Chapter

Auditory Brainstem Response with Cognitive Interference in Normal and Autism Spectrum Disorder Children - Understanding the Auditory Sensory Gating Mechanism

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Abstract

Earlier studies disputed the influence of higher-order function such as attention or cognitive inhibition on the auditory brainstem response (ABR) result. In short, the ABR result was considered similar with or without the subject paying attention. However, in the last few years, there has been growing evidence that the higher-order function may influence the ABR findings provided the sensory gating system of the brain is triggered by any cognitive interference activities. This chapter will explain the concept of auditory sensory gating, a method to measure auditory sensory gating, and at the end of the chapter, preliminary findings concerning the ABR with cognitive interference among ten normally developing children are presented. This chapter will also share a case study that compared auditory sensory gating capacity in normal and children with mild autism spectrum disorder (ASD).

Keywords: auditory brainstem response, auditory sensory gating, Stroop task, cognitive interference, autism

1. Introduction

The auditory system through corticofugal projections connects the auditory cortex to the lower structures at the brainstem such as cochlear nucleus, inferior colliculus, and superior olivary complex [1, 2]. The auditory corticofugal system refers to the descending efferent pathway that arises from the auditory cortex. This efferent pathway plays an important role for the auditory cortex to control certain functions of the brainstem. Structures at the higher and lower brainstem on the other hand are the neural generators for the auditory brainstem response (ABR), which is one of the auditory evoked potentials (AEP) [3, 4]. Sensory gating has been reported as one of the sensory processing mechanisms generated from the corticofugal pathway [5, 6]. Since the sensory gating mechanism is known to cross this corticofugal pathway, it was hypothesized that the sensory gating processing may therefore affect the neural activity at the brainstem region and perhaps could affect the ABRs findings [1].

2. Sensory gating

The ability to filter irrelevant and repetitive stimuli and to focus only on one specific task is called sensory gating [7, 8]. Sensory gating is important to prevent sensory overload, in which individuals need to divide their attention to multiple sensory stimulations at the same time. This sensory gating response reflects the filtering function of the brain and plays a critical role as a protective mechanism of brain function. The sensory gating response through the neural inhibition mechanism prevents excessive irrelevant stimuli and sensory overload from being processed by higher brain structures. Through this process, the brain is able to process all the important information and relevant stimuli efficiently [8].

2.1 Auditory sensory gating

While sensory gating is a generic terminology that covers all sensory modalities, the auditory sensory gating is referred to as an ability of the human brain to filter unwanted or repeatable auditory input to avoid sensory overload. With optimum auditory sensory gating abilities, a human is able to focus on the target auditory signal while the other unwanted sound will remain as a background [9]. This will help individuals to listen and focus especially when they are in an environment with high background noise.

According to Jones et al. [9], auditory sensory gating is related to some of the cognitive mechanisms, namely latent inhibition and attentional inhibition, and therefore it is related to a specific-target goal set by the brain and control by the attention. A deficit in auditory sensory gating leads to abnormal sensory processing and this typically happens in children with certain disorders, for example, attention deficit hyperactivity disorder (ADHD) [10], autism spectrum disorder (ASD) [11, 12], and those with poor mental health conditions such as schizophrenia [13].

3. Assessment for auditory sensory gating

Auditory sensory gating can be measured using a perceptual scale questionnaire, behavioral psychological assessment, and auditory evoked potentials (AEP) assessments. Some examples of perceptual scale questionnaires to measure some component of sensory gating are the sensory gating inventory (SGI) [7] or structured interview for assessing perceptual anomalies (SIAPA) [14]. These scales consist of items that describe daily situations of an individual that cover their sensory processing activities involving all the sensory modalities including those from the auditory system. Individuals are asked to rate the item in the questionnaire according to the Likert scale if the situation of the sensory processing activities is relevant or not relevant to them. Recently, the sensory gating scale has been adapted for children as a parental-perceptual questionnaire in the Malay language [15].

The second method to measure auditory sensory gating is by using a cognitive interference test that is normally classified as a psychological assessment. This assessment requires individuals to do certain tasks behaviorally pertaining to the sensory gating. One of the examples of cognitive interference tests that can indirectly measure sensory gating is the Stroop task [16]. In the Stroop task, a cognitive interference effect can be elicited using color matching [17] or counting-digit techniques [18]. In Stroop counting-digit techniques, series of single digits numbers are presented repeatedly (number 4, presented as "4" or "444" or "444") to the study participants. These number series are further divided into congruent or incongruent, and additional neutral characters. Congruent number series consists of the number that is equivalent to the frequency of that number in the series (number four (4) presented four times (4444)). Incongruent number series consists of the number that is not similar with the frequency of that number in the series (number four (4) presented one time 4). For neutral series, it consists of a character that has no meaning related to the presented number (#presented four times (####). In the Stroop task assessment, patients need to indicate the frequency of the congruent, incongruent, or neutral number by ignoring the actual number or character itself. For example, for the incongruent series of *444*, the patient needs to indicate to the assessor that the frequency of the number is three instead of the number itself as four. This incongruence number series is thought to produce cognitive interference that leads to a longer reaction time for the patient to do the task and to trigger a higher number of incorrect answers in comparison to the congruence or neutral number series [19].

The third method to measure auditory sensory gating is by using auditory evoked potentials (AEP) tests. AEP is an objective measure of the auditory system neural activity in response to acoustic stimulation [20]. In standard AEP (also called obligatory AEP), the patient does not need to do anything, except relax. Recording electrodes are placed around their scalp. The recording electrodes pick up the brain's electrical activity, following acoustic or sound stimulation. The most common AEP to measure auditory sensory gating is the P1 or often called P50 component [21]. Most recently, auditory brainstem response (ABR) has been used as well to measure auditory sensory gating but with the conditions that the ABR needs to be conducted while the subject is performing certain psychological assessments (example; Stroop task) [19, 22, 23]. Both assessments are discussed in the next section.

3.1 Electrophysiology test: P50

Auditory sensory gating is well known to be recorded using the AEP test, in specific, the P50 auditory sensory gating test [21]. P50 auditory sensory gating is elicited by presenting a pair of acoustic stimuli separated by short inter-stimulus intervals. The first stimulus of the pair elicits the initial P50 neural activity, and the second stimulus of the pair measures the filtering or the gating process [24]. This filtering processing is reflected by the amount of neural inhibition where the P50 amplitude will be reduced from the stimulation of the second acoustic stimulus of the pair. Auditory sensory gating from P50 is measured by the differences in the P50 amplitudes elicited from the first stimulus of the pair and the second stimulus of the pair. It is thought that the P50 from the second stimulus of the pair triggered the neural inhibition because of the short inter-stimulus interval from the first stimulus of the pair. This short inter-stimulus interval is shorter than the neural recovery period thus causing a reduction in the P50 amplitude. The lack of auditory sensory gating differences between the first stimulus and second stimulus of the pair is associated with auditory sensory gating deficit. Auditory sensory gating deficit from P50 assessment was found in patients with attention deficit hyperactivity disorder (ADHD) [10], schizophrenia [13], and an autism spectrum disorder [11]. Early identification of auditory sensory gating deficit in children can serve as a predictive measure of future mental health issues as shown in the previous literature [25].

3.2 Electrophysiology test: ABR sensory gating

Few studies in the last 10 years have reported the potential to measure auditory sensory gating from the auditory efferent pathways by eliciting auditory brainstem response (ABR) and modulating the ABRs using attentional tasks [19, 22, 23]. These findings were inconsistent with some of the earlier studies that found no significant influence of the attention to the ABR findings thus dismissing the neural inhibition activities that occur in the efferent pathway between the level of the auditory cortex and the brainstem [26, 27].

To record an ABR with attention modulation, the participant needs to perform certain psychological tasks while the ABR is being acquired. Among psychological tasks that have been used in the ABR acquisition are the working memory task [23], Stroop task [19, 22] (see Section 3), and visual and auditory discrimination tasks [26]. Stroop task has been used to measure auditory sensory gating in recent studies [19, 22]. In this auditory sensory gating test, the patients are required to count the frequency of congruent and incongruent digits while the ABR is acquired from the patient. For congruent, the digit is consistent with the frequency of the digit presented, for example, number 3 is presented 3 times (*333*). For incongruent, the digit is not consistent with the frequency of digit presented, such as digit of 3 are presented 5 times (*33333*). The ABR wave V amplitude will reduce when the study participants are introduced with cognitive interference elements like the incongruent numbers; this is related to the auditory sensory gating inhibition.

Two recent studies investigated the influence of cognitive interference using ABR concurrent with Stroop task in adults. In the first study, Brännström et al. [19] recorded the ABR waveforms using 3000 Hz tone burst stimulus in twenty adult subjects together with active Stroop task procedure. The authors found the ABR wave V amplitudes did not change with the presence of cognitive interference in comparison with the baseline ABR. However, the authors identified a significant relationship between the response time and the ABR wave V amplitude. In detail, as the response time increases by the cognitive interference, it follows with a reduction in the ABR wave V amplitude, suggesting that cognitive interference is in proportion with the neural inhibition. In addition, Brännström et al. [19] also found some of their subjects showed significantly larger inhibition and some did not, which suggests auditory sensory gating abilities are varied between subjects. Dzulkarnain et al. [22] studied the influence of cognitive interference on the ABR findings in 23 adult participants that were further categorized as Huffaz and non-Huffaz. Similar to Brännström et al. [19] findings, the authors found no significant difference in the ABR wave V amplitude with and without cognitive interference in both within and between groups analysis. The authors also found only half of their study participants had a significant neural inhibition from the high cognitive interference activities.

4. New findings

To date, studies that investigated the influence of cognitive interference or auditory sensory gating using ABR are only limited to the adult as the study participants. To the author's knowledge, there is no known study that investigates the influence of cognitive interference in the children population. The ABR results with cognitive interference from the adult population may not be applicable to the children population possibly due to the differences in their structure and function of the auditory system, particularly at the auditory cortex and circuits surrounding them, and it may take up to the age of 20 years to reach full maturation state [28]. Because of that, a study to understand the auditory sensory gating mechanism in the children population is required.

In this chapter, preliminary data obtained from ten typically developing children (age between 8 and 12 years old) is presented. This study aims to investigate the auditory sensory gating mechanism using ABR with cognitive interference specifically using Stroop interference task in children. A case study on ABR sensory gating was later described. The case study was conducted in a mild autism spectrum disorder child and a comparison with a typically developing child was made.

All children had normal hearing and middle ear function based on their pure tone audiometry and tympanometry findings. The study took place in the electrophysiology room of the International Islamic University Malaysia (IIUM) Hearing and Speech Clinic. ABRs were acquired from the study participants at 70 dBnHL using 1000 Hz alternating tone-burst stimulus with 2-0-2 stimulus envelope and Blackman gating function (4 milliseconds duration). Ipsilateral electrode montage was used to record the ABR neural activities at 20 milliseconds time window with stimulus repetition rate set at 33.1 Hz. No contralateral masking noise was applied since minimal cross-over was anticipated when using 3A insert earphone. The recording was conducted using the Interacoustic Eclipse auditory evoked potential system. The ABR signals were averaged using the Bayesian averaging technique until the Stroop task procedure completed with a minimum of 2000 sweeps. The ABR was filtered using a 3000–30 Hz bandpass filter and any signals that exceeded 40 μV were rejected by the automatic artifact rejection system.

During the ABR acquisition, the participant performed Stroop counting-digit task procedure as outlined in Section 3. **Table 1** summarized the test items used in each Stroop task condition (congruent, incongruent, and neutral). These test items were randomly presented and were set to only 52 trials for each Stroop task condition that later corresponds to the final number of ABR sweeps at the end of the recording. In short, the total number of ABR sweeps was determined by the duration for each participant to complete each of the Stroop task test condition (congruent, incongruent, and neutral). Stroop counting-digit task was created using E-Prime version 3.0 software and the digit was displayed on the screen of a laptop. As highlighted in Section 3, participants need to count the frequency of the digit or character while ignoring the actual number itself. Subsequently, they need to press the frequency of the digit in the number series using the appropriate "key" on the keyboard of a laptop.

4.1 Preliminary findings

4.1.1 Data analysis

The analysis of this study focuses on the ABR wave V peak, specifically its absolute latencies, amplitudes, and the amount of neural inhibition. The ABR absolute latencies are determined from the onset of the stimulus until the time it took for the action potential to produce the peak of ABR wave V. The amplitude of wave V was determined from the peak of wave V to the preceding trough. The amount of neural inhibition or ABR sensory gating was determined from the amplitude of ABR wave V from the incongruent condition minus the amplitude of ABR wave V from the neutral

	Stroop task conditions		
	Congruent	**Incongruent**	**Neutral**
Test items	• 1 • 22 • 333 • 4444	• 11 • 111 • 1111 • 2 • 222 • 2222 • 3 • 33 • 3333 • 4 • 44 • 444	• # • ## • ### • ####

Table 1.
The test items used in each Stroop task condition (congruent, incongruent, and neutral).

test condition. The percentage of the neural inhibition was calculated from the formula recommended by Dzulkarnain et al. [22]. The percentage of correct responses that indicates the percentage of trials that were correctly identified in each Stroop task condition was also calculated. The reaction time that indicates the time taken by the child to provide the answer was also analyzed. Stroop interference for both reaction time and percentage of correct response was also computed from the differences in the Stroop task results of incongruent and neutral test conditions.

There was no significant difference ($p > 0.05$) in the ABR wave V amplitudes and latencies between the ABRs recorded under incongruent test condition (latencies: M = 7.46, SD = 0.57; amplitudes: M = 0.63, SD = 0.18) and neutral test condition (latencies: M = 7.54, SD = 0.90; amplitudes: M = 0.70, SD = 0.24) consistent with small effect size ($d < 0.3$). In general, this result indicates there was no significant influence of the cognitive interference on the ABR wave V amplitudes and latencies. The result also showed no significant difference ($p > 0.05$) in the percentage of correct response and reaction time between incongruent test condition and neutral test condition with moderate effect size ($d < 0.5$) as shown in **Table 2**.

No significant relationship was identified for Stroop interference for reaction time and percentage of the correct response with the ABR sensory gating ($p > 0.05$). **Table 3** shows the percentage of wave V reduction following with cognitive interference in each study participant. Of the 10 study participants, 8 children show a reduction in their ABR wave V amplitude from the incongruent cognitive load and interference task. Although neural inhibition can be seen in the majority of the study participants, statistically, cognitive interference has no influence on the ABR findings in children as shown in this study.

4.1.2 Case study

Figure 1 shows the ABR waveforms recorded from 1 typically developing child (age: 6-year-old) and autism spectrum disorder (ASD) child (age: 9-year-old) under three Stroop task conditions.

	Incongruent	Neutral	P-value	Effect size
% correct response	99.02% (1.67)	99.41% (1.32)	0.17	0.26
Reaction time (milliseconds)	1038.25 (193.73)	964.39 (145.97)	0.19	0.43

Table 2.
Percentage of correct response and reaction time in Stroop incongruent and neutral conditions.

Subject ID	Incongruent minus neutral ABR wave V amplitude (μV)%
101	1.7
102	−40.09
103	68.05
104	−10.97
105	−14.32
106	29.98
107	−12.12
108	−20.66
109	−27.81
110	−7.18

Table 3.
Percentage of ABR wave V amplitude reduction Following cognitive interference in all subjects.

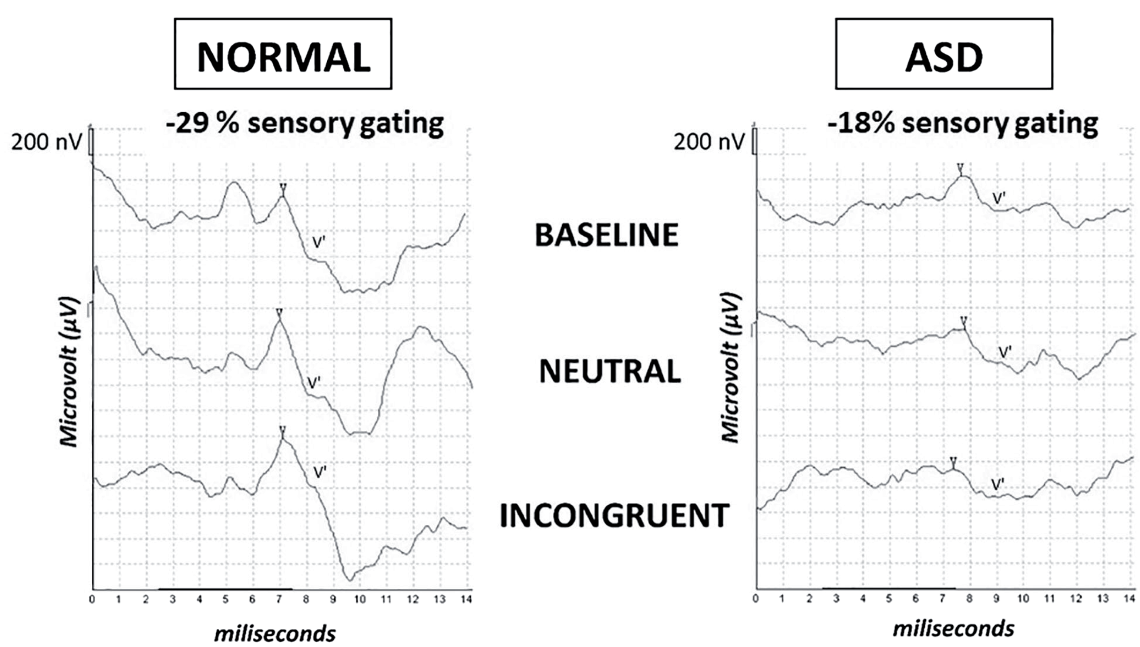

Figure 1.
The ABR waveforms recorded from 1 typically developing child (age: 6-year-old) and autism spectrum disorder (ASD) child (age: 9-year-old) under three Stroop task conditions.

Table 4 shows the Stroop-counting digit results in both ASD children and typical developing children. Results showed that the ASD child (-18%) has less inhibition or lower ABR sensory gating amplitude than a typically normal developing child (-29%) when comparisons of the ABR amplitude between those under

	ASD	TD
Reaction time (milliseconds)	1173	782
Correct response (%)	98%	100%
Stroop interference reaction time (milliseconds)	413	129
Stroop interference correct response (%)	−1.67	0

ASD: Autism spectrum disorder; TD, typical developing child.

Table 4.
The Stroop counting digit results in autism and typically developing child.

cognitive interference (incongruent) and without cognitive interference (neutral) was made descriptively. The ASD child also had a longer reaction time and a lower percentage of correct Stroop task responses under the Stroop task with cognitive interference (incongruent) than the typically normal developing child. In addition, the ASD child had also lower Stroop interference effects for the percentage of correct response but higher Stroop interference effect for reaction time descriptively. Overall, this case study showed that ASD children took a longer time to do the Stroop task under cognitive interference test conditions and this corresponds with a lower neural inhibition as shown by their ABR findings. This case study indicates a promising finding for future research if more data are collected for both normal and ASD children.

5. Summary and future direction

Our preliminary data in children have shown that the auditory brainstem response was not affected by the cognitive interference in typically developing children. Having said that, the majority of the study participants' ABRs showed evidence of neural inhibition, following cognitive interference. In general, our preliminary data partly coincide with Brännström et al. [19] findings that found an association between cognitive interference with the reduction in the ABR amplitude.

While our findings were inconclusive to relate the cognitive inhibition from the auditory cortex efferent pathways with the reduction in the neural activity at the brainstem, a few considerations should be taken in the future study to better understand the auditory sensory gating mechanism. One of the considerations is to ensure the residual noise level is kept constant throughout the ABRs recording among the Stroop task conditions. It is a well-known fact that the ABR amplitude is highly influenced by noise and therefore the conclusion of the study can be confounded by this factor. Next, future studies need to consider the ABR test-retest reliability values as an indicator of whether truly clinical changes have occurred in the ABR findings [29]. The third consideration is to explore the ABR recorded with cognitive interference among patients with known sensory gating deficit such as ADHD, autism, or schizophrenia since our case study has given some indication that differences may exist in the ABR sensory gating findings between a typically developing child and those with potential sensory gating deficits.

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Conflict of interest

The authors declare no conflict of interests.

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