Reactivity of alpha rhythms to eyes opening (the Berger effect) during menstrual cycle phases

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1. Introduction

1.1. Menstrual cycle modulation of alpha EEG activity

Hormonal variations occur to a great extent during the menstrual cycle (MC), and these variations can influence emotion, behavior and cognition (see for review Sundström-Poromaa and Gingnell, 2014). For this reason the menstrual cycle is an excellent model allowing examination of the influence of endogenous sex hormones on the neuronal activity underlying a broad range of behavior. Often menstrual cycle phases are distinguished according to changing basal body temperature, and/or self-reports, rather than the dynamics of hormone levels. However, following Walker (1997), we combined these measures and divided each menstrual cycle into five phases, individually set: (1) menstrual (MP) – from the first up to the last day of menstruation; (2) follicular (FP) – from the day after menstruation until increasing basal body temperature by 0.5–1°C; (3) ovulatory (OP) – from the first day of basal body temperature increase to the first day of the saliva progesterone level increasing ≥ 20%; (4) luteal (LP) – from the next day until the first day of progesterone level reduction by ≥ 20%; (5) premenstrual phase (PMP) – from the next day until the first day of bleeding (see Fig. 1).

EEG alpha activity is one of the key indicators of cortical reactivity (Bazanova and Vernon, 2014), but there are relatively few EEG studies that have examined menstrual phase modulation of alpha amplitude, and their results are largely inconsistent (Creutzfeldt et al., 1976; Becker et al., 1982; Solis-ortiz et al., 1994). The inconsistency of EEG data during the MC could be due to methodological differences, such as the different determinations of MC phase, and different approaches to alpha activity assessment. However, a few studies (Becker et al., 1982; Bazanova et al., 2014; Brötzner et al., 2014) are in agreement that the hormonal state of the luteal phase (with the highest progesterone level) is characterized by increased peak alpha frequency. Apart from alpha amplitude and peak frequency, the MC modulation of the third key indicator of alpha activity – amplitude suppression in response to eyes open (the Berger effect) – is still uninvestigated.
1.2. The Berger effect (alpha amplitude suppression)

Essentially, the suppression of amplitude in response to eyes opening (the Berger effect) is the defining characteristic of EEG alpha. This effect has recently been proposed as a promising avenue of study in the search for putative endophenotypes (Loo et al., 2010), as well as helping to identify individual cognitive strategies (Loo and Smalley, 2008; Ivanitsky et al., 2009). The magnitude of the Berger effect might explain the large inter-individual variability in the power and frequency of the alpha rhythm (Kirschfeld, 2005). As an index of cortical activation (Schimke et al., 1990; Laufs et al., 2006; Barry et al., 2007, 2009, 2011; Cho et al., 2008) its modulation by such neurosteroids as estrogen and progesterone (Herzog, 2007; Finocchi and Ferrari, 2011) highlights its importance here.

1.2.1. The Berger effect in different frequency ranges

If different frequency bands within the range of the extended alpha band are considered, at least two distinct patterns of alpha desynchronization can be observed. Several independent research groups have found that low and high frequency alpha oscillations respond differently to visual stimulation (Pfurtscheller and Lopes da Silva, 1999; Hanslmayr et al., 2007; Mazaheri and Jensen, 2006). Desynchronization of lower alpha (in the range of about 6–11 Hz) is obtained in response to almost any type of task, and probably helps to identify individual cognitive strategies (Loo and Smalley, 2008; Ivanitsky et al., 2009). The magnitude of the Berger effect might explain the large inter-individual variability in the power and frequency of the alpha rhythm (Kirschfeld, 2005). As an index of cortical activation (Schimke et al., 1990; Laufs et al., 2006; Barry et al., 2007, 2009, 2011; Cho et al., 2008) its modulation by such neurosteroids as estrogen and progesterone (Herzog, 2007; Finocchi and Ferrari, 2011) highlights its importance here.

1.2.2. Berger effect duration

In addition to magnitude of amplitude suppression, the Berger effect can be quantified by duration of the alpha blocking (Barry and Beh, 1972; Michel et al., 1994; Bazanova and Vernon, 2014). The exact significance of the relation between duration of desynchronization and physiological meaning of the Berger effect remains to be resolved. While it was found that the mean duration of alpha desynchronization is a U-shaped function of sensitivity (Berlyne et al., 1967), it was also demonstrated that the duration of the Berger effect increases with complexity in cognitive tasks (Kaufman et al., 1989, 1990; Michel et al., 1994). Berlyne and McDonnell (1965) supposed that the duration of desynchronization marks the extent to which the impact of a stimulus pattern activates the arousal system, and this is also changed during the menstrual cycle (Armbruster et al., 2014).

1.2.3. Alpha band width where the Berger effect appears

It is known that measures of alpha activity are influenced by the boundaries chosen for the frequency band (Schimke et al., 1990; Bazanova, 2011). Individual alpha bandwidth can vary in accordance with cortical activation (Kaiser, 2005; Lauts et al., 2006) and efficiency of cognitive and musical performance (Bazanova and Aftanas, 2008; Alekseeva et al., 2012), being narrow in less academically successful students and wider in more successful students (Bazanova and Aftanas, 2008). So, individual alpha bandwidth can be considered as an indicator of the relative activity of the different frequency generators included in the cortical activation (Mihić et al., 2015). Together with the magnitude and duration of the Berger effect, individual alpha bandwidth can be used as a characteristic of cortical activation, and consequently as an index of variability of neuronal generators included in that activation (Kaiser, 2005). We propose that extending the upper alpha boundary (and thus increasing the bandwidth) could be induced by the increase of progesterone level that raises the variability of high-frequency impulses (Koulen et al., 2008).

1.3. This study

Here we hypothesize that different measures of alpha reactivity to opening the eyes will differ with menstrual cycle phase. We propose that magnitude of alpha suppression in response to eyes open will be increased at those phases of the MC that are characterized by a high level of estrogen, known as a neuronal-excitability hormone (Verrotti et al., 2007; Heimovics et al., 2012; Wibowo et al., 2012), and will decrease at phases with high progesterone, known as a neuroinhibitory steroid (Herzog, 2007; Finocchi and Ferrari, 2011). Because the dominant alpha frequency range is changing during the MC, we suggest that the Berger effect will depend on the phase of menstrual cycle differently in low and high alpha frequency ranges.

Although both progesterone and estrogen vary though the MC, there are substantial difficulties in studying the interrelationships among estrogen activity and psychophysiological indices. First, the estrogen level in saliva is very low, but with large variability (Ju et al., 1999). Second, it is known that in healthy pre-menopausal women, concentrations of estrogen's metabolite, 2-methoxyestrone, is 2–3 fold higher than average menstrual cycle estrogen levels (Lakham et al., 2003; Tofovic, 2010). Therefore, it is difficult to detect differences in estrogen and its metabolite levels. Hence we will study the Berger effect indices in relation to the menstrual cycle phases and salivary progesterone level.

EMG will be used to monitor forehead muscle activity involved in psychoemotional tension or mental stress (Cacioppo et al., 1988; Malmo and Malmo, 2000; Wijman et al., 2011). We also investigate cortisol levels at the time of EEG and EMG recording in order to determine reactivity of free salivary cortisol concentration in response to eyes open as an activation index (Charlton, 1995) and at morning as a stress state index (Selye, 1976). We expect that cortisol level as a stress state index will not change during the menstrual cycle (Watanabe and Shirakawa, 2015), but salivary cortisol level could increase in response to eyes open at the follicular phase, when sensitivity is enhanced (Bazanova and Mernaya, 2008).
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