *Reading the Quran: The Contemporary Relevance of the Sacred Text of Islam.* New York, NY: Oxford University Press.

Sperry, R. W., Gazzaniga, M. S., & Bogen, J. E. (1969). Interhemispheric relationships: the neocortical commissures; syndromes of hemisphere disconnection. *Handbook of clinical neurology*, *4*(273-290).

Turner, M. L., & Engle, R. W. (1989). Is working memory capacity task dependent?. *Journal of memory and language*, *28*(2), 127-154.

Unsworth, N. (2016). Working memory capacity and recall from long-term memory: Examining the influences of encoding strategies, study time allocation, search efficiency, and monitoring abilities. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *42*(1), 50.

Unsworth, N., Fukuda, K., Awh, E., & Vogel, E. K. (2015). Working memory delay activity predicts individual differences in cognitive abilities. *Journal of cognitive neuroscience*.

Vallar, G., & Baddeley, A. D. (1982). Short-term forgetting and the articulatory loop. *The Quarterly Journal of Experimental Psychology*, *34*(1), 53-60.

Van den Noort, M. W., Bosch, P., & Hugdahl, K. (2006). Foreign language proficiency and working memory capacity. *European Psychologist*, *11*(4), 289-296.

Wagner, D. A. (1978). Memories of Morocco: The influence of age, schooling, and environment on memory. *Cognitive Psychology*, *10*(1), 1-28.

Wagner, A. D., & Gabrieli, J. D. (1998). On the relationship between recognition familiarity and perceptual fluency: Evidence for distinct mnemonic processes. *Acta Psychologica*, *98*(2), 211-230.

Zoccolotti, P., De Luca, M., Di Pace, E., Gasperini, F., Judica, A., & Spinelli, D. (2005). Word length effect in early reading and in developmental dyslexia. *Brain and language*, *93*(3), 369-373.