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Verbal and visuospatial working memory during pregnancy: EEG correlation between the prefrontal and parietal cortices

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ABSTRACT

Pregnancy is a dynamic process during which significant cognitive changes take place. It has been suggested that working memory (WM) is affected during gestation as a result of functional changes among cortical areas, such as the prefrontal and parietal cortices. This study examined cortical electroencephalographic correlations (rEEG) during performance of WM tasks in each trimester of pregnancy. Forty women were divided into 4 groups: first (T1), second (T2), and third (T3) trimester of pregnancy, and a control group of non-pregnant women. Electroencephalographic activity (EEG) was recorded from the frontopolar, dorsolateral and parietal cortices during performance of one verbal and one visuospatial working memory task. Only groups T2 and T3 showed increased onset latency in the visuospatial WM. During the verbal WM task, the T1 group showed a higher correlation between dorsolateral areas in the theta and alpha bands, as well as a lower left prefrontal-parietal correlation in the gamma band. During the visuospatial WM task, the T1 and T3 groups showed a higher left EEG correlation in the delta and alpha1 bands, whereas T2 presented a higher right prefrontal-parietal correlation in the gamma band. Although pregnancy had only a subtle effect on the visuospatial WM task, these different patterns of cortical synchronization in each trimester of pregnancy could represent adaptive mechanisms that enabled the pregnant women to focus their attention and use more cognitive resources and so adequately solve the WM tasks.

1. Introduction

Pregnancy is one of the most important phases of a woman's reproductive cycle; a period characterized by a series of physiological, neurological, metabolic and endocrinological changes that support fetal growth and development in the future mother, while maintaining maternal homeostasis and preparing for lactation (King, 2000). A substantial number of pregnant women report various cognitive changes during pregnancy and the postpartum period, with memory deficits being the most common complaint (Brett & Baxendale, 2001). Various studies have evaluated whether these subjective appraisals of memory difficulties reflect objective impairment, but have failed to yield consistent results. In particular, the literature related to the executive component of working memory (WM) has demonstrated inconsistences, as some studies failed to detect any deficits of this kind (Casey, 2000; Henry & Rendell, 2007), while others report significant impairment (Casey, Huntsdale, Angus, & Janes, 1999). For example, Henry and Rendell (2007) found evidence of the impact of pregnancy on WM by showing that: (1) pregnant women rated their WM significantly worse than non-pregnant women; and (2) these differences persisted postpartum. Onyper, Searleman, Thacher, Maine, and Johnson (2010) in contrast, found no significant differences between pregnant women and non-pregnant controls on tests of short-term and working memory.

Some of the discrepancies in these findings may arise from methodological differences and/or the period of pregnancy in which the evaluations of WM were conducted, as these are two potential determinants of the magnitude of the effects of pregnancy on WM.

As is well-known, significant changes occur in the levels of several hormones during pregnancy, highlighted by the gradual increase of progesterone, estradiol and other hormones that reach maximum levels just before birth (Russell, Douglas, & Ingram, 2001). Both cerebral functionality and cognition are affected by these hormones as, for example, studies have demonstrated that significant changes occur in the degree of cortical synchronization in relation to the phase of the

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menstrual cycle (Solis-Ortiz et al., 2009; Solís-ortíz, Ramos-Loyo, Arce, Guevara, & Corsi-Cabrera, 1994). Similarly, it has been shown that the hormonal changes characteristic of pregnancy are also related to women's performance on various cognitive tasks (Buckwalter et al., 1999). Studies with rats, mean while, have shown that several brain structures, including the preoptic area, amygdala, prefrontal cortex, and nucleus accumbens, manifest important changes in neuroplasticity during gestation, associated with the secretion of sex steroid hormones and peptides unique to the condition of pregnancy (Afonso, Sison, Lovic, & Fleming, 2007; Kinsley et al., 1999; Pawluski, Lambert, & Kinsley, 2016; Russell et al., 2001).

Although the neural system responsible for WM is known to involve a large number of brain regions, evidence from neurophysiological and lesion studies shows that the prefrontal cortex is a critical component (Fuster, 2000; Goldman-Rakic, 1990); especially the dorsolateral region and its functional connections with the posterior parietal cortex in relation to both verbal and visuospatial WM processes (Fuster, 2001).

One method used to measure brain functionality consists in recording electroencephalographic activity (EEG). Several changes in specific EEG bands have been associated with specific cognitive and physiological states. For example, the slow waves of the delta band are often found during attention in relation to internal processing during performance of mental tasks (Fernández et al., 1995; Harmony, 2013; Harmony et al., 1996; Vogel, Broverman, & Klaiber, 1968), while the theta band is detected during relaxation, meditation (Buzsáki, 2002) and memory processes (Klimesch, Doppelmayr, Russegger, & Pachinger, 1996; Klimesch et al., 2001; Sarnthein, Petsche, Rappelsberger, Shaw, & Von Stein, 1998; Sauseng, Klimesch, Schabus, & Doppelmayr, 2005). The Alpha band, mean while, has been associated with attentional processes (Cooper, Croft, Dominey, Burgess, & Gruzelier, 2003; Foxe & Snyder, 2011; Payne, Guillory, & Sekuler, 2013), whereas the fast frequencies of the beta and gamma band have been related to wakefulness (Basar, Basar-Eroglu, Karakas, & Schürmann, 2000) and activities that require consciousness and perception (Basar et al., 2000; Blinowska & Durka, 2006). In particular the gamma band is involved in both the perception and maintenance of information during a delay (Tallon-Baudry, Bertrand, Delpuech, & Pernier, 1996), which is indicative of its crucial participation in WM.

Electroencephalographic correlation (rEEG) is a mathematical index that makes it possible to determine the degree of similarity between two EEG signals and, hence, the possible functional relation among different brain regions (Guevara & Corsi-Cabrera, 1996). This correlation method has been used by several researchers to determine whether the functional connectivity between brain regions changes in relation to different emotional and cognitive states (Corsi-Cabrera, Arce, Ramos, & Guevara, 1997; Corsi-Cabrera, Meneses, & Molina, 1987; Costa, Rognoni, & Galati, 2006). In fact, a low correlation between frontal regions in the alpha band and an increased fronto-parietal correlation in the theta band have been associated with executive functions, such as visuospatial WM (Sauseng et al., 2004, 2005).

Other studies have provided clear evidence of a functional hemispheric specialization of WM in adulthood. Adults exhibit brain lateralization when responding and, possibly, further refinement of the left hemisphere in verbal processes, while the right hemisphere specializes in visuospatial processes (Ojemann & Dodrill, 1985; Scherf, Sweeney, & Luna, 2006; Smith & Jonides, 1997; Smith & Milner, 1981).

Although cortical EEG bands have been related to cognitive processes, and several studies have shown that these processes are affected during pregnancy, it is still not known whether EEG correlations between the prefrontal and parietal cortices change during pregnancy while performing WM tasks. Therefore, the purpose of this study was to compare, on the one hand, the behavioral parameters of verbal and visuospatial WM tasks and, on the other, to compare the degree of cortical synchronization between the prefrontal and parietal cortices while performing both WM tasks during the three trimesters of pregnancy.

Considering the pivotal role that the prefrontal and parietal cortices play in modulating memory processes, we hypothesized that distinct degrees of inter- and intrahemispheric synchronization between the prefrontal-parietal regions would be detected on the different WM tasks. Because the most marked hormonal changes occur in the first and third trimesters of pregnancy, we expected, in accordance with the literature, higher rEEG in the theta and gamma bands in the hemisphere specialized for each task (verbal-left; visuospatial-right). Finally, we hypothesized that pregnant women in these periods will present poorer performance on both verbal and visuospatial WM tasks than non-pregnant controls.

Analyzing the possible behavioral and electroencephalographic differences while performing verbal and visuospatial WM tasks during the three trimesters of pregnancy could help clarify contradictory results in the literature regarding the impact that pregnancy may exert on cognitive processes.

2. Materials and methods

2.1. Participants

A total of 40 women, divided into 4 groups of 10 participants each, took part in the study. Three groups included women in different trimesters of pregnancy, as follows: trimester one (T1), 1–12 weeks of gestation; trimester two (T2), 13–28 weeks of gestation; and trimester three (T3), 29–42 weeks of gestation. The fourth group consisted of non-pregnant women as controls (CO). None of the control women had ever been pregnant. The pregnant women were all primigravid and their medical histories reported uncomplicated pregnancies, defined as a single pregnancy with no known fetal abnormalities or poor fetal growth. All groups were recruited via flyers posted in public places. Participation was voluntary. All the women were right-handed, healthy, and had no known medical or psychiatric conditions that might affect their cognitive functioning. Subjects were matched by demographic characteristics, as all participants completed a preliminary procedure that included a demographic questionnaire on their age, education, health, and other details. They also completed the Beck Anxiety Inventory (Beck, Epstein, Brown, & Steer, 1988), the Beck Depression Inventory (Beck, Steer, & Brown, 1996), and the brief version of WAIS-III (Wechsler, 2010) to measure IQ.

All procedures involved in this experiment were approved by the Institutional Ethics Committee in accordance with the ethical standards laid down in the 1964 Helsinki Declaration. All participants gave their informed consent prior to their inclusion in the study.

2.2. Behavioral measures

All participants completed the Digit Span sub-test of the WAIS-III (Wechsler, 2010). Digit sequences were presented backwards (two trials per item, 2–8 digits) as a measure of verbal WM. For the Digit span backward task (DSB), the examiner read a sequence of numbers and the examinee had to repeat the numbers in reverse order, following the procedure described in Wechsler (2010). The parameters measured were: number of correct trials (CT), and the longest sequence or span (LSS).

After completing the DSB, the Corsi Block-tapping task (CBT) was applied to measure visuospatial WM. A computerized version of the CBT (CubmemPC.exe) was used (Guevara, Sanz-Martin, Hernández-González, & Sandoval-Carrillo, 2014), in which 10 blue cubes are shown on a computer screen against a rectangular gray background. The task begins when the participant touches the computer's touch screen to automatically initiate a sequence of cubes. To emulate the sequence of cubes that the examiner taps, the program changes the color of the tapped cubes from blue-to-yellow (1-s duration), one-by-one and sequentially, to form a series of bins, whose length increases progressively up to a series of 7 cubes (4 trials for each length).