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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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:

"لا يشكو الناس ولا يشكرن الله"

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

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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*

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

*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.
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 GmbH, 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 GmbH, 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 dropout 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*

<table>
<thead>
<tr>
<th>Electrode</th>
<th>Correct</th>
<th></th>
<th></th>
<th></th>
<th>Incorrect</th>
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<td>End of</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>sentence</td>
<td>sentence</td>
<td>sentence</td>
<td></td>
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<td>FM</td>
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<td>0.17</td>
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<td>0.33</td>
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<td></td>
<td></td>
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</tr>
<tr>
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<td>-0.12</td>
<td>0.12</td>
<td>0.09</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>0.29</td>
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<td></td>
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<td>-0.33</td>
<td>0.53</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>-0.05</td>
<td>0.12</td>
<td></td>
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</tr>
<tr>
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<td>-0.06</td>
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<td></td>
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<tr>
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<td>0.29*</td>
<td>-0.28</td>
<td>0.42</td>
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</tr>
<tr>
<td>PL</td>
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<td>-0.27</td>
<td>0.50</td>
<td></td>
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</tr>
</tbody>
</table>

*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 $\times$ Trigger $\times$ 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):

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

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 $\lambda_i$. $t_{\text{crit}}$ is represented by the critical t-value and $\text{MSE}_{\text{within}}$ represents the t-contrasts error factor. Three $t_{\text{crit}}$ 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 ($t_{\text{crit}}(47) = 2.01$, two-tailed), at 0.01 ($t_{\text{crit}}(47) = 2.86$, two-tailed) and at 0.001 ($t_{\text{crit}}(47) = 3.51$, two-tailed). Inputting the $t_{\text{crit}}$ values and $\text{MSE}_{\text{within}} = 182.17$ 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 $\text{MSE}_{\text{within}}$ value ($\text{MSE}_{\text{within}} = 158.44$) but the same three $t_{\text{crit}}$ 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 $5\mu V$ (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.
Beginning of Sentence for Adults

Effect size

Threshold

P<0.001
P<0.01
P<0.05
End of Sentence for Children

Effect size
Threshold
p < .001
p < .01
p < .05

Threshold
End of Sentence for Adults

Effect size
Threshold
$p < 0.001$
$p < 0.01$
$p < 0.05$
Condition differences at the beginning of sentence

Effect size
Threshold
- $p = 0.001$
- $p = 0.01$
- $p = 0.05$
Condition differences at the end of sentence

Effect size

Threshold

\[ p = 0.001 \]

\[ p = 0.01 \]

\[ p = 0.05 \]
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 4c; 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

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

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.
Informed Consent: Event-related potentials study

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

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
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
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

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.

<table>
<thead>
<tr>
<th>When:</th>
<th>Which hand do you prefer?</th>
<th>Do you ever use the other hand?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Writing:</td>
<td>L R Either</td>
<td>Yes No</td>
</tr>
<tr>
<td>Drawing:</td>
<td>L R Either</td>
<td>Yes No</td>
</tr>
<tr>
<td>Throwing:</td>
<td>L R Either</td>
<td>Yes No</td>
</tr>
<tr>
<td>Using Scissors:</td>
<td>L R Either</td>
<td>Yes No</td>
</tr>
<tr>
<td>Using a Toothbrush:</td>
<td>L R Either</td>
<td>Yes No</td>
</tr>
<tr>
<td>Using a Knife (without fork):</td>
<td>L R Either</td>
<td>Yes No</td>
</tr>
<tr>
<td>Using a Spoon:</td>
<td>L R Either</td>
<td>Yes No</td>
</tr>
<tr>
<td>Using a Broom (upper hand):</td>
<td>L R Either</td>
<td>Yes No</td>
</tr>
<tr>
<td>Striking a Match:</td>
<td>L R Either</td>
<td>Yes No</td>
</tr>
<tr>
<td>Opening a Box (lid):</td>
<td>L R Either</td>
<td>Yes No</td>
</tr>
<tr>
<td>Which foot do you kick with?</td>
<td>L R Either</td>
<td>Yes No</td>
</tr>
<tr>
<td>Which eye do you use when only using one?</td>
<td>L R Either</td>
<td>Yes No</td>
</tr>
</tbody>
</table>
Are any of the following family members left-handed? (check all that apply)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Father</td>
<td></td>
</tr>
<tr>
<td>Mother</td>
<td></td>
</tr>
<tr>
<td>Sister</td>
<td></td>
</tr>
<tr>
<td>Brother</td>
<td></td>
</tr>
<tr>
<td>Children</td>
<td></td>
</tr>
</tbody>
</table>

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

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

2. 108:3

**Trial 2**

1. 101:6

2. 98:2

3. 100:7

**Trial 3**

1. 93:5

2. 88:7

3. 87:18
4. 87:9

وَذَكَّرُواْ أَنَّ فَاعِلَ الْذَّكَرِ

**Trial 4**

1. 85:7

وَهُمْ عَلَىٰ مَا يَفْعَلُونَ بِالْمُؤْمِنِينَ شَهَوَةً

2. 86:7

يَخْرُجُ مِنَ الْصُّبْرِ وَالْإِثْرِ

3. 84:7

فَأَمَّا مَنْ أُوقِى كَنَّبَهُ بِالْقُرْآنِ

4. 83:13

إِذَا نَزَلَ عَلَيْهِ ابْتِغَاءُ أَسْطُرُ الْأَوْلِينَ

5. 82:6

يَا أَيُّهَا الَّذُينَ آمَنُوا مَعَ رَبِّكَ الْحَكِيمِ

**Trial 5**

1. 78:39

ذَٰلِكَ الْيَوْمُ الْخَيْرُ فِي مَنْ شَاءَ أُحِبَّ إِلَىٰ رَبِّهِ مَثَابًا

2. 79:40

وَأَمَّا مَنْ حَافَ مَقَامَ رَبِّهِ وَنَهَى الْنَّفْسُ عَنِ الْهَوَىٰ

3. 78:37

رَبُّ السَّمَاوَاتِ وَالأَرْضِ وَمَا بَيْنَهُمَا الرَّحْمَنُ لَا يُمْثَلُونَ مِنْهُ خَطَابًا

4. 78:14

وَآذَّنُنَا مِنَ الْمُعْصِرَاتِ مَا نَجَاجًا
Auditory Interference

Trial 1

1. 105:1

2. 111:5

Trial 2

1. 103:2

2. 100:11

3. 113:4

Trial 3

1. 91:8

2. 97:2
3. 99:2

وَأَخْرَجْتَ الْأَرْضَ أَنْقَلَا لَهَا

4. 78:11

وَجَعَلْنَاهَا بِهِ نَهَارٌ مَعَاشًا

Trial 4

1. 99:6

يَوْمَ يَصُدُّ النَّاسُ أَشَاتَا لَيْسَ أَيْدَى أَعْمَالِهِمْ

2. 98:1

لَمْ يَنْظُرُ الَّذِينَ كَفَرُوا مِنْ أُهُلِ الْكِتَابِ وَالْمُشْرِكِينَ مِنْ فِيْقِينَ حَتَّى

3. 90:17

نَرَكَانِ مِنَ الدِّينِ آمَنُوا وَتَوَاصُوا بِالصَّدْرِ وَتَوَاصُوا بِالرَّحْمَةِ

4. 85:8

وَمَا نَقُولُ مِنْهُمْ إِلَّا أَنْ يُؤُمِّنُوا بِبَلَاءِ الْعَزِيزِ الْحَمِيدِ

5. 79:46

كَانَتْ يَوْمَ يُرُونُهَا لَنْ يُبَيِّنَ نَا أَعْشَى أَوْ ضَحْيًا

Trial 5

1. 83:34

فَلَيْوَمَ الْذِينَ آمَنُوا مَنْ أَكْفَارَ يُضْحَكُونَ

2. 89:23

وَجَابَ يَوْمَ يَتِمُّ اللَّيْلُ إِلَى الْيَوْمِ الْقَرْيَةِ إِلَى النَّسَنِ وَأَنَّى لَهُ

الْذِّكْرُ وَاحِدٌ
3. 83:26

Control

Trial 1

1. 114:4

Trial 2

1. 96:5
2. 100:3

3. 102:4

Trial 3

1. 97:5

2. 93:4

3. 95:5

4. 91:11

Trial 4

1. 84:8

2. 89:16

3. 90:19
4. 83:32
وَإِذَا رَأَوْهُمْ فَأُلْوَى إِنْ هُنَّ لآٓلِهَةٌ إِلَّا لَّهُمْ

5. 88:17
أَفَلَا يَنظُرُونَ إِلَّا إِلَى آٓلِهِ مَكَّةَ ؟ُهُمْ عُدَّةٌ مَّجَالِدُ

Trial 5

1. 83:29
إِنَّ الَّذِينَ أُخَرِّجُوا ثُمَّ أَمَنتُوا يُصَلِّونَ

2. 81:29
وَمَا نَتَّصَلِّونَ إِلَّا أَن يُشَاءَ اللَّهُ رَبُّ الْعَلِيمِينَ

3. 85:10
إِذَّ أَلَّذِينَ فَنُونَ الْمُؤْمِنِينَ وَالْمُؤْمِنَاتِ فَمَا لَهُمْ عَذَابٌ عَدَابٌ جَهَنَّمَ

4. 84:21
وَإِذَا فَرَأَوْا عَلَيْهِمْ فَقَرَءَ أَنْ لَا يُسَبَدُونَ

5. 84:25
إِلَّا أَلَّذِينَ أُمِنَّوا وَأَعْمَلُوا الصَّالِحَتَ فَهُمْ أُجُرُّ غَيْرِ مَسْئِلٌ

6. 84:6
يَتَأَلَّقُهَا الإِلَّهُمَّ إِنَّكَ كَادَّ إِلَى رَبِّكَ كَدَحًا فَمَلِئْتَهُ
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.
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.
Raw BESA Headmaps
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.
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


