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Temporal evolution of event-related desynchronization in acute stroke: A pilot study

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HIGHLIGHTS

- Event related synchronization/desynchronization (ERD/S) accompanies stroke recovery.
- Both contra- and ipsilesional changes are observed.
- ERD/S may assist in stroke prognostication and rehabilitation.

ABSTRACT

Objective: Assessment of event-related desynchronization (ERD) may assist in predicting recovery from stroke and rehabilitation, for instance in BCI applications. Here, we explore the temporal evolution of ERD during stroke recovery.
Methods: Ten stroke patients and eleven healthy controls were recruited to participate in a hand movement task while EEG was being recorded. Four measurements were conducted in eight patients within four months. We quantified changes of ERD using a modulation strength measure, S_m, which represents an area and amplitude of ERD.
Results: 7/8 patients showed good recovery. Absence-or-reduction of ipsilesional modulation was initially found in stroke patients but not in the healthy controls. In the patient group, two evolutions were found in 6/8 patients: a significant increase in ipsilesional S_m; and a decreasing trend in contralesional S_m. In the only non-recovery patient, absence of ipsilesional modulation was observed, while his contralesional S_m increased with time after stroke.
Conclusion: The two evolutions presumably reflect the reorganization of brain networks and functional recovery after acute stroke. The significant increase of ipsilesional S_m in patients with a good recovery suggests an important role of this hemisphere during recovery.
Significance: Improved understanding of ERD in acute stroke may assist in prognostication and rehabilitation.

1. Introduction

Stroke is one of the leading causes in adults' disabilities. In the US alone, about 800,000 new stroke cases are diagnosed, annually. About half of the adult stroke patients suffer from moderate to severe loss of some motor skills (Roger et al., 2012; Hayes et al., 2003). Various mechanisms are involved in stroke recovery including (i) restitution of non-infarcted penumbral areas; (ii) resolution of diaschisis; (iii) brain plasticity; and (iv) behavioral compensation (Kwakkel et al., 2004). Among these, only the first three reflect true recovery from stroke, while behavioral compensation is found in patients who compensate for their loss of function with other movement strategies.

In this study, we focus on brain plasticity, which is one of the key mechanisms in stroke recovery, characterized by a functional and anatomical reorganization of the central nervous system (CNS). These changes occur at various spatial scales. At the microscopic level, dendritic and axonal sprouting are two typical phenomena in the peri-infarct cortex (Benowitz and Carmichael, 2010; Hosp and Luft, 2011) that may partially compensate for neuronal loss in this area (Carmichael, 2006; Brown et al., 2010). At a larger spatial scale, cortical reorganization has been reported in several studies, too. For instance, using transcranial magnetic

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stimulation (TMS), shifts in corticomotor representation on the affected hemisphere compared to the non-affected healthy hemisphere were found (Byrnes et al., 1999, 2001). In a recent study using magnetoencephalography (MEG), a transient enlargement of motor areas during stroke recovery was observed (Roiha et al., 2011).

Several functional magnetic resonance imaging (fMRI) studies have explored cortical reorganization in stroke patients performing movement tasks. In a study with eight acute stroke patients, increased activation was observed in various areas, including the contralesional (ipsilateral) sensorimotor cortex, contralesional posterior parietal, bilateral prefrontal regions (Marshall et al., 2000). Similar findings, observed in both the motor and non-motor related brain areas of both hemispheres, were reported by Feydy et al. (2002), Ward et al. (2003a) and Grefkes et al. (2008). Lateralized activation towards the ipsilesional hemisphere and a decrease of contralesional activation were two typical evolutions in patients with good recovery (Marshall et al., 2000; Feydy et al., 2002; Ward et al., 2003b).

Reorganization of cortical networks can also be studied with the electroencephalography (EEG). In acute cortical stroke, slow activity (1–4 Hz) over the affected hemisphere is typically increased with a reduction of relatively fast activity (8–13 Hz, or 15–25 Hz) (Cohen et al., 1976; Finnigan et al., 2007; Carmichael and Chesselet, 2002; van Putten and Tavy, 2004; Finnigan and van Putten, 2013). During recovery, a shift towards a normal spectral distribution is observed (Finnigan et al., 2007; Finnigan and van Putten, 2013; Fernández-Bouzas et al., 2002; Murri et al., 1998; Nuwer et al., 1987).

Only a few EEG studies in stroke patients have been performed during active movement. In 1980, Pfurtscheller and Aranibar showed a reduction of Event-Related Desynchronization (ERD) on the affected hemisphere as compared to the unaffected hemisphere in cortical stroke patients with mild hemiparesis, during performance of hand movement (Pfurtscheller et al., 1980). This reduction has also been reported in later studies (Stępień et al., 2010). A concomitant increase in ERD on the contralesional hemisphere during finger extension was reported by Gerloff et al. (2006).

In this study we explore the spatiotemporal dynamics of cortical reorganization in acute hemispheric stroke patients. We will use ERD during active movement of the paretic arm, evaluated over the course of several months after the insult. In particular, we will focus on the role of the ipsi- and contralesional hemisphere in successful recovery of upper extremity function.

2. Methods

2.1. Subjects

Ten acute hemispheric stroke patients (mean age: 64.9 years, S.D. 13.4, five female, nine left hand motor deficit) and eleven age-matched healthy controls (mean age: 57 years, S.D. 7.8, nine female, ten right handed) were recruited to participate in this study. All patients suffered from a first-time-ever ischemic hemispheric stroke, with no other neurological disorders. The patients were recruited from the stroke unit of the Medisch Spectrum Twente (MST) hospital within 7–14 days after stroke onset. The study was approved by the local ethical committee of the MST. Demographic and clinical data of the patients are summarized in Table 1. Magnetic resonance or computed tomography imaging was performed in every stroke patient to confirm the diagnosis and detect the infarct location ***(see Supplementary Figure S1).

2.2. EEG recording

All experiments were conducted in a shielded room. 60-channel EEG recordings (TMS International, The Netherlands) were made using Ag/AgCl electrodes. The sampling frequency was set at 5 kHz. All electrode impedances were kept below 5 kOhm. Two reference electrodes were placed over the left and the right mastoids. All signals were first down-sampled to 500 Hz and spatially filtered using a surface Laplacian estimated from spherical spline interpolation. All 1st row electrodes (T7, FT7, F7, AF7, FP1, FPz, FP2, AF8, F8, FT8, and T8) and some 2nd row electrodes (F5, AF3, AF4, and F6) were excluded to avoid possible EMG-contaminated signals. All signals were also visually inspected by an experienced neurologist for the presence of muscle or ocular artifacts.

2.3. Experimental design

We employed an ERD measure to investigate changes of the patients' brain networks during stroke recovery. ERD is quantified from the percentage change of idle rhythm between the relaxed condition (baseline) and the motor imagery-or-execution condition. ERD can be found either in mu- (8–13 Hz) or beta rhythms (15–25 Hz) depending on subject (Blankertz et al., 2011; Kübler et al., 2005; Wolpaw and McFarland, 2004; Müller-Putz et al., 2010; Hari and Salmelin, 1997). A selection between these two rhythms was done in the calibration phase, prior to the experiment (see below). During the experiment, two types of movies were shown: (i) a baseline movie (idle) and (ii) a hand movie (active). The two types of movies were used as the clues to either relax-and-perform-no-movement (idle) or imitate/image the movement seen on the screen. Three different baseline movies were: (i) two-moving-balls (2B); (ii) a slowly-moving-flower (FL); and (iii) a grid (GR). The GR was the only static movie of the three, showing white stripes against a black background. Two identical hand moving movies showing either left or right hand opening and closing were shown. Every baseline movie lasted 10 s, every hand movie lasted 10 s. (after the artifact rejection each movie lasted ~8 s.). Each measurement consisted of two parts: (i) calibration and (ii) motor execution, which will be explained next.

2.3.1. Calibration

During the calibration phase, we presented three different "baseline movies" and the "hand movie". Being a ratio, ERD depends on the signal power of the sensorimotor rhythm (SMR; mu or beta band) during baseline (Tangwiriyasakul et al., 2013). By first presenting three different baseline movies, we aimed at finding the baseline movie with maximum SMR power. During the baseline movie, the subject was asked to relax and to neither perform nor image any movement. During presentation of the hand movie the subject was asked to observe the hand movement and synchronously image the movement (the choice of active period during hand movie could be either observe-and-image or observe-and-execute movement (Kaiser et al., 2011); to prevent tiredness we asked to only observe-and-image the movement during the calibration phase). We showed a dominant hand movie for the healthy subject and a non-paretic hand movie for the stroke patients, in total eight trials of each baseline movie and 24 hand movies. It was proven in a nearly identical experiment (see Tangwiriyasakul et al., 2013) that to reach a stable ERD we need ≈7 trials per condition, each of which must last at least 5 s. Maximal SMR-power was analyzed at C3 (C4) during the right (left) hand movie. To find the optimal baseline movie, the EEG signals from each trial were first partitioned into periods corresponding to the visual inputs (three baselines or hand movie). Second, we further classified trials of the hand movie into three groups, depending on their previous adjacent baseline movie. Next,