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EEG phase synchronization during emotional response to positive and negative film stimuli

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Abstract

In the present study the patterns of interdependency between different brain regions were investigated as volunteers looked at emotional and non-emotional film stimuli. The main goal was to evaluate the emotion-related differences and to check their consistency during the elaboration of the same type of stimuli in repeated presentations. A measure called synchronization index (SI) was used to detect interdependencies in EEG signals. The hypotheses were that emotional-information processing could involve variation in synchronized activity and that two valence-specific emotions – happiness and sadness – differ from each other. The SI obtained was compared among the various experimental conditions and significant changes were found. The results demonstrated an overall increase of SI during emotional stimulation and, in particular, during sadness, which yielded a pattern involving a large exchange of information among frontal channels. On the other hand, happiness was associated with a wider synchronization among frontal and occipital sites, although happiness itself was less synchronized. We conclude that the SI can be successfully applied for studying the dynamic cooperation between cortical areas during emotion responses.

Keywords: EEG; Phase synchronization; Emotion

Neural assemblies provide a conceptual framework for the integration of distributed neural activity [21]. We can define neural assemblies as distributed networks of neurons transiently linked by reciprocal dynamic connections. The intricate connectivity among functionally specialized groups of neurons is an outstanding characteristic of mammalian brains, which are primarily characterized by the ability to integrate information [20]. However, the specific nature of such interactions remains a point of debate. There are various modes of reciprocal interaction. One of these is phase synchronization among the participating neuronal groups. Direct evidence supporting synchrony as a basic mechanism for brain integration has recently been provided in relation to memory [10,12], learning [17], visual perception [14], binding processes [18], selective attention [11,19] and musical hearing [6]. Most of the works investigating the role of the synchronized activity focused on cognitive processes. Up to now, affective cortical activation and the effects of different emotions have received little attention in synchronization EEG studies. Signals have been studied while people watched emotional stimuli, both pictures and film clips. Researchers used power spectrum analysis to measure the event-related de-synchronization (ERD) and synchronization (ERS)—in other words, the decrease and the increase in power distribution [13]. Findings supported the evidence that synchronization changes were the result of emotional arousal and valence, as evidenced in the frequency range, and involved hemispheric asymmetries [4]. Very interesting results were gathered by such non-linear measures as dimensional complexity, a measure which is able to characterize specific cortical activity changes related to emotional experiences. Emotional activation was associated with an overall increase of complexity in the interaction among cortical regions. On the other hand, emotional valence could not be clearly associated with specific effects [1,3]. Further studies found that emotional arousal led to more complex and less predictable cortical dynamics, where positive emotions were related to a higher complexity in posterior areas and to a lower complexity in frontal areas than that evidenced with negative emotions [2]. The enhanced information exchanges between widely separated dynamical systems were observed in response to emotionally positive induction. In turn, the negative stimuli were found to involve a dynamical

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decoupling between anterior and posterior cortical regions with a processing center in the left prefrontal region [5].

The present study aimed to investigate the underlying cortical mechanism of emotional processing further, examining the pattern of synchronization between each couple of EEG signals recorded at different cortical sites. In order to achieve this goal, phase synchronization was examined as a measure to investigate the relation between the temporal structures of the signal regardless of signal amplitude. Two signals are said to be synchronous if their rhythms coincide. In its classical sense, the term synchrony has been applied to the signal that had a dominant oscillatory mode around a chosen frequency. To investigate whether two systems show phase synchronization, it is first of all necessary to know their phase variables. This is non-trivial for many non-linear model systems and even more difficult when dealing with noisy time-series of unknown origin. In this work we have followed the analytic signal approach to determine the instantaneous phase of the signal. A good estimator of the degree of phase synchronization between two signals is the synchronization index (SI) defined as:

$$\gamma^2_{n,m} = \langle \cos\, \phi_{n,m}(t) \rangle^2 + \langle \sin\, \phi_{n,m}(t) \rangle^2$$

where the brackets denote the average over time; it varies from 0 to 1. The advantage of this index over other ones is that its computation involves no parameters [15].

Despite the information that SI could provide to EEG studies, there are not any studies that utilize this type of index in the complex world of emotion, to best of our knowledge. In this study the changes of SI patterns were analyzed during responses to emotionally-laden external stimulation, using non-emotional and emotional film stimuli differentiated for valence.

We addressed three principal hypotheses: (i) the synchronization index among different EEG channels increases during the elaboration processing of a stimulus with respect to rest; (ii) a further increment in synchronized activity occurs in responses to emotional stimuli with respect to neutral, due to the recruitment of wider brain resources and a greater exchange of information among interacting areas; (iii) this enhancement of synchronization could take place in a more specific effect of emotional valence, with different SI patterns between positive and negative emotions. Finally, stimuli were presented three times comparing EEG responses to the same stimulus in order to check the consistency of SI pattern related to specific emotional information processing.

Thirty healthy, right-handed student volunteers participated in the experiment (15 males, 15 females), ranging in age from 18 to 26 years (mean 20.7 S.D. 2.17). None of the subjects reported any neurological disorders, psychiatric diseases, or were on medication. All had normal or corrected to normal vision.

Stimuli consisted of three sequences (120 s long) representing different emotional scenarios of happiness, sadness and neutral content extracted from commercial films. The films were edited by cutting any detail from the original sequences that could elicit emotional responses different from the target one. Such details included facial expressions or characters' actions. The stimuli obtained were pre-tested on a sample of judges ($N = 30$), who made self-reports in which they labeled the emotion experienced during the vision of films and rated the pleasantness and arousal level on a Likert scale ranging from 0 to 10. The clips were classified as producing the specific target emotional state, with a high concordance between expected and self-reported emotion (k-Cohen = .89, $p < .001$). The complexity of semantic content, defined as the exact understanding of what was happening in the clips, was assessed by an interview. The happiness sequence depicted lovers' encounters. The sadness sequence depicted the death of a significant person. Finally, the neutral sequence depicted a series of routine actions. All the stimuli were colored, presented without sound and balanced in their depiction of the presence of human beings as well as in the relative complexity of their semantic content.

The subjects were seated in comfortable chairs in the recording room and the experimental procedure was explained. The subjects were told to look at the TV screen placed in front of them and to concentrate on the film. At the end of each clip they had to answer some questions about their emotional experience while they were watching the stimuli.

The experiment began with a 300-s baseline recording of resting EEG, followed by the emotional film clips in random order. Each clip trial consisted of: (1) a brief time (3 s.) when a cross appeared on the screen; (2) the clip presentation for 120 s; (3) a 1-min post-film rest period, and (4) subjective ratings, which assessed the subjects' emotional reactions during the previous film. Subjects were asked to rate the pleasantness level, the arousal level, the intensity level of experienced emotion on a scale from 1 (not at all) to 9 (fully experienced emotion) and to rate the emotional state that they experienced during the trial on a rating scale including five primary emotions in random order: happiness, sadness, anger, fear, and disgust (from 1, indicating that the emotion was not at all present, to 9, indicating that it was felt very strongly). At the end of this first experimental session, the emotional films were repeated two times, counterbalancing the presentation order between subjects. Finally, a second eyes-closed baseline of 300 s was recorded.

EEG was recorded from 19 sites (Fp1, Fp2, F7, F8, F3, F4, Fz, C3, C4, Cz, T3, T4, T5, T6, P3, P4, Pz, O1, O2), which refer to linked earlobes. A ground electrode was attached to the center of the forehead. Vertical EOG was measured with electrodes 2 cm above and below the middle of the right eye in order to facilitate ocular artifact scoring, and remove them from the EEG recordings.

EEG and EOG signals were amplified by a multi-channel bio-signal amplifier (band pass 0.3–70 Hz) and A/D converted at 256 Hz per channel with 12-bit resolution and 1/8-2 μV/bit accuracy. The impedance of recording electrodes was monitored for each subject prior to data collection and the threshold was always kept below 5 kΩ.

EEG data was pre-processed using independent component analysis (ICA) [9] removing artifacts from the traces. ICA is generally applicable for removal of a wide variety of EEG artifacts. It simultaneously separates the EEG and its artifacts into independent components based on the statistics of the data, ICA does this without relying on the availability of one or more reference channels for each type of artifact. This avoids the problem of the potential mutual contamination of regressing and regressed