

## Brain sources of EEG gamma frequency during volitionally meditation-induced, altered states of consciousness, and experience of the self

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### Abstract

Multichannel EEG of an advanced meditator was recorded during four different, repeated meditations. Locations of intracerebral source gravity centers as well as Low Resolution Electromagnetic Tomography (LORETA) functional images of the EEG ‘gamma’ (35–44 Hz) frequency band activity differed significantly between meditations. Thus, during volitionally self-initiated, altered states of consciousness that were associated with different subjective meditation states, different brain neuronal populations were active. The brain areas predominantly involved during the self-induced meditation states aiming at visualization (right posterior) and verbalization (left central) agreed with known brain functional neuroanatomy. The brain areas involved in the self-induced, meditative dissolution and reconstitution of the experience of the self (right fronto-temporal) are discussed in the context of neural substrates implicated in normal self-representation and reality testing, as well as in depersonalization disorders and detachment from self after brain lesions. © 2001 Elsevier Science Ireland Ltd. All rights reserved.

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## 1. Introduction

The search for the neural correlates of consciousness is experiencing an unprecedented interest in the scientific community (see Atkinson et al., 2000, for a recent review). This search aims at identifying neural processes that characterize distinct states of consciousness (e.g. dream, hypnosis, wakefulness) or specific contents of consciousness. The content or state of consciousness can be altered by numerous external factors, such as chemical agents (drugs), but also by various forms of external information input, e.g. hypnotic suggestions (Isotani et al., 2001). On the other hand, there are many reports on changes of the state of consciousness as experienced subjectively that were caused by purely internal factors (Pardo et al., 1993; Fink et al., 1999; Kimbrell et al., 1999; Neuper et al., 1999). These changes reportedly can be achieved by self-induction, executing mental routines such as self-hypnosis, autogenic training or meditational exercises. The question arises whether these subjectively experienced differences are associated with measurable differences of brain activity.

A particular component of brain electric activity, the EEG '40-Hz' or 'gamma' frequency band, was described as a prominent characteristic of brain electric activity during meditation (Banquet, 1973). The 40-Hz frequency band has also been hypothesized to play an important role in the brain mechanisms of normal, conscious experience (the 'binding problem') as well as of consciousness in general (Gray et al., 1989; Kulli and Koch, 1991; Singer et al., 1997), after having been reported earlier in various orienting and problem-solving conditions in animal and man (Domino and Ueki, 1960; Bouyer et al., 1980; Spydell and Sheer, 1982). Specifically, gamma band activity has been proposed to act as a mechanism for visual representation of objects and for binding distinct aspects of object perception into a coherent and unitary concept (for review, see Tallon-Baudry and Bertrand, 1999).

We utilized an opportunity to study the brain electric activity of an experienced meditator in order to test whether subjectively different meditations, i.e. different altered states of conscious-

ness, are associated with the activity of different neuronal ensembles that work at the 40-Hz-frequency band. Two independent space-oriented approaches were employed for the analysis of the 27-channel brain electric data: source gravity center localization in the frequency domain (Lehmann and Michel, 1990) and cortical distribution of the generator activity [Low Resolution Electromagnetic Tomography (LORETA), Pascual-Marqui et al., 1994, 1999]. The analyses yielded converging results, describing significantly different brain regions as active during the different meditations.

## 2. Methods

### 2.1. Subject, design and data acquisition

Multichannel EEG was recorded from a long-term, advanced meditator (59 years old) during five different meditations. The meditator is a Buddhist Lama, Ole Nydahl, of the Karma Kagyü lineage who teaches Diamond Way Buddhism at various centers. In the evening of July 29, 1999, after a workshop that O.N. held at Herzberg, Aarau, Switzerland, we recorded his EEG during the following five meditations that O.N. described as clearly different subjective experiences: During meditation #1, 'Buddha in front of me', and meditation #2, 'Buddha above', concentration was focused on a visualization of Buddha in front of (above) the meditator. During meditation #3, the verbalization of a 100-Syllables Mantra (Nydahl, 1990, p. 51), the meditator silently recited a sequence of words. During meditation #4, 'self-dissolution', the meditator concentrated on the experience of dissolution of the self into a boundless unity (emptiness). During meditation #5, 'self-reconstitution', the meditator concentrated on experiencing the reconstitution of the self.

Twenty-seven electrodes were placed according to the modified nomenclature of the American Electroencephalographic Society (1994) on the following scalp locations: Fp1/2, Fpz, F7/8, F3/4, Fz, FC1/2, T7/8, C3/4, Cz, CP1/2, P7/8, P3/4, Pz, PO3/4, O1/2, Oz. Additionally, the EOG was recorded in two channels from electrodes at

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