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Oscillatory cortical activity during a motor task in a deafferented patient

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Abstract

Little is known about the influence of the afferent peripheral feedback on the sensorimotor cortex activation. To answer this open question we investigated the alpha and beta band task-related spectral power decreases (TRPow) in the deafferented patient G.L. and compared the results to those of six healthy subjects. The patient has been deafferented up to the nose for 24 years but her motor fibers are unaffected and she can perform complex motor tasks under visual control. We recorded EEG (58 scalp positions) as well as the exerted force during a visuomotor task. The subjects had to maintain in precision grip an isometric force at 15% of the maximal voluntary contraction. In the patient we found a significantly higher alpha band spectral power during rest and larger alpha TRPow decreases during the motor task when compared to the healthy subjects' data. In contrast, we did not observe any significant differences between patient and controls for the beta band TRPow. The results indicate an altered functional alpha band network state in the patient, probably due to the chronic deafferentation leading to a deep 'idling' state of the contralateral sensorimotor area.

Keywords: EEG; Spectral power; Alpha; Beta band; Isometric force; Precision grip

Previous EEG and MEG studies have shown that the amplitude decrease in alpha and beta band cortical oscillations, called event-related desynchronization (ERD) [21], consistently reflects the functional activation of the sensorimotor areas during the preparation of a fast voluntary movement [2,9,22,26].

Amplitude decrease in alpha- and beta-frequency range was described not only during motor preparation but also during a continuous motor performance by Manganotti et al. [16] who investigated task-related spectral power changes during a sequence of finger movements. These authors actually introduced the term of task-related power (TRPow), which differs from ERD, as steady-state changes are studied rather than phasic changes associated with a fast movement. They found that the movement sequences were associated with TRPow decreases in alpha- and beta-frequency bands over the bilateral sensorimotor and parietal areas, with contralateral preponderance. The spatial extent and the magnitude of the spectral power decreases were greater for sequences of higher complexity than for the simpler one. Using electrocorticogramm in a visuomotor decision task Crone and coworkers [3–5] also focused on spectral power changes during isometric muscle contraction and found amplitude decrease in alpha- and beta-frequency range.

Little is known about the influence of the afferent peripheral feedback on the contralateral sensorimotor cortex activation, as reflected in the TRPow decrease. Deafferented patients are the model of choice to provide an answer to this question. Therefore, we investigated the TRPow decreases in the alpha and beta range during a motor task requiring holding isometric force in precision grip in the deafferented patient G.L. and compared her

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data with those of healthy controls. This patient is a clear experimental model as she does not have any proprioceptive input from the periphery but still can perform movements.

The deafferented patient G.L., a right-handed 55-year-old woman participated in the study (For detailed clinical description, see Forget and Lamarre [10] and http://deafferented.apinc.org//). In brief, after two episodes of polyneuropathy (at the age of 27 and 31) the patient has been suffering from a strong sensory impairment of the whole body up to the nose due to affected large diameter peripheral sensory myelinated fibers. The impairment was documented by sural biopsy. The patient has a total loss of touch, vibration, pressure and kinaesthetic senses, and no tendon reflexes in the four limbs. Pain and temperature sensations are still present. The motor fibres are not affected and the patient can perform complex motor behaviour under visual guidance. Six healthy female (mean age 55 ± 3.5 years) without any history of neurological disease participated in the study as age-matched control subjects. The handedness of patient and controls was tested according to the Oldfield questionnaire [19].

All subjects participated according to the declaration of Helsinki, with informed consent and the approval of the local ethics committee.

During the experimental session, the subject was sitting in an electrically shielded, dimly lit room.

The right hand and arm were supported in a rigid cast. At the beginning of the experiment there was a rest period consisting in holding the manipulandum without exerting any force. This period lasted ninety seconds and was used as a baseline. After that the subject had to hold a force transducer between thumb and index finger and to maintain a constant isometric force (Fig. 1A).

The exerted force was 15% of the individual maximum voluntary contraction determined prior to the experiment. The target force and the exerted force were displayed on a screen in front of the subject. The task included 10 holding periods, with randomized times of 10, 20 and 30 s to avoid habituation effect. A schematic outline of the experimental paradigm is shown in Fig. 1B. Instruction for the beginning and end of the force generation and holding were given verbally with two commands "start" and "stop". The subjects had several practice holding periods prior to the experiment until they reached a stable motor performance.

Electrical potentials (bandpass 0–200 Hz, sampling rate 1000 Hz) were recorded from 58 scalp positions, equally distributed over both hemispheres (NeuroScan, El Paso, TX, USA). The electrooculogram (EOG, same bandpass and sampling rate as for EEG) was recorded to exclude trials contaminated with eye movements from further analysis. The force was recorded by a force transducer (same bandpass and sampling rate). EEG, EOG, and force traces were stored and analysed off-line.

Artifact rejection was visually performed off-line trial-by-trial to exclude segments with eye movement, and force profiles not confined within the force requirements. Manual markers were put separately for the rest period (R1-R2) and for the force holding periods (P1-P2) (Fig. 1B). To avoid transient effects, data related to the force ramp phase were not dealt with in this study. Continuous data, in-between the markers, was further segmented into successive epochs of 1024 ms duration (allowing for a frequency resolution of 0.98 Hz). This was done as well for the rest as for the force holding periods. The signal was then transformed into the reference free current source density distribution (CSD) which reflects the underlying cortical activity avoiding smearing effects [18]. The CSD algorithm was estimated using the spherical spline interpolation method [20]. For spectral power analysis, the discrete Fourier transform was calculated for each epoch for the whole 1–500 Hz frequency range. The resulting power spectra were further averaged over the epochs. A total of 60 artifact-free epochs were analyzed for each subject.

Task-related power decreases at each electrode were obtained by subtracting the spectral power during rest from the corresponding spectral power during the task. Only electrodes over the contralateral sensorimotor area (C3A, C3, C3P) are reported here. TRPow decreases ('activation') are expressed as negative values while TRPow increases are expressed as positive values. The maxima of the spectral power changes within alpha (8–12 Hz) and beta band (15–30 Hz) were determined individually.

To normalize the individual data, EEG spectral power data was logarithmically transformed according to the following equation:

$$f(x) = \log 10(20 + \boldsymbol{x}) - \log 10(20)$$

where $\boldsymbol{x}$ is the untransformed respective power.

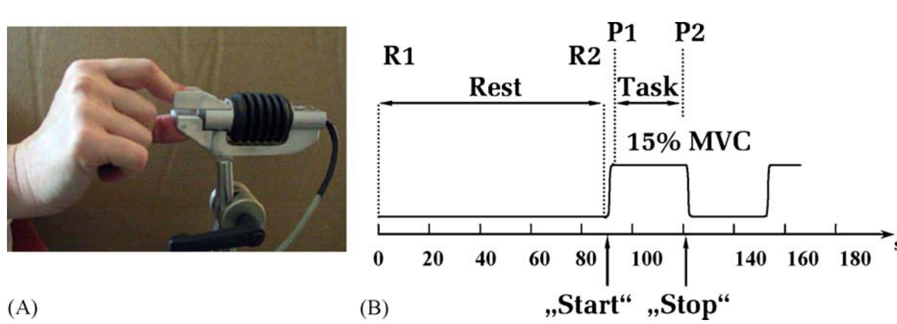

Fig. 1. (A) Experimental set-up. The hand of one control subject with the isometric contraction force transducer. (B) Experimental task: after an initial rest period, subjects were asked to generate an isometric contraction between their thumb and index finger of the right hand until reaching 15% MVC and to maintain the force up to the instruction to stop (holding time here: 30 s). R1 and R2, onset and end of the rest period, respectively. P1 and P2, onset and end of the analyzed force holding period, respectively. "Start" and "Stop" correspond to the instructions verbally given to the subject to exert force.

To investigate the alpha and beta band EEG spectral power and their modulation during the task (TRPow), the analysis consisted of a three-way ANOVA with repeated measures on the three factors. In this ANOVA design the first factor was a between subjects factor "group" with 2 levels (patient and controls). The second factor was the within subject factor "task" with 2 levels (rest and force holding). The third factor was the within subject factor "band" with 2 levels (alpha and beta band).

Two force parameters were analyzed for each subject: First, the standard deviation of the mean force averaged over the holding periods and second, the macrovariation defined as the absolute difference between the successive force holding periods.

To account for the inter-subject variability, values corresponding to these force parameters were logarithmically transformed according to the transformation:

$$f(\boldsymbol{x}) = \log(\log(\boldsymbol{x})),$$

where $\boldsymbol{x}$ is the untransformed respective force parameter.

The analysis of the force data was based on a *t*-test analysis where the two parameters were compared between patient and controls.

The patient G.L. performed the precision grip force task almost as well as the control subjects. No differences in the SD between patient and controls were observed. The analysis of the force only indicated a tendency for higher force macrovariation between the successive holding periods in the patient than in the controls ($T = -2.13$, $p = 0.08$).

The individual spectral power values for alpha and beta band during rest and task are displayed for the patient and the controls in Fig. 2A, and the mean values in Fig. 2B. The alpha band spectral power of the patient during rest and task was outstanding in comparison to that of the controls, especially for the rest. The ANOVA showed significant main effect of the factors "group" ($F = 42.66$, $p = 0.0013$) and "task" ($F = 28.04$, $p = 0.0032$). Significant were also the interactions "task × group" ($F = 6.42$, $p = 0.05$), "band × task" ($F = 14.46$, $p = 0.0126$) and "band × task × group" ($F = 15.43$, $p = 0.01$). The post hoc analysis for the alpha band during rest and task revealed significantly higher spectral power for the patient G.L. as compared to the controls ($F = 24.02$, $p = 0.0045$ for rest and $F = 6.78$, $p = 0.048$ for task). No significant group differences were observed for the beta band (Fig. 2B).

With respect to the TRPow decreases from rest to task, the mean frequency maxima in the alpha band were at 9.44 ± 1.54 Hz for the controls and at 9.77 Hz for the patient G.L. In the beta range, the mean TRPow decrease maxima were at 20.67 ± 3.44 Hz for the controls and at 18.55 Hz for the patient. The differences in TRPow frequency decreases were not significant.

The individual amplitude of the TRPow decrease are displayed in Fig. 3A which shows that only the alpha band TRPow decrease was outstanding, being much larger in the patient than in the controls. This effect is also seen in Fig. 3B which displays the mean values for patient and controls and the significant task effect for the alpha band for the patient only.

This study was designed to answer the question what is the influence of the afferent sensory feedback from the periphery on the activation of the contralateral sensorimotor area, as reflected in the alpha and beta band spectral power changes. For this purpose, we compared the results from an exceptional deafferented patient with those of healthy controls during rest and during a motor task. We revealed two main findings:

1. During rest, we found a significantly higher alpha band spectral power in the patient than in the controls. This finding can be interpreted in the framework of the "idling" theory first formulated by Adrian and Matthews [1]. These authors described a system which is neither receiving nor processing sensory information as an 'idling system'. Later, Pfurtscheller et al. [24] defined an 'idling mode' for cortical regions which pass from 'cortical work' during preparation and execution of a given movement into a state of 'nil work' or idling. Such regions are processing less information at a specific instant of time, as no further motor commands are sent to the muscles and transient afferent stimuli from cutaneous and

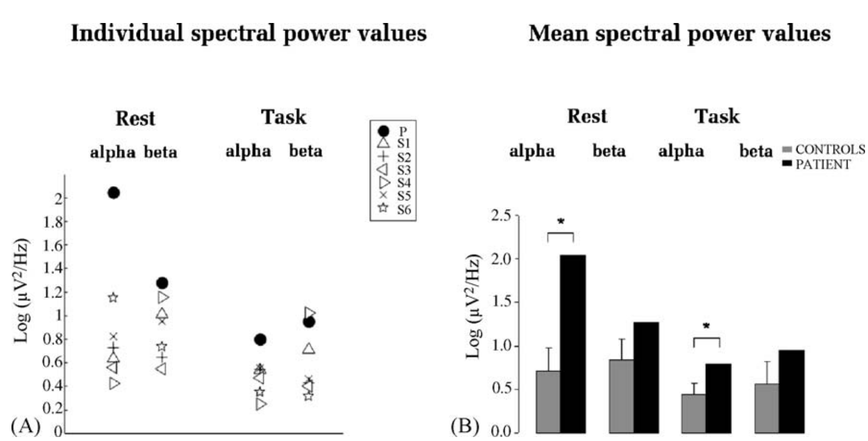

Fig. 2. (A) Individual alpha and beta band spectral power for the patient (P) and for six controls (S1–S6) over the contralateral sensorimotor (SM1c) area during rest and task. The alpha band spectral power values for the patient G.L. are outstanding. (B) Mean spectral power values for the patient G.L. and for the controls during both rest and task for alpha and beta band. The asterisk denotes statistically significant group difference. Note the higher alpha band spectral power values for the patient for both rest and task.

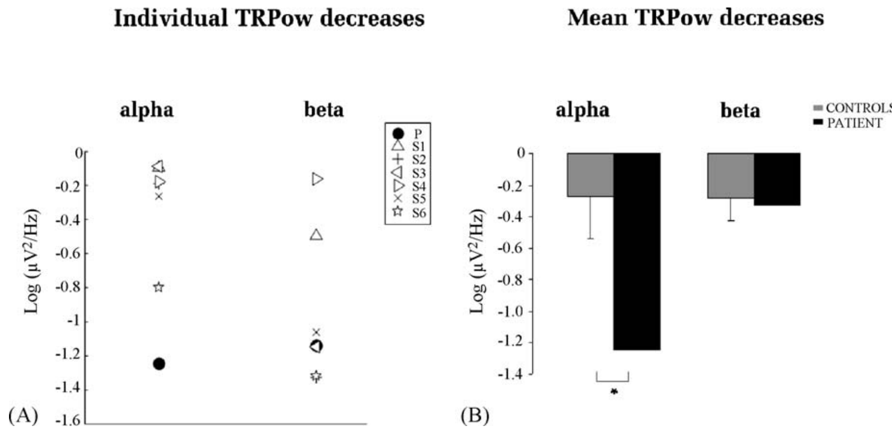

Fig. 3. (A) Individual alpha and beta band task-related spectral power (TRPow) decrease values for the patient G.L. and for the controls over SM1c. (B) Mean values for alpha and beta band TRPow decreases for the patient G.L. and for the controls. The asterisk denotes statistically significant group difference. Note the stronger TRPow decreases in the patient in the alpha band.

proprioceptive receptors are not reaching the somatosensory cortex any more. Cortical sensorimotor areas which are not involved in planning and execution of specific movements would tune themselves into an idling mode or ‘nil working’ state. The results of the present study are consistent with this postulate. It is reasonable to think that during the rest period, all subjects found themselves into an ‘idling state’ where ‘little’ information, particularly somatosensory information, had to be processed. The higher alpha band spectral power in the patient G.L. may be a sign of an even lower charge of sensory information due to the chronic deafferentation. Thus, our results are well in line with the hypothesis of somatosensory “cortical idling” [14].

2. When a sustained isometric contraction was performed the amplitude of the power spectra diminished for both alpha and beta band spectral power. The alpha band TRPow decrease when passing from a rest or “idling” state into an active or “working state” has been well reported [8,11,24,27]. These studies suggested that the alpha band desynchronization represents an electrophysiological correlate of cortical activation related to information processing, selective attention, motor preparation and execution. Further, they showed that the magnitude of the TRPow decrease reflects the mass of networks involved in the performance of a specific task at a specific moment of time. The fact that the magnitude of the TRPow decrease increases with task complexity has been confirmed by others [6,7,12,16,27]. The significantly larger alpha band TRPow decrease in the patient may indicate that the sustained isometric contraction represented a more demanding task for her than for the controls. This is supported by the stronger macrovariation of her force over the successive holding epochs, which is probably related to the absence of proprioceptive feedback, as already suggested by other studies with the same patient [13,15] and during experimental deafferentation [17].

It has been suggested that the beta rhythm is generated in the motor cortex [9,23,25] and that the beta band TRPow decreases are reflecting the preparation and execution of appropriate motor programs. Therefore, the absence of significant difference in the beta band oscillatory activity between patient and controls is not surprising as the patient G.L. can perform motor tasks under visual guidance and thus, still has almost normal motor function.

Altogether, our findings showed a significantly higher alpha band spectral power during rest and significantly higher alpha band TRPow decreases during task in the deafferented patient G.L. This altered functional alpha-band network state is probably due to the chronic deafferentation leading to a deep ‘idling’ state of the contralateral sensorimotor area. In contrast, the beta band oscillatory cortical network state remains unaffected after chronic deafferentation.

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