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Time-dependent cortical asymmetries induced by emotional arousal: EEG analysis of event-related synchronization and desynchronization in individually defined frequency bands

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Abstract

Event-related desynchronization (ERD) and synchronization (ERS) in the individually defined theta, alpha-1, alpha-2 and alpha-3 frequency bands were measured in 20 healthy subjects in response to International Affective Picture System (IAPS) stimuli with low, moderate and high arousal (LA, MA and HA) content. The 62-channel EEG, skin conductance response (SCR) and heart rate (HR) were simultaneously recorded while subjects viewed sequentially presented pictures and subjectively rated them after each presentation. In the theta band, both MA and HA vs. LA stimuli induced larger synchronization over the left anterior and bilaterally over posterior cortical leads. However, rather unexpectedly, both MA and HA vs. LA stimuli yielded larger alpha-1 synchronization, predominantly over occipital leads. In both theta and alpha-1 bands, affectively salient stimuli prompted larger ERS against the background of the overall dominance in power synchronization of posterior regions of the right hemisphere, irrespective of stimulus category. Finally, in the alpha-3 band, HA stimuli induce a lateralized time-dependent power increase over anterior leads of the left hemisphere. The hemispheric asymmetries revealed point to recruitment of not only posterior regions of the right hemisphere (theta and alpha-1 bands), but also of anterior regions of the left hemisphere (theta and alpha-3 bands) in affect analysis beyond valence dimension. In terms of affective chronometry, the significant arousal × time interactions clearly indicate that in the theta frequency band discrimination of affective stimuli has already started at 200 ms post-stimulus, whereas in the alpha-1 and alpha-3 bands this process is delayed by up to 800–1200 ms.

Keywords: EEG; Emotion; Emotional arousal; Theta; Alpha; Event-related desynchronization and synchronization; Hemispheric asymmetry; Skin conductance; Heart rate; Affective chronometry

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1. Introduction

Along with valence (pleasant/unpleasant), arousal (high/low) dimension of emotion experience has consistently emerged from multidimensional scaling and factor-analytical studies of self-reported emotion (e.g. Russel and Bullock, 1985; Watson and Tellegen, 1985). Contemporary research on cortical correlates of emotion function have started to take into account this distinction (e.g. Lang et al., 1998; Muller et al., 1999; Aftanas et al., 2001; Junghofer et al., 2001). Due to ambiguity of the arousal concept, repeatedly discussed in the psychophysiological literature (for review see Venables, 1984; Heller et al., 1997), the arousal dimension of emotion function has received little attention in EEG investigations. Consistent with the hypothesis that posterior regions of the right hemisphere are involved in the modulation of *emotion-related arousal* (Heller, 1993), scarce EEG (Nitschke et al., 1999; Davidson et al., 2000a), ERPs (Junghofer et al., 2001), autonomous (e.g. Heilman et al., 1978), neuropsychological (Heller et al., 1997) and fMRI (Lang et al., 1998) findings suggest this association. However, it is yet undetermined how cortical EEG asymmetries, emerging during affective processing, vary with the judged *arousal* of affectively salient stimuli. It is also unclear when, where and at which frequencies it occurs.

The experimental paradigm used in our prior study (Aftanas et al., 2001) was a good starting point for investigating how regional cortical activity varies as a function of arousal, EEG frequency and time course of affective responses. This paradigm controls for several potentially confounding variables. First, IAPS stimuli (Lang et al., 1999) enable control for valence and arousal dimensions. Stimuli are presented for 6 s. This standard time recommended for self-report rating of IAPS stimuli (Bradley and Lang, 1994) is acceptable for detecting both early (evaluative) and later (experiencing) aspects of affective processing in EEG investigations (e.g. Muller et al., 1999; Aftanas et al., 2001). Second, participants are instructed to attend to the pictures, but no overt response is required, so inherent affective reactions to these stimuli, rather than cognitive information-processing, are enhanced. Third, cortical activity is investigated using the event-related synchronization/desynchronization (ERD/ERS) method (Pfurtscheller and Aranibar, 1977). Sensory, cognitive and motor processing can result in changes in the ongoing EEG in the form of event-related desynchronization (ERD) or synchronization (ERS). Both phenomena are time-locked to the event and highly frequency band-specific. Traditionally, ERD is interpreted as a correlate of an activated cortical area with increased excitability and the ERS in the alpha and lower beta bands can be interpreted, at least under certain circumstances, as a correlate of a deactivated cortical area. Spatial mapping of ERD/ERS can be used to study the dynamics of cortical activation patterns (Pfurtscheller and Lopes da Silva, 1999). Few previous studies on the ERD/ERS responses to emotion-related stimuli have examined the narrow frequency bands of the EEG and revealed that this EEG quantification method can uncover the cortical correlates of relatively small differences in emotion processing (Aftanas et al., 1996a,b, 2001; Krause et al., 2000) and personality (Aftanas et al., 1996b), as well as a dissociation between the neural correlates of the processing of different types of emotional stimuli (Aftanas et al., 1996a,b, 2001; Krause et al., 2000). However, since fixed frequency bands blur specific relationships between cognitive performance and power measurements, narrow theta, alpha-1, alpha-2 and alpha-3 frequency bands are individually defined in relation to the individual alpha frequency (Doppelmayr et al., 1998a). Fourth, the use of a high-resolution 62-electrode recording montage provides more adequate topography of regional hemispheric activation patterns during emotional processing. Fifth, the simultaneously recorded SCR and electrocardiogram (ECG) data give important support to the proposal that picture differences are attributable to emotional arousal.

The present experiment, based on the merits of both the ERD/ERS method and IAPS stimuli set, was undertaken to examine whether arousal dimension of an emotion function would be associated with ERD/ERS measures of interhemispheric asymmetries in the anterior–posterior di-