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# Neuro Cognitive Improvement During Pregnancy: An Auditory Event Related Potential (ERP) and Neuropsychological Study

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## Abstract

**Background:** Although there is increasing research interest in auditory cognitive function among pregnant women, little is known about auditory cognitive function during the second (mid) and third trimesters of pregnancy. Therefore, we investigated auditory cognitive and behavioral functions during the mid- and third trimesters of pregnancy using event related potentials (ERPs) and neuropsychological tests, respectively.

**Methods:** ERPs were examined using a 128-sensor net, and the PAS, WCST, ZCT, RAVLTIM, RAVLTD, RAVLTT were administered as neuropsychological assessment tools. Thirty-nine participants were recruited as a control group (G1, n=15, non-pregnant), mid trimester (G2, n=12, 13-26 weeks), and third trimester (G3, n=12, 26-40 weeks). The auditory oddball paradigm was used during the ERP examination. Subjects silently counted the number of occurrences of a target tone while ignoring the standard tone.

**Results:** The value of mean differences of two stimuli were measured in case of amplitudes of P50, N100 and P300 ERP components. The highest (significantly) amplitudes were found in three, three and two sites in P50, N100 and P300 ERP components, respectively. Pregnant group (G2 and G3 both) evoked the highest (significantly) amplitudes in three, one and two sites in P50, N100 and P300 components, respectively, comparing with the control group (G1). Within pregnant group, G3 possesses the highest (significantly) amplitudes at 2 sites (out of 3) in P50, 1 site (out of 3) in N100 and 1 site (out of 2) in P300 components. The highest amplitude of P300 was observed in G2 comparing with the G3. G2 subjects achieved the highest (significantly/nearly significantly) scores on the WCST, RAVLTIM; where G1 subjects had the highest score in ZCT among groups.

**Conclusion:** These findings indicate that pregnant women exhibit good auditory attention, memory and executive function. Pregnant women exhibited better auditory cognitive function in the second trimester compared with those in the third trimester of pregnancy.

**Keywords:** Pregnancy; Auditory cognition; WCST; PAS; ZCT; RAVLTs; P300; P50; N100

## Introduction

Cognitive functioning is essential for the maintenance of social responsibilities, family, and work. Any deficit in cognitive function can have a negative impact on functioning in daily life. Several studies have investigated the cognitive function of pregnant women, often reporting a tendency for pregnant women to be forgetful, with impaired focus [1] and poor memory [2]. Cognitive changes during pregnancy are thought to be related to hormonal fluctuations [3,4] and depression [5]. However, previous studies of cognitive abilities among pregnant women have often involved subjective measures, and cognitive findings may be affected by factors related to depression. Therefore, the current study integrated both objective and subjective tests using event related potentials (ERPs) and neuropsychological tests, respectively. In humans, pregnancy involves three trimesters. Each trimester is associated with fluctuations of sex hormones to support and maintain fetal development. The current study was performed to compare the auditory cognitive function of pregnant women using auditory oddball stimuli in the mid and third trimesters of pregnancy.

The recruitment of neural resources is important for assessing attention deficits among pregnant women. ERPs are an electrophysiological tool that can be used to investigate brain activity during cognitive processing and can play a valuable role in assessing attention by measuring the amplitudes and latencies of various ERP components. ERP measurement enables evaluation of electrophysiological signals from the brain that occur directly after the

presentation of a stimulus event. ERP is a non-invasive technique that is safe to implement with patients as well as healthy subjects [6]. ERPs provide a convenient tool not only for attention study, but also for recognition memory, visual working memory and long-term memory [7]. In one study, visual cognitive function was investigated using different faces and shapes among third trimester pregnant women, revealing that pregnant women had poorer visual cognitive control and reduced P300 amplitude [8]. Another study reported that a pregnant group exhibited greater amplitudes and latencies of the P300 component compared with the control group [9].

A recent study combining ERPs and neuropsychological measures was conducted with mid trimester pregnant women, reporting mild auditory cognitive functional impairment among pregnant women, with no impairment of executive function and auditory memory [10]. However, to date, no previous studies have examined the cognitive function of pregnant women between mid and third trimester pregnancy using both ERPs and neuropsychological measures. Therefore, the current study sought to assess auditory cognitive function among mid and third trimester pregnant women using ERPs and neuropsychological tests. The current findings may help future studies elucidate the precise characteristics of neuronal network processing among pregnant women, aiding the development of therapeutic or rehabilitation approaches for improving auditory cognition among pregnant women.

## Methods

### Subjects

Thirty-nine subjects were recruited with control (G1) (mean age  $\pm$  SD  $32.59 \pm 3.75$ ,  $n=15$ ) and pregnant subjects. Pregnant subjects were divided into two subgroups based on the stage of pregnancy: second trimester (G2) ( $27.19 \pm 2.92$ ,  $n=12$ ) and third trimester (G3) ( $27.89 \pm 4.57$ ,  $n=12$ ) groups. The second trimester, also known as the mid trimester, occurs from 13 to 26 weeks, and the third trimester occurs within 27 to 40 weeks of gestation [1]. Subjects in the first trimester of pregnancy were not included in the current study because of safety concerns. All participants in both groups were age and education matched, not under treatment or have any major diseases for example hypertension, diabetes, kidney diseases, obesity, drug addiction etc and all women have 1-3 child/children. We included all participants in both groups within 20-40 years old as this are the childbearing age [11] education was more than STPM (Sijil Pelajaran Tinggi Malaysia: 13 education years) as low education reflects lower cognitive function (attention) [12,13], even major diseases and drug addiction also reflects on cognitive function [14-16]. There are cognitive function differences between single and married women. Therefore, we matched all participants in both groups as married with 1-3 children [17].

This study was approved by the Human Ethical Committee of Universiti Sains Malaysia (USM). Written informed consent was obtained from all participants prior to the experiment. Neuropsychological tests were conducted by an expert clinical

neuropsychologist. ERPs were recorded in the Laboratory for MEG and ERP studies at Hospital Universiti Sains Malaysia (HUSM) using a 128-electrode sensor net.

### ERP procedure

E-Prime v 2.0 software (Psychology Software Tools, Inc, Sharpsburg, Pennsylvania, USA) was used for presentation of stimuli, timing operations and data collection. Participants were seated in a dimly lit room with headphones placed on both ears, while wearing a 128-electrode sensor net. Subjects were instructed to silently count the target tones (60 dB sound pressure level (SPL) which were low frequency (20%) with high pitch (2000 Hz)), presented binaurally, while ignoring standard tones (60 dB SPL, high frequency (80%) and low pitched (1000 Hz)). Tone duration was 100ms with a rise/fall time of 10ms. All data were recorded using Net-Station software (Electrical Geodesics, Inc., Eugene, OR, USA). The amplitudes of the P50, N100 and P300 ERP components were analyzed at 19 electrode locations in 10-20 system.

### Neuropsychological tests

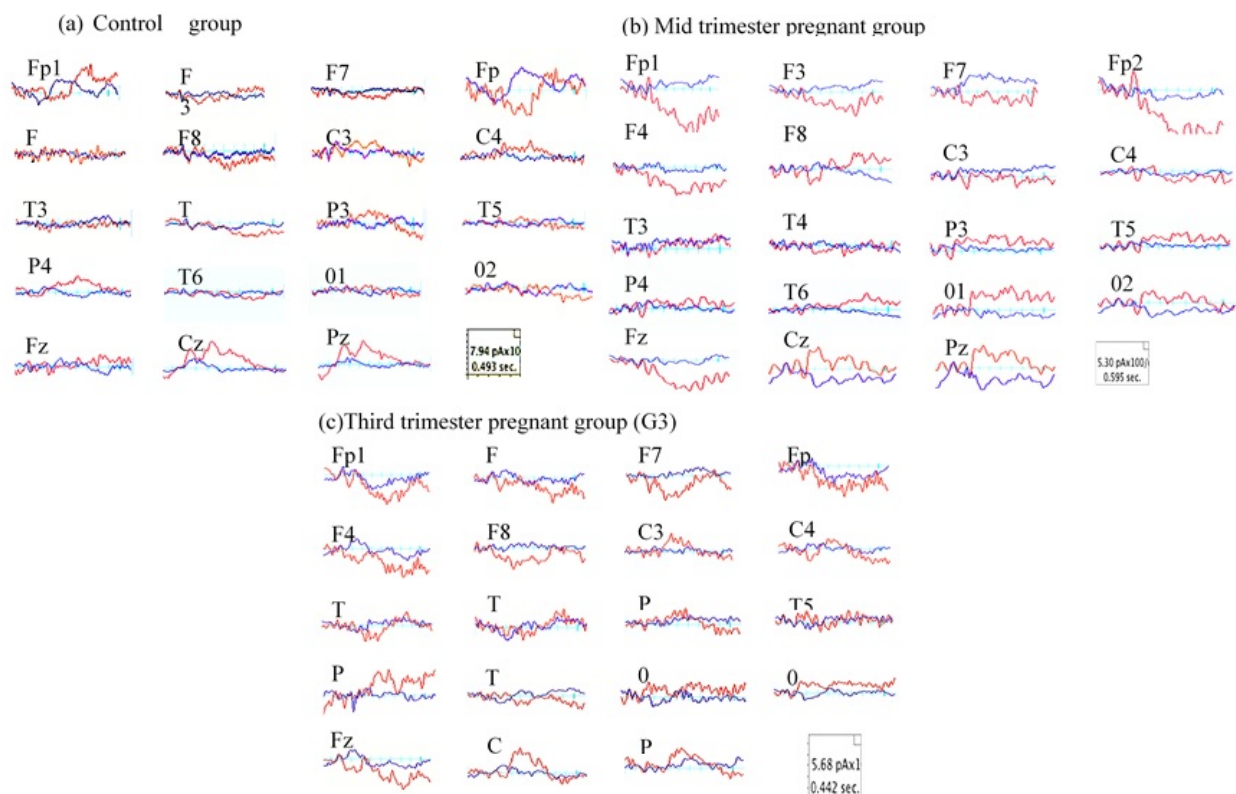
Subjects were assessed using a range of neuropsychological tests. The Controlled Oral Word Association (COWA or PAS), Wisconsin card sorting test (WCST), Zazzo's cancellation test (ZCT) were performed to assess executive functions, the Rey Auditory Verbal and Learning Test (RAVLT) was used to assess auditory attention and memory assessment among groups.

### Data analysis

A band-pass filter was set to 0.3-50 Hz with 0.5 Hz stimulus rate. The electrode impedance was kept below 50 K $\Omega$ . Data were segmented from 100 ms before stimulus presentation to 800 ms after stimuli. Artefacts such as eye blink, eye movements and movement artefacts, were removed using the artefact detection tool in Net-Station software. Baseline correction was performed 100 ms before stimuli. We examined the mean differences in amplitudes of the P50, N100 and P300 ERP components between responses to the target and standard stimuli, using 19 electrode channels (FP1, FP2, F3, F4, F7, F8, Fz, C3, C4, Cz, P3, P4, Pz, T3, T4, T5, T6, O1 and O2). To identify significant differences, the ERP and neuropsychological test data were analyzed using SPSS24 software with one-way ANOVA. The significance level was set to  $p \leq 0.05$ .

## Results

**Figure 1** shows the grand average waveforms of the P50, N100 and P300 ERP components, comparing the neural responses towards auditory stimulation between the control group (G1) (**Figure 1a**), the mid trimester pregnancy group (G2) (**Figure 1b**) and the third trimester pregnancy group (G3) (**Figure 1c**). **Tables 1, 2 and 3** show the mean differences of amplitudes in the P50, N100 and P300 components, respectively, in responses to target and standard stimuli, between the three groups.



**Figure 1** Grand average waveforms of the P50, N100 and P300 ERP components during target and standard stimuli within control (a) mid trimester pregnancy (b) third trimester pregnancy (c) groups at 19 electrodes sites (n=15, n=12, n=12 respectively). Standard stimuli (blue color) and target stimuli (red color).

### P50 ERP Component

The amplitudes of the P50 ERP component were more clearly identified in the G3 group compared with the G2 and G1 groups. Significantly greater amplitudes of P50 ERP

component were evoked across three channels (F7,  $p = 0.034$ , and C3,  $p = 0.034$ ;  $G3 > G1 > G2$ ) (T4,  $p = 0.031$ ;  $G2 > G3 > G1$ ). The group effects were  $F(df) = 3.660 (2, 36)$ ,  $F(df) = 3.679 (2, 36)$  and  $F(df) = 3.797 (2, 36)$ , respectively (**Table 1**).

**Table 1** The amplitudes of P50 ERP component were shown across groups (control, 2nd trimester pregnancy and 3rd trimester pregnancy).

Sites	Control (G1) (mean $\pm$ SD)	2nd trimester Pregnancy(G2) (mean $\pm$ SD)	3rd trimester Pregnancy(G3) (mean $\pm$ SD)	F(df)	p
		P50 ERP Component Amplitudes (in mV) (mean $\pm$ SD)			
Fz	1.27 $\pm$ 0.61	1.30 $\pm$ 0.57	1.70 $\pm$ 1.11	1.222 (2,36)	0.305
Cz	0.70 $\pm$ 0.53	1.00 $\pm$ 0.76	1.02 $\pm$ 0.53	1.263 (2,36)	0.294
Pz	1.07 $\pm$ 0.80	1.13 $\pm$ 0.88	1.52 $\pm$ 0.85	1.122 (2,36)	0.335
Fp1	1.60 $\pm$ 1.06	2.24 $\pm$ 1.23	1.80 $\pm$ 0.92	1.878 (2,36)	0.166
Fp2	1.63 $\pm$ 1.67	2.14 $\pm$ 1.29	2.55 $\pm$ 0.85	3.058 (2,36)	0.058
F3	1.16 $\pm$ 0.48	1.20 $\pm$ 0.63	1.53 $\pm$ 0.68	1.513 (2,36)	0.232
F4	0.93 $\pm$ 0.47	1.20 $\pm$ 0.80	1.22 $\pm$ 0.77	0.804 (2,36)	0.455
F7	1.11 $\pm$ 0.65	1.05 $\pm$ 0.60	1.71 $\pm$ 0.85	3.660 (2,36)	0.034
F8	0.98 $\pm$ 0.70	1.89 $\pm$ 0.97	1.23 $\pm$ 0.73	0.317 (2,36)	0.73
C3	0.86 $\pm$ 0.32	0.76 $\pm$ 0.39	1.12 $\pm$ 0.32	3.679 (2,36)	0.034

C4	0.80 ± 0.33	1.06 ± 0.80	1.11 ± 0.59	1.086 (2,36)	0.347
T3	1.17 ± 0.67	0.92 ± 0.63	1.53 ± 1.09	2.061 (2,36)	0.14
T4	0.72 ± 0.36	1.36 ± 1.07	0.81 ± 0.28	3.797 (2,36)	0.031
T5	1.09 ± 0.71	0.97 ± 0.71	1.26 ± 0.78	0.504 (2,36)	0.608
T6	0.84 ± 0.34	1.30 ± 1.11	0.82 ± 0.53	1.959 (2,36)	0.154
P3	0.93 ± 0.54	0.87 ± 0.69	1.19 ± 0.54	1.052 (2,36)	0.359
P4	0.82 ± 0.40	1.08 ± 0.95	0.84 ± 0.49	0.700 (2,36)	0.502
O1	1.05 ± 0.41	1.32 ± 1.07	1.30 ± 0.76	0.572 (2,36)	0.569
O2	1.00 ± 0.42	0.94 ± 0.93	1.40 ± 0.84	1.416 (2,36)	0.254

\*Note: p≤0.05

### N100 ERP Component

Total three electrode channels showed significant difference among groups. G3 evoked significant difference amplitudes at Cz between groups (F (df) = 4.542 (2, 36), p = 0.017,

G3>G2>G1) (Table 2). The significantly greater amplitudes were observed in the G1 group at other two sites, F8 (F (df) = 3.503 (2,36), p = 0.039) and T4 (F (df) = 4.005 (2,36), p = 0.026, G1>G3>G2) (Table 2).

**Table 2** The amplitudes of N100 ERP component were revealed across groups (control, 2nd trimester pregnancy and 3rd trimester pregnancy).

Sites	Control (G1) (mean ± SD)	2nd trimester Pregnancy(G2) (mean ± SD)	3rd trimester Pregnancy(G3) (mean ± SD)	F(df)	p
Fz	1.25 ± 0.88	0.93 ± 1.03	1.72 ± 1.26	1.970 (2,36)	0.152
Cz	0.63 ± 0.86	1.42 ± 1.07	1.69 ± 1.03	4.542 (2,36)	0.017
Pz	0.67 ± 1.07	1.63 ± 1.42	2.30 ± 2.52	3.269 (2,36)	0.048
Fp1	1.58 ± 1.45	1.47 ± 1.48	2.04 ± 1.57	0.526 (2,36)	0.595
Fp2	1.97 ± 1.41	1.73 ± 1.36	2.62 ± 2.42	0.941 (2,36)	0.399
F3	1.25 ± 1.18	0.94 ± 0.81	1.90 ± 1.21	2.825 (2,36)	0.071
F4	1.32 ± 1.13	0.83 ± 0.85	1.37 ± 1.45	1.017 (2,36)	0.371
F7	1.04 ± 1.28	0.90 ± 0.80	1.23 ± 0.97	0.335 (2,36)	0.717
F8	1.28 ± 0.72	0.53 ± 0.72	0.73 ± 1.07	3.503 (2,36)	0.039
C3	1.09 ± 0.68	0.82 ± 0.45	1.46 ± 0.99	2.796 (2,36)	0.073
C4	1.30 ± 0.70	0.87 ± 0.70	1.22 ± 1.09	1.219 (2,36)	0.306
T3	1.19 ± 0.91	0.93 ± 1.00	1.39 ± 0.94	0.817 (2,36)	0.449
T4	1.16 ± 0.47	0.53 ± 0.79	0.68 ± 0.67	4.005 (2,36)	0.026
T5	1.00 ± 0.93	1.30 ± 0.98	1.55 ± 1.13	1.037 (2,36)	0.364
T6	1.02 ± 0.55	1.10 ± 1.00	1.11 ± 0.95	0.054 (2,36)	0.947
P3	0.93 ± 0.62	1.12 ± 0.73	1.41 ± 0.99	1.350 (2,36)	0.271
P4	1.25 ± 0.45	0.84 ± 0.56	1.22 ± 1.02	1.728 (2,36)	0.19
O1	0.96 ± 0.64	1.80 ± 1.25	1.42 ± 1.90	3.030 (2,36)	0.059
O2	0.72 ± 0.83	1.62 ± 1.79	1.52 ± 1.37	1.936 (2,36)	0.157

\*Note: p≤0.05

### P300 Component

Between-group comparisons of the P300 ERP component are shown in Table 3. Significant differences in amplitudes were identified at Fz (G3>G2>G1) and FP1 (G2>G3>G1) ( $p =$

0.028 and  $p = 0.015$ , respectively). The group effects were F (df) = 3.925 (2,36) and F (df) = 4.625 (2,36), respectively (Table 3). Within pregnant group, G2 evoked higher amplitudes of P300 component at FP1 ( $8.28 \pm 4.52 \mu\text{V}$ ) comparing with the G3 group at Fz location ( $5.87 \pm 2.73 \mu\text{V}$ ) (Table 3).

**Table 3** The amplitudes of P300 ERP component were shown among groups (control, 2nd trimester pregnancy and 3rd trimester pregnancy).

Sites	Control (G1) (mean $\pm$ SD)	2nd trimester Pregnancy(G2) (mean $\pm$ SD)	3rd trimester Pregnancy(G3) (mean $\pm$ SD)	F(df)	p
		P300 ERP Component Amplitudes (in $\mu\text{V}$ ) (mean $\pm$ SD)			
Fz	3.03 $\pm$ 2.45	5.09 $\pm$ 3.21	5.87 $\pm$ 2.73	3.925 (2,36)	0.028
Cz	0.63 $\pm$ 2.40	2.02 $\pm$ 2.37	1.27 $\pm$ 2.23	1.417 (2,36)	0.254
Pz	1.19 $\pm$ 2.25	1.30 $\pm$ 3.53	1.56 $\pm$ 3.18	0.052 (2,36)	0.949
Fp1	4.25 $\pm$ 3.92	8.28 $\pm$ 4.52	7.85 $\pm$ 3.48	4.625 (2,36)	0.015
Fp2	6.16 $\pm$ 3.45	7.20 $\pm$ 5.10	6.73 $\pm$ 4.94	0.215 (2,36)	0.808
F3	2.50 $\pm$ 3.67	4.02 $\pm$ 2.65	5.00 $\pm$ 2.60	2.415 (2,36)	0.102
F4	3.46 $\pm$ 2.43	3.24 $\pm$ 2.57	5.87 $\pm$ 5.20	2.359 (2,36)	0.107
F7	2.23 $\pm$ 2.92	2.93 $\pm$ 1.97	3.60 $\pm$ 3.36	0.847 (2,36)	0.436
F8	3.04 $\pm$ 2.43	3.15 $\pm$ 3.20	2.81 $\pm$ 1.14	0.067 (2,36)	0.936
C3	1.26 $\pm$ 1.19	1.47 $\pm$ 1.84	1.25 $\pm$ 1.25	0.110 (2,36)	0.896
C4	1.58 $\pm$ 1.13	1.88 $\pm$ 1.40	1.48 $\pm$ 1.80	0.305 (2,36)	0.739
T3	2.43 $\pm$ 2.11	1.80 $\pm$ 2.39	2.28 $\pm$ 3.25	0.261 (2,36)	0.772
T4	2.79 $\pm$ 2.05	2.20 $\pm$ 2.02	2.76 $\pm$ 2.59	0.344 (2,36)	0.711
T5	1.99 $\pm$ 1.64	0.89 $\pm$ 2.04	1.17 $\pm$ 1.68	1.571 (2,36)	0.22
T6	1.85 $\pm$ 1.27	1.38 $\pm$ 1.53	1.51 $\pm$ 2.06	0.359 (2,36)	0.7
P3	1.11 $\pm$ 1.19	0.37 $\pm$ 1.69	1.03 $\pm$ 2.37	0.844 (2,36)	0.437
P4	1.50 $\pm$ 1.65	0.93 $\pm$ 1.28	0.69 $\pm$ 2.17	0.852 (2,36)	0.434
O1	2.26 $\pm$ 2.96	1.07 $\pm$ 3.57	1.73 $\pm$ 2.21	0.618 (2,36)	0.544
O2	1.82 $\pm$ 1.42	1.35 $\pm$ 2.52	1.26 $\pm$ 1.47	0.373 (2,36)	0.691

\*Note:  $p \leq 0.05$

### Neuropsychological Tests

The neuropsychological test scores are shown for the three groups in Table 4. Six neuropsychological tests were conducted. The highest (significantly) scores were found in WCST, ZCT and nearly significant difference was in RAVLTim within group.

For the WCST, the highest scores (lowest marks in case of WCST) were found in the G2 group, compared with the G1 and G3 groups (G2>G1>G3). In case of the ZCT, and the results revealed that the G1 group had the highest (significantly) score, followed by the G3 and G2 groups (G1>G3>G2).

The highest scores on the RAVLT were achieved in the G2 group, followed by the G3 and G1 groups. In the RAVLTim, G2 subjects exhibited the nearly significant ( $p = 0.099$ ) (the highest score among three groups), while G1 subjects exhibited the lowest scores (G2>G3>G1). The WCST (F (df) = 843.776 (2,36),  $p = 0.001$ ) and ZCT (F (df) = 528.598 (2,36),  $p = 0.001$ ) revealed significant differences between groups.

In contrast, no significant between-group differences were found in PAS ( $p = 0.693$ ), RAVLTs ( $p = 0.375$ ) or RAVLTdr ( $p = 0.505$ ) (Table 4).

**Table 4** The scores of different neuropsychology tests among G1, G2 and G3.



Neuro-psychology test	Control (G1) (mean $\pm$ SD)	2nd trimester Pregnancy (G2) (mean $\pm$ SD)	3rd trimester Pregnancy(G3) (mean $\pm$ SD)	F(df)	p
PAS	41.50 $\pm$ 9.95	45.58 $\pm$ 17.41	45.00 $\pm$ 11.64	0.370 (2,36)	0.693
WCST	2.14 $\pm$ 1.41	1.58 $\pm$ 1.83	2.42 $\pm$ 1.73	843.776 (2,36)	0.001
ZCT	27.50 $\pm$ 1.95	26.75 $\pm$ 2.90	26.42 $\pm$ 2.27	528.598 (2,36)	0.001
RAVLTs	50.93 $\pm$ 6.31	58.00 $\pm$ 19.99	56.33 $\pm$ 11.06	1.009 (2,36)	0.375
RAVLTim	5.29 $\pm$ 2.61	7.83 $\pm$ 3.97	7.08 $\pm$ 2.27	2.471 (2,36)	0.099
RAVLTdr	17.00 $\pm$ 6.86	13.00 $\pm$ 6.45	16.67 $\pm$ 13.46	0.698 (2,36)	0.505

\*Note: p $\leq$ 0.05

## Discussion

The current study assessed auditory cognitive function assessment using the ERP components of the P50, N100 and P300 evoked by auditory oddball stimuli, reflecting auditory sensory gating, perception and attention, respectively. Meanwhile, executive function and auditory attention and memory of subjects were assessed through four neuropsychological tests: the PAS, WCST, ZCT and RAVLT (RAVLTs, RAVLTim and RAVLTdr).

The current finding that the G3 group exhibited the greatest (significantly) P50 and N100 amplitudes is in accord with a previous study regarding the progesterone levels at different stages of pregnancy, reporting higher levels in the third trimester compared with pregnant women in the second trimester and a non-pregnant group [18]. The P50 and N100 ERP components indicated the sensory gating and sensory perception, respectively and their relationship with higher order cognitive function (attention) is negative [19]. The early P50 and N100 components reflect the neural origin of somatosensory processing, which is also known as sensory gating of cognitive function, as indicated by Desment and Tomberg's finding that the somatosensory processes underlying early ERP components are sensitive to cognitive factors determining the direction of attention [20]. Studies suggested that higher amplitudes of P50 ERP component indicated sensory overload which is the failure of filtering mechanism [21-23] and it leads inadequate attention [22,23]. Low amplitudes and short latencies in both the P50 and N100 components are thought to indicate good cognitive performance [24]. A review by Luck reported that the P50 component in response to auditory clicks reflects the flow of auditory information from the thalamus to the auditory cortex. Thus, this component is thought to be related to sensory gating detection, or pre-attentive processing directed towards a stimulus [25]. A study by Begum et al. of auditory cognitive functional assessment during the second trimester of pregnancy focused on the N100 and P300 ERP components using an auditory oddball paradigm. Based on Begum et al. findings, we examined whether a third trimester pregnant group exhibited reduced auditory perception compared with a second trimester pregnant group [10]. In the current study, the G3 group exhibited the greatest (significantly) P50 (at three

sites out of three) and N100 amplitudes (at one sites out of three), and the highest (significantly) P300 amplitudes at one site out of two sites (**Tables 1-3**). Moreover, the G2 group exhibited the smallest (significantly) amplitudes of the N100 component at two sites (F8, T4), indicating that G2 subjects may have exhibited better auditory perception compared with G3 subjects. Kumar and Magon suggested that higher progesterone levels during third trimester pregnancy can reduce cognitive function (attention) [26] but the level of attention still greater than control participants. Taking all the suggestions, we assume that G3 subjects have sensory overload (as significant highest amplitude in P50 at 3 sites), less sensory perception (as significant highest amplitude in N100 at one site) comparing with the G1 and G2 which might be the effect of high progesterone during 3rd trimester of pregnancy.

It was documented that higher amplitude of the P300 amplitude can be evoked during higher attention [27]. The P300 amplitude was increased [9,10] and decreased [7,8] in different studies in pregnant group. However, the experimental paradigm was different in each study. The current P300 results suggest higher auditory cognitive function/attention (significant higher amplitudes of P300 at two sites) among pregnant groups (G2 and G3) comparing with the G1 group. P300 amplitude was the greatest (significantly) in the G2 group (at FP1) and second greatest at Fz, suggesting a high level of auditory cognitive function/attentional function in the second trimester of pregnancy. Comparing the two sites of P300 amplitudes at FP1 and Fz, G2 subjects evoked higher P300 amplitude (at FP1, 8.28  $\pm$  4.52  $\mu$ V) comparing with the G3 subjects (at Fz, 5.87  $\pm$  2.73  $\mu$ V) (**Table 3**). These P300 findings may suggest that later stages of pregnancy involve reduced attention comparing with the 2nd trimester pregnant group but still better attention than control group (higher P300 amplitude comparing with G1) (**Table 3**).

The G2 group exhibited better executive function in terms of auditory attention and memory, compared with the G3 group. However, the ERP results need to be integrated with neuropsychological testing to provide comprehensive understanding of executive functions in auditory memory and attention. The current neuropsychological test data (**Table 4**) revealed that the G2 group exhibited the highest scores on the WCST (significantly) and RAVTIM (nearly significantly), while

the second-highest scores were achieved by the G3 group on the ZCT and RAVTIM. The G1 subjects revealed the highest (significantly) score in ZCT and 2nd highest score in WCST (**Table 4**). Overall, pregnant group (G2, G3) revealed better performance compared with the G1 group as pregnant group gained the highest scores at two tests (significantly) and control group gained the highest in one test (significantly). On the other hand, the high performance of the G2 group may suggest better executive function, auditory memory and attention than the G3 group.

The good performance of WCST test was based on the low error rate, while the good performance in the RAVLT and ZCT tests depends on the higher score [28,29]. There is lack of neuropsychology studies on pregnant women using various types of tests. However, one study used concept shifting test (CST), Stroop test, letter digit substitution test (LDST), visual verbal word learning test (WLT) to assess speed processing, memory and attention among pregnant women. This study found that the performance of pregnant women was poorer compared with the control group [30]. However, these tests are different from our current study and we found that pregnant group performed better compared with the control which is the opposite interpretation from Groot et al. study. As our 2nd trimester group revealed the highest score in two tests compared with the 3rd trimester group, therefore we conclude that 2nd trimester subjects performed better than 3rd trimester subjects.

## Conclusion

The current results indicated improved auditory cognitive function among pregnant subjects compared with non-pregnant groups. In addition, neuropsychological test results indicated better executive function, auditory memory and attention during mid trimester than third trimester pregnancy. To our knowledge, no previous study has used combined ERP and neuropsychological tests to compare cognitive function between different trimesters of pregnancy using auditory oddball stimulation. The current findings have a range of potential applications and may aid pregnant women to develop better therapeutic strategies to improve their quality of life.

## Conflicts of Interest and Funds

All authors declared that they have no conflicts of Interest. This study was supported by the short-term grant of Universiti Sains Malaysia (USM) (304/PPSP/61313160).

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