



Original Article

Auditory sensory gating in Huffaz using an auditory brainstem response with a psychological task: A preliminary investigation

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المخلص

أهداف البحث: تهدف هذه الدراسة للتحقق من قدرة البوابات الحسية السمعية لدى الحفاظ باستخدام فحص استجابة جذع الدماغ السمعي مع أو بدون المهام النفسية.

طرق البحث: تم اشراك ٢٣ مشاركاً في هذه الدراسة. منهم ١١ من الحفاظ الذين يحفظون ٣٠ جزءاً من القرآن الكريم و١٢ من غير الحفاظ كمجموعة التحكم. كان لجميع المشاركين إدراك سمع طبيعي وتم إخضاعهم لفحص استجابة جذع الدماغ السمعي مع أو بدون المهام النفسية. تمت استجابة جذع الدماغ السمعي عند ٧٠ ديسيبل باستخدام ٣٠٠٠ هرتز نغمة تحفيز اندفاعية مع ٢-٠-٢ دورة بمعدل تكرار للتخفيف ٤٠ هرتز. كما تم قياس إشارة استجابة جذع الدماغ السمعي سعة ٥ واختفائها ومقارنتها إحصائياً. تم عمل اختبار المدى الرقمي الأمامي لتحديد سعة الذاكرة العاملة للمشاركين.

النتائج: لم يوجد اختلاف كبير في إشارة استجابة جذع الدماغ السمعي سعة ٥ واختفائها بين الحفاظ وغير الحفاظ في استجابة جذع الدماغ السمعي مع أو بدون المهام النفسية. لم يكن هناك أيضاً فرق كبير في إشارة استجابة جذع الدماغ السمعي سعة ٥ واختفائها عند المجموعتين مع أو بدون المهام النفسية. بالإضافة لذلك، لم يلاحظ هناك اختلاف كبير في المدى الرقمي لدرجة الذاكرة العاملة بين المجموعتين.

الاستنتاجات: في هذه الدراسة، اعتماداً على نتائج استجابة جذع الدماغ السمعي، أظهر الحفاظ نفس سعة البوابات الحسية السمعية مثل مجموعة غير الحفاظ. وكانت نتائج استجابة جذع الدماغ السمعي متسقة مع المدى الرقمي لدرجة اختبار الذاكرة العاملة. يعني هذا أن لدى المجموعتين أداء ذاكرة عمل متماثلة. ومع ذلك، النتائج محدودة فقط لطرق التقييم المحددة المستخدمة في هذه الدراسة.

الكلمات المفتاحية: استجابة جذع الدماغ السمعي؛ البوابات الحسية السمعية؛ مهمة سنروب؛ التدخل المعرفي؛ الذاكرة العاملة

Abstract

Objective: This study aims to investigate the auditory sensory gating capacity in Huffaz using an auditory brainstem response (ABR) test with and without psychological tasks.

Methods: Twenty-three participants were recruited for this study. The participants were comprised of 11 Huffaz who memorized 30 chapters of the Islamic Scripture (from the Quran) and 12 non-Huffaz as the control group. All participants had normal hearing perception and underwent an ABR test with and without psychological tasks. The ABR was elicited at 70 dB nHL using a 3000 Hz tone burst stimulus with a 2-0-2 cycle at a stimulus repetition rate of 40 Hz. The ABR wave V amplitude and latencies were measured and statistically compared. A forward digit span test was also conducted to determine participants' working memory capacity.

Results: There were no significant differences in the ABR wave V amplitudes and latencies between Huffaz and non-Huffaz in ABR with and without psychological tasks. There were also no significant differences in the ABR wave V amplitudes and latencies in both groups of ABR with and without psychological tasks. In addition, no significant differences were identified in the digit span working memory score between both groups.

Conclusions: In this study, based on the ABR findings, Huffaz showed the same auditory sensory gating capacity as the non-Huffaz group. The ABR result was consistent with the digit span working memory test score. This

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finding implies that both groups have similar working memory performance. However, the conclusion is limited to the specific assessment method that we used in this study.

Keywords: Auditory brainstem response; Auditory sensory gating; Cognitive interference; Stroop task; Working memory

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Introduction

Sensory gating is the human brain's ability to filter unnecessary or repeatable information to prevent sensory overload.¹ Sensory gating that is specific to hearing is typically referred to as auditory sensory gating. The brain's ability to filter auditory information has been associated with cognitive abilities,² working memory, and attention.³

Auditory sensory gating can be measured using a sensory gating scale questionnaire,⁴ a psychological task like a "Stroop task",^{5,6} the P50 auditory sensory gating test,⁷ and the auditory brainstem response (ABR) conducted with psychological tasks.^{3,8} Each of these tests have their own advantages; for example, the sensory gating scale questionnaire and the Stroop task measurements depend on a subject's responses either by filling out a validated questionnaire or by performing certain psychological tasks and being rated accordingly. In contrast, the P50 auditory sensory gating test and the ABR are not dependent on direct responses from subjects, but rather by capturing electrical brain activities using electrodes placed on the scalp. P50 auditory sensory gating is conducted by presenting a pair of stimuli, where the first stimulus measures initial neural activity and the second measures the filtering or gating process.⁹ In contrast, ABR sensory gating is conducted using a psychological task concurrent with the ABR acquisition, including the previously mentioned Stroop task. In this task, patients are required to count the number of digits that are congruent (such as number 3 presented as '333') or incongruent (such as number 3 presented as '3333') while brainstem electrical activities are captured by the surface electrodes.⁸ The ABR Wave V amplitude is reduced when the subject is performing a task that is consistent with auditory sensory gating inhibition following a cognitive load.

Auditory sensory gating from an electrophysiological assessment is measured by the difference between either P50 or ABR Wave V peaks under stressful conditions (either with a cognitive load or a short inter-stimulus interval) and controlled conditions. Lower auditory sensory gating differences between a standard and stressful recording suggest a sensory gating deficit. Sensory gating deficits from these assessments have been reported in patients with attention deficit hyperactivity disorder (ADHD),⁹ schizophrenia,¹⁰ and an autism spectrum disorder.¹¹ Whilst substantial

studies have been conducted on patients with various pathologies, there are no reports in the literature that investigate auditory sensory gating in subjects with special abilities or skills. However, previous studies have shown that children with early musical training exposure have a robust speech auditory brainstem response correlated with their superior literacy and language abilities.¹² Therefore, based on this finding there is also a possibility that auditory sensory gating results will be different in subjects with special skills (such as musical training experience) than subjects without those skills.

As has been established, the sensory gating mechanism can be influenced by working memory capacity. Jones et al.² and Panahi et al.¹³ investigated the relationship between working memory and cognitive function with auditory sensory gating. Both studies found that working memory, cognitive function, and sensory gating are interrelated, where a lower sensory gating ratio is associated with excellent working memory and cognitive performance. Therefore, there is a possibility that members of the population with known memorization abilities could also have high sensory gating capacity. One such example is those who memorize Islamic scriptures from the Holy Quran, better known as Huffaz. Typically, Huffaz undergo an extensive memorization process in order to recite the entire 30 chapters (Juzu') of the Quran, which involves encoding the Quranic texts through attention, storing of information, and retrieving information from memory.¹⁴ People who undergo this process have been shown to exhibit good cognitive performance including a high intelligence quotient.^{14,15} For example, Nawaz and Jahangir¹⁴ investigated the academic achievements of 36 Huffaz university students before and after their Quran memorization training. The results revealed that the students' academic achievements were significantly higher post-memorization training compared to pre-training.

Considering that there are no known studies on the auditory sensory gating capacity among Huffaz, this study was warranted. In line with this, the present study further investigates the auditory sensory gating capacity in Huffaz using the ABR test with and without psychological tasks. It is hypothesized that Huffaz who undergo extensive memorization training could elicit a better auditory sensory gating response than those without such training.

Materials and Methods

The study protocol was cleared by the IIUM Research and Ethics Committee with the ethical clearance number.

Participants

Twenty-three students from higher learning institutes aged between 21 and 24 years were recruited in this study. The participants were divided into two groups: the Huffaz group and the non-Huffaz group (11 Huffaz, 12 non-Huffaz). All study participants met the following inclusion criteria: (i) a hearing threshold of no more than 20 dB at the octave frequency of between 250 Hz and 8000 Hz in both ears, (ii) no history of otological disorders, and (iii) passed

tympanometry and acoustic reflex testing. All participants from the Huffaz group had graduated from a tahfiz institution (Quran memorisation centre) within the past 3 years. These Huffaz participants were still in a tahfiz placement class at university to ensure that their Quranic memorization remains intact.

ABR procedure

The study took place in an electrophysiology room at an audiology clinic that was electrically shielded. All participants who met the inclusion criteria proceeded with the ABR test. Four skin areas of the study participants were cleaned before the recording session to reduce electrical impedance and to remove any unwanted substances and possible dead skin using NuPrep skin preparation gel. The four areas were the high forehead, the right and left ear mastoids, and the lower forehead. Next, Ambu disposable Neuroline 720 silver/silver chloride electrodes were placed on the prepared area with the non-inverting electrode placed on the high forehead, the ground electrode on the lower forehead, and the inverting electrode on both the left and right ear mastoids. Electrode impedance was maintained below 5 k Ω with balanced inter-electrode impedance. Next, insert phones were placed into both ear canals (the right ear was the test ear and the left ear was the non-test ear).

All unused electrical equipment was switched off to reduce electrical interference that could affect the ABR recordings. The participants were asked to sit on a chair in a resting position and to reduce any substantive movement and muscular noise during ABR with psychological tasks. The ABR was acquired using two-channels of the evoked potentials testing in the Interacoustic Eclipse system. The ABR was elicited in the right ear using a 3000 Hz alternating tone burst with a 2-0-2 stimulus envelope using a Blackman gating function at a presentation rate of 40 Hz. The stimulus level was set at 70 dB nHL with a 30 dB nHL white noise masker simultaneously placed in the left ear. The ABR was averaged 4000 times using the Bayesian averaging technique with 40 μ V as the artefact rejection level to improve the signal-to-noise ratio.¹⁶ A bandpass filter of 30–3000 Hz was used to filter the ABR from any unrelated activities. A duration of 17 ms was used in this test, as it was anticipated that the ABR would be completed within this timeframe.

For each study participant, two types of ABRs were acquired. The first ABR was the standard ABR recording and the second was conducted alongside a psychological task, also known as a Stroop task (explained in the subsequent section). In each ABR type, the ABR was repeated to check for waveform repeatability and reliability. All ABR recordings had a signal-to-noise ratio of 3:1 to ensure high ABR recording quality.¹⁶ The ABR from the 4000 averages was also divided into two separate buffers for repeatability verification. Only waveforms that exceeded 70% repeatability were included in the data analysis.

ABR with psychological task

In the ABR test with a psychological task, the participants were asked to complete the Stroop task during the recording. The Stroop task was operated on a laptop (2.5 GHz and

8 GB RAM) using the E-Prime 2.0 software. The Stroop task was customized using the E-Prime 2.0 software from Brännström et al.⁸

The Stroop task consists of a series of 61 numbers displayed in front of the participants on a laptop. The numbers are single digits that are presented repeatedly (number 3, presented as '3', '333', or '3333'). The number series was further divided into congruent, incongruent, and neutral numbers that were randomly presented to participants. Of these 61 trials, 13 were congruent, 35 were incongruent, and 13 were neutral. Numbers that are defined as congruent displayed the respective digit equivalent to the total number of the actual digit in the sequence (for example, the number three (3) displayed three times (333)); Incongruent numbers are when the displayed number differs from the total number in the sequence (number three (3) displayed once (3)); and neutral is defined as numbers that have no semantic meaning related to the number expressed (##presented three times (###)).¹⁷ The numbers were displayed for 4000 ms before the software moved to the next number. To perform this task, participants were instructed to determine the frequency of a single digit in each series and to subsequently press corresponding keyboard buttons as quickly as possible. The Stroop task was completed first before the ABR signal averaging ended at 4000 averages.

Procedure for working memory test

To support the ABR with psychological task findings, all participants were required to complete a forward digit span working memory test. This test was administered using Psychology Experiment Building Language (PEBL) software version 2.1.¹⁸ In this test, each participant was asked to observe and listen to a series of numbers starting at 3-digits in length. Each participant was required to memorize the series of digits, including its sequence by typing it on a keyboard. Adaptive procedures were used when the length of the digit increased or decreased based on the correct or incorrect memory recall. Each series of digit lengths was presented three times for 1000 ms and required a minimum of two correct recalls before the length could be increased. A working memory capacity was estimated based on the highest average digit length number recalled by each participant.

Waveform analysis

The analysis of this study focused only on the ABR Wave V peak, specifically absolute latencies, amplitudes, and ABR sensory gating. Only Wave V was considered because this peak corresponds to the auditory sensory gating function at higher brainstem for cognitive inhibition and working memory capacity (lateral lemniscus and inferior colliculus).³ In addition to this, only Wave V can be captured using a stimulus with a longer duration (tone-burst) due to its nature as a slow wave component.^{19,20} To ensure that the ABR was present, the authors visually checked the repeatability of the ABR waveforms, cross checked the ABR signal to the noise ratio (minimum 3:1), the response confidence of 99% (Fmp 3.1), and the cross-correlation values (minimum 70%). The ABR Wave V amplitude was

measured from the peak of Wave V to the Wave V following trough. Wave V ABR latency was determined from the onset of the stimulus to the maximum peak of the pre-determined Wave V. The decision on peak labelling was decided based on the consensus from both the first and second authors. The ABR sensory gating percentage was calculated using the following formula:

$$\frac{\text{ABR Wave V amplitude with Psychological task}}{\text{ABR Wave V amplitude without Psychological task}} \times 100\%$$

Statistical analysis

Using visual inspection and the Shapiro Wilk normality test, the data fulfilled the parametric assumptions ($p > 0.05$). An independent sample t-test was performed at a 95% confidence level to compare the mean differences in the ABR Wave V absolute latencies and amplitudes between Huffaz and non-Huffaz groups in both the ABRs with and without the Stroop tasks. Independent sample t-tests were also used to compare the mean differences in the ABR sensory gating percentage and digit forward span test score between the Huffaz and non-Huffaz groups. Furthermore, a paired sample t-test was performed to compare the mean differences in the ABR Wave V amplitude and latencies between the ABR with and without the Stroop task for both the Huffaz and non-Huffaz groups. All statistical analyses were conducted using SPSS version 20.0. The effect size was determined using Cohen’s d formula to support the statistical analysis. In the effect size, the differences between the variables could be classified as large ($d > 0.8$), medium ($d > 0.5$), or small ($d < 0.4$) despite the significance levels.²¹

Results

All participants’ ABRs were identified at 70 dB nHL with and without the Stroop task. Figure 1 illustrates the ABR waveforms from one of the study participants. Table 1 shows the mean and standard deviation of the ABR Wave V absolute latencies and amplitudes for both the Huffaz and non-Huffaz groups with and without psychological tasks. Based on the paired t-test analysis, there was no

Table 1: Mean of absolute latencies and amplitudes of wave V ABR with and without Stroop tasks for both the Huffaz and Non-Huffaz Group. Statistical comparison is provided in the last column.

Variable	Huffaz Mean (SD) (n = 11)	Non-Huffaz Mean (SD) (n = 12)	t (21)	p-value	Effect Size
Wave V absolute latency without Stroop Task (ms)	6.00 (0.14)	5.99 (0.16)	0.32	0.42	0.33
Wave V absolute latency with Stroop Task (ms)	5.98 (0.13)	6.01 (0.15)	-0.50	0.63	0.21
Wave V amplitudes without Stroop Task (µV)	0.52 (0.11)	0.49 (0.12)	0.50	0.69	0.25
Wave V amplitudes with Stroop Task (µV)	0.50 (0.14)	0.46 (0.14)	0.73	0.47	0.29

significant difference in the ABR Wave V absolute latencies and amplitudes between the ABR with and without psychological tasks (Stroop task) in each group ($p > 0.05$) with a small effect size ($d = 0.15-0.34$). The independent t-test results also showed that there was no significant difference in the ABR Wave V latencies and amplitudes between the two groups in each of the ABR with and without psychological task (Stroop task) ($p > 0.05$) with a small effect size ($d = 0.21-0.33$).

There was also no significant difference in the ABR sensory gating percentage between the Huffaz ($M = 98.40$, $SD = 21.83$) and non-Huffaz groups ($M = 98.04$, $SD = 34.86$) ($t_{21} = 0.03$, $p = 0.98$) with a small effect size ($d = 0.01$). Of all the study participants ($n = 23$), only 12 showed a reduction in ABR Wave V amplitude following the ABR conducted with a psychological task. Furthermore, the independent t-test showed no significant difference in the Forward PEBL digit span working memory test score between the Huffaz ($M = 7.91$, $SD = 1.14$) and non-Huffaz

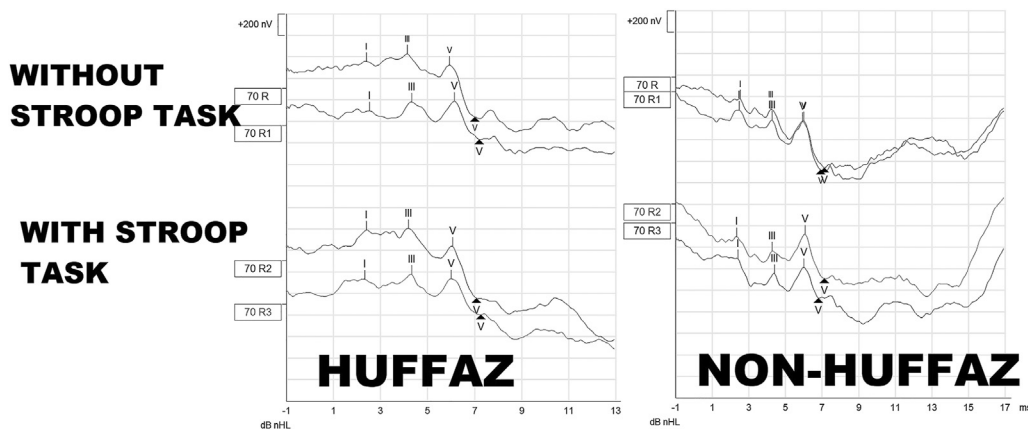


Figure 1: ABR waveforms from Huffaz and Non-Huffaz group with and without psychological tasks.

groups ($M = 7.67$, $SD = 1.30$) ($t_{21} = 0.03$, $p = 0.64$) with a small effect size ($d = 0.20$).

Discussion

This study investigated auditory sensory gating capacity among the Huffaz through ABR tests with and without an accompanying psychological task. The ABR results (amplitude and latency of Wave V) between the Huffaz and non-Huffaz with and without a cognitive load were compared. In order to strengthen the ABR sensory gating results, working memory capacities between these two groups were also compared using a forward digit span test.

This study found no differences in the ABR with and without a cognitive load (psychological task) in both the Huffaz and non-Huffaz groups. This result was inconsistent with the study performed by Sörqvist et al.,³ which used ABR tests with accompanying psychological tasks.⁸ Sörqvist et al.³ reported that the ABR Wave V amplitude was significantly lower when patients were performing a psychological task and the amplitude of Wave V was also reduced as a function of the cognitive load in the psychological task. However, the findings in this study are partly consistent with the study by Brännström et al.,⁸ who investigated the influence of auditory sensory gating towards the ABR Wave V amplitude in twenty normal-hearing subjects based on the Stroop task. Similar to the outcome of this study, the report showed no significant influence by auditory sensory gating on ABR amplitudes. One of the proposed reasons for the differences seen in this study compared to the literature could be due to the cognitive load used. In this study, the cognitive load was restricted to a maximum of 61 and consisted of a combination of trials of no cognitive load (neutral), low cognitive load (congruence), and high cognitive load (incongruent). As highlighted by Brännström et al.,⁸ cognitive load may only be influenced by the incongruent trials, meaning that using a combination of series that include congruent and neutral trials may have prevented sensory gating from being elicited in the ABR waveforms. Fewer trials, coupled with the simultaneous use of congruent and incongruent trials in this study, could have been insufficient in triggering cognitive interference; as a result, no changes were observed in the ABR results with the psychological task in participants of the Huffaz group compared to the non-Huffaz group. The second possible factor is the complexity of the task used in this study compared to the task used in the previous study.³ A study by Sörqvist et al.³ used various working memory capacity tasks (of different sizes) including one group that was given additional background noise under 'active listening conditions'. Active listening conditions are expected to trigger more cognitive interference since the background noise could be suppressed by the auditory system through the sensory gating mechanism. The mechanisms involved could be from the medial-olivocochlear efferent system²² through a stapedial reflex²³ or from the primary auditory cortex.²⁴ Medial-olivocochlear efferent system fibres from the superior olivary complex are thought to be responsible for turning off the function of the outer hair cell through

hyperpolarization when noise is presented contralaterally.²² In stapedial reflexes, a loud tone could be attenuated from the involuntary contraction of the stapedial muscle to protect the auditory system from excessive noise.²³ In addition, the abilities of the auditory cortex neuron cell to segregate target signal and noise to an appropriate signal-to-noise ratio may also assist in helping the individual to suppress noise.²⁴ In conclusion, these three mechanisms could trigger more cognitive interference and will jointly assist the auditory sensory gating mechanism to suppress noise and other irrelevant input.

This study suggests no difference in the auditory sensory gating capacity among the Huffaz and non-Huffaz groups. The result from the forward digit span working memory test was also in line with the ABR sensory gating finding, which suggests that there is no difference in the working memory capacity between these two groups. The non-significant difference between these two groups could be due to the insufficient number of incongruent trials used, and the relatively low complexity of the task given in this study. Additionally, as reported in previous studies, the non-significant difference in this finding does not rule out general superior performance in members of the population with special skills, and Huffaz specifically, due to four possible factors.^{14,25–27} Firstly, the ABR test only reflects the far-field brain electrical activity evoked by the specific sound from the auditory system, and does not measure the entire process of sensory gating.²⁸ Sensory gating not only measures the sensory processing of the auditory system, but it also involves other systems such as vision, touch, smell, and proprioception. A similar performance in auditory sensory gating will not reflect the sensory gating function for the other sensory modalities. In addition, only a few studies pertaining to ABR sensory gating are reported in the literature compared to the P50 sensory gating that is generated from the auditory cortex. There is a possibility that the sensory gating elicited by P50 is more accurate in measuring auditory sensory gating capacity compared to the ABR, since reduced P50 sensory gating has been shown in many populations with sensory gating deficits.^{1,29} This notion is supported by the fact that only half of the study participants from both groups showed a significant reduction in the ABR Wave V amplitude following cognitive load interference. A similar finding was reported in the recent ABR sensory gating experiment by Brännström et al.,⁸ where only 4 out of 20 participants showed a reduction in ABR amplitude with a psychological task.

Secondly, there is also a possibility that memorizing Quranic verses affects long-term memory capacity rather than only the working memory capacity. Although some studies suggest a direct relationship between working memory and long-term memory,^{30,31} there is a possibility that repeated memorization only triggers the long-term buffer storage capacity (long-term memory) rather than the short-term buffer capacity (working memory).³² Thirdly, a previous study has shown that working memory capacity may be influenced by the level of an individual's intelligence.³³ Individuals with a high level of intelligence

may be able to perform better in the working memory test than those with a standard level of intelligence. Therefore, there is a possibility that some participants from the non-Huffaz group may have a higher intelligence level than the Huffaz group. This could explain the lack of differences in the working memory score and the ABR sensory gating percentage between the non-Huffaz and Huffaz groups. Fourthly, the duration of the training received by the Huffaz group may have also influenced the results of this study. The majority of participants only received recent formal education training at the Hafiz institution with no formal or informal training as Huffaz during pre-school or primary school. Early training of Quranic memorization, especially during early childhood, may enhance brain development and may produce better outcomes compared to those who learn to memorize the Quran at a later stage in life. This notion is in line with previous reports on early musical training enhancing neural plasticity, hence promoting rapid cognitive development.³⁴ The absence of early training as a Huffaz may be one of the factors contributing to the non-significant finding in the ABR sensory gating and working memory capacity observed in this study.

The limitations of this study are acknowledged. The cognitive load in the psychological task was limited to 61 trials, which could have influenced the effects on auditory sensory gating that were observed in this study. In addition, the psychological task used in this study was a combined series of trials using no cognitive load (neutral), low cognitive load (congruence), and high cognitive load (incongruent). The recorded ABR corresponds to the summation of the task that consists of these three levels of cognitive load abilities. The use of combined cognitive loads in the ABR recording may have indirectly influenced the findings observed in this study.

Conclusions

This study suggests that there was no difference in the auditory sensory gating and working memory capacity between the Huffaz and non-Huffaz groups. There was also no difference in the ABR recording with and without accompanying psychological tasks. It is worth noting, however, that the conclusion is limited to the study participants, equipment, stimulus, psychological task, and the recorded parameters used in this study.

Recommendations

It is recommended that future studies explore the use of ABR with psychological tasks among highly experienced Huffaz, such as Huffaz that received early education training. The ABR with psychological tasks should consist of tasks that have a high cognitive load and level of complexity, in order to elicit cognitive inhibition.

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Conflict of interest

The authors have no conflict of interest to declare.

Ethical approval

This study was ethically approved by International Islamic University Malaysia Research Ethics Committee on 14 December 2018 with the approval code: IREC 2018-271.

Authors contributions

AAAD conceived and designed the study, provided research materials, obtained research funding, analysed the ABR data, performed the final statistical analysis, and wrote the second and all the subsequent drafts of the manuscript. AKA performed the ABR Stroop task experiment, conducted the working memory test, analysed the ABR data, performed the initial statistical analysis, and wrote the initial and final drafts of the manuscript. NHS revised the design of the study, wrote the software code for the Stroop task, assisted in the working memory capacity analysis, and wrote the final draft of the manuscript. All authors have critically reviewed and approved the final draft and are responsible for the content and similarity index of the manuscript.

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