Hormones and Behavior 116 (2019) 104575

Contents lists available at ScienceDirect

Hormones and Behavior

journal homepage: www.elsevier.com/locate/yhbeh

Cognitive, neural and endocrine functioning during late pregnancy: An Event-Related Potentials study

Ora Fiterman[a], Sivan Raz[a,b,*]

[a] Department of Behavioral Sciences, The Center for Psychobiological Research, The Max Stern Yezreel Valley College, Israel
[b] Department of Psychology, Tel Hai College, Israel

ARTICLE INFO

Keywords:
Pregnancy
Cognition
Event-Related Potentials
Cortisol reactivity
Response inhibition

ABSTRACT

This study investigated cognitive, neural and endocrine function during late pregnancy. One of the first to examine brain ERPs in pregnant women, the study is unique in its focus on response inhibition function. In the study, cognitive function was evaluated by a digit-symbol coding test, an arithmetic ability test, and a visual stop-signal task which places enhanced demands on impulse control and response inhibition, considered a hallmark of executive function. Brain activity was measured by scalp-recorded Event-Related Potentials (ERPs) during the stop-signal task. HPA axis reactivity was assessed by measuring salivary cortisol levels before and after experimental sessions. Test performance, ERPs and cortisol reactivity were compared across groups of 23 women in their third trimester of pregnancy and 22 non-pregnant controls. Pregnant women scored lower than the control group on the digit–symbol coding test. On the stop-signal task, both groups had similar error rates, but pregnant women had longer response times to Go trials. On the Stop condition of the task in which a response must be inhibited, pregnant women demonstrated significantly better performance. At the electrophysiological level, in response to Go stimuli pregnant women exhibited greater amplitude of P2 than controls. In response to Stop-signals, pregnant women had lesser amplitudes of P1 and N2 and greater amplitude of P3. Cortisol reactivity to the test session was significantly more pronounced in non-pregnant women with significant correlations found between cortisol reactivity and behavioral responses. The results suggest that response patterns of women in late pregnancy are less impulsive and more cautious and controlled.

1. Introduction

Studies that have assessed subjective reports of cognitive change during pregnancy find that most pregnant women perceive their cognitive functioning as being adversely affected. They subjectively rate themselves as having poorer memory, attention and concentration abilities relative to the pre-pregnancy period (Brett and Baxendale, 2001; Christensen et al., 1999; Crawley et al., 2003; Crawley et al., 2008; Henry and Rendell, 2007). Empirical studies in this field have focused primarily on memory function and have yielded inconsistent results (Henry and Rendell, 2007). While some studies support the self-reported memory decline during pregnancy (Brett and Baxendale, 2001; Buckwalter et al., 1999; Crawley et al., 2008; de Groot et al., 2006; Farrar et al., 2014; Macbeth and Luine, 2010; Rendell and Henry, 2008), others have failed to identify any impairment (Casey et al., 1999; Christensen et al., 2010; Crawley et al., 2003; Logan et al., 2014; Onyper et al., 2010), and still others suggest specific pregnancy-related advantages and improvements in certain memory tasks (Christensen et al., 1999; Anderson and Rutherford, 2012).

Similar inconsistencies in results emerge in the far fewer studies that have assessed other aspects of cognition such as attention and executive function during pregnancy; some studies report, for example, attention deficits in pregnant women (de Groot et al., 2003), while others fail to recognize pregnancy-related changes in attention (Crawley et al., 2008; Buckwalter et al., 1999; Farrar et al., 2014). These discrepancies may be due to methodological variations, e.g. using different types of tasks, with each task examining a specific aspect of cognition; as well as discrepancies in comparison groups and participants' characteristics such as stage of pregnancy and parity. All in all, the relatively small number of objective studies on cognitive function during pregnancy draws a complex picture and does not entirely support the frequently self-reported cognitive decline among pregnant women.

If pregnancy involves cognitive changes of some sort, it is reasonable to speculate that these are mediated by, or associated with, pregnancy-related physiological processes, particularly those related to the nervous and endocrine systems. Little research has been carried out on

* Corresponding author at: The Max Stern Yezreel Valley College, Emek Yezreel 19300, Israel.
E-mail address: sivanr@yvc.ac.il (S. Raz).

https://doi.org/10.1016/j.yhbeh.2019.104575
Received 9 October 2018; Received in revised form 29 July 2019; Accepted 19 August 2019
Available online 26 August 2019
0018-506X/

the neural and/or hormonal changes accompanying the perceived cognitive changes. Research in non-human females (especially rodents) indicates a number of morphological and neurochemical changes occurring throughout the brain during pregnancy (Kinsley et al., 2006). Many of these changes occur in brain regions known to underlie cognition, such as the hippocampus, cortex, limbic system and olfactory bulb (Rendell and Henry, 2008). However, very little is known about neuroanatomical and neurofunctional changes in the brain of pregnant women. In an MRI study, Oatridge et al. (2002) reported an overall decrease in brain volume during pregnancy, with the brain returning to preconception size in the postpartum period. Hoekzema et al. (2016) found pregnancy-related reductions in gray matter volume in regions subserving social cognition. These reductions endured for at least two years post-pregnancy. Concerns about the safety of brain imaging (e.g. fMRI and PET) during pregnancy may have hampered neurofunctional research from proceeding. Roos et al. (2011) examined neural circuitry involved in processing fear-relevant stimuli during pregnancy using Near-Infrared Spectroscopy (NIRS), which is non-invasive and involves no harmful radiation. They found altered prefrontal cortex function during processing of fear-relevant stimuli in pregnant women when compared with controls and suggested that the underlying neuroanatomical basis for cognitive-affective alterations during pregnancy may include frontal-amygdala circuitry. Bannbers et al. (2013) used event-related functional magnetic resonance imaging and found that women in postpartum (within 48 h of delivery and at 4–7 weeks postpartum) displayed lower activity during response inhibition task in the bilateral inferior frontal gyri and precentral gyri compared to non-postpartum controls. However, this study did not examine neurofunctional changes during pregnancy.

The non-invasive Event-Related Potentials (ERPs) technique may provide another safe means for assessing brain function during pregnancy (Maupin et al., 2015). ERPs are scalp-recorded electro-encephalographic (EEG) measurements of the activity of neural populations in response to a stimulus. ERPs offer excellent temporal precision and resolution in measuring the dynamic nature of the neural activity underlying sensory and cognitive processing. Studies on ERP correlates of cognitive function during pregnancy are scarce (Olofsson et al., 2005; Rutherford et al., 2016; Rutherford et al., 2017), with only one study examining ERPs in response to visual stimuli (Raz, 2014). This study assessed sustained attention by using a visual oddball task in which pregnant and non-pregnant women had to point out as quickly as possible the occurrence of a “target” (deviant, rare) stimulus while withholding response to any “non-target” (standard, frequent) stimulus. Results showed pregnancy-related cognitive modulations accompanied by alterations in amplitudes of the N170 and P300 ERP components.

Pregnancy involves drastic endocrine changes, including considerable change in the function of the hypothalamic-pituitary-adrenocortical (HPA) axis. The HPA axis is considered a critical physiological system that mediates response to stress and psychological and physiological arousal. In the face of environmental stressors, the HPA axis is activated, resulting in the secretion of cortisol from the adrenal cortex to the blood stream. The secretion of cortisol, which represents a biological indicator of arousal, is an adaptive response that alerts the individual to environmental changes and promotes the recovery of homeostasis (Foley and Kirschbaum, 2010). Cortisol has been shown to affect cognitive function since it is capable of modulating psychological processes related to attention, learning and memory through its action at receptors in limbic structures such as the amygdala and hippocampus (Fairchild, 2012). In general, pregnancy is characterized by a progressive increase in plasma concentrations of CRH, ACTH and cortisol (Brunton et al., 2008; de Weerth and Buitelaar, 2005), while the diurnal rhythm of cortisol mainly remains the same (Kivlighan et al., 2008). However, despite the high levels of basal cortisol, pregnancy has been repeatedly shown to be a physiological state in which HPA axis responsiveness to stressors is markedly attenuated. Progressive dampening of the HPA axis and attenuation of behavioral stress responses during pregnancy have been reported mainly in female rodents (Brunton et al., 2008) and, to a lesser extent, in women (de Weerth and Buitelaar, 2005; Kammerer et al., 2002). It has been suggested that attenuated reactivity of the HPA axis may work to protect mother and offspring from the adverse effects of arousal and stress (Brunton and Russell, 2008; Brunton et al., 2008; Macbeth and Luine, 2010).

The aim of the present study was to investigate pregnancy-related behavioral, neural and endocrine correlates of cognitive function. The pregnancy group comprised of women in the third trimester of pregnancy since most studies in this field reported more significant cognitive and endocrine changes during late stages of pregnancy (e.g. Brunton and Russell, 2008; Brunton et al., 2008; Christensen et al., 2010; de Weerth and Buitelaar, 2005; Foley and Kirschbaum, 2010; Henry and Rendell, 2007; Kammerer et al., 2002; Raz, 2014). Specifically, cognitive function was evaluated by a digit-symbol coding test that measures attention and visuomotor ability, an arithmetic test that measures arithmetic/computational ability, and a visual stop-signal task. The mental arithmetic task, in addition to measuring specific cognitive ability, is also frequently used as a method to induce stress in the field of psychophysiology (Castaldo et al., 2015; de Weerth and Buitelaar, 2005; Karthikeyan et al., 2011; Karthikeyan et al., 2012; Kirschbaum et al., 1993). The stop-signal task, one of the most widely used behavioral paradigms in studies of cognitive control, was performed while electrophysiological recording took place. This attentional task places enhanced demands on response inhibition and impulse control by inducing a strong response set (the participant is expected to respond most of the time but occasionally must inhibit his/her tendency to respond). Stopping a response requires a fast control mechanism that prevents the execution of the motor response. Response inhibition, i.e. the ability to inhibit inappropriate or irrelevant responses, is a hallmark of executive function that allows individuals to restrain habitual responses, detect errors, and learn from errors by behavioral adaptation (Li et al., 2008; Lijffijt et al., 2005; Logan, 1994; Verbruggen and Logan, 2008). The stop-signal task has been suggested as a promising tool for the evaluation of behavioral impulsivity in various clinical and normative populations (Chamberlain and Sahakian, 2007; Dimoska and Johnstone, 2007). Impulse control may be of importance in promoting pregnant woman's health and successful development of the fetus. We hypothesized that pregnant women will demonstrate better capability in inhibiting their tendency to respond on stop-signal trials.

Existing literature include some adult stop-signal ERP studies in non-clinical populations (though most studies were done on children). Several ERP components (e.g. N2 and P3) with a fronto-central or central scalp distribution have been linked with the response inhibition process as their amplitude is augmented in Stop trials relative to Go trials. Importantly however, unlike the present study, most of existing adult studies used auditory stop-signals and focused on differences between successful and unsuccessful stop trials (Dimoska et al., 2006; Kok et al., 2004; Ramautar et al., 2004). The present study was not interested in general effects of the stop signal task within a single group, but rather in inhibitory control differences between pregnant and non-pregnant women. To our knowledge, no ERP study to date has examined attention and response inhibition in pregnant women using a stop-signal task. Given the lack of previous studies in this field (response inhibition-related ERPs during pregnancy), our ERP analyses are partly exploratory in nature. To examine HPA axis responsiveness, levels of cortisol in saliva were measured before and after completion of the test session, which may be considered a mild cognitive psychological stressor (de Weerth and Buitelaar, 2005; Karthikeyan et al., 2011). We expected attenuated cortisol reactivity in pregnant women relative to controls. Test performance, ERPs and cortisol reactivity to the mental-cognitive challenge were compared across groups of pregnant (third trimester) and non-pregnant women. Correlations between cortisol reactivity and behavioral and ERP responses were also evaluated. Such correlations were not previously explored in pregnant women.

The estimated prevalence of perinatal anxiety disorders varies considerably between studies, with inconclusive evidence as to whether prevalence among pregnant women differs from that of non-pregnant populations. However, many studies do suggest that pregnancy is a time of increased vulnerability for the development of anxiety and report high incidence of antenatal anxiety disorders (Biaggi et al., 2016; Giardinelli et al., 2012; Goodman et al., 2014; Raz, 2014; Ross and McLean, 2006; Viswasam et al., 2019). It is therefore important, in the context of the present study, to take anxiety levels of pregnant and non-pregnant women into consideration, and to control for possible involvement of anxiety in between-group differences in neurocognitive function and cortisol reactivity. The present sample thus included only women with no known prior history or current diagnosis of mental disorders including anxiety, and trait and state anxiety levels were assessed.

2. Methods

2.1. Participants

Twenty-three pregnant women in the third trimester of pregnancy and 22 non-pregnant women participated in this study. The sample consisted of college administrative and academic staff as well as undergraduate and graduate students. All participants were Jewish women with Hebrew as their mother tongue. Inclusion criteria required that pregnant participants be: 18 years of age or older, not currently suffering from a serious medical condition, experiencing normal current pregnancies, and without a history of adverse pregnancy-related conditions or terminations. The cut-off gestational age for inclusion in the study was 26 weeks. Non-pregnant control participants were matched to the pregnant group for age, ethnicity, socioeconomic status, educational level and number of children. 50% of pregnant women and 48% of non-pregnant women were mothers; children were over 1 year of age. Characteristics of pregnant and non-pregnant women are reported in Table 1. All participants had normal or corrected-to-normal vision, and none had a prior history of neurological or psychiatric disorders. Written informed consent was obtained from all participants with undergraduate students given course credit according to their academic requirements and staff members participated voluntarily. The study was approved by the institutional review board.

2.2. Measures

2.2.1. State-trait anxiety inventory

State Anxiety (SA) and Trait Anxiety (TA) were measured by the Spielberger State-Trait Anxiety Inventory (STAI) (Spielberger et al., 1983). The STAI state scale consists of 20 statements asking people to describe how they feel at a particular moment in time rated on a 4-point intensity scale ranging from ‘not at all’ to ‘very much so’. The STAI trait scale consists of 20 statements describing how people generally feel rated on a 4-point frequency scale ranging from ‘almost never’ to ‘almost always’. Scores range from 20 (low anxiety) to 80 (high anxiety). Cronbach's alpha value for the current sample was 0.786 for the State anxiety scale and 0.862 for the Trait anxiety scale.

Table 1
Characteristics of pregnant and non-pregnant women with respect to age, education level, number of children, gestational age and levels of state- and trait anxiety.

	Pregnant (n = 23)			Non-pregnant (n = 22)			
	Mean	SD	Range	Mean	SD	Range	*p*
Age (years)	33.74	4.80	23–42	31.50	6.53	22–44	0.20
Education (years)	17.74	2.94	13–21	17.09	2.32	13–21	0.49
Number of children	0.78	0.90	0–2	1.00	1.19	0–3	0.42
Gestational age (weeks)	32.00	3.69	26–37	–	–	–	
State anxiety	51.74	2.28	47–56	52.68	1.58	50–56	0.12
Trait anxiety	32.96	4.61	27–43	34.09	8.92	22–61	0.60

2.2.2. Digit-symbol coding test

A subtest taken from the Wechsler Adult Intelligence Scale - Third Edition (WAIS–III) (Wechsler, 1997). This test consists of a look-up table showing pairs of digits and hieroglyphic-like symbols and rows of boxes with a digit in the top section of the box and an empty space in the bottom section. Using the index of digit-symbol pairs, the subjects are asked to draw the appropriate symbol under each number. The grade on this subtest is determined by the number of symbols copied correctly within a time frame of 120 s. This subtest measures attention and visual-motor speed and complexity. The maximum grade is 131.

2.2.3. Arithmetic ability test

A 32-question test consisting of various arithmetic problems that can be solved without the use of a calculator (Raz and Leykin, 2015). The test included 19 problems taken from Raven's Progressive Matrices Test (Raven, 1938), a widely used, nonverbal test of analytic intelligence which has been found to predict performance on a wide range of reasoning tasks (Carpenter et al., 1990). Questions suitable for participants above the age of 14 were chosen; additionally, 13 basic arithmetic problems consisting of addition, subtraction, division, multiplication and simple exponentiation operations were devised, such as: 60: [20:(9–4) + 3 × 3 + 2]. In accordance with the Raven test, there were eight possible answers for the arithmetic problems. Participants had 13 min in total to complete the test, and in order to increase the perceived importance of the test, logos of the academic institution, the council for higher education, and the national institute for testing and evaluation were visible on top of each booklet. Cronbach's alpha value was 0.816.

2.2.4. Stop-signal task

The task consisted of 288 photographs of faces (50% male) taken from a standardized face database (Lundqvist et al., 1998). Facial expressions were angry or neutral with 50% probability. These stimuli were presented randomly, one at a time, at the center of a computer screen against a white background, for 500 ms; 75% of the trials were “Go” trials in which participants had to identify the facial expression (angry/neutral) of the stimuli by pressing the left or right button of a computer mouse. Participants were instructed to respond as quickly as possible without compromising accuracy. On a random 25% of trials (“Stop” trials), the Go stimulus was immediately followed (and replaced) by a 250 ms visual stop-signal- a red X mark, and participants had to withhold/inhibit any response to the primary Go stimulus, regardless of the facial expression (response inhibition). Each trial was followed by a blank screen for an inter-trial interval of 1250 ms. The experiment was preceded by a short practice block. During the session, subjects were seated in an armchair, 80 cm away from a 19″ computer screen. Responses could be made during stimulus presentation as well as during inter-trial intervals. Participants were asked to refrain from making eye movements and blinking, as much as possible, throughout the session. The duration of the task is about 9 min.

Error rates on Go and Stop trials and response times on Go trials (GoRTs) were extracted for analyses.

2.2.5. EEG/ERP recording; data acquisition

EEG was recorded continuously during the stop-signal task using a 64-channel Hydro Cel Geodesic Sensor Net, Net Amps 300 amplifier, and Net Station, Version 4.2, software (Electrical Geodesics Inc., Eugene, OR) at 250 Hz with 0.1 Hz high-pass and 100 Hz low-pass filtering. Electrode impedances were maintained below 60 kΩ. All channels were referenced to the vertex sensor during acquisition. After

acquisition, during "offline" processing, the continuous EEG was filtered with a 1–30 Hz band-pass filter and segmented by condition into 800 ms stimulus-locked epochs, ranging from100 ms pre-stimulus to 700 ms post-stimulus. Epochs contaminated with vertical eye movements (eye blinks; ± 140 μV) and horizontal eye movement (± 55 μV) artifacts, as identified by computerized algorithm and verified by visual inspection, were eliminated. In addition, a recording segment was marked bad if it contained more than ten bad channels. Individual bad channels were replaced on a segment-by-segment basis with spherical spline interpolation. After artifact correction, an average of 86.5% of the 288 trials was retained in the analysis. Total trial numbers included in the analyses did not differ between groups. Averaged ERP data were base line corrected and re-referenced into an average reference frame. All stimulus presentations and behavioral response collections were controlled by a PC computer running E-prime 2.0 software (Psychology Software Tools Inc., PA).

2.2.6. Target-evoked ERP components

Based on previous ERP stop-signal studies (Dimoska et al., 2006; Dimoska and Johnstone, 2007; Di Russo et al., 2016; Johnstone et al., 2013; Kok et al., 2004; Ramautar et al., 2004; Ramautar et al., 2006; Shen et al., 2011) and following inspection of scalp topography distributions, we quantified the peak amplitudes of the face sensitive N170 (150–180 ms post-stimulus) and P2 (180–340 ms post-stimulus) in response to Go stimuli (time-locked to the face stimuli), and P1 (110–180 ms post-stimulus), N2 (230–350 ms post-stimulus) and P3 (350–500 ms post-stimulus) in response to Stop stimuli (time-locked to the stop sign). N170 was analyzed for occipitotemporal channels (average of channels 29, 30, 32, 35, 39, 43, 44, 47). P2 to Go stimuli was analyzed for two scalp locations: posterior parietal-occipital (average of channels 33, 34, 35, 36, 37, 38, 39) and frontal (average of channels 2, 3, 5, 6, 8, 9, 10, 11). P1 to Stop stimuli was analyzed for posterior parietal-occipital channels (average of channels 33, 35, 36, 37, 38, 39) and frontal channels (average of channels 3, 4, 6, 7, 9, 54).[1] N2 was analyzed for right frontal channels (average of channels 4, 51, 53, 54, 57, 59, 60) and P3 to Stop stimuli was analyzed for centroparietal channels (average of channels 4, 7, 16, 21, 28, 31, 34, 40, 41, 42, 51, 54). For the electrode array, see Fig. 1.

2.2.7. Cortisol saliva assessment and analysis

Salivary cortisol levels were measured twice during the experimental session: at the beginning of the experiment (base-line; T1) and 20 min after completion of the last task (T2). Subjects were instructed not to eat, drink (except for plain water), chew gum, smoke or brush teeth for 60 min prior to their arrival at the lab. They rinsed their mouth thoroughly with cold water prior to collection of the saliva samples; 2 mL samples of saliva were collected into polypropylene tubes. Samples were maintained at room temperature until the session was completed and then frozen at −20 °C until assayed. All samples remained frozen prior to assay and then were centrifuged at 2000 ×*g* for 10 min. Salivary cortisol concentrations were analyzed in duplicate (the average of the duplicates was used in all analyses) using a commercial Enzyme-Linked Immunosorbent Assay (ELISA) kit (IBL International, Hamburg, Germany) according to manufacturer's protocol.

[1] Polarity conventions at the field of ERP studies are highly inconsistent. ERP waveforms can be plotted with upward deflections indicating positive or negative potentials at the active electrode relative to the reference electrode. Both conventions are used in the literature and no consensus exists as to which is preferable. When comparing waveforms to those in the literature, it is essential to consider differences in recording system and reference method (Duncan et al., 2009; Picton et al., 2000). In this study, all channels were referenced to the vertex sensor during acquisition and then re-referenced into an average reference frame. This resulted in positive going posterior P1 and P2 with a corresponding frontal polarity reversal mirroring posterior effects (see also: Bloom et al., 2013; Flaisch et al., 2010; Mensen et al., 2014).

2.3. Procedure

Pregnant and non-pregnant participants were invited to the laboratory. Upon arrival at the lab, experimenters confirmed that participants had adhered to all instructions as delineated above; participants were then asked to rinse their mouths thoroughly with cold water. Subsequently, they completed the first collection of saliva samples (T1). Participants then completed the state-trait anxiety inventory, the stop-signal task with EEG-ERP recording, the digit symbol-coding test and the arithmetic ability test. Twenty minutes after completion of the arithmetic ability test, participants were asked for the second time to rinse their mouths thoroughly with cold water and provided the second saliva sample (T2). Participants were allowed to have short breaks between tasks. All experimental sessions took place between the hours of 12:00–17:00. See Fig. 2 for schematic description of the procedures during the experimental session.

2.4. Statistical analysis

Between-subject differences in state and trait anxiety, digit-symbol coding test, and arithmetic ability test performance were analyzed by independent-sample *t*-tests.

In analyses of the behavioral and ERP data related to the stop-signal task, angry and neutral faces stimuli were combined to create a single variable (Go stimuli), since preliminary analyses performed with both angry and neutral faces showed neither main effects of facial expression nor interaction effects between facial expression and pregnancy status. As a result, behavioral function and brain activation reflected both general and emotional face processing. To examine group differences in error rates we conducted mixed-model 2 × 2 ANOVA, with Condition (Go/Stop) as the within-subject factor, and Group (pregnant/non-pregnant) as the between-subject factor. Independent sample *t*-tests and paired-sample *t*-tests were used for post-hoc comparisons. Group differences in GoRTs were assessed by independent sample *t*-test. To assess the relationship between pregnancy and brain activity, we used independent sample *t*-tests to analyze amplitudes of the pre-selected ERP components in response to Go and Stop stimuli. The Bonferroni correction was used to adjust for multiple testing. Only results that remained significant after the correction are reported. To assess cortisol reactivity, we used a 2 × 2 mixed-design ANOVA. Time (T1-base-line/T2–20 min post-test session) was the within-subject factor, and Group (pregnant/non-pregnant) was the between-subject factor. Follow-up independent sample *t*-tests were used to break down main effects of Group and interaction effects. Pearson analysis was used to test correlations between levels of cortisol and behavioral and ERP results.[2] Numeric electrophysiological and behavioral results are presented as Mean ± SEM (the standard error of means) both in the text and in the figures.

3. Results

3.1. State-trait anxiety inventory

No differences in trait or state anxiety were found between pregnant and non-pregnant women ($p = 0.598$; $p = 0.116$, respectively).

3.2. Digit–symbol coding test

One participant from each group was excluded from analysis due to familiarity and previous experience with this test. Pregnant women had

[2] Preliminary correlation analyses within the pregnant group showed no significant correlations between tests performance/ERPs/cortisol levels and gestational length. Therefore, further analyses were not adjusted for gestational length.

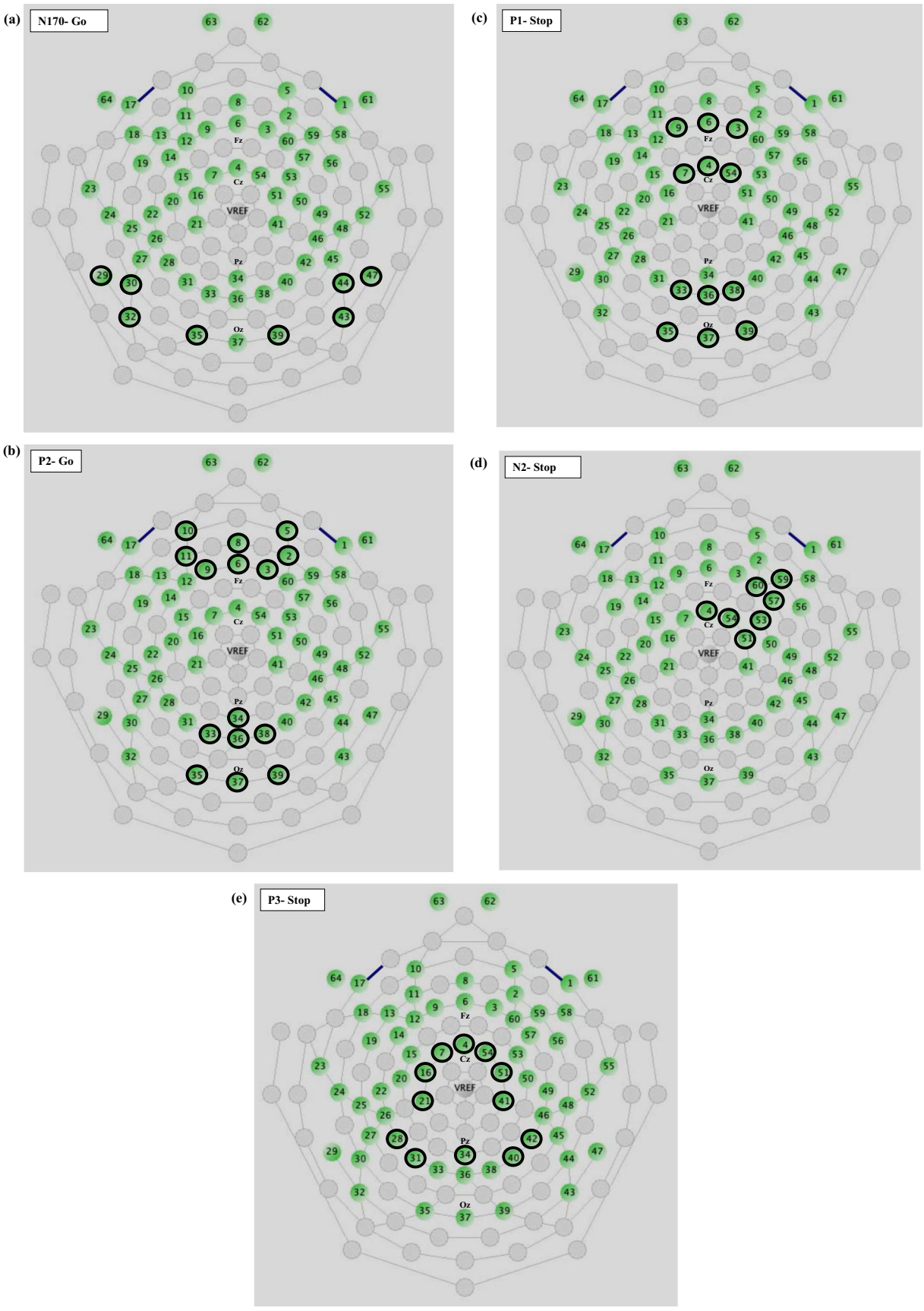

Fig. 1. Layout of the electrode array and electrodes chosen for analyses of N170 & P2 to Go stimuli (a, b), P1, N2 & P3 to Stop stimuli (c, d, e).

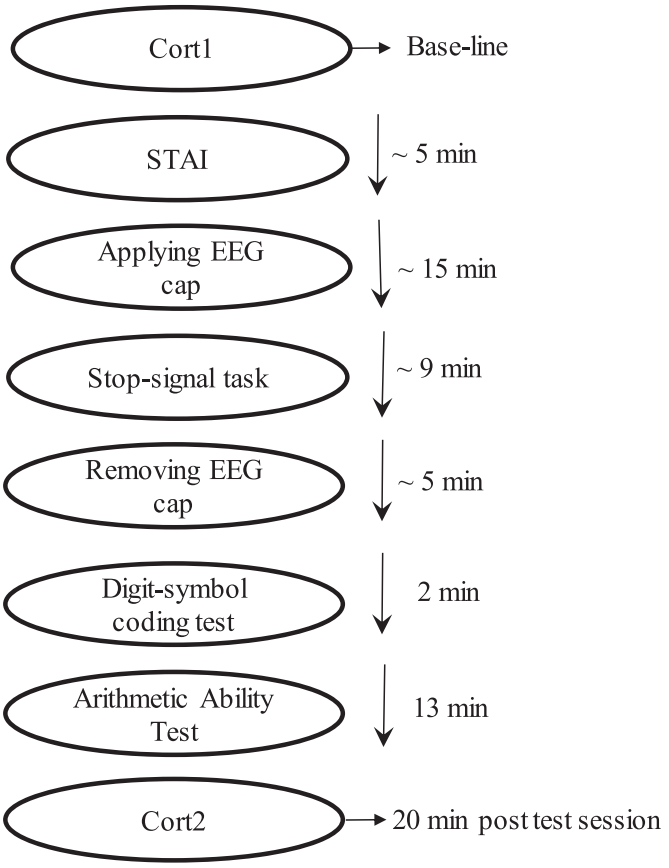

Fig. 2. Schematic description of the procedures during the experimental session.

poorer performance on the digit-symbol coding test (79.54 ± 2.30) compared to non-pregnant women (86.85 ± 2.69) [t(41) = −2.07, $p = 0.045$, Cohen's d = 0.63].

3.3. Arithmetic ability test

No differences were found between pregnant and non-pregnant women for this test ($p = 0.98$).

3.4. Stop-signal task behavioral results

One participant from the control group was excluded from behavioral analyses due to equipment malfunction.

Analysis revealed a significant within-subject effect of Condition [F(1,42) = 17.41, $p = 0.0001$, $\eta^2p = 0.29$], with higher error rates on Stop trials (36.90% ± 4.62) than on Go trials (19.41% ± 2.26). There was also a significant Condition × Group interaction effect [F(1,42) = 5.35, $p = 0.026$, $\eta^2p = 0.11$]. Post-hoc analysis showed that pregnant women had significantly lower error rates on Stop trials than non-pregnant women [t(42) = −2.18, $p = 0.035$, Cohen's d = 0.65], while no such difference was found for Go trials ($p = 0.91$). In addition, follow-up comparisons (paired-sample *t*-tests) showed that non-pregnant women had significantly higher error rates on Stop trials compared to Go trials [t(20) = 4.26, $p = 0.0001$, Hedges's g = 0.35], while no such difference was found for pregnant women ($p = 0.17$) (Fig. 3a).

Pregnant women had longer GoRTs (978.27 ms ± 36.26) relative to non-pregnant women (848.31 ms ± 49.74) [t(42) = 2.14, $p = 0.038$, Cohen's d = 0.64] (Fig. 3b).

3.5. Stop-signal task electrophysiological results

One participant from the pregnant group and two participants from the non-pregnant group were excluded from ERP analyses due to excessive artifacts in the EEG data.

3.5.1. N170 to Go stimuli (150–180 ms post-stimulus)

The Go face stimuli resulted in pronounced N170 in both pregnant and non-pregnant participants; however, no significant between-group effects were found for this component.

3.5.2. P2 to Go stimuli (180–340 ms post-stimulus)

Analysis of P2 to Go stimuli at frontal channels revealed that pregnant women had more pronounced (more negative) P2 amplitude (−2.56 μV ± 1.62) compared to non-pregnant women (−1.38 μV ± 1.76) [t(40) = −2.26, $p = 0.029$, Cohen's d = 0.70] (Fig. 4). No between group differences were found at posterior channels.

3.5.3. P1 to Stop stimuli (110–180 ms post-stimulus)

Analysis of P1 to Stop stimuli at posterior parietal-occipital channels revealed that non-pregnant women had greater (more positive) P1 amplitude (4.23 μV ± 2.51) than pregnant women (2.60 μV ± 2.29) [t(40) = −2.19, $p = 0.034$, Cohen's d = 0.68]. Over frontal channels, corresponding effects were apparent with reversed polarity; non-pregnant women had greater (more negative) P1 amplitude (−1.81 μV ± 1.21) compared to pregnant women (−0.97 μV ± 0.70) [t(40) = 2.68, $p = 0.012$, Cohen's d = 0.84] (Fig. 5).

3.5.4. N2 to Stop stimuli (230–350 ms post-stimulus)

Analysis of N2 to Stop stimuli at right frontal channels revealed that non-pregnant women had greater (more negative) N2 amplitude (−1.21 μV ± 1.24) compared to pregnant women (−0.32 μV ± 0.86) [t(40) = 2.72, $p = 0.010$, Cohen's d = 0.83] (Fig. 6).

3.5.5. P3 to Stop stimuli (350–500 ms post-stimulus)

Analysis of P3 to Stop stimuli at centroparietal channels revealed that pregnant women had greater (more positive) P3 amplitude (1.45 μV ± 0.96) compared to non-pregnant women (0.56 μV ± 1.22) [t(40) = 2.61, $p = 0.013$, Cohen's d = 0.81] (Fig. 7).

3.6. Cortisol saliva levels

Saliva samples of two participants from each group were excluded from analysis due to contamination with blood.

Cortisol levels 20 min post-test session (T2; 1.04 μg/dL ± 0.03) were higher than base line cortisol levels (T1; 0.94 μg/dL ± 0.03) in both groups [F(1,39) = 22.55, $p = 0.0001$, $\eta^2p = 0.37$], suggesting that the HPA axis was activated during the test session. There were also significant differences in cortisol levels between the groups [F(1,39) = 20.25, $p = 0.0001$, $\eta^2p = 0.34$], such that pregnant women had lower cortisol levels (0.90 μg/dL ± 0.04) than non-pregnant women (1.09 μg/dL ± 0.03). Importantly however, these main effects were subsumed under a significant Time × Group interaction effect [F(1,39) = 4.86, $p = 0.033$, $\eta^2p = 0.11$]. Follow-up paired comparisons showed that cortisol reactivity was more pronounced in non-pregnant women [t(19) = −4.04, $p = 0.001$, Hedges's g = 1.07] than in pregnant women [t(20) = −2.40, $p = 0.026$, Hedges's g = 0.31] (Fig. 8a). Another way to look at this interaction is to calculate the difference in cortisol levels between T2 and T1 (T2 – T1), and to compare this difference between the two groups. *t*-Test analysis revealed that the difference in cortisol levels between T2 and T1 was significantly higher in the non-pregnant group than in the pregnant group [t(39) = −2.20, $p = 0.033$, Cohen's d = 0.69] (Fig. 8b).

Cortisol reactivity was negatively correlated with GoRTs ($r = -0.38$, $p = 0.008$), and positively correlated with error rates on

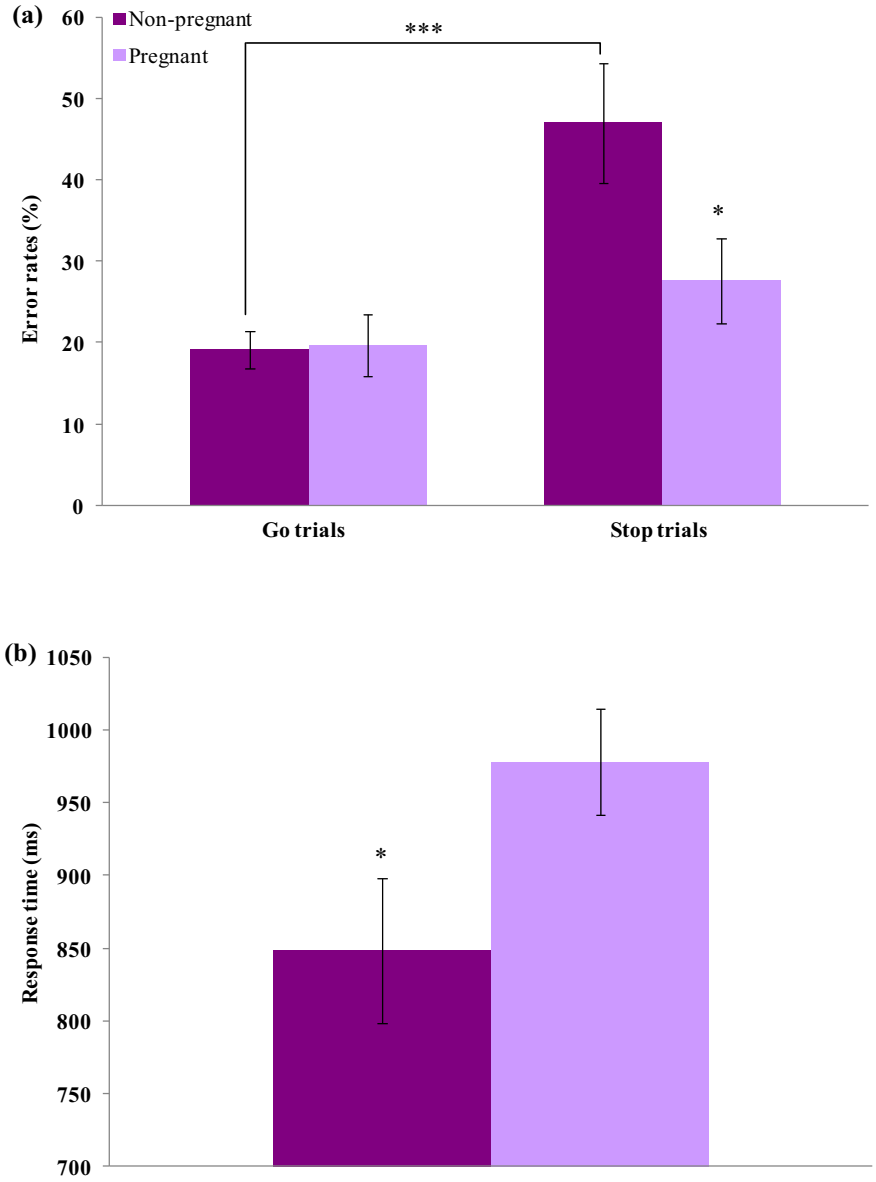

Fig. 3. Mean error rates (a), and response times on Go trials (GoRT) and on Stop trials (SSRT) (b), for pregnant and non-pregnant women. *$p < 0.05$, **$p < 0.01$, ***$p < 0.0001$. Error bars represent SEM.

Stop trials ($r = 0.39$, $p = 0.005$).

4. Discussion

In this study, cognitive, neural and hormonal functions were assessed in women in the third trimester of pregnancy and in non-pregnant comparison women. On the Digit-symbol coding test which measures attention and visual-motor speed, the pregnant group scored significantly lower than the control group. These results are consisted with our hypothesis and are in line with Henry and Sherwin (2012) who also reported that women in late pregnancy performed worse than controls on the Digit-symbol coding test. The lowered test performance among pregnant women was not due to higher error rates in matching the appropriate symbol to each number, but rather to the fact that they completed fewer symbols within the specified time frame; i.e. pregnant women were as accurate, but slower, than non-pregnant controls. A similar pattern of results was found on the Go condition of the Stop-signal task: while pregnant and non-pregnant women did not differ with respect to error rates, pregnant women had significantly longer (slower) GoRTs than controls. Women's tendency to react more slowly during late pregnancy has been reported by others (Crawley et al., 2008; Henry and Sherwin, 2012; Raz, 2014). Importantly, however, pregnant women demonstrated significantly better performance than controls on the Stop condition of the Stop-signal task in which a response must be inhibited. Response inhibition is considered a key measure of executive control and has been used extensively in cognitive neuroscience, cognitive psychology and psychopathology. Response inhibition deficits have been strongly associated with several psychological and neurological disorders such as attention-deficit/hyperactivity disorder (ADHD), obsessive-compulsive disorder (OCD), conduct disorder (CD), substance abuse, and frontal brain damage (Alderson et al., 2007; Chambers et al., 2009; Groman et al., 2009; Oosterlaan et al., 1998; Verbruggen and Logan, 2009). Successful inhibition allows for the suppression of no longer required, unsafe or inappropriate behavioral responses and supports goal-directed, flexible, and adaptive behavior in a constantly changing environment. Results of the present study suggest enhanced inhibitory control function among pregnant women relative to controls. It seems that pregnant women tend to have a more cautious, less

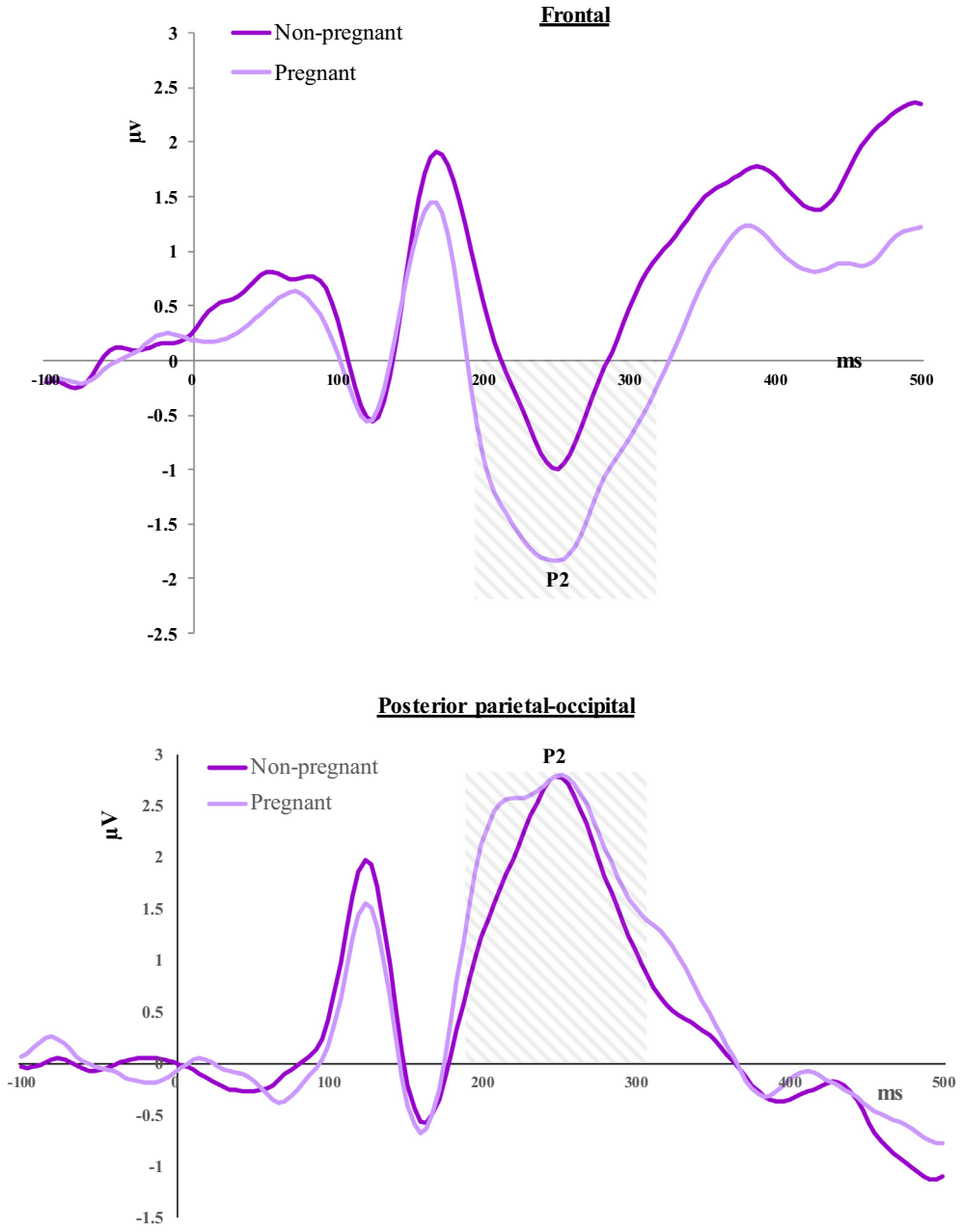

Fig. 4. Grand averaged ERPs to Go stimuli for the pregnant and non-pregnant groups; P2 at frontal and posterior parietal-occipital channels.

impulsive, pattern of behavior, reflected in fewer errors on the Stop task. This may suggest better monitoring and adjustment of response strategies to achieve an optimal balance between the conflicting demands of the Go and Stop tasks. Success in Stop trials may come at the cost of slower RTs in Go trials which may explain the longer GoRTs found for the pregnant group (i.e. trading speed in the Go task for success in the Stop task when a stop-signal is expected to occur).

At the electrophysiological level, neural activation in pregnant women engaged in the stop-signal task differed significantly from that of controls. Pregnant women exhibited greater amplitudes of the P2 ERP component in response to Go stimuli. P2 originates in the visual association cortex and is thought to represent inhibition of further processing of sensory input via automatic stimulus identification and discrimination/classification, or inhibition of other channels of information competing for attention (Barry et al., 2003). It is believed to index the early attentional recruitment that forms a basis for subsequent cognitive processing (Key et al., 2005; Yuan et al., 2008). Interestingly, many studies have shown larger P2 amplitudes following auditory and visual stimuli in individuals with ADHD relative to controls (Barry et al., 2003). Augmentation of P2 may reflect the recruitment of additional brain resources for perceptual processing of Go stimuli; and may partly explain the longer motor response times evident in pregnant women on the Go condition.

On the Stop condition of the task, we found that pregnant women exhibited significantly lesser amplitudes of the P1 ERP component in response to Stop-signals relative to controls. P1 is an early sensory component generated by extrastriate visual areas in the initial perceptual stage of information processing. It is the first component of the visual ERP waveform to be reliably modulated by voluntary attention and it is considered an index of attention-related processes and mobilization of attentional resources (Luck, 2012).

In accordance with the P1 results, pregnant women also had smaller frontocentral N2 amplitude to stop stimuli relative to controls. The N2 component is related to conflict monitoring processing and assumed to

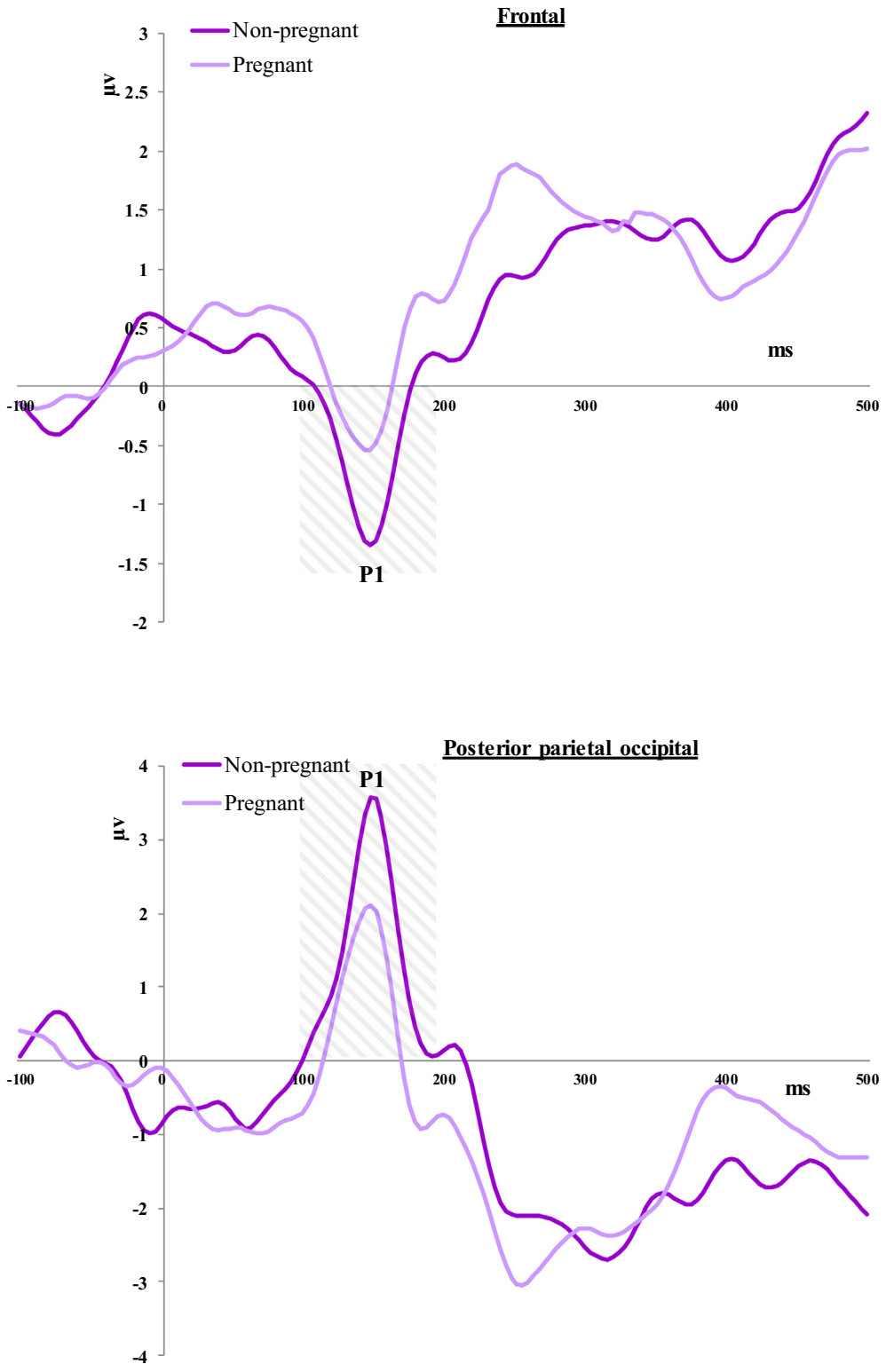

Fig. 5. Grand averaged ERPs to Stop stimuli for the pregnant and non-pregnant groups; P1 at frontal and posterior parietal-occipital channels.

reflect the inhibition of the pre-potent response in Stop trials. It has been interpreted as a neural signal that precedes or initiates active inhibition of a button-press response and has been suggested as a sensitive measure of online inhibitory processing (Donkers and van Boxtel, 2004; Folstein and Van Petten, 2008; Kok et al., 2004). In a visual Go-NoGo task, Prox et al. (2007) found increased N2 for ADHD adults compared to healthy controls. They suggested that ADHD adults have to trigger the inhibition process more strongly in order to compensate for their impairment. It is possible that the smaller P1 and N2 amplitudes found in pregnant women may indicate higher pregnancy-related efficiency of neural activation when a pending response should be suppressed.

Group differences were also found for the P3 ERP component; Pregnant women had more pronounced P3 amplitude at centroparietal channels. P3 has been linked with inhibitory executive control and is

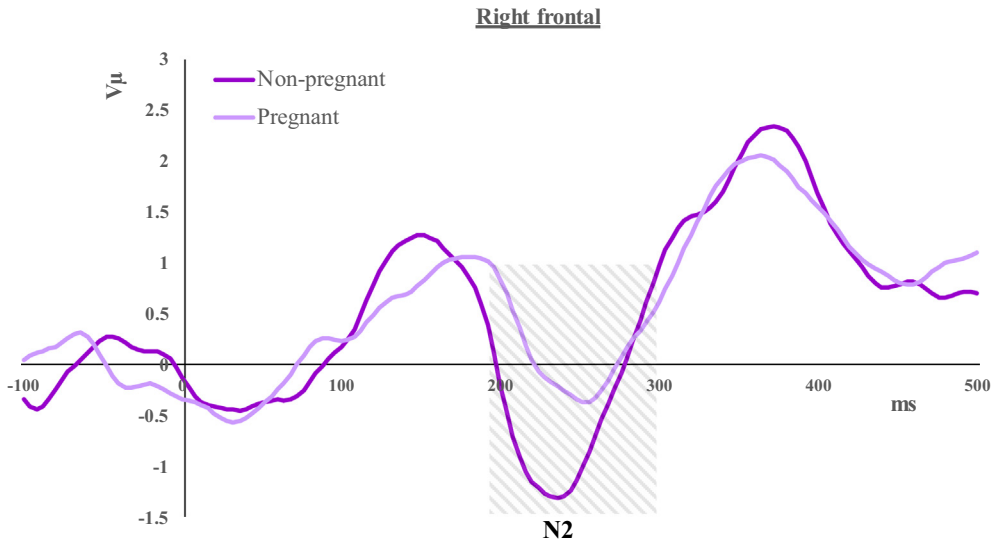

Fig. 6. Grand averaged ERPs to Stop stimuli for the pregnant and non-pregnant groups; N2 at right frontal channels.

thought to reflect inhibition process activated when an urgent stopping is required (Dimoska et al., 2006; Dimoska and Johnstone, 2007; Kok et al., 2004). Larger P3 to stop trials may reflect a more successful stopping in the context of stop-signal tasks. Reduced P3 on inhibition trials, has been reported in several clinical and normative populations characterized by impulsivity (Bekker et al., 2005; Dimoska and Johnstone, 2007; Overtoom et al., 2002). Thus, together with the better performance on the Stop condition of the task found for the pregnant group, neural (P1 & P3) and behavioral (error rates) results converge to suggest more efficient mechanisms of inhibitory control leading to less impulsive responsivity and better response inhibition function during late pregnancy compared with controls.

Endocrine results showed that pregnant women had lower levels of salivary cortisol than controls immediately before and 20-min after the test session. The finding of lower baseline levels of cortisol is not in line with previous reports indicating gradual increase in baseline cortisol during pregnancy (de Weerth and Buitelaar, 2005; Mastorakos and Ilias, 2003; Sandman et al., 2006). However, unlike the present study, some of these studies evaluated plasma cortisol (Davis et al., 2011; Mastorakos and Ilias, 2003; Sandman et al., 2006), and many have focused on the cortisol awakening response (CAR) (Buss et al., 2009; Entringer et al., 2010; Hellgren et al., 2013). Never the less, this finding should be replicated in additional studies with larger samples. Importantly, as expected, cortisol reactivity to the test session was significantly more pronounced in non-pregnant women. It is well established that the maternal HPA axis undergoes adaptations through pregnancy that might contribute to avoidance of adverse effects of stress and psychological arousal on mother and offspring. The responsiveness of the HPA axis to stressors is progressively attenuated from mid-pregnancy onwards. Suppressed HPA axis responses to a wide range of psychological and physical stressors during late pregnancy and lactation were found in female rodents and, to a lesser extent, in women (Brunton et al., 2008; Brunton and Russell, 2008; de Weerth and Buitelaar, 2005; Kammerer et al., 2002; Macbeth and Luine, 2010). Exposure to stress and glucocorticoids during pregnancy may adversely affect the development of physiological systems in the fetus, resulting in increased susceptibility to several diseases and psychological disorders in adulthood (Barker, 2002). High levels of cortisol during pregnancy

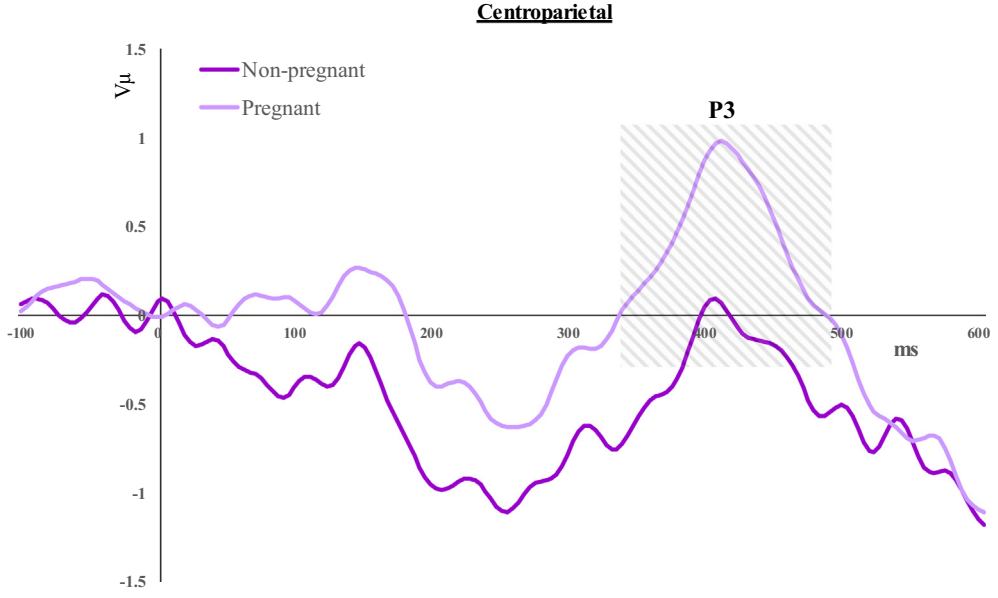

Fig. 7. Grand averaged ERPs to Stop stimuli for the pregnant and non-pregnant groups; P3 at centroparietal channels.

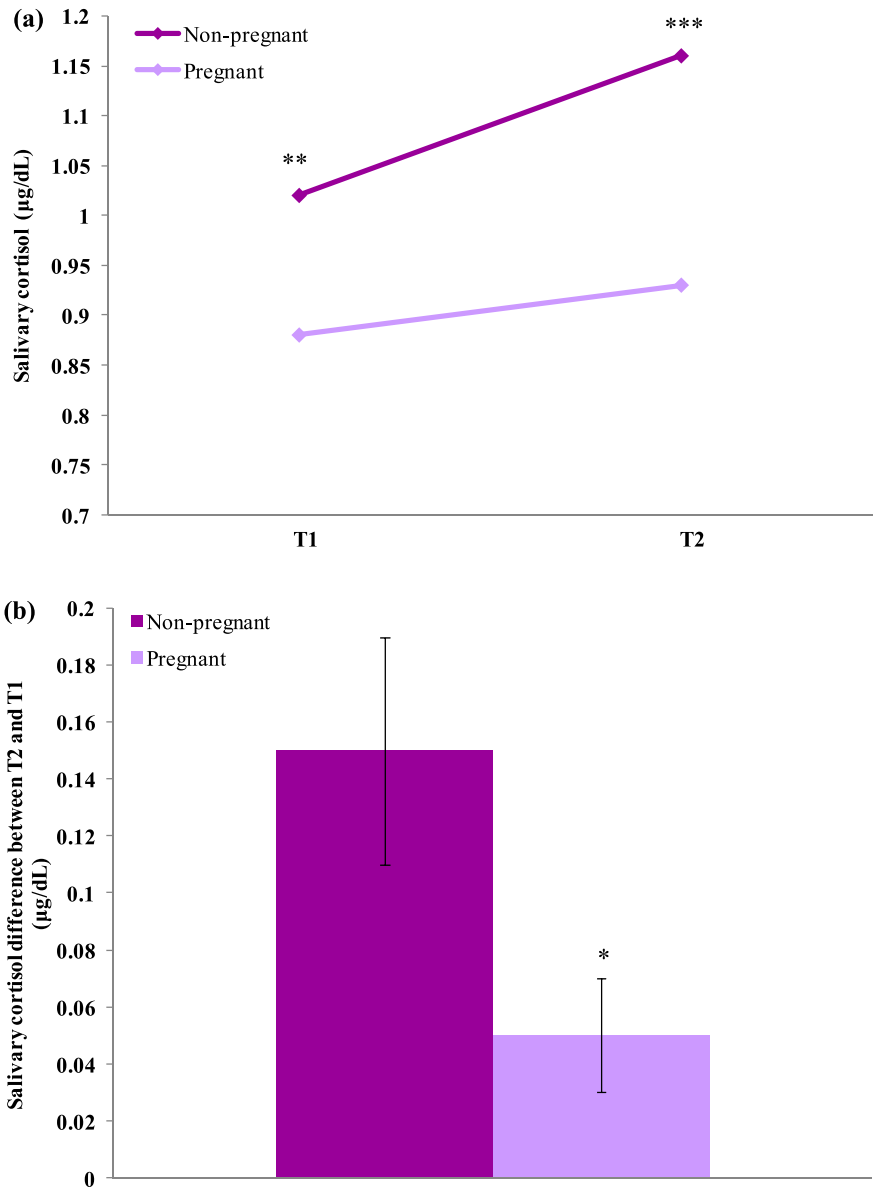

Fig. 8. (a) Salivary cortisol in pregnant and non-pregnant groups at base-line (T1), and 20 min after the test session (T2). (b) Differences in cortisol between T2 and T1 for the pregnant and non-pregnant groups. $*p < 0.05$, $**p < 0.01$, $***p < 0.0001$. Error bars represent SEM.

have been also associated with shorter gestational age and lower birthweight of neonates as well as smaller head circumference, abdominal circumference, and biparietal diameter (Bolten et al., 2011; Field et al., 2006). It has been postulated that HPA axis hyporesponsiveness acts to buffer the impact of stress, reducing fetal exposure to excess glucocorticoids, thereby minimizing the risk of detrimental fetal programming (Brunton and Russell, 2008; Welberg and Seckl, 2001). Results of the present study provide additional support to the concept of HPA axis hyporesponsiveness to psychological arousal/stress during human late pregnancy. Interestingly, significant correlations were found between the degree of cortisol reactivity (the difference in cortisol levels between pre and post-test session) and behavioral responses: The lower the cortisol reactivity, the longer the response times to Go stimuli and the smaller the error rates on Stop trials. These results highlight the possible involvement and contribution of pregnancy-related changes in HPA axis and cortisol responsiveness to the cognitive and neural alterations seen here in pregnant women. It should be noted that pregnant and non-pregnant women did not differ in their mean levels of trait and state anxiety, alleviating the concern of confound between 'being pregnant' and 'being anxious'.

In the interpretation of our results, a few considerations need to be taken into account: The present study included both primigravid and multigravid women (matched with nulliparous and multiparous controls). Future studies may attempt to control for reproductive history, parity and mothering by, for example, including only primigravid and nulliparous women; or comparing primigravid and multigravid women. It is also worthwhile to prospectively explore cognitive, ERP and cortisol changes from early to late pregnancy and from late pregnancy to postpartum.

The sample used is relatively small and included college administrative and academic staff and undergraduate/graduate students, thus, the mean level of education was relatively high. This may affect participants' attitude, motivation and performance and may limit the generalizability of results to the general pregnant population. Replication of the results in larger and more representative samples of varying education, socioeconomic status, and ethnicity will help establish the generalizability of our results. Future studies may also include a more thorough assessment of potentially related personality

factors such as impulsivity. Finally, while levels of cortisol were clearly affected by the experimental challenge (were significantly higher post-test than pre-test), the present study was not designed as a 'classic' stress study. Future studies should further investigate stress-related neurocognitive processes and cortisol reactivity during pregnancy. Such studies may include tasks and stimuli known to induce higher levels of psychological stress (e.g. the 'Trier Social Stress Test'), as well as a non-stress control condition, and a more thorough assessment of cortisol reactivity and recovery by measuring levels of cortisol on several time points before, during and after the experimental session. Correlations between cortisol reactivity and test performance were analyzed here for the whole sample since the relatively small samples did not allow for sufficient statistical power to analyze correlations separately for each group. Future studies with larger samples should address this limitation to further validate the relation between cortisol and neurobehavioral function in pregnancy.

In conclusion, this study is one of few conducted to date examining brain ERPs in pregnant women and the first to focus on response inhibition function. Taken together, the current results suggest that response patterns of women in late pregnancy, while engaged in cognitive tasks, tend to be less impulsive and more cautious, restrained and controlled; trading speed for accuracy. While being slower to produce motor responses to target stimuli, pregnant women were significantly better at withholding unnecessary responses when signaled to do so. They also had moderated electrophysiological neural responses to stop-signals associated with lower levels of cortisol and reduced cortisol reactivity to test-related psychological stress. From an evolutionary perspective, heightened precautionary behavior, attenuated physiological and psychological arousal and reduced maternal stress response, is warranted during pregnancy to optimize fetal growth and development (Hahn-Holbrook et al., 2011). Contrary to the subjective perception of overall cognitive decline frequently reported by pregnant women, our results indicate that some domains of cognitive function may be actually improved in pregnant women when compared with non-pregnant women.

Acknowledgments

This study was supported by the research authority of the Max Stern Yezreel Valley College.

References

Alderson, R.M., Rapport, M.D., Kofler, M.J., 2007. Attention-deficit/hyperactivity disorder and behavioral inhibition: a meta-analytic review of the stop-signal paradigm. J. Abnormal. Child. Psycho. 35, 745–758.
Anderson, M.V., Rutherford, M.D., 2012. Cognitive reorganization during pregnancy and the postpartum period: an evolutionary perspective. Evolution. Psychol. 10, 659–687.
Bannbers, E., Gingnell, M., Engman, J., Morell, A., Sylvén, S., Skalkidou, A., 2013. Prefrontal activity during response inhibition decreases over time in the postpartum period. Behav. Brain Res. 241, 132–138.
Barker, D.J., 2002. Fetal programming of coronary heart disease. Trends. Endocrinol. Metabolism. 13, 364–368.
Barry, R.J., Johnstone, S.J., Clarke, A.R., 2003. A review of electrophysiology in attention deficit/hyperactivity disorder: II. Event-related potentials. Clin. Neurophysiol. 114, 184–198.
Bekker, E.M., Overtoom, C.C.E., Kenemans, J.L., Kooij, J.J.S., de Noord, I., Buitelaar, J.K., et al., 2005. Stopping and changing in adults with ADHD. Psychol. Med. 35, 807–816.
Biaggi, A., Conroy, S., Pawlby, S., Pariante, C.M., 2016. Identifying the women at risk of antenatal anxiety and depression: a systematic review. J. Affect Dis. 191, 62–77.
Bloom, E.L., Potts, G.F., Evans, D.E., Drobes, D.J., 2013. Cue reactivity in smokers: an event-related potential study. Int. J. Psychophysiol. 90, 258–264.
Bolten, M.I., Wurmser, H., Buske-Kirschbaum, A., Papoušek, M., Pirke, K.M., Hellhammer, D., 2011. Cortisol levels in pregnancy as a psychobiological predictor for birth weight. Arch. Women's. Mental. Health. 14, 33–41.
Brett, M., Baxendale, S., 2001. Motherhood and memory: a review. Psychoneuroendocrinol 26, 339–362.
Brunton, P.J., Russell, J.A., 2008. The expectant brain: adapting for motherhood. Nat. Rev. Neurosci. 9, 11–25.
Brunton, P.J., Russell, J.A., Douglas, A.J., 2008. Adaptive responses of the maternal hypothalamic-pituitary-adrenal axis during pregnancy and lactation. J. Neuroendocrinol. 20, 764–776.
Buckwalter, J.G., Stanczyk, F.Z., McCleary, C.A., Bluestein, B.W., Buckwalter, D.K., Rankin, K.P., et al., 1999. Pregnancy, the postpartum, and steroid hormones: effects on cognition and mood. Psychoneuroendocrinology 24, 69–84.
Buss, C., Entringer, S., Reyes, J.F., Chicz-DeMet, A., Sandman, C.A., Waffarn, F., Wadhwa, P.D., 2009. The maternal cortisol awakening response in human pregnancy is associated with the length of gestation. Am. J. Obstetrics. Gynecol. 201, 398-e1.
Carpenter, P.A., Just, M.A., Shell, P., 1990. What one intelligence test measures: Atheoretical account of the processing in the Raven Progressive Matrices Test. Psychol. Rev. 97, 404–431.
Casey, P., Huntsdale, C., Angus, G., Janes, C., 1999. Memory in pregnancy. II: Implicit, incidental, explicit, semantic, short-term, working and prospective memory in primigravid, multigravid and postpartum women. J. Psychosom. Obstet. Gynecol. 20, 158–164.
Castaldo, R., Melillo, P., Bracale, U., Caserta, M., Triassi, M., Pecchia, L., 2015. Acute mental stress assessment via short term HRV analysis in healthy adults: a systematic review with meta-analysis. Biomed. Signal. Processing. Control. 18, 370-377.
Chamberlain, S.R., Sahakian, B.J., 2007. The neuropsychiatry of impulsivity. Curr. Opinion. Psychiatry. 20, 255–261.
Chambers, C.D., Hugh, G., Bellgrove, M.A., 2009. Insights into the neural basis of response inhibition from cognitive and clinical neuroscience. Neurosci. Biobehav. Rev. 33, 631–646.
Christensen, H., Poyser, C., Pollitt, P., Cubis, J., 1999. Pregnancy may confer a selective cognitive advantage. J. Reproductive. Infant. Psychol. 17, 7–25.
Christensen, H., Leach, L.S., Mackinnon, A., 2010. Cognition in pregnancy and motherhood: prospective cohort study. British. J. Psychiatry. 196, 126–132.
Crawley, R.A., Dennison, K., Carter, C., 2003. Cognition in pregnancy and the first-year post-partum. Psychol. Psychotherapy. Theory. Res. Practice. 76, 69–84.
Crawley, R., Grant, S., Hinshaw, K., 2008. Cognitive changes in pregnancy: mild decline or societal stereotype? App. Cogn. Psychol. 22, 1142–1162.
Davis, E.P., Glynn, L.M., Waffarn, F., Sandman, C.A., 2011. Prenatal maternal stress programs infant stress regulation. J. Child Psychol. Psychiatry 52, 119-129.
de Groot, R.H., Hornstra, G., Roozendaal, N., Jolles, J., 2003. Memory performance, but not information processing speed, may be reduced during early pregnancy. J. Clin. Exp. Neuropsychol. 25, 482–488.
de Groot, R.H.M., Vuurman, E.F.P.M., Hornstra, G., Jolles, J., 2006. Differences in cognitive performance during pregnancy and early motherhood. Psychol. Med. 36, 1023–1032.
de Weerth, C., Buitelaar, J.K., 2005. Physiological stress reactivity in human pregnancy: a review. Neurosci. Biobehav. Rev. 29, 295–312.
Di Russo, F., Lucci, G., Sulpizio, V., Berchicci, M., Spinelli, D., Pitzalis, S., Galati, G., 2016. Spatiotemporal brain mapping during preparation, perception, and action. NeuroImage 126, 1–14.
Dimoska, A., Johnstone, S.J., 2007. Neural mechanisms underlying trait impulsivity in non-clinical adults: stop-signal performance and event-related potentials. Prog. Neurpsychopharmacol. Biological. Psychiatry. 31, 443–454.
Dimoska, A., Johnstone, S.J., Barry, R.J., 2006. The auditory-evoked N2 and P3 components in the stop-signal task: indices of inhibition, response-conflict or error-detection? Brain Cogn. 62, 98–112.
Donkers, F.C.L., van Boxtel, G.J.M., 2004. The N2 in go/no-go tasks reflects conflict monitoring not response inhibition. Brain Cogn. 56, 165–176.
Duncan, C.C., Barry, R.J., Connolly, J.F., Fischer, C., Michie, P.T., Näätänen, R., Van Petten, C., 2009. Event-related potentials in clinical research: guidelines for eliciting, recording, and quantifying mismatch negativity, P300, and N400. Clin. Neurophysiol. 120, 1883–1908.
Entringer, S., Buss, C., Shirtcliff, E.A., Cammack, A.L., Yim, I.S., Chicz-DeMet, A., et al., 2010. Attenuation of maternal psychophysiological stress responses and the maternal cortisol awakening response over the course of human pregnancy. Stress 13, 258-268.
Fairchild, G., 2012. Hypothalamic-pituitary-adrenocortical axis inattention-deficit hyperactivity disorder. In: Stanford, C., Tan-nock, R. (Eds.), Behavioral Neuroscience of Attention Deficit Hyperactivity Disorder and Its Treatment. Current Topics in Behavioral Neuroscience 9. Springer-Verlag, Berlin, Heidelberg, pp. 93–111.
Farrar, D., Tuffnell, D., Neill, J., Scally, A., Marshall, K., 2014. Assessment of cognitive function across pregnancy using CANTAB: a longitudinal study. Brain Cogn. 84, 76–84.
Field, T., Hernandez-Reif, M., Diego, M., Figueiredo, B., Schanberg, S., Kuhn, C., 2006. Prenatal cortisol, prematurity and low birthweight. Infant. Behav. Dev. 29, 268–275.
Flaisch, T., Häcker, F., Renner, B., Schupp, H.T., 2010. Emotion and the processing of symbolic gestures: an event-related brain potential study. Soc. Cogn. Affective. Neurosci. 6, 109–118.
Foley, P., Kirschbaum, C., 2010. Human hypothalamus-pituitary-adrenal axis responses to acute psychosocial stress in laboratory settings. Neurosci. Biobehav. Rev. 35, 91–96.
Folstein, J.R., Van Petten, C., 2008. Influence of cognitive control and mismatch on the N2 component of the ERP: a review. Psychophysiol 45, 152–170.
Giardinelli, L., Innocenti, A., Benni, L., Stefanini, M.C., Lino, G., Lunardi, C., Svelto, V., Afshar, S., Bovani, R., Castellini, G., Faravelli, C., 2012. Depression and anxiety in perinatal period: prevalence and risk factors in an Italian sample. Arch. Women's Ment. Health. 15, 21–30.
Goodman, J.H., Chenausky, K.L., Freeman, M.P., 2014. Anxiety disorders during pregnancy: a systematic review. J. Clin. Psychiatry 75, 1153–1184.
Groman, S.M., James, A.S., Jentsch, J.D., 2009. Poor response inhibition: at the nexus between substance abuse and attention deficit/hyperactivity disorder. Neurosci. Biobehav. Rev. 33, 690–698.
Hahn-Holbrook, J., Holbrook, C., Haselton, M.G., 2011. Parental precaution: neurobiological means and adaptive ends. Neurosci. Biobehav. Rev. 35, 1052–1066.
Hellgren, C., Akerud, H., Skalkidou, A., Sundström-Poromaa, I., 2013. Cortisol awakening response in late pregnancy in women with previous or ongoing depression.

Psychoneuroendocrinol 38, 3150-3154.
Henry, J.D., Rendell, P.G., 2007. A review of the impact of pregnancy on memory function. J. Clin. Exp. Neuropsychol. 29, 793–803.
Henry, J.F., Sherwin, B.B., 2012. Hormones and cognitive functioning during late pregnancy and postpartum: a longitudinal study. Behav. Neurosci. 126, 73.
Hoekzema, E., Barba-Müller, E., Pozzobon, C., Picado, M., Lucco, F., García-García, D., Ballesteros, A., 2016. Pregnancy leads to long-lasting changes in human brain structure. Nat. Neurosci. https://doi.org/10.1038/nn.4458.
Johnstone, S.J., Barry, R.J., Clarke, A.R., 2013. Ten years on: a follow-up review of ERP research in attention-deficit/hyperactivity disorder. Clin. Neurophysiol. 124, 644–657.
Kammerer, M., Adams, D., Von Castelberg, B., Glover, V., 2002. Pregnant women become insensitive to cold stress. BMC. Pregnancy. Childbirth. 2, 8.
Karthikeyan, P., Murugappan, M., Yaacob, S., 2011. A review on stress inducement stimuli for assessing human stress using physiological signals. In: Signal Processing and Its Applications (Cspa), 2011 IEEE 7th International Colloquium on. IEEE, pp. 420–425.
Karthikeyan, P., Murugappan, M., Yaacob, S., 2012. A study on mental arithmetic task based human stress level classification using discrete wavelet transform. In: Sustainable Utilization and Development in Engineering and Technology 2012 IEEE Conference on. IEEE, pp. 77–81.
Key, A.P.F., Dove, G.O., Maguire, M.J., 2005. Linking brain waves to the brain: an ERP primer. Dev. Neuropsychol. 27, 183–215.
Kinsley, C.H., Trainer, R., Stafisso-Sandoz, G., Quadros, P., Marcus, L.K., Hearon, C., Lambert, K.G., 2006. Motherhood and the hormones of pregnancy modify concentrations of hippocampal neuronal dendritic spines. Hormones. Behavior. 49, 131–142.
Kirschbaum, C., Pirke, K.M., Hellhammer, D.H., 1993. The 'Trier Social Stress Test' - a tool for investigating psychobiological stress responses in a laboratory setting. Neuropsychobiol 28, 76–81.
Kivlighan, K.T., DiPietro, J.A., Costigan, K.A., Laudenslager, M.L., 2008. Diurnal rhythm of cortisol during late pregnancy: associations with maternal psychological well-being and fetal growth. Psychoneuroendocrinology 33, 1225–1235.
Kok, A., Ramautar, J.R., De Ruiter, M.B., Band, G.P.H., Ridderinkhof, K.R., 2004. ERP components associated with successful and unsuccessful stopping in a stop-signal paradigm. Psychophysiol 41, 9–20.
Li, C.S.R., Chao, H.H.A., Lee, T.W., 2008. Neural correlates of speeded as compared with delayed responses in a stop signal task: an indirect analog of risk taking and association with an anxiety trait. Cereb. Cortex 19, 839–848.
Lijffijt, M., Kenemans, J.L., Verbaten, M.N., van Engeland, H., 2005. A meta-analytic review of stopping performance in attention-deficit/hyperactivity disorder: deficient inhibitory motor control? J. Abnormal. Psychol. 114, 216.
Logan, G.D., 1994. On the ability to inhibit thought and action: a user's guide to the stop signal paradigm. In: Dagenbach, D., Carr, T.H. (Eds.), Inhibitory Processes in Attention, Memory and Language. Academic.
Logan, D.M., Hill, K.R., Jones, R., Holt-Lunstad, J., Larson, M.J., 2014. How do memory and attention change with pregnancy and childbirth? A controlled longitudinal examination of neuropsychological functioning in pregnant and postpartum women. J. Clin. Exp. Neuropsychol. 36, 528–539.
Luck, S.J., 2012. Event-related potentials. In: Long, D.L. (Ed.), APA Handbook of Research Methods in Psychology. American Psychological Association, Washington, DC, USA, pp. 1–18.
Lundqvist, D., Flykt, A., Öhman, A., 1998. The Karolinska Directed Emotional Faces-KDEF. CD-ROM from Department of Clinical Neuroscience, Psychology section, Karolinska Institutet, Stockholm, Sweden91-630-7164-9.
Macbeth, A.H., Luine, V.N., 2010. Changes in anxiety and cognition due to reproductive experience: a review of data from rodent and human mothers. Neuroscience and Biobehav. Rev. 4, 452–467.
Mastorakos, G., Ilias, i., 2003. Maternal and fetal hypothalamic-pituitary-adrenal axes during pregnancy and postpartum. Ann. N. Y. Acad. Sci. 997, 136-149.
Maupin, A.N., Hayes, N.J., Mayes, L.C., Rutherford, H.J., 2015. The application of electroencephalography to investigate the neural bases of parenting: a review. Parenting 15, 9–23.
Mensen, A., Poryazova, R., Schwartz, S., Khatami, R., 2014. Humor as a reward mechanism: event-related potentials in the healthy and diseased brain. PLoS One 9, e85978.
Oatridge, A., Holdcroft, A., Saeed, N., Hajnal, J.V., Puri, B.K., Fusi, L., 2002. Change in brain size during and after pregnancy: study in healthy women and women with preeclampsia. Am. J. Neuroradiol. 23, 19–26.
Olofsson, J.K., Broman, D.A., Wulff, M., Martinkauppi, M., Nordin, S., 2005. Olfactory and chemosomatosensory function in pregnant women assessed with event-related potentials. Physiol. Behav. 86, 252–257.
Onyper, S.V., Searleman, A., Thacher, P.V., Maine, E.E., Johnson, A.G., 2010. Executive functioning and general cognitive ability in pregnant women and matched controls. J. Clin. Exp. Neuropsychol. 32, 986–995.
Oosterlaan, J., Logan, G.D., Sergeant, J.A., 1998. Response inhibition in AD/HD, CD, comorbid AD/HD+ CD, anxious, and control children: a meta-analysis of studies with the stop task. J. Child. Psycho. Psychiatry. 39, 411–425.
Overtoom, C.C., Kenemans, J.L., Verbaten, M.N., Kemner, C., van der Molen, M.W., van Engeland, H., et al., 2002. Inhibition in children with attention-deficit/hyperactivity disorder: a psychophysiological study of the stop task. Biol. Psychiatry 51, 668–676.
Picton, T.W., Bentin, S., Berg, P., Donchin, E., Hillyard, S.A., Johnson, R., Taylor, M.J., 2000. Guidelines for using human event-related potentials to study cognition: recording standards and publication criteria. Psychophysiolo 37, 127–152.
Prox, V., Dietrich, D.E., Zhang, Y., Emrich, H.M., Ohlmeier, M.D., 2007. Attentional processing in adults with ADHD as reflected by event-related potentials. Neurosci. Lett. 419, 236–241.
Ramautar, J.R., Kok, A., Ridderinkhof, K.R., 2004. Effects of stop-signal probability in the stop-signal paradigm: the N2/P3 complex further validated. Brain Cogn. 56, 234–252.
Ramautar, J., Kok, A., Ridderinkhof, K.R., 2006. Effects of stop-signal modality on the N2/P3 complex elicited in the stop-signal paradigm. Biol. Psychol. 72, 96–109.
Raven, J.C., 1938. Progressive Matrices: A Perceptual Test of Intelligence. HK Lewis, London.
Raz, S., 2014. Behavioral and neural correlates of cognitive–affective function during late pregnancy: an Event-Related Potentials study. Behav. Brain Res. 267, 17–25.
Raz, S., Leykin, D., 2015. Psychological and cortisol reactivity to experimentally induced stress in adults with ADHD. Psychoneuroendocrinol 60, 7–17.
Rendell, P.G., Henry, J.D., 2008. Prospective-memory functioning is affected during pregnancy and postpartum. J. Clin. Exp. Neuropsychol. 30, 913–919.
Roos, A., Robertson, F., Lochner, C., Vythilingum, B., Stein, D.J., 2011. Altered prefrontal cortical function during processing of fear-relevant stimuli in pregnancy. Behav. Brain Res. 222, 200–205.
Ross, L.E., McLean, L.M., 2006. Anxiety disorders during pregnancy and postpartum period: a systematic review. J. Clin. Psychiatry. 67, 1285–1298.
Rutherford, H.J., Graber, K.M., Mayes, L.C., 2016. Depression symptomatology and the neural correlates of infant face and cry perception during pregnancy. Soc. Neurosci. 11, 467–474.
Rutherford, H.J., Byrne, S.P., Austin, G.M., Lee, J.D., Crowley, M.J., Mayes, L.C., 2017. Anxiety and neural responses to infant and adult faces during pregnancy. Biol. Psychol. 125, 115–120.
Sandman, C.A., Glynn, L., Schetter, C.D., Wadhwa, P., Garite, T., Chicz-DeMet, A., Hobel, C., 2006. Elevated maternal cortisol early in pregnancy predicts third trimester levels of placental corticotropin releasing hormone (CRH): priming the placental clock. Peptides 27, 1457-1463.
Shen, I.H., Tsai, S.Y., Duann, J.R., 2011. Inhibition control and error processing in children with attention deficit/hyperactivity disorder: an event-related potentials study. Int. J. Psychophysiol. 81, 1–11.
Spielberger, C.D., Gorsuch, R.L., Lushene, R., Vagg, P.R., Jacobs, G.A., 1983. Manual for the State-trait Anxiety Inventory. Consulting Psychologists Press, Palo Alto, CA.
Verbruggen, F., Logan, G.D., 2008. Response inhibition in the stop-signal paradigm. Trends Cogn. Sci. 12, 418–424.
Verbruggen, F., Logan, G.D., 2009. Models of response inhibition in the stop-signal and stop-change paradigms. Neurosc. Biobehav. Rev. 33, 647–661.
Viswasam, K., Eslick, G.D., Starcevic, V., 2019. Prevalence, onset and course of anxiety disorders during pregnancy: a systematic review and meta analysis. J. Affect. Dis. https://doi.org/10.1016/j.jad.2019.05.016. In Press.
Wechsler, D., 1997. Wechsler Intelligence Scale for Adults, Third Edition. Psychological Cooperation, San Antonio, TX.
Welberg, L.A., Seckl, J.R., 2001. Prenatal stress, glucocorticoids and the programming of the brain. J. Neuroendocrinol. 13, 113–128.
Yuan, J., He, Y., Qinglin, Z., Chen, A., Li, H., 2008. Gender differences in behavioral inhibitory control: ERP evidence from a two-choice oddball task. Psychophysiol 45, 986–993.