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Research Report

Bursts of 15–30 Hz oscillations following noxious laser stimulus originate in posterior cingulate cortex

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ABSTRACT

Previous EEG studies reported the presence of synchronised 15–30 Hz oscillations in vertex electrodes following innocuous somatosensory stimulation and noxious laser stimulation. The purpose of the present study was to analyse the sources of poststimulus increases of 15–30 Hz oscillations during noxious laser stimulation of four different body regions and to compare the sources of the poststimulus synchronisation with the sources of the N2 component of laser-evoked potential (LEP). In 10 healthy subjects, moderately painful laser stimuli were applied to the dorsum of the right hand, dorsum of the right foot, right groin, and right side of the face. EEG data, recorded from 111 scalp sites, were analysed using event-related desynchronisation method and source dipole analysis. A profound amplitude increase of 15–30 Hz oscillations peaking 1–2 s after noxious laser stimulation was found during stimulation of each body part. The sources of these oscillations were located in the dorsal posterior cingulate cortex and showed no somatotopic arrangement. The sources of the N2–LEP component were located in the anterior mid-cingulate cortex 25–30 mm rostral to the sources of 15–30 Hz oscillations. The amplitude of the poststimulus synchronisation of 15–30 Hz oscillations correlated ($P<0.05$) with the amplitude of N2–LEP component. Results show that noxious laser stimuli induce bursts of 15–30 Hz oscillations in the posterior cingulate cortex. The poststimulus increases of 15–30 Hz oscillations may stand for transient cortical inhibition possibly aiding temporary suppression of motor programs that have been primed by noxious stimulation.

1. Introduction

Laser stimulation is used in clinical studies to evaluate the integrity of the peripheral and central nociceptive systems (Bromm and Treede, 1991; de Tomasso, 2008; Gibson et al., 1994; Hansen et al., 1996; Lorenz et al., 1996; Truini et al., 2009a, b; Vartianen et al., 2008). EEG potentials evoked by laser stimulus reveal two major negative components. During stimulation of the hand, the earlier N1 component occurs with the latency of 150–180 ms in temporal electrodes. The

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subsequent N2 component (160–350 ms) shows a clear negative maximum in vertex electrodes and originates in the anterior cingulate cortex (Garcia-Larrea et al., 2003; Perchet et al., 2008; Schlereth et al., 2003). Both LEP components were frequently used in neurophysiological experiments to analyse the sensory, attentional, and cognitive aspects of nociceptive processing (de Tomasso et al., 2008; Garcia-Larrea et al., 1997; Iannetti et al., 2005; Legrain et al., 2002; Legrain et al., 2003; Mouraux and Plaghki, 2007; Ohara et al., 2004b; Valeriani et al., 2008). Recently, nociceptive specificity of the N2 component and possibly of the whole LEP waveforms has been brought into doubt by demonstration that 79% of the N2 component could be explained by sensory nonspecific, multimodality effects (Mouraux and Iannetti, 2009) and by the finding that saliency of laser stimulus rather than intensity was reflected in the amplitude of N2 component (Iannetti et al., 2008).

However, noxious and innocuous somatosensory stimuli are followed by two types of electrocorticographic and neuromagnetic responses. One type of response shows a tight phase coupling with the stimulus onset and corresponds to LEP. Another type of response is not phase-locked to the stimulus and manifests in amplitude variations of ongoing oscillatory cortical activity. The phase-unlocked cortical responses can be analysed using the event-related desynchronisation method (Pfurtscheller and Aranibar, 1977) and other methods (Greimann and Pfurtscheller, 2006) that transform the EEG/MEG signals into power–time series representing amplitude variations of certain cortical oscillations in select frequency band.

Innocuous tactile and electrocutaneous stimuli are followed by amplitude decreases of the cortical 8–14 Hz and 15–30 Hz oscillations occurring in bilateral primary sensorimotor cortices with a latency of 0.2–0.5 s (Gastaut et al., 1952; Kuhlman, 1978; Pfurtscheller, 1981; Stancak et al., 2003) (reviewed in Stancak, 2006). Innocuous somatosensory stimuli are also followed by amplitude increases of 15–30 Hz oscillations occurring in the contralateral primary sensorimotor cortex (Pfurtscheller et al., 2001; Salmelin and Hari, 1994; Stancak et al., 2003) and in the medial frontal cortex (Brovelli et al., 2002).

Noxious laser stimuli show similar poststimulus decreases of 8–14 Hz and 15–30 Hz power as innocuous somatosensory stimuli (Ohara et al., 2004a; Ploner et al., 2005; Raij et al., 2004). A small number of studies have reported the presence of amplitude increases of cortical oscillations following noxious laser stimuli (Domnick et al., 2009; Mouraux et al., 2003). These studies involved either a small number of electrodes (Mouraux et al., 2003) or focused on select vertex electrodes (Domnick et al., 2009). Therefore, the cortical generators of the 15–30 Hz oscillatory increase following noxious laser stimulation remain to be disclosed.

Clinical utilisation of laser-evoked potentials involves comparisons of LEPs related to stimulations of different parts of the body. Somatotopic organisation of the cingulate cortex during innocuous and noxious peripheral nerve stimulation has been indicated in fMRI maps (Arienzo et al., 2006). Therefore, to explore further the spatiotemporal patterns and cortical sources of the 15–30 Hz oscillatory and N2–LEP responses, noxious laser stimuli were applied to four different body regions (hand, foot, groin, and face).

2. Results

2.1. *Behavioural data*

The stimulus duration and intensity as well as subjective intensity and unpleasantness of the four types of stimuli were analysed using one-way analysis of variance for repeated measures with four levels. Subjects reported a sharp pricking pain of moderate intensity during laser stimulation. Average pain intensity and unpleasantness of laser stimuli applied to the four different body regions ranged from 4.4 to 5.3 to and was equal for each of the four body parts according to one-way ANOVA for repeated measures ($P>0.05$).

2.2 *Poststimulus synchronisation of 15–30 Hz oscillations and LEPs*

All subjects showed a strong synchronisation of 15–30 Hz oscillations occurring during stimulation of each of the four body parts in the central midline electrodes centred around Cz. Fig. 1 illustrates the poststimulus band power increase of 24–26 Hz oscillations and laser-evoked potentials during stimulation of the right hand (Figs. 1A–D), foot (Figs. 1E–H), groin (Figs. 1I–K), and face (Figs. 1M–P) in one representative subject. The poststimulus increases of 24–26 Hz oscillations were prominent over the vertex (Figs. 1A, E, I, and M). There were no clear spatial differences in the topography of the poststimulus ERS in the four types of stimulation. Figs. 1B, F, J, and N show the averaged band-pass-filtered 24–26 Hz oscillations locked to the amplitude maxima of band power identified during the poststimulus period (0.6–2 s) in all trials. The isopotential maps of the 24–26 Hz oscillations in every type of stimulation showed one spatial maximum at vertex electrodes indicating the presence of a radial source dipole located in the medial frontal or parietal cortex. Figs. 1C, G, K, and O show isopotential maps of the N2–LEP component with

Fig. 1 – Event-related synchronisation and laser-evoked potentials during stimulation of the hand (A–D), foot (E–H), groin (I–L), and face (M–P) in one representative subject. (A) Time–frequency plot (upper panel), power-time course (bottom panel), and topography (left panel) of 24–26 Hz oscillation during laser stimulation of the right hand. (B) The band-pass-filtered 24–26 Hz oscillations (upper panel), and the isopotential map of the averaged band-pass-filtered activity (lower panel). (C) Laser-evoked potential at the vertex electrode (upper panel) and the isopotential map of the N2 component (lower panel). (D) Location of the source dipoles of the laser-evoked potential (blue circles) and 24–26 Hz oscillations (red circles). The dipole orientations are indicated by vectors pointing away from the negative maximum. The legends in E–H (foot), I–L (groin), and M–P (face) correspond to the legends in A–D (hand).