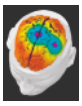
Gamma-Oscillation in Human Pain: Spatio-Temporal Dynamics



Andrew C.N. Chen (*) and Christoph S. Herrmann (**)

(*) Human Brain Mapping & Cortical Imaging Laboratory, International Doctoral School in Biomedical Sciences & Engineering, Aalborg University, Denmark; (**) Max-Planck-Institute of Cognitive Neuroscience, Leipzig, Germany

Introduction

The dynamics of cortex driven by noxious median nerve stimulation (left hand) were recorded with early SEP (eSEP) and studied with gamma-band analysis. Gamma-binding has been hypothesized for feature extraction and integration in perception. This study aimed to delineate the spatio-temporal dynamics of gamma activation for understanding the cerebral processing of human pain.

The temporal-spatial evolution of the brain activities can best be analyzed and understood in the time-frequency domain of EEG compared to the traditional use of time-domain analysis in ERP. We applied a wavelet time-frequency analysis to differentiate the brain dynamics between non-painful and painful somatosensory stimulation.

Methods

ERP was recorded from 12 healthy males (age: 26.8 +/-5.2) for 31 electrodes (bandwidth 0.1-100 Hz, 2K Hz sampling, 600 trials with stimulation at 3 Hz). Subjects were stimulated to evoke somatosensory evoked potentials at 2 stimulation intensities (non-pain and pain) tailored individually. The averaged eSEPs (window: 0 ms - 250 ms) were then subjected to a wavelet analysis of the gamma-band. The eSEP was convolved with Morlet wavelets. In order to generate maps of activity, we extracted 1-80 Hz frequency lines from the time-frequency maps, representing the absolute amount of oscillations for a certain period of time.

In order to avoid a loss of statistical power that is inherent when repeated measures ANOVAs are used to quantify multi-channel EEG data (Oken, 1986), selected electrode sites were pooled to six topographical regions of interest (ROIs). The regions included the following electrodes:

Left anterior region (LAR): FP1, F7, F3, FC5
Left central region   (LCR): C3, C3', T3, PC5
Left posterior region (LPR): P3, T5, O1, PC1

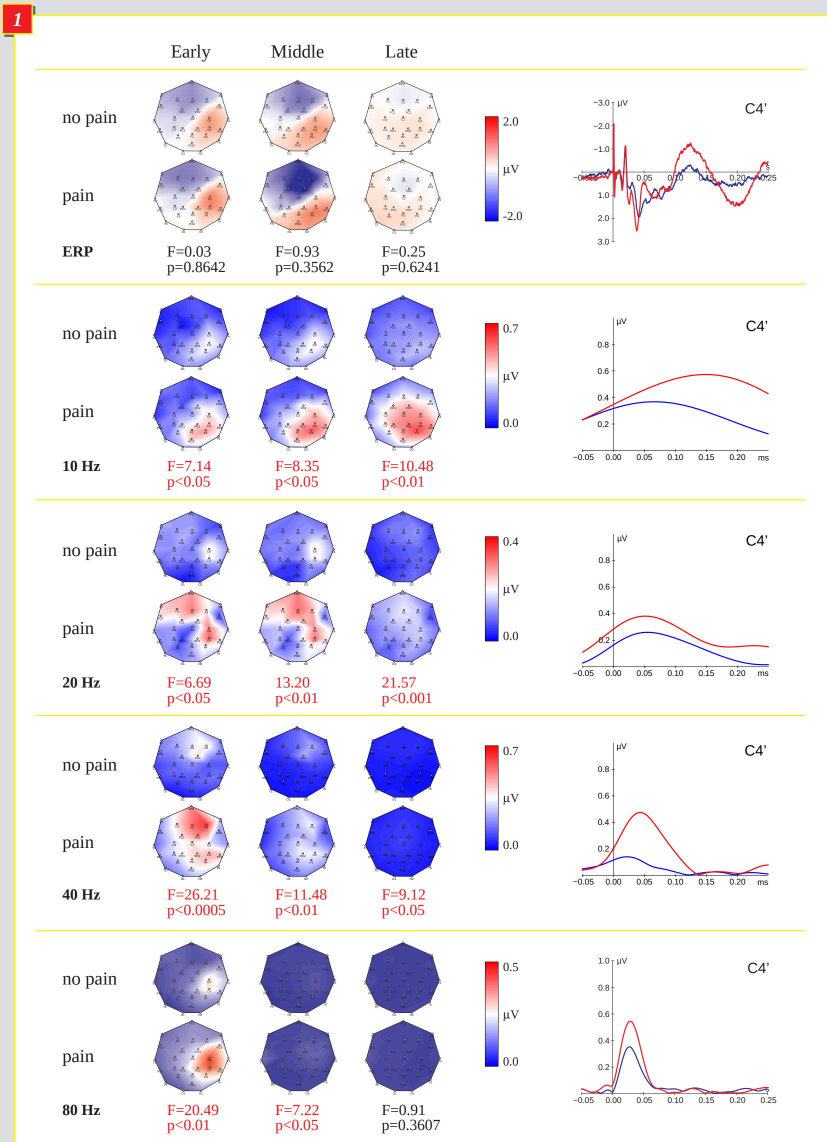
Regions over the right hemisphere included the homologous electrodes. For statistical analyses ERP amplitudes were pooled across the electrodes in each of the ROIs. ERP components were defined as mean amplitudes in the following time intervalls: 20..50 ms (early), 50..100 ms (middle) and 100..250 ms (late).

Repeated-measures ANOVAs with factors topography (anterior, central, posterior), hemisphere (left, right) and condition (pain, no-pain) were conducted to assess the effects of the experimental variables on a variety of dependent variables. ANOVAs were computed on averages of the abovementioned time intervals for both ERP and gamma data.

For analysis of frequency-selective activity, we used a wavelet decomposition as described in Herrmann et al. (1999). Maps were calculated for each of the frequencies 10 Hz, 20 Hz 40 Hz and 80 Hz. We investigated the temporal smearing of the 10 % amplitude for all frequencies. The temporal smearing of a sinusoidal component in the decomposed signal can be up to 30 ms at 10 Hz and will be smaller than 10 ms above 20 Hz. The maximum of the component will remain at the same latency.

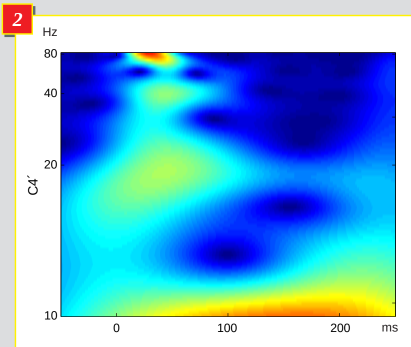
Results

1



Maps of individual frequencies and time courses of electrode C4'.

2



Time-frequency plane of electrode C4'. Three early frequency components are visible at 20, 40 and 80 Hz and a late component at 10 Hz.

Results

As early as 30 ms after stimulation, the difference between pain and no-pain was most pronounced in the 80 Hz activity in the hand area over C4 contralateral to the stimulated hand with a central-parietal topography. Following this early activation, a 40 Hz activity peaked at 44 ms and was significantly higher for the pain condition at the same site in C4. This activity has two foci in frontal and central regions. Immediately after that, an ensuing 20 Hz activity peaked at 46 ms which was again higher for the pain condition than the no-pain condition, with a fronto-central topgraphy around C4. While the frontal activity was bilateral, the central activity was only present over the stimulated sensory area. Finally, the 10 Hz activity had its maximum in the late time window at 160 ms (C4). The topography is centro-parietal and has its maximum over the contralateral right hemisphere.

3

	F4	C4	P4	O2
10 Hz	237	160	141	112
20 Hz	74	46	54	76
40 Hz	38	44	43	44
80 Hz	38	30	26	37

Latency of maxima in electrodes over the right hemisphere for all investigated frequency bands. A possible path of propagation is indicated by solid arrows. Electrodes which are activated simultaneously are shaded gray.

Discussion

We showed that the evoked response in EEG reflects many different aspects of human information processing, if different frequencies are looked at individually. The spatial and temporal aspects can be much better dissociated than in the ERP. As can be seen in Figure 3, the 80 Hz activity peaks first in the central/parietal region and then propagates to frontal and occipital regions from there. Then, the 40 Hz activity peaks in the frontal region. According to oscillator theory this could be due to the second harmonic frequency (80 Hz) triggering the neural 40 Hz oscillators. The 40 Hz activity then spreads to central/parietal and occipital regions. At 46 ms the 20 Hz activity peaks over the central/parietal region. This could again be a frequency shift, as has been described by Traub et al. (1999) where they show how gamma induces beta activity. After the 20 Hz activity has spread to occipital electrodes (it lasts until 164 ms over =2), the 10 Hz activity is triggered at 112 ms and propagates to frontal regions. In addition, we also found a frontal/parietal 40 Hz response which has been hypothesized as conscious somatic perception by Desmedt et al. (1994). Albeit, our activity occurs in a very early time interval (44 ms) and must be considered pre-attentive if brought into context with somatosensory binding.

Conclusion

Time-frequency analysis of EEG proves to be highly sensitive in differentiating painful from non-painful somatosensory stimulation. This study established a temporal-spatial EEG frequency resonance model in sensory processing. Early processes are fast while later processes spread out temporally. This could be due to different neural oscillators which trigger each other and propagate their activity over the cortex.

References

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