ORIGINAL ARTICLE

Cognitive Interference Effects of Colour-Word and Counting Stroop Task on the Auditory Brainstem Response (ABR) in Children and Adults

Nur Hafizah Sulaiman[1,2], Muhamad Kamarul Asyraf Bakri[1], Muhammad Imran Yusri[1], Rina Kartini Alhawari[1], Ahmad Aidil Arafat Dzulkarnain[1,2*]

[1]Department of Audiology and Speech-Language Pathology, Kulliyyah of Allied Health Sciences, International Islamic University Malaysia, 25200 Kuantan, Pahang, Malaysia
[2]Children Health and Wellbeing Research Group, Kulliyyah of Allied Health Sciences, International Islamic University Malaysia, 25200 Kuantan, Pahang, Malaysia

ABSTRACT

Background: Auditory sensory gating refers to the brain's ability to suppress irrelevant auditory information from further processing. Recent studies have explored the use of the counting Stroop task, performed concurrently with the auditory brainstem response (ABR) test, to assess sensory gating at the brainstem level. However, the classical colour-word Stroop task, which is known to elicit stronger cognitive interference, has not yet been examined in conjunction with ABR testing. Therefore, this study aimed to compare the effects of cognitive interference induced by the colour-word and counting Stroop tasks on ABR outcomes. **Methods:** Seven children and eleven adults with normal hearing participated in this study. Each participant underwent ABR testing concurrently with both Stroop task types (colour-word and counting). For each task, two Stroop conditions (incongruent and neutral) were administered. Four measurement parameters (Stroop interference of percentage of correct responses and response time, and cognitive interference of ABR wave V amplitude and latency) were analysed using within-group comparisons to examine differences between the two types of Stroop task. **Results:** No statistically significant differences were observed in any measurement parameters between the two types of Stroop task for either age group. However, medium to large effect sizes were found among children in Stroop interference of response time and cognitive interference of wave V amplitude. **Conclusion:** Although no significant differences were identified, the colour-word Stroop task appeared to elicit slightly stronger cognitive interference in children, potentially reflecting greater inhibitory control demands. Clinically, these findings suggest that combining the colour-word Stroop task with ABR testing may provide a more sensitive approach for assessing inhibitory control of sensory gating at the brainstem level in children and for identifying those with atypical inhibitory control abilities.

Keywords:
Sensory gating; auditory sensory gating; auditory brainstem response; colour-word Stroop task; counting Stroop task

INTRODUCTION

Sensory gating is a fundamental neural mechanism, which regulates the brain's sensitivity to incoming stimuli by selectively filtering out redundant and irrelevant information to prevent sensory overload, thereby allowing attentional and cognitive resources to be efficiently allocated to relevant stimuli (Jones et al., 2016). Although sensory gating occurs across multiple sensory modalities, in the auditory domain, it is referred to as auditory sensory gating. This term reflects the brain's ability to filter out repetitive or unwanted auditory stimuli to maintain optimal auditory processing efficiency (Dzulkarnain et al., 2021).

Auditory sensory gating can be evaluated using various assessment methods, including perceptual rating questionnaires, behavioural psychological assessment, and electrophysiological recordings of auditory evoked potential (AEP) (Dzulkarnain et al., 2021,). Among these, the most established method involves the paired-click paradigm during electroencephalography (EEG), which assesses the suppression of event-related potentials (ERPs), such as P50, N100, and P200. This method primarily measures cortical sensory gating, involving cortical brain regions such as the superior temporal gyrus (STG) and Heschl's gyrus (Knott et al., 2009; Korzyukov et al., 2007; Potter et al., 2006; Villarreal & Hunter, 2015).

To assess sensory gating at the subcortical level, particularly within the auditory brainstem, recent research has combined the auditory brainstem response (ABR) test with concurrent cognitive tasks such as the Stroop task (Brännström et al., 2018; Dzulkarnain et al., 2020, 2021; Shahrudin et al., 2023). These studies have primarily employed the counting Stroop task, in which participants

* *Corresponding author.*
E-mail address: ahmadaidil@iium.edu.my

Journal homepage: https://journals.iium.edu.my/ijahs/index.php/IJAHS
EISSN NO 2600-8491

view digits on a screen, count the number of digits presented, and press the corresponding number key on the keyboard. During the incongruent condition of the counting Stroop task, where the number of digits displayed does not match its numerical value (e.g., "11", "222", "3333", "4", etc.), cognitive interference arises due to conflict between the automatic process of naming the digit and the task-required process of counting the digits. This cognitive interference increases cognitive load and engages inhibitory control mechanisms associated with sensory gating (Hershman et al., 2024; Scarpina & Tagini, 2017). Consequently, activation of the sensory gating system suppresses the processing of irrelevant stimuli, including the auditory stimuli presented during the concurrently recorded ABR, leading to reduced neural responsiveness as reflected by a decrease in ABR wave V amplitude (Brännström et al., 2018; Dzulkarnain et al., 2021; Shahrudin et al., 2023; Sörqvist et al., 2012). This cross-modal suppression, involving inhibitory interactions between visual and auditory modalities, is referred to as cross-sensory gating (Magnée et al., 2009; Schramm et al., 2023).

While the counting Stroop task has been frequently employed in previous ABR-based studies to evaluate sensory gating at the brainstem level, the colour-word Stroop task, which is the classical and most commonly used variant, has not yet been examined in this context. Recent meta-analytic evidence by Müller et al. (2024) indicates that the colour-word Stroop task induces the strongest cognitive interference effects on behavioural performance, as reflected in longer response time compared to other Stroop variants. Given this finding, it remains unclear whether the stronger cognitive interference elicited by the colour-word Stroop task would lead to greater modulation of subcortical auditory responses as measured by the ABR.

Therefore, the present study aimed to compare the effects of cognitive interference induced by the colour-word Stroop task and the counting Stroop task on ABR outcomes in two age groups: children and adults. By exploring both behavioural and electrophysiological indices, this study sought to determine whether differences in task-related cognitive interference are reflected not only in behavioural performance measures but also in neural responses at the auditory brainstem level.

METHODOLOGY

Ethics

Ethical approval for this study was obtained from the Research Ethics Committee of the International Islamic University Malaysia (IIUM) (Ref: KAHS 101/24). Prior to participation, written informed consent was secured, following a full disclosure of the study's objectives, procedures, potential risks and benefits, and anticipated outcomes.

Participants

Seven children (four males, three females), aged 10 to 17 years, and eleven adults (six males, five females) with normal hearing participated in this study. Children aged 10 years old and older were recruited because sensory gating is expected to mature by approximately 8 years of age, and the reading fluency required to read the colour word in the color-word Stroop task is typically fully achieved by around 9 years of age.

Procedure

Preliminary hearing assessments

To ensure normal hearing sensitivity, all participants completed hearing assessment, which was conducted using an Interacoustics AC40 pure-tone audiometer to measure audiometric thresholds and a Grason-Stadler TympStar Pro middle ear analyser to evaluate middle-ear compliance. Participants were classified as having normal hearing if both ears met all of the following criteria: (i) pure-tone audiometric thresholds of 20 dB HL or better from 250 to 8000 Hz, (ii) a type A tympanogram with peak compliance between 0.25 to 1.05 (children) or 0.3 to 1.7 (adults) ml, peak pressure between -100 to +50 (children) or ±50 (adult) decapascal (daPa), and ear canal volume between 0.3 to 0.9 (children) or 0.9 to 2.0 (adult) cm^3, and (iii) the presence of acoustic reflex at 1000 Hz.

Development of counting and colour-word Stroop task

The counting and colour-word Stroop tasks were developed using E-prime software to present the Stroop trials, record responses, and analyse participants' performance. Each Stroop task consisted of two conditions: incongruent and neutral.

For the counting Stroop task, digits (1 – 4) were used as test stimuli. In the incongruent counting condition, digits were displayed in quantities that did not match their numerical value (e.g., "11", "111", "1111", "2", "222", "2222", "3", "33", "3333", "4", "44", and "4444"). Participants were instructed to count the number of digits displayed, rather than identify the digit itself, and to enter their responses using a wireless numerical keypad to minimise movement-related artifacts during ABR recording. Only the 1 to 4 keys were programmed as response options in E-prime, while other keys were deactivated. For example, the “1” key corresponded to a single digit (e.g.: “1”), the “2” key to two digits (e.g.: “11”), the “3” key to three digits (e.g.: “111”) and the “4” key to four digits (e.g.: “1111”). In the neutral counting condition, the symbol “#” was displayed instead of digits, appearing one to four times (e.g., “#”, “##”, “###”, and “####”). Participants were instructed to count the number of symbols and respond using the same keypad configuration.

For the colour-word Stroop task, colour names in Malay (“MERAH”, “BIRU”, “HIJAU”, and “KUNING”) were used as stimuli. In the incongruent colour-word condition, each word was presented in a colour different from its meaning (e.g., “**MERAH**” shown in blue, “**BIRU**” shown in green, etc.). Participants were instructed to identify the colour of the word rather than read it and respond via the same numerical keypad. The keypad was programmed as follows: “1” for blue, “2” for green, “3” for red, and “4” for yellow. To minimise additional cognitive load from the arbitrary association between the numeric keys and the colours, coloured-stickers corresponding to each colour were placed on the key. In the neutral colour-word condition, the stimulus “XXXX” was presented in the same four colours (red, blue, green, and yellow), serving as the baseline measurement. Participants were required to identify the colour of the “XXXX” stimulus using the keypad.

Each condition of each Stroop task comprised 60 randomised trials. Stimuli were presented at the centre of the screen for a maximum of 4000 ms, preceded by a 1000-ms fixation cross. The next item appeared automatically after a response or once the time limit was reached.

ABR test parameters

ABRs were recorded using an Interacoustics Eclipse system. Narrowband (NB) CE-chirps centred at 1 kHz were presented at 70 dBnHL via insert earphones. Stimuli were delivered at a rate of 27.7 Hz with alternating polarity. Responses were recorded over a 20-ms time window using both ipsilateral and contralateral montages. Electrodes were placed with the non-inverting electrode on the high forehead, inverting electrodes on both earlobes, and the ground electrode on the nape of the neck. Contralateral recording was employed to facilitate identification of wave V, as ipsilateral montages often result in fused wave IV and V complexes (Dzulkarnain et al., 2014). Bayesian weighted averaging was applied, and artifact rejection was set at ±40 µV to minimise noise contamination. Filters were set at 30 Hz (high-pass) and 3000 Hz (low-pass) to capture the spectral energy of the ABR, which typically ranges between 100 and 1000 Hz (British Society of Audiology [BSA], 2019).

The number of averages was not fixed and varied, depending on the duration each participant took to complete the Stroop task. ABR recording continued until the participant had responded to all task items, resulting in variable recording durations and consequently variable numbers of averages. Nevertheless, a minimum of 2000 sweeps was ensured for each ABR recording, in line with conventional signal-averaging requirements (BSA, 2019). To ensure reliability and comparability, only recordings with at least 2000 averages and a multiple points F-statistics (FMP) ratio ≥ of 3:1 was included in the analysis.

ABR with Stroop task

Prior to ABR testing with the Stroop task, participants completed a 20-item practice trial for each Stroop task, containing an equal mix of incongruent and neutral trials. Written feedback was displayed on the screen after each trial, and participants were required to achieve at least 80% accuracy before proceeding. If this criterion was not met, the practice trial automatically restarted.

ABRs were then recorded during each of the Stroop conditions (incongruent and neutral) for both types of Stroop task (counting and colour-word). For each condition, two ABR recordings were obtained to verify waveform repeatability, resulting in eight recordings per participant. All recordings were conducted while participants remained seated and focused on the screen. The order of the Stroop task type and conditions was randomised across participants.

Following data collection, two behavioural outcomes (response time and percentage of correct responses) were retrieved from E-prime’s E-Merge and E-DataAid applications. The E-prime software automatically recorded the response time for each trial, which was then averaged for each condition of the Stroop task. Participant responses were automatically logged and later manually verified against the correct answers to calculate a percentage score of correct responses. Using the average response time and percentage of correct responses from the incongruent and neutral conditions, Stroop interference of response time and percentage of correct responses was calculated for each type of Stroop task by subtracting the neutral condition’s value from the incongruent condition’s value (see Eq. (1) and Eq. (2)). The Stroop interference is typically used as a measurement of inhibitory control ability (Forte et al., 2024).

Stroop interference of response time (1)

$$\text{Response time of incongruent condition} - \text{Response time of neutral condition}$$

Stroop interference of percentage of correct responses (2)

$$\text{Percentage of correct responses of incongruent condition} - \text{Percentage of correct responses of neutral condition}$$

For ABR outcomes, waveforms were visually inspected by two experienced clinical audiologists. Latencies and amplitudes of wave V were retrieved, and cognitive interference of wave V amplitude and latency was calculated for each type of Stroop task by subtracting the neutral condition values from those obtained in the incongruent condition (see Eq. (3) and Eq. (4).

Cognitive interference of wave V amplitude (3)

$$\text{Wave V amplitude of incongruent condition} - \text{Wave V amplitude of neutral condition}$$

Cognitive interference of wave V latency (4)

$$\text{Wave V latency of incongruent condition} - \text{Wave V latency of neutral condition}$$

Data Analysis

Data were first examined for normality prior to inferential analysis. Normality was evaluated through visual inspection of histograms, evaluation of skewness (acceptable range: ±1) and kurtosis (acceptable range: ±3), and the Shapiro-Wilk test ($p > 0.05$) as described by Sharif (2019). Based on normality results, either parametric or non-parametric tests were applied in the subsequent inferential analyses. Within-group comparisons of Stroop interference (percentage of correct responses and response time) and cognitive interference (ABR wave V amplitude and latency) between colour-word and counting Stroop tasks were analysed using either a paired-sample t-test or a Wilcoxon signed-rank, as appropriate. Effect sizes were calculated using Cohen's *d* for the paired-sample t-test and interpreted as small (0.2), medium (0.5), or large (0.8), or using the *r* for the Wilcoxon signed-rank test and interpreted as small (0.1 - < 0.3), medium (0.3 - < 0.5), or large (≥ 0.5).

RESULTS

Differences in Stroop Interference and Cognitive Interference of the ABR Test in Adults

Table 1 presents the within-group comparisons of Stroop interference of percentage of correct responses and response time, as well as cognitive interference of wave V amplitude and latency, between the colour-word and counting Stroop tasks in adults.

A Wilcoxon signed-rank test was conducted to compare the Stroop interference of the percentage of correct responses between the colour-word Stroop task (*Mdn* = 0.99, *IQR* = 1.48) and the counting Stroop task (*Mdn* = 0.98, *IQR* = 1.53). The results indicated no significant difference between the two tasks, $Z = -0.965$, $p = 0.287$, $r = 0.29$, consistent with a medium effect size. A paired sample t-test was conducted to compare the Stroop interference of response time between using the colour-word Stroop task (*M* = 97.82, *SD* = 10.59) and the counting Stroop task (*M* = 55.83, *SD* = 61.28). No significant difference was also found, $t(10) = 0.977$, $p = 0.352$, $d = 0.30$, consistent with a small to medium effect size.

For ABR cognitive interference, Wilcoxon signed-rank tests were conducted to compare both measurement parameters (wave V amplitude and latency) between the colour-word and counting Stroop tasks. The results indicated no significant differences in either measurement parameter between the two tasks (cognitive interference of wave V amplitude: colour-word, *Mdn* = -0.015, *IQR* = 0.098; counting, *Mdn* = -0.009, *IQR* = 0.064; $Z = -0.267$, $p = 0.790$, $r = 0.08$; cognitive interference of wave V latency: colour-word, *Mdn* = -0.06, *IQR* = 0.123; counting, *Mdn* = -0.01, *IQR* = 0.105; $Z = -0.578$, $p = 0.563$, $r = 0.17$), consistent with small effect sizes for both measures.

Differences in Stroop Interference and Cognitive Interference of the ABR Test in Children

Table 2 presents the within-group comparisons of Stroop interference of percentage of correct responses and response time, as well as cognitive interference of wave V amplitude and latency, between the colour-word and counting Stroop tasks in children.

A paired-sample t-test was conducted to compare Stroop interference for both measures (percentage of correct responses and response time) between the colour-word and counting Stroop tasks. The results indicated no significant differences in either measurement parameter between the two tasks (Stroop interference of percentage of correct response: colour-word, *M* = 0.99, *SD* = 0.08 counting, *M* = 0.98, *SD* = 0.040; $t(6) = 0.81$, $p = 0.45$, d =

0.31; Stroop interference of response time: colour-word, $M = 163.51$, $SD = 240.35$; counting, $M = 93.09$, $SD = 112.65$; $t(6) = 2.23$, $p = 0.059$, $d = 0.84$), indicating a small to medium effect size for percentage of correct response and a large effect size for response time.

For the ABR cognitive interference, a Wilcoxon signed-rank test was conducted to compare the cognitive interference of wave V amplitude between the colour-word (*Mdn* = -0.02, *IQR* = 0.42) and counting Stroop tasks (*Mdn* = 0.38, *IQR* = 0.39). The results indicated no significant difference between the two tasks, $Z = -1.104$, $p = 0.32$, $r = 0.42$, although a medium effect size was observed. A paired-samples t-test was conducted to compare the cognitive interference of wave V latency between the colour-word ($M = 0.154$, $SD = 0.244$) and the counting Stroop Task ($M = 0.016$, $SD = 0.184$). The results indicated no significant difference between the two tasks, $t(6) = 1.10$, $p = 0.32$, $d = 0.42$, consistent with a small to medium effect size.

Table 1: Within-group comparisons of Stroop interference and cognitive interference between the colour-word and counting Stroop task in adults

Interference Index	**Types of Stroop Task**	**Mean (SD)* / Median (IQR)****	**Test Statistics**	***p*-value**	**Effect Size (*d* / *r*)**	**Interpretation**
Stroop interference of percentage of correct responses	Colour-word	0.99 (1.48)**	*Z*(10) = –0.965	0.287	*r* = 0.29	Small
	Counting	0.98 (1.53)**				
Stroop interference of response time	Colour-word	97.82 (103.59)*	*t*(10) = 0.977	0.352	*d* = 0.30	Small–medium
	Counting	55.83 (61.28)*				
Cognitive interference of wave V amplitude	Colour-word	–0.015 (0.098)**	*Z*(10) = –0.267	0.790	*r* = 0.08	Small
	Counting	–0.009 (0.064)**				
Cognitive interference of wave V latency	Colour-word	–0.06 (0.123)**	*Z*(10) = –0.578	0.563	*r* = 0.17	Small
	Counting	–0.01 (0.105)**				

Note: * = value for Mean (SD); ** = value for Median (IQR); SD = standard deviation; IQR = interquartile range

Table 2: Within-group comparisons of Stroop interference and cognitive interference between the colour-word and counting Stroop task in children

Interference Index	**Types of Stroop Task**	**Mean (SD)* / Median (IQR)****	**Test Statistics**	***p*-value**	**Effect Size (*d* / *r*)**	**Interpretation**
Stroop interference of percentage of correct responses	Colour-word	0.039 (0.089)*	*t*(6) = 0.81	0.45	0.31	Small–medium
	Counting	-0.033 (0.040)*				
Stroop interference of response time	Colour-word	163.51 (240.35)*	*t*(6) = 2.23	0.059	0.84	Large
	Counting	93.09 (112.65)*				
Cognitive interference of wave V amplitude	Colour-word	-0.02 (0.42)**	*Z*(6) = -1.104	0.32	0.42	Medium
	Counting	0.38 (0.39)**				
Cognitive interference of wave V latency	Colour-word	0.154 (0.244)*	*t*(6) = 1.10	0.32	0.42	Small–medium
	Counting	0.016 (0.184)*				

Note: * = value for Mean (SD); ** = value for Median (IQR); SD = standard deviation; IQR = interquartile range

DISCUSSION

The present study examined differences in behavioural performance on Stroop tasks and electrophysiological responses measured through ABR to assess the effects of cognitive interference elicited by two types of Stroop tasks: the colour-word Stroop task and the counting Stroop task. Overall, the findings revealed no significant differences in Stroop interference (measured by percentage of correct responses and response time) or cognitive interference (measured by ABR wave V amplitude and latency) between the two types of Stroop task in either age group. However, medium to large effect sizes observed in several comparisons, particularly in Stroop interference of response time and cognitive interference of wave V amplitude among children, suggest that task-related variations in cognitive processing demands, especially in inhibitory control, may exist.

Effects on Behavioural Performance of Stroop Task

The absence of statistically significant differences in Stroop interference between the colour-word and counting Stroop tasks suggests that both tasks engage similar inhibitory control mechanisms. Conceptually, the two Stroop paradigms share comparable cognitive demands, as in both tasks, participants are required to attend to a physical dimension of the stimulus (i.e., colour in the colour-word Stroop task and quantity in the counting Stroop task), while ignoring its symbolic dimension (i.e., word meaning in the colour-word Stroop task and digit identity in the counting Stroop task) (Hershman et al., 2024).

At the neurocognitive level, findings from neuroimaging studies have demonstrated that both types of Stroop tasks activate overlapping neural networks, particularly the prefrontal cortex, anterior cingulate cortex (ACC), and parietal cortex (Bush et al., 1998, 2006; Christensen et al., 2011; Freund et al., 2021; Müller et al., 2024). The ACC primarily detects and evaluates cognitive conflict, while the prefrontal cortex implements top-down inhibitory control to resolve such conflict (Ehlis et al., 2024; Shenhav et al., 2013). Meanwhile, the parietal cortex contributes to maintaining sustained attention toward task-relevant features of the stimulus in the presence of more salient but irrelevant features of the stimulus. Activation of parietal cortex during both Stroop tasks has also been associated with the processing of numerical quantity in the counting Stroop task and with lexical or word-reading processes in the colour-word Stroop task (Adleman et al., 2002; Freitas et. al., 2023; Tang et al., 2009). These overlapping neural substrates likely account for the comparable behavioural performance observed between the two types of Stroop task in the present study.

Among children, however, a trend toward longer response times during the incongruent condition of the colour-word Stroop task compared to the counting Stroop task (resulting in greater Stroop interference of response time) was observed. Although this difference did not reach statistical significance, the large effect size suggests a potentially meaningful variation in cognitive load. Upon closer examination, this pattern may reflect a speed-accuracy trade-off (Forte et al., 2024). Since Stroop interference in accuracy (percentage of correct responses) did not differ significantly between the two tasks, it is plausible that children prioritised accuracy over speed when performing the more cognitively demanding colour-word Stroop task. This behaviour suggests that children exercised greater caution and inhibitory control to maintain accuracy, resulting in slower response time. Collectively, these findings imply that the incongruent colour-word Stroop task may impose greater cognitive interference than the incongruent counting Stroop task among developing populations (children).

Effects on Electrophysiological Responses of ABR

Consistent with the behavioural findings, no significant differences were observed in the cognitive interference measurement of ABR between the colour-word and counting Stroop tasks. As both tasks likely impose comparable cognitive demands and engage similar inhibitory control mechanisms, the degree of cognitive interference elicited by each task appears relatively equivalent. Consequently, the level of neural suppression reflected in ABRs was also comparable across both tasks, as evidenced by the absence of statistically significant differences in the cognitive interference of wave V amplitude and latency among both children and adults.

A closer examination of the cognitive interference of wave V amplitude among children, however, revealed a medium effect size, suggesting a potential trend worth noting. Specifically, the colour-word Stroop task demonstrated a more negative pattern of cognitive interference, whereas the counting Stroop task exhibited a positive pattern. The negative interference pattern in the colour-word Stroop task indicates that the wave V amplitude during the incongruent condition was smaller than that observed during the neutral condition. This reduction in amplitude aligns with previous literature suggesting that increased cognitive load and conflict, such as those experienced during the incongruent Stroop condition, can activate the sensory gating mechanism that suppresses neural responsiveness to the concurrent auditory stimuli presented during the ABR test (Brännström et al., 2018; Dzulkarnain et al., 2021; Shahrudin et al., 2023; Sörqvist et al., 2012). Such suppression, manifested as a decrease in ABR wave V amplitude, likely reflects the reallocation of attentional and processing resources toward resolving cognitive conflict rather than processing auditory input (Brännström et al., 2018; Dzulkarnain et al., 2021; Shahrudin et al., 2023; Sörqvist et al., 2012).

In contrast, the positive interference pattern observed in the counting Stroop task, where wave V amplitude was slightly larger during the incongruent condition, may reflect an absence of substantial neural suppression. This could suggest that the level of cognitive interference induced by the counting Stroop task was not sufficient to strongly engage the sensory gating system. In other words, the neural resources required to resolve conflict in the counting Stroop task may not have been extensive enough to interfere with concurrent auditory processing, resulting in a relatively stable or slightly enhanced ABR response. This interpretation is consistent with prior research suggesting that early auditory processing, as reflected in the ABR, is relatively resilient to mild cognitive load (Brännström et al., 2018).

Taken together, these findings suggest that although both Stroop tasks engage similar inhibitory control mechanisms behaviourally, the colour-word Stroop task may impose a somewhat greater cognitive load at the neural level. This is reflected in the direction of change in wave V amplitude, even though this difference did not reach statistical significance.

Developmental Differences in the Effects of Different Types of Stroop Tasks

Although no statistically significant differences were found in any measurement parameters between the colour-word and counting Stroop tasks among both children and adults, a consistent pattern of medium to large effect sizes was observed only among children. Specifically, the medium and larger effect sizes in Stroop interference of response time and cognitive interference of wave V amplitude, respectively, were evident in the child group. These findings suggest that cognitive interference effects are more pronounced during the colour-word Stroop task among children, as reflected by longer response times and reduced wave V amplitude during the incongruent condition. This pattern implies that children are more susceptible to the higher cognitive load and conflicts induced by the colour-word Stroop task compared to adults. This interpretation aligns with previous studies reporting that cognitive interference effects are much stronger in children, who generally exhibit less efficient response inhibition than adults (Ménétré & Laganaro, 2023).

Several developmental factors may account for these differences. Previous research indicates that the ability to detect cognitive conflict (conflict detection) typically matures around the age of 10 (Ménétré & Laganaro, 2023). However, the ability to resolve such conflicts (conflict resolution) continues to develop through late childhood and adolescence and reaches adult-like levels only in late adolescence or early adulthood (Forte et al., 2024; Jongen & Jonkman, 2008; Ménétré & Laganaro, 2023). Neuroimaging evidence further supports this view, showing that the maturation of conflict resolution abilities parallels the structural and functional brain development, particularly involving the prefrontal cortex (Luna et al., 2010), which is among the last brain regions to mature (Ferguson et al., 2021; Forte et al., 2024; Güntekin et al., 2023). Besides, during the developmental period, neural networks undergo gradual structural changes, including synaptic pruning, grey matter thinning, and myelination (Jongen & Jonkman, 2008), which collectively contribute to improved efficiency in inhibitory control function.

Moreover, although the neural networks involved in inhibitory control in children and adults share common regions such as the ACC and the prefrontal cortex, an activation of additional brain regions was identified in children, mainly in the orbito-frontal regions. The requirement of these additional brain areas may reflect compensatory mechanisms, indicating that children require greater neural resources to achieve successful inhibition (Ménétré & Laganaro, 2023). This is consistent with the notion that the more practiced or automated a cognitive ability becomes, the fewer neural regions are required for its execution (Yotsumoto et al., 2008).

CONCLUSION

The present study investigated the effects of cognitive interference elicited by two types of Stroop tasks, the colour-word and counting Stroop tasks, on behavioural performance and electrophysiological responses measured via ABR among children and adults. Although no statistically significant differences were observed in Stroop interference or in the cognitive interference of ABR between the two tasks, the pattern of results and the medium to large effect sizes observed among children suggest meaningful variations in task-related cognitive processing demands. Specifically, the colour-word Stroop task appeared to impose greater cognitive interference, thereby eliciting stronger inhibitory control, as reflected by longer response times and reduced ABR wave V amplitude during the incongruent condition. These findings suggest that, although both Stroop paradigms engage overlapping inhibitory control mechanisms, the colour-word Stroop task may induce stronger cognitive conflict, particularly during developmental stages when executive functions are still maturing. From a clinical perspective, the greater susceptibility of children to cognitive interference induced by the colour-word Stroop task, and its corresponding effect on ABR, suggests that this paradigm could serve as a sensitive electrophysiological marker for assessing inhibitory control abilities in children. Such an approach may aid in the early identification of children with atypical inhibitory control, including those with auditory processing disorder (APD) or related neurodevelopmental conditions.

ACKNOWLEDGEMENT

This research was funded by the Ministry of Higher Education, Malaysia through the Fundamental Research Grant Scheme (FRGS) (Project ID: FRGS/1/2024/SKK06/UIAM/02/4).

REFERENCES

Adleman, N. E., Menon, V., Blasey, C. M., White, C. D., Warsofsky, I. S., Glover, G. H., & Reiss, A. L. (2002). A developmental fMRI study of the Stroop color-word task. *NeuroImage, 16*(1), 61–75. https://doi.org/10.1006/nimg.2001.1046

Brännström, K. J., Wilson, W. J., & Waechter, S. (2018). Increasing cognitive interference modulates the amplitude of the auditory brainstem response. *Journal of the American Academy of Audiology, 29*(06), 512–519. https://doi.org/10.3766/jaaa.17003

British Society of Audiology (BSA) (2019). *Recommended procedure auditory brainstem response (ABR) testing in babies.* Bathgate: British Society of Audiology.

Bush, G., Whalen, P. J., Rosen, B. R., Jenike, M. A., McInerney, S. C., & Rauch, S. L. (1998). The counting Stroop: an interference task specialized for functional neuroimaging--validation study with functional MRI. *Human Brain Mapping, 6*(4), 270–282. https://doi.org/10.1002/(SICI)1097-0193(1998)6:4%3C270::AID-HBM6%3E3.0.CO;2-0

Bush, G., Whalen, P. J., Shin, L. M., & Rauch, S. L. (2006). The counting Stroop: a cognitive interference task. *Nature Protocols, 1*(1), 230–233. https://doi.org/10.1038/nprot.2006.35

Christensen, T. A., Lockwood, J. L., Almryde, K. R., & Plante, E. (2011). Neural substrates of attentive listening assessed with a novel auditory Stroop task. *Frontiers in Human Neuroscience, 4*(236), 1-12. https://doi.org/10.3389/fnhum.2010.00236

Dzulkarnain, A. A. A., Tengku Zam Zam, T. Z. H., Azed, Z., Zuri, M. I. R., & Sulaiman, N. H. (2014). Effects of electrode positions on tone-burst-evoked auditory brainstem responses (ABR) in Humans. *Middle-East Journal of Scientific Research, 21*(8), 1180-1187. https://doi.org/10.5829/idosi.mejsr.2014.21.08.84167

Dzulkarnain, A. A. A., Azizi, A. K., & Sulaiman, N. H. (2020). Auditory sensory gating in Huffaz using an auditory brainstem response with a psychological task: A preliminary investigation. *Journal of Taibah University Medical Sciences, 15*(6), 495–501. https://doi.org/10.1016/j.jtumed.2020.08.007

Dzulkarnain, A. A. A., Sulaiman, N. H., Shahrudin, F. A., Sidek, S. N., Md. Yusof, H., & Khalid, M. (2021). Auditory brainstem response with cognitive interference in normal and autism spectrum disorder children - Understanding the auditory sensory gating mechanism. In *IntechOpen*. IntechOpen. https://doi.org/10.5772/intechopen.101135

Ehlis, A.-C., Zarantonello, L., Haeussinfer, F. B., Rohe, T., Rosenbaum, D., Fallgatter, A. J., & Maier, M. J. (2024). The DLPFC is centrally involved in resolving Stroop conflicts, suppressing distracting sensory input within the auditory and visual system. *Frontiers in Psychology, 15*, 1427455. https://doi.org/10.3389/fpsyg.2024.1427455

Ferguson, H. J., Brunsdon, V. E. A., & Bradford, E. E. F. (2021). The developmental trajectories of executive function from adolescence to old age. *Scientific Reports, 11*(1), 1382. https://doi.org/10.1038/s41598-020-80866-1

Forte, G., Troisi, G., Favieri, F., & Casagrande, M. (2024). Inhibition changes across the lifespan: experimental evidence from the Stroop task. *BMC Psychology*, *12*(1), 366. https://doi.org/10.1186/s40359-024-01844-0

Freitas, P. M., Haase, V. G., & Wood, G. M. (2023). The neural correlates of interference effects of numerical Stroop task: An ALE meta-analysis and connectometry. *Progress in brain research, 282*, 71–93. https://doi.org/10.1016/bs.pbr.2023.10.003

Freund, M. C., Bugg, J. M., & Braver, T. S. (2021). A representational similarity analysis of cognitive control during color-word Stroop. *The Journal of neuroscience: the official journal of the Society for Neuroscience, 41*(35), 7388–7402. https://doi.org/10.1523/JNEUROSCI.2956-20.2021

Güntekin, B., Alptekin, S., Yıldırım, E., Aktürk, T., Uzunlar, H., Çalışoğlu, P., Ada, F. E., Atay, E., & Ceran, Ö. (2023). Immature event-related alpha dynamics in children compared with the young adults during inhibition shown by day-night Stroop task. *Frontiers in human neuroscience, 17*, 1218559. https://doi.org/10.3389/fnhum.2023.1218559

Hershman, R., Keha, E., Sapir, A., Weiss, E. M., Henik, A., & Kaufmann, L. (2024). Evidence for two types of task conflict in a color-digit Stroop task. *Journal of cognition, 7*(1), 54. https://doi.org/10.5334/joc.386

Jones, L. A., Hills, P. J., Dick, K. M., Jones, S. P., & Bright, P. (2016). Cognitive mechanisms associated with auditory sensory gating. *Brain and cognition, 102*, 33–45. https://doi.org/10.1016/j.bandc.2015.12.005

Jongen, E. M. M., & Jonkman, L. M. (2008). The developmental pattern of stimulus and response interference in a colour-object Stroop task: an ERP study. *BMC Neuroscience, 9, 82.* https://doi.org/10.1186/1471-2202-9-82

Knott, V., Millar, A., & Fisher, D. (2009). Sensory gating and source analysis of the auditory P50 in low and high suppressors. *NeuroImage, 44*(3), 992–1000. https://doi.org/10.1016/j.neuroimage.2008.10.002

Korzyukov, O., Pflieger, M. E., Wagner, M., Bowyer, S. M., Rosburg, T., Sundaresan, K., Elger, C. E., & Boutros, N. N. (2007). Generators of the intracranial P50 response in auditory sensory gating. *NeuroImage, 35*(2), 814–826. https://doi.org/10.1016/j.neuroimage.2006.12.011

Luna, B., Padmanabhan, A., & O'Hearn, K. (2010). What has fMRI told us about the development of cognitive control through adolescence? *Brain and cognition, 72*(1), 101–113. https://doi.org/10.1016/j.bandc.2009.08.005

Magnée, M. J. C. M., Oranje, B., Engeland, H. V., Kahn, R. S., & Kemner, C. (2009). Cross-sensory gating in schizophrenia and autism spectrum disorder: EEG evidence for impaired brain connectivity? *Neuropsychologia, 47*(7), 1728–1732. https://doi.org/10.1016/j.neuropsychologia.2009.02.012

Ménétré, E., & Laganaro, M. (2023). The temporal dynamics of the Stroop effect from childhood to young and older adulthood. *PloS one, 18*(3), e0256003. https://doi.org/10.1371/journal.pone.0256003

Müller, V. I., Cieslik, E. C., Ficco, L., Tyralla, S., Sepehry, A. A., Aziz-Safaie, T., Feng, C., Eickhoff, S. B., & Langner, R. (2024). Not All Stroop-type tasks are alike: Assessing the impact of stimulus material, task design, and cognitive demand via meta-analyses across neuroimaging studies. *Neuropsychology review*, 10.1007/s11065-024-09647-1. Advance online publication. https://doi.org/10.1007/s11065-024-09647-1

Potter, D., Summerfelt, A., Gold, J., & Buchanan, R. W. (2006). Review of clinical correlates of P50 sensory gating abnormalities in patients with schizophrenia. *Schizophrenia bulletin, 32*(4), 692–700. https://doi.org/10.1093/schbul/sbj050

Scarpina, F., & Tagini, S. (2017). The Stroop color and word test. *Frontiers in psychology, 8*, 557. https://doi.org/10.3389/fpsyg.2017.00557

Schramm, M., Fjaellingsdal, T. G., Aslan, B., Jung, P., Lux, S., Schulze, M., & Philipsen, A. (2023). Electrophysiological evidence for increased auditory crossmodal activity in adult ADHD. *Frontiers in neuroscience, 17,* 1227767. https://doi.org/10.3389/fnins.2023.1227767

Shahrudin, F. A., Dzulkarnain, A. A. A., Chahed, N., Ahmad Basri, N., Jamal, F. N. Sidek, S. I., Md. Yusof, H., & Abd. Hamid, S. R. (2023). Auditory sensory gating in auditory brainstem response (ABR) with psychological task in autism spectrum disorder (ASD) child: A case study. *International Journal of Allied Health Sciences, 7*(5), 512-527, https://doi.org/10.31436/ijahs.v7i5.878

Sharif, S. (2019). *Statistics for nonstatisticians.* Khazanah Darulaman.

Shenhav, A., Botvinick, M. M., & Cohen, J. D. (2013). The expected value of control: an integrative theory of anterior cingulate cortex function. *Neuron, 79*(2), 217–240. https://doi.org/10.1016/j.neuron.2013.07.007

Sörqvist, P., Stenfelt, S., & Rönnberg, J. (2012). Working memory capacity and visual-verbal cognitive load modulate auditory-sensory gating in the brainstem: toward a unified view of attention. *Journal of cognitive neuroscience*, *24*(11), 2147–2154. https://doi.org/10.1162/jocn_a_00275

Tang, J., Critchley, H. D., Glaser, D. E., Dolan, R. J., & Butterworth, B. (2009). Imaging informational conflict: A functional magnetic resonance imaging study of numerical Stroop. *Journal of cognitive neuroscience, 18*(12), 2049-2062. https://doi.org/10.1162/jocn.2006.18.12.2049

Villarreal, G., & Hunter, M. A. (2015). Auditory M50 sensory gating deficit and superior temporal gyrus pathology in posttraumatic stress disorder. In *Springer eBooks* (pp. 1–11). Springer Nature. https://doi.org/10.1007/978-3-319-08613-2_100-1

Yotsumoto, Y., Watanabe, T., & Sasaki, Y. (2008). Different dynamics of performance and brain activation in the time course of perceptual learning. *Neuron, 57*(6), 827–833. https://doi.org/10.1016/j.neuron.2008.02.03