4. The EEG and the Depth of Meditation by Ulrich Ott

Abstract

The different EEG frequencies observed during meditation are often explained with varying degrees of "meditation depth". The present study tried to replicate the finding of synchronized fast EEG activity during "deep meditation". In order to clarify the features of deep meditative states, interviews with 30 persons, practicing Yoga, Buddhist and Transcendental Meditation, were conducted and a questionnaire with 47 items was constructed. A factor analysis of 300 questionnaires revealed three dimensions of deep meditation: (1) mystical experience, (2) "nirvana"-factor, and (3) mental and bodily relaxation. Drawings of the time course of meditation depth correlated with the dimensions in various ways showing that the term "deep meditation" may qualify states that differ markedly. A psychophysiological study failed to replicate the finding of fast EEG activity during deep meditative states. It is outlined how more specific hypotheses about EEG changes related to different stages of meditation could be tested in future studies.
Keywords: EEG – meditation depth – questionnaire – factor analysis

Introduction

Since the discovery of the Electroencephalogram (EEG) researchers have tried to correlate states of consciousness with distinct EEG patterns. This endeavor has partly been successful in the sense that the general activation level is indeed mirrored by the dominating EEG frequency band. During an excited or aroused waking state beta activity (13 to 30 Hz) appears, whereas during relaxed states, in most subjects alpha activity (8 to 13 Hz) predominates, especially when eyes are closed. When falling asleep during the first sleep stages, theta activity (4 to 7 Hz) becomes prominent and during deep sleep typically slow delta waves (below 4 Hz) occur.
Soon after meditation research had reached its peak at the end of the seventies, West (1980) concluded in a review that

> „A summary ... reveals the following generally agreed EEG changes during meditation:
> (1) On beginning meditation alpha amplitude increases and in some cases alpha frequency slows by 1–3 cps.
> (2) Later in meditation trains of theta rhythms occur, often intermixed with alpha, especially when the subject is experienced at meditation.
> (3) During deep meditation, 'samadhi' or 'transcendence', bursts of high frequency beta 20-30 or 40 cps can occur.
> (4) At the end of meditation alpha sometimes persists even with eyes open." (p. 459)

The occurrence of alpha activity at the beginning stages of meditation is to be expected and is not at all an indicator for a meditation-specific state (e.g. an "alpha experience"), because it can also be observed in subjects that are simply asked to sit down, to close their eyes and to relax. The theta rhythms, that occur later in meditation, especially in advanced subjects, have sometimes been interpreted as light sleep, but in most studies, the subjects reported to have been aware and were indeed fully responsive.
Only two studies found a third EEG pattern of fast waves in the beta and even gamma (30 to 60 Hz) range. In both studies it was observed only in a few subjects with extended practice and it was related to experiences of very "deep meditation" labeled as "samadhi" (Das & Gastaut, 1955) and "transcendence" (Banquet, 1973).

A striking feature of the observed fast EEG activity was the unusual high amplitude (30 to 60 µV) and the simultaneous occurrence of synchronized activity at all leads. The amplitude of gamma or 40 Hz-activity rarely exceeds 10 µV and is associated with the *local* binding of cell assemblies into synchronously firing neural nets.
The interest in the 40 Hz-EEG-activity has increased enormously in the last few years, because the coherent firing of neural nets in the gamma frequency band has been proposed as a solution for the so-called binding problem (Singer, 1993). According to this hypothesis, the activation evoked in different parts of the cortex, that process and represent different features of a stimulus, are integrated or bound together into a unified percept by coherent oscillations in the gamma frequency range.
Llinás and Ribary (1992) discovered a sweep of the gamma waves over the cortex ("rostrocaudal scan") in magnetoencephalographic recordings, and suggest that it stems from two distinct thalamocortical resonance loops, which provide the content and context of information processing and cognition ("global binding"). Maybe the observed phase lag of the gamma oscillations is necessary to prevent the brain from entering a state of global synchronization; such a state would disable any information processing (Singer, 1993).
A general increase of gamma activity is typically associated with a subjective state described as attentive, concentrated, vigilant, and focused (Sheer, 1984). Das and Gastaut (1955) and Banquet (1973) took the fast waves of high amplitude as evidence for high levels of cortical arousal during "deep" meditative states, in contrast to the superficial states realized by beginners. This view was also propagated by Peper and Ancoli (1979), who postulated an EEG continuum of meditation with theta/alpha and fast beta (=gamma) as endpoints. They suggested to form groups according to the predominating EEG frequency and to compare the subjective experiences, that had been assessed insufficiently until then.
The definitions of the "deep" states, provided by Das and Gastaut (1955) and Banquet (1973), were indeed very unsatisfactory, and apparently the subjective experience wasn't assessed with adequate instruments at all. Therefore it seemed to be necessary to replicate and further explore the global synchronization of gamma activity during deep meditation.
From the perspective of 40 Hz-research the meditation state is interesting too, because it combines intensive concentration with bodily relaxation (Sheer, 1984), an important advantage, because muscular artifacts in the gamma frequency range are difficult to differentiate from real EEG activity.
The present article describes a study that tried to replicate the gamma synchronization during "deep meditation" and to assess the subjective experiences associated with this EEG pattern (Ott, 2000). Based on the current theories regarding the functional meaning of gamma oscillations (Llinás & Ribary, 1992, Sheer, 1984, Singer, 1993), it was postulated that a global synchronization would be characterized by intensive concentration and wakefulness ("awakening"), a loss of time sense, and a feeling of all-encompassing unity ("all is one"; everything is bound into one single percept, no more differentiation between the individual and the surrounding world).
The realization of the research project required (1) to win experienced subjects to participate in the study, (2) to develop an instrument to assess the depth of meditation qualitatively and quantitatively, and (3) to carry out psychophysiological measurements with advanced subjects in the laboratory.

The development of the questionnaire and the dimensions of deep meditation

Method

The participants were recruited by means of a questionnaire survey at ten meditation centers in Frankfurt/Main (4 Yoga, 3 Buddhist/Zen, 3 Transcendental Meditation). The questionnaire contained questions about the meditation practice and the frequency of several experiences assumed to be indicative for deep meditation states (feelings of unity, peace, love, extraordinary wakefulness, pure consciousness, being flooded by light etc.; see Ott, 2000). Persons who indicated that these experiences occurred often or nearly always during meditation were asked to participate in a detailed interview.
The primary goal of the interviews was to clarify the concept of "meditation depth" and to develop a psychometric instrument for its quantitative assessment (Müller, 1997). 30 subjects (17 female, 13 male) were willing to participate in the semi-structured interviews. Half practiced Transcendental Meditation, a third of them Yoga meditation, and the remaining ones practiced Buddhist meditation for an average of 10 years (0.5 to 30 years).
In the first part of the interview they were asked to give a free description of deep meditation; in the second part 216 statements were presented and they had to rate the suitability of each item to describe deep meditation. The presented items were the result of the revision of a larger items pool (N=1024) taken from the following questionnaires: *Fragebogen OAV zur quantitativen Erfassung außergewöhnlicher Bewusstseinszustände*, *Assessment schedule for altered states of consciousness*, *Phenomenology of Consciousness Inventory*, *Dimensions of Attention Questionnaire*, *Post-Session Questionnaire, Phenomenology of Meditation Questionnaire*, *Profiles of Meditation Experience* (references in Müller, 1997, Ott, 2000). Based on the ratings and a content analysis of the free descriptions, 47 items describing the features of deep meditation were selected and included in a questionnaire. In addition, a coordinate system to draw a line, representing the time course of meditation depth during a session was included (see appendix 1). A set of ten copies of the questionnaire was sent to the 56 persons who had given their address in the questionnaire survey with the request to complete them immediately after the meditation sessions. A full set of ten questionnaires was filled in and returned by 30 subjects (20 practiced Transcendental Meditation, 5 Yoga, and the remaining ones Buddhist or other meditation methods for an average of 10 years; 20 had already participated in the interviews).
These 300 questionnaires were factor-analyzed (principal component analysis, varimax rotation) to elucidate the dimensionality of deep meditation and to facilitate the correlation analysis with drawings of meditation depth.

Results

The factor analysis resulted in eight factors with an Eigenvalue above 1, but the Scree-Test suggested a solution with only two factors. By increasing the number of factors stepwisely, it turned out that the best compromise in respect to parsimony, differentiation, and interpretability was the solution with three factors. The explained variance of 57% increased only negligibly with additional factors (Müller, 1997).
The first factor was named "mystical experience". The items loading high on this factor, which contributes 25% to the explained variance, are listed in table 1. They express strong positive feelings of love, joy and happiness, the experience of getting in contact with a higher force or something divine, feelings of being united with others and the inner self, and experiences of energy and light. Altogether the items give a representative description of the key features of mystical experiences as described e.g. by Stace (1961).

Table 1: Items, loading high on the factor “mystical experience”.

Item	Loading
I felt love.	0,87
I felt something divine.	0,85
Love seemed to me to be the origin or the principle of all things.	0,83
I felt united with a higher force.	0,78
I myself or parts of me were transformed into light.	0,77
I felt that I had a deep and clear understanding of what was happening around me.	0,77
I had a feeling of limitless joy.	0,76
I felt that life was very precious to me.	0,76
I perceived light within me or around me.	0,75
I felt a most deep and fervent affinity with all.	0,74
I myself or parts of me were transformed into energy.	0,71
I had a powerful feeling of energy or a dynamic force.	0,66
I felt extremely happy.	0,66
I felt at one with all.	0,64
I had a feeling of freedom or liberation.	0,63
I found the way to the core of my own being, I was at one with my own self.	0,62

The second factor was labeled “nirvana”-factor (Sanskrit *nirvana* for *extinguish*; not in the sense of *relief* or *bliss*). It explains 16% of the variance and is composed of items, which describe the total vanishing of thoughts, feelings, sensations, and even the ego, resulting in a state of pure awareness and deep absorption.

Table 2: Items, loading high on the “nirvana”-factor.

Item	Loading
My field of awareness was void of all sensations, feelings and thoughts.	0,81
All thought processes came to a standstill.	0,80
I was no longer conscious of the fact that I was meditating.	0,74
I was - (pure being, existence itself).	0,72
I forgot everything around me.	0,72
I was completely absorbed in meditation.	0,68
Only the present moment in time existed for me.	0,68
I lost all sensation of time.	0,66
I felt no desires.	0,66
My experience could not be adequately expressed in words.	0,66
I was no longer aware of my body.	0,63
My ego dissolved.	0,63
I meditated easily, without making any effort at all.	0,60

The third factor, explaining also 16% of the variance, was called “mental and bodily relaxation”, because it combines items that articulate the reduction of emotional stress and ruminating thoughts as well as those describing a slow-down of the breath and the reduction of muscular tension, i.e. the bodily aspects of a relaxation response.

Table 3: Items loading high on the factor “mental and bodily relaxation”.

Item	Loading
I had a feeling of complete harmony within me.	0,74
I was free of all worries and fears.	0,73
I felt entirely safe and secure.	0,69
My body felt very much at ease and free of tension.	0,67
My breathing became slow and barely perceptible.	0,67
At times I felt physically quite light.	0,62
I stopped comparing and differentiating things.	0,61
I was absolutely certain that what I experienced was real.	0,60
Contrasts and contradictions seemed to dissolve.	0,58
I had a deep sense of satisfaction.	0,58
I felt a deep quiet.	0,57
I experienced a deep feeling of peace within me.	0,55

The internal consistency (Cronbach’s alpha) proved to be high (Müller, 1997): “mystical experience” = 0.96, “nirvana” = 0.93, and “mental and bodily relaxation” = 0.92.
The examination of the values of the three factors within the ten sessions rated by each subject showed a considerable variability (examples are given in Ott, 2000, figure 10, p. 68). The same held true for the drawings of the meditation depth, which showed distinct courses of meditation depth (see Müller, 1997), which reached not always the same level of depth. The maximum and the average meditation depth were determined by dividing the drawn lines into 50 intervals and measuring the depth with a resolution of 12 levels (see diagram in part A of the questionnaire in appendix 1).
Afterwards the factor values were correlated with the parameters of the drawings for each subject. In 22 of the 30 subjects, at least one correlation of a factor with a parameter of the drawing of meditation depth reached significance (see Ott, 2000, table 14, p. 70). There was no consistent correlation pattern: in some cases only one of the factors correlated with the drawing (mystical experience 3 times, “nirvana”-factor 6 times, relaxation 4 times), in others all three factors (3 times) or combinations of two factors (e.g. 5 times “nirvana”-factor and relaxation).
“Deep meditation” is obviously not a one-dimensional construct. At least three dimensions were found that characterize deep meditative states. By means of the questionnaire it was now possible to determine the meditation depth of a session in relation to an individual reference point and to assess the associated changes in subjective experience. Thus, the prerequisites for the psychophysiological measurements were fulfilled.

The psychophysiological study

Method

Only subjects who had filled in at least five questionnaires in relation to meditation sessions at home were invited to participate, because the quality of the meditation in the laboratory was to be evaluated in order to guarantee the external validity of the results.
20 subjects (12 female, 8 male) were willing to participate in the screening study that was carried out to identify subjects with enhanced gamma activity during meditation. Besides, the screening study was an opportunity for the subjects to get used to the laboratory.
A small recorder system (mini-Vitaport, Ingenieurbüro Becker, Karlsruhe) was used to record the EEG (Cz against right mastoid, sampled with 256 Hz, time constant 0.3 seconds, low pass filter 100 Hz), the electrodermal activity (EDA), and the respiration. The subjects were asked

to meditate as usual for at least 15 minutes (the upper limit was set to one hour). The spectral power in the gamma band (36 to 44 Hz) was calculated for epochs of 4 seconds after applying a Hanning window; the next epoch overlapped 2 seconds with the preceding, so that a high-resolution time course of the gamma power was obtained. Subjects who showed a gamma power above 10 μV^2 during the meditation session were selected for the main study.
The final sample consisted of 10 subjects (3 female, 7 male; average age of 45 years) with an average meditation experience of 17 years (8 practiced Transcendental Meditation and 2 practiced Yoga).
Before the meditation began the subjects were asked to just sit in silence for 5 minutes and then to count backwards from 200 in steps of 7. These control conditions were introduced to test if the expected increase in gamma activity would be related to deep meditation only. A control group of subjects without meditation experience was investigated with the same procedure, practicing breath counting instead of meditation.
It was left open to the subjects if they want to sit on a reclining chair or on a cushion on the floor. The light in the shielded laboratory room was dimmed to a convenient level and the subjects were left alone. Video recordings of the meditation sessions were made to check for movement artifacts. The physiological recordings were performed with a Vitaport-2 recording system, that allowed to record the electrocardiogram (ECG), the muscle activity in the neck (EMG), and the movements of the body in addition to the EEG (Cz against linked mastoids, sampled at 512 Hz, time constant 0.33 seconds, low pass filter 128 Hz), the EDA, and the respiration. The power in the gamma band was calculated as described above for all conditions.
After the meditation the subjects filled in the questionnaire and were interviewed on possible disturbances.

Results

The amount of gamma activity neither differed between the three conditions nor between the meditation and the control group. All increases in gamma EEG power above 10 μV^2 could be traced back to movement artifacts, namely gradual changes of the head position or motor acts like yawning, coughing or swallowing. A global increase in gamma activity in the EEG was not found although the questionnaire data showed that the meditation in the laboratory was rated as deep by the subjects.

Discussion

It is common in meditation research to attribute different EEG patterns to different levels of meditation depth: alpha activity at the beginning of meditation, later on trains of theta activity in advanced subjects, and sometimes beta and gamma activity during very deep states (West, 1980). The present study failed to replicate the global synchronization of fast activity during deep meditation, reported by Das and Gastaut (1955) and Banquet (1973).
Although it was attempted to find subjects with long-standing experience they were maybe not able to enter similar deep states; particularly, since the measurements were performed typically in the afternoon after work. Assuming that deep states are only seldom reached, the chance to register such a rare event could be increased by repeated measurements, for example, during a retreat of several weeks.
The EEG was registered only at one position in order to reduce disturbances of the subjects. While an unusual high gamma power at one electrode could serve as an indicator for a global synchronization, more subtle changes in the distribution of the gamma activity could not be detected. A high-resolution mapping of gamma EEG activity should be used in further studies of the different meditation states and techniques (see below).

The restriction to the area around Frankfurt/Main was a severe limitation, too; it may be more promising to investigate recognized meditation masters in the eastern countries, who are able to enter discrete meditation states at will.
The finding of the three dimensions of deep meditation indicates that there is no simple relationship between meditation depth and the EEG. There exists no single state that can be called “deep meditation”, but several different states. Only, when clearly defined and differentiated, will it become possible to identify specific EEG correlates of these deep meditative states.

Further research

Subjects who experience certain types of deep meditative states could be identified by means of the questionnaire in order to form groups and compare their EEG patterns (e.g. “mystical” versus “nirvana” versus “relaxed”). Although practicable, such an approach would just follow the traditional habit in meditation research to find the EEG correlates of “meditation states”. The drawings of the time course of meditation depth showed oscillations, as well as slow or fast monotonous increases during the sessions. Thus, meditation is actually not a static *state,* but a *process* resulting from the dynamic interaction of the applied *method* and the resulting experiences. The investigation of the meditation process should be directed to the *micro-level* (second-to-second fluctuations during one session) as well as the *macro-level* (changes in the range of days to years) to follow the long-term development of meditation skills.
Instead of searching for a coarse correlation between the EEG and a “meditative state” it would be more promising to formulate specific hypothesis, that relate the different cognitive processes during meditation to distinct changes in the EEG (frequency and topography). This requires to take a closer look at the meditation methods first of all and to reformulate the traditional instructions in the language of cognitive psychology. Thus, a kind of “experimental meditation” (Deikman, 1963) methodology could be developed as a research tool for the scientific exploration of consciousness states in experimental psychology.
The different phases of Raja-Yoga (Vivekananda, 1988), for instance, could be translated to experimental paradigms like “sensory deprivation” (pratyahara) or “sustained attention with identification” (dharana and dhyana) and linked to specific hypotheses regarding changes in the gamma-EEG (Ott, 2000).
Maybe such an approach, that integrates the knowledge of the traditional meditation schools in modern science, is able to achieve a rational understanding of the final meditation states of enlightenment and to refine the methods for attaining them.

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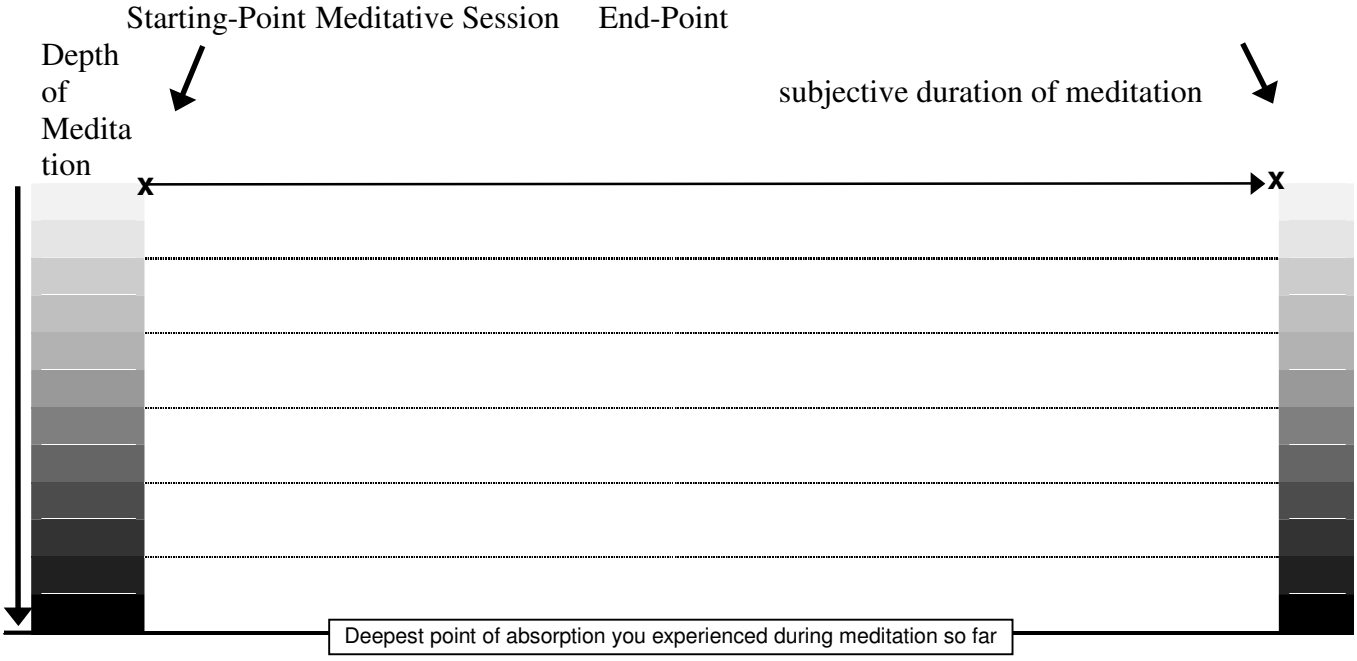
Meditation Depth Questionnaire Appendix 1

A) Please describe briefly the course of your meditation by drawing a continuous line from the starting-point to the end-point on the diagram to show how deep your meditation was.



B) Please indicate to what extend the following statements describe your experience during the deepest phase(s) of meditation. Please put a cross in the appropriate box on the right.

The statement describes my experience during the deepest phase(s) of meditation:	not at all ⟷ very good				
My body seemed to expand far beyond its normal Limits.					
Contrasts and contradictions seemed to dissolve.					
I stopped comparing and differentiating things.					
I felt at one with all.					
My field of awareness was void of all sensations, feelings and thoughts.					
I was in a state of deep relaxation.					
I had a powerful feeling of energy or a dynamic force.					
I meditated easily, without making any effort at all.					
I lost all sensation of time.					
All thought processes came to a standstill.					
Only the present moment in time existed for me.					
I experienced an intense quietude.					
I experienced a deep feeling of peace within me.					
My breathing became slow and barely perceptible.					
I myself or parts of me were transformed into light.					
My ego dissolved.					
I felt love.					
I myself or parts of me were transformed into energy.					

The statement describes my experience during the deepest phase(s) of meditation:	not at all ⟷ very good				
I felt extremely happy.					
I was completely absorbed in meditation.					
I was wide awake.					
I perceived light within me or around me.					
I had a feeling of limitless joy.					
I was no longer aware of my body.					
My consciousness was completely clear.					
I felt that life was very precious to me.					
I had a deep sense of satisfaction.					
My body felt very much at ease and free of tension.					
At times I felt physically quite light.					
I felt that I had a deep and clear understanding of what was happening around me.					
I felt a most deep and fervent affinity with all.					
I forgot everything around me.					
I felt no desires.					
I felt a deep quiet.					
I found the way to the core of my own being, I was at one with my own self.					
I felt entirely safe and secure.					
I was absolutely certain that what I experienced was real.					
Love seemed to me to be the origin or the principle of all things.					
I had a feeling of freedom or liberation.					
I felt united with a higher force.					
I felt something divine.					
I was no longer conscious of the fact that I was meditating.					
I hat a feeling of complete harmony within me.					
I was - (pure being, existence itself).					
I was free of all worries and fears.					
My experience could not be adequately expressed in words.					
I experienced myself as a detached observer watching inner processes as they went on.					

C) In the space below please describe any other experiences during meditation that are not covered by the above statements.

D) Meditation Session Data

Date: Beginning: ☐ Durati☐ Minutes

I meditated □ alone □ in a group of ☐ participants

Many thanks for your cooperation in this project!