

Samatha Meditation and Neurofeedback

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Abstract

This is a preliminary report on an EEG study of samatha meditation, a core Buddhist practice so far little studied scientifically. Unlike the more familiar mindfulness meditation practices, samatha meditation aims to develop attention and concentration to high levels, to access the states of absorption known as the *jhānas*. This paper highlights the implicit self-directed neurofeedback nature of this technique, where a self-generated internal mental object is the parallel to the conventional neurofeedback monitor. Some preliminary findings are described, including (1) the prevalence of low frequency activity sometimes including delta waves normally seen only in stage 3 sleep, or pathological states, (2) the use of sLoreta to identify underlying cortical sources, and (3) the ability of some experienced samatha meditators to access high energy states with similarities to epileptic seizures. Although preliminary, these early results suggest themes and directions to pursue, and indicate that the samatha technique has relevance to, better understanding processes of attention, to sleep studies, and to the degree of resilience to seizures in epilepsy sufferers.

Keywords: samatha meditation, neurofeedback, jhāna, epilepsy, sleep studies

Introduction

Meditation practices are now well-established as beneficial in improving well-being, increasing relaxation and reducing stress. Indeed, mindfulness techniques are now routinely incorporated into approved behavioural treatments for chronic depression (mindfulness-based cognitive therapy, MBCT; see Ospina et al., 2008, for a survey of meditation practices in health care). Studies of meditation, including EEG and fMRI studies, are also now prevalent and well-established (for example Cahn and Polich, 2006; Travis and Shear, 2010; Lutz et al., 2008), and attempt to look at the underlying neurological processes in meditation, with varied success.

In 2010, a private research project was started to look at EEG recordings of experienced meditators following a Samatha meditation tradition. This tradition will be described more fully in the next section, but in brief it is a core practice found in various guises in all the main Buddhist meditation traditions whether in SouthEast Asia, Tibet, or China, or Japan. It is an inwardly directed focused practice that develops attention and concentration to high levels, culminating in the *jhānas*, or absorptions, as a basis for developing insight into the self experience, and, in the Buddhist context, freedom from suffering, and ultimately enlightenment.

Having worked for many years in mental health, a background to this study has been an awareness that many mental health disorders are disorders of attention, with the question as to whether the highly specialised development of attention in samatha meditation might throw light on the detailed neurological processes of attention, with possible treatment applications. Those working in mental health (or health generally), know that extreme states (including pathological states), or states very different from normal, can be extremely helpful in understanding what is “normal”. This is also a motivation to this study.

This paper describes intriguing parallels between the technique of samatha meditation used to develop highly focused inner attention, and the modern technique of neurofeedback (Dennison, 2013). In the case of samatha meditation, the feedback “loop” uses an internally arising “mental object”, rather than the external monitor and feedback prompt of modern day neurofeedback. Preliminary results of the EEG study will be described only briefly here, but sufficient to suggest directions for further study. More detailed analyses will follow in subsequent publications.

Samatha Meditation

Samatha meditation *per se* has received only limited attention so far in EEG and fMRI studies. This is because many meditation practices in the West emphasise mindfulness as the main factor, and do not aim to specifically develop focal concentration to the level of the *jhānas*. In fact until recently these practices have mainly been found only in monastic settings, often the so-called “forest traditions”, rather than practiced by lay Westerners. Exceptions are some limited studies of advanced Tibetan practitioners (Lehmann et al., 2001; Lutz et al., 2004), where the practice of samatha meditation is an essential part of all Tibetan meditation traditions under the name *shyiné*. Also an isolated study of a single meditator following a samatha tradition taught in Sri Lanka (Haggerty et al., 2013).

The pali term *samatha* is used in Southeast Asia and the West; the alternatives being the sanskrit, *shamatha*, and the Tibetan, *shyiné*. All are normally translated as “Calm” or “Tranquility” or “Peaceful Abiding”. A useful review of samatha meditation is Wallace (1999).

In the West, generally, samatha meditation is only relatively recently becoming better understood. Even in some Buddhist countries, a degree of wariness is often apparent around the “magical” side of Buddhist practice associated with the *jhānas*, which can lead to these practices being played down, or even restricted in being taught. In Thailand, for example, the national promotion of the Burmese Vipassanā school from the 1960s onwards, led to the dissolution of many previously samatha-oriented meditation centres. However, samatha meditation has survived, as it has since the time of the Buddha, as the central heart of Buddhist meditation.

The main form of samatha meditation taught by the Buddha was *ānāpānasati*, or mindfulness of breathing. Other samatha techniques are often used for specific character types, and take different objects than the breath as the focus to develop attention. These include the *kasinas*, such as a disk of earth, a colour, water, or fire, or an opening onto space, among others. Visualisation of the Buddha is also a popular practice, with several variations, particularly in the Tibetan tradition, as is *metta*, or loving-kindness practice. However, all these forms when developed as samatha meditation, eventually lead to the experience of an internal mental object as the counterpart sign of the original object, which then becomes the focus or guide for the meditator into the deeper levels of concentration and absorption.

Subjects for this study belong to a lay tradition of ānāpānasati (mindfulness of in and out breathing) meditation established in the West from Thailand in 1963, taught first in London, then Cambridge, and continued under the auspices of The Samatha Trust, established as a UK Charitable Organisation in 1973 (samatha.org) Most of the participants have over 10 years' experience of this technique, some over 40 years, and include a wide range of occupations, including a number of mental health professionals well able to articulate their subjective experiences in the light of Western psychological models, as well as within the Buddhist context. Some have also spent periods in monastic settings in Thailand or Sri Lanka. We are grateful for the helpful cooperation of the Samatha Trust, and for the involvement of the willing participants.

Samatha Meditation: Implicit Neurofeedback?

Samatha meditation begins by the meditator giving attention to a meditation object, which in the case of ānāpānasati is the in and out breath. To begin with there are many distractions, and each time the meditator catches a distraction he/she returns attention to the breath. This involves a mental act of placing attention, together with another process of sustaining the attention (in pali, *vitakka* and *vicāra*, respectively). Much of the development of samatha may be described as the development of attention, with an increasingly subtle awareness of feeling and perception. Psychologically, the choice of the breath as meditation object is very interesting; the breath is always with us, often as a completely automatic unconscious process, but it can be made fully conscious. It is also intimately linked to our emotional feeling state, as is well known to anyone working in mental health.

As a meditator becomes more skilled at regulating their attention on the breath, breathing becomes more peaceful and subtle, and feelings of pleasure and contentment develop. At this stage the meditator will begin to sense their attention and concentration strengthening by certain “signs”, in particular, as described in the ancient texts of the *Visuddhimagga* or *Vimuttimaggā* (see References), by the arising of a *nimitta*, an internal mental object. The *nimitta* is the mark or sign for a particular meditator, and for the specific meditation object, that characterises his/her awareness, and the degree of concentration (“sign” is in fact the usual translation of the pali *nimitta*). For example, in everyday life joy and happiness may be accompanied by a sense of lightness of body and mind, sometimes tears, and sometimes a prickling of the fine hairs on the arms or head. These may be said to be the *signs* of joy and happiness. In samatha meditation, the *nimitta* is the sign of a deepening inner concentration, and of a turning away from dependence on outer sense objects. Some regard it as equivalent to an awareness of the mind itself.

The *nimitta* varies according to a meditator's perception; however, it is always associated with some degree of satisfaction or pleasant feeling. In the case of ānāpānasati it may have a tactile sense of touch, more subtle than the actual sensation of the breath touching the nostril; and often is “felt” as bright, and may indeed for many meditators take the form of light.

At this stage the samatha meditator takes the *nimitta* as the object of meditation, supported by the breath, as a means to deepen their practice into the progressive experience of the “form” or *rūpa jhānas*. The *nimitta* acts as a guide. Wallace (1999) mentions the philosophical question in Buddhist psychology as to whether it is possible for the mind to be aware of itself. If a meditator tries to be aware of the mind directly, as an “object”, an artificial subject-object split is created, leading to an infinite regress. It is as

though the *nimitta* allows the meditator to sense his mind and awareness indirectly without the usual verbal subject-object mode of conceptualising objects.

Traditionally, there are four *rūpa jhānas*, characterized by 5 factors: *vitakka* (placement of attention), *vicāra* (sustained attention), *pīti* (bodily pleasure), *sukha* (mental bliss), and *ekagatta* (one pointedness of mind). All 5 factors are present in the 1st *rūpa jhāna*; *pīti*, *sukha* and *ekagatta* in the 2nd *rūpa jhāna*; *sukha* and *ekagatta* in the 3rd *rūpa jhāna*; while only *ekagatta* remains in the finely balanced 4th *rūpa jhāna*. The *nimitta* is an essential factor in guiding the meditator through the four *rūpa jhānas*. There are a further four formless or *arūpa jhānas* where the meditator lets go of limits, including the *nimitta*, to refine awareness even further to explore the roots of the sense of self and perception.

Parallels with neurofeedback

Understanding feedback forms part of systems control theory; how to make a system behave as desired, or how to improve its functioning in the presence of unknown disturbances, or “noise” (Aström and Murray, 2009). In feedback, a closed loop is created between the current state of a system and the desired state, with a third factor that is a measure of the mismatch or error between the two states. Feedback was an essential development in early radio receivers to allow them to stay reliably tuned to a signal, particularly weak signals. Any deviation or error is fed back to adjust tuning in the appropriate direction for the radio to stay tuned. Positive feedback is also used to amplify signals, particularly in the presence of noise.

The human body also has many implicit feedback systems that allow the body to self-regulate. Blood glucose regulation for example is based on a feedback loop where the pancreas monitors blood sugar levels and secretes either insulin or glucagon to reduce or increase the glucose level in the blood, depending on the mismatch, to a healthy level. This raises the interesting question as to how the body knows what is a healthy level, which presumably reduces to the deeply evolved survival instinct; and the immune system as a whole may be the deepest level of this “instinct towards health”.

In neurofeedback where part of the neurological system has become out of balance, it is the clinician who identifies the imbalance and feeds back the “error” to the patient. The patient then attends to the feedback, closing the feedback loop, and is asked to “intend” to change the balance of the system, and is given positive feedback if he/she succeeds.

In samatha meditation, the meditator from the beginning has an intention to develop a more focused attention to the breath, a more peaceful state, and not be distracted by “noise”. He places attention on the breath (*vitakka*), and monitors both those occasions when he becomes distracted (patiently returning attention to the breath), as well as when attention is undistracted and sustained (*vicāra*). “Noise” in systems-speak corresponds to the “hindrances” in meditation-speak – distractions by the outer senses, internal thinking and other particularly mental restlessness. The practice of *vitakka* and *vicāra* corresponds to an error detection mode between a current and aimed-for state. Increased peacefulness and satisfaction corresponds to the first signs of positive feedback.

So far this process is similar to other mindfulness meditation practices, but at this point samatha meditation takes another direction. As the meditator withdraws from a consciousness dominated by the external senses, and discursive thinking, the internal mental image or *nimitta* arises, and the meditator makes this the guide. From here on the *nimitta* performs a role uncannily similar to the neurofeedback monitor. As the meditator

works through the development of the *jhānas* to ever deeper and more tranquil states, the *nimitta* in parallel reflects the success of the practice by becoming more subtle and vivid, providing positive feedback. “Vivid” does not necessarily mean visually bright, although it can include that; it also means more “alive” and absorbing. The subjective experience of the meditator is of an increasingly deep and stable peacefulness, accompanied by a heightened energy and vividness of awareness. This may relate to the amplification capacity of positive feedback, perhaps more apparent in this meditation situation than in conventional neurofeedback where simple rebalancing is more the aim.

EEG Study

The 2010-12 pilot study used 19 electrodes and a Contec 2400 amplifier with a sampling rate of 200 Hz and an upper frequency limit of 30 Hz. From 2014 recordings were extended to cover a frequency band from DC to 150 Hz, using a Mitsar 202 amplifier, at a sampling rate of 500 Hz, using 31-electrode EasyCaps. Electrode placement follows the international 10-10 system, and analysis is carried out using WinEEG. Some preliminary findings only are described here, from the pilot study, with more detailed analyses to follow.

1. The prevalence and role of low frequency gamma and theta activity. Some (not all) samatha meditators show an excess of low frequency delta and theta activity compared to the resting state. This appears particularly in the early stages of approaching, and developing, *jhāna*. In some cases delta, and even sometimes very slow wave activity below 0.5 Hz, occur to degrees normally only seen in stage 3 sleep, or in pathological cases.

A more moderate example is shown in Figures 1a and 1b, taken from a 100-second artifact-free recording of a 54-year-old male meditator with approximately 25 years experience. Fig. 1a shows spectral power plots while this meditator worked on developing the 2nd and 3rd *rūpa jhānas* characterised by (his subjective experience) strong waves of peacefulness and bliss. Fig. 1b shows the corresponding (surface) scalp spectra at each electrode site.

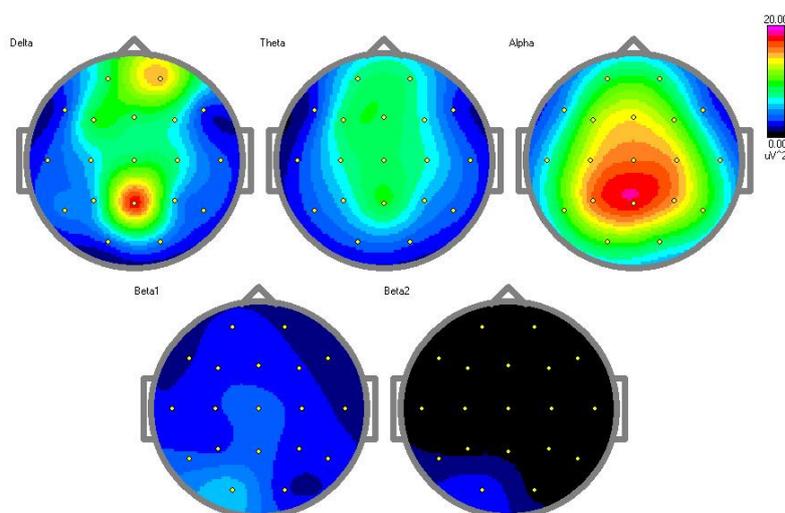


Figure 1a Spectral power plots (μV^2); delta 0.5-4.0 Hz, theta 4-8 Hz, alpha 8-13 Hz, beta1 13-21 Hz, beta2 21-30Hz

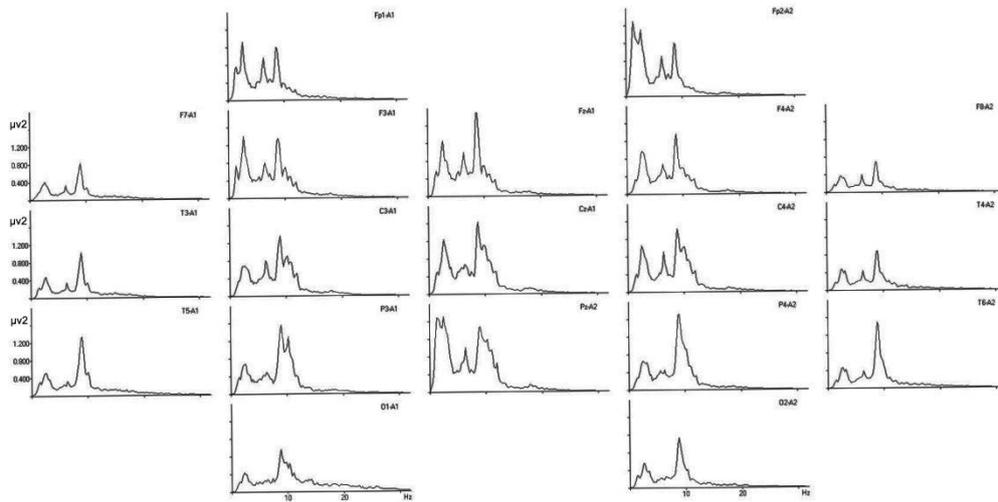


Figure 1b Spectral power plots (μV^2) at each scalp location

The plots show three distinct spectral peaks in the delta (2.69 Hz), theta (6.35 Hz) and alpha (8.8 Hz) bands. Beta activity centred on 18 Hz is very weak in comparison. The raw eeg record for this meditator shows many strong alpha bursts lasting typically 1-3 seconds, highly correlated across the head, and frequently appearing to move front to back with a time phase difference of $\sim 10\text{-}30\text{ms}$, which may correspond to the subjective experience of waves of joy this meditator reported. The same segment was analysed into independent component spectra, and the first two components are shown in Figure 2. These two components account for 52.1% of the variance of the total eeg signal (Cmpt 1, 42.8%; Cmpt 2, 9.3%), so other components are relatively insignificant.

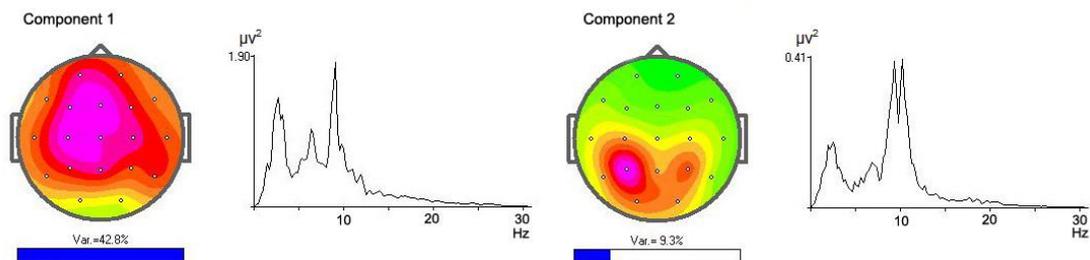


Figure 2 Components 1 and 2 from an independent component analysis (ICA)

1. Underlying cerebral sources.

The spatial maps associated with these two strongest independent components were calculated using low-resolution tomography (sLORETA) (Pascual-Marqui, 1999; Pascual-Marqui et al., 1994), to locate the underlying cerebral sources, and Figure 3 shows the sLORETA distributions of mean current source activity in three slices (axial, sagittal, and coronal), for the two components, based on the Talairach human brain model.

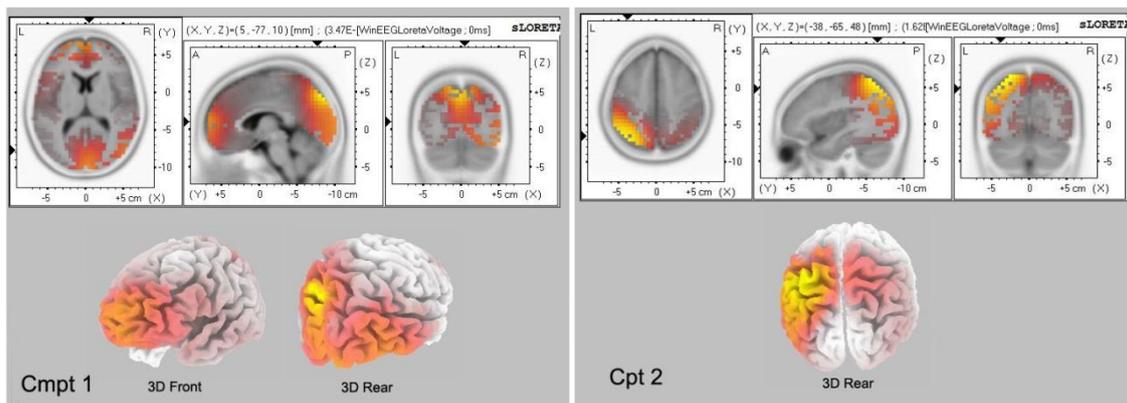


Figure 3 Underlying sources computed with sLoreta for components 1 and 2

Component 1 which is by far the strongest, accounting for 42.8% of the eeg signal's overall variance, comprises two sources. The strongest is centred on Brodmann area 7, medial precunius at MNI (Montreal Neurological Institute) coordinates $X=0, Y=-80, Z=45$. The other, also strong, is frontal centred on Brodmann area 10, the medial frontal gyrus at MNI coordinates $x=-5, Y=61, Z=4$. Brodmann 7, the medial precunius, is believed to be related to self-reflection, spatial orientation and goal-intentions (Kaiser Brodmann Atlas); while Brodmann 10, medial frontal gyrus, is part of the default mode network regarded as involved in higher order abstractive thought related to the self-experience (Legrand and Ruby, 2009; Christoff, 2009).

Component 2 accounts for 9.3% of the total eeg signal variance and is centred on a single source at Brodmann 7, superior parietal lobule, at MNI coordinates $x=-25, Y=-65, Z=65$. This left parietal region is involved in spatial orientation, particularly visually, which in this case of inner directed attention would suggest abstract visualisation. The superior parietal lobule connects to the limbic system via the cingulum, which is involved in thought processes of correcting mistakes (Kennerley et al., 2006). It is tempting to speculate that this component 2 is related to the error correction mode of this form of samatha meditation in regulating attention as the meditator approaches the absorption of the *jhānas*, for this particular meditator, and perhaps supports the main component 2 of his *jhāna* practice.

3. Seizure-like activity.

An intriguing characteristic of this tradition of samatha meditation is that some experienced meditators are able to generate highly energised states which, when recorded by EEG, appear remarkably similar in appearance to epileptic seizures; with the difference that the meditator can cause the state to arise at will, with no discomfort, and can return to a stable state, also at will. The technique is used on occasions when the practice may have become dull, and invariably after arousing energy the meditator is able to deepen his/her practice. In Buddhist terms this technique corresponds to arousing *pīti* (joy, energisation) followed by *pasaddhi* (tranquilisation).

Figure 4 shows an example of an eeg record of this phenomenon. As with epilepsy seizure recordings, a big problem in analysis is how to assess the contribution of physical movement artifacts, and to what extent they mask and confuse attempts to identify underlying sources.

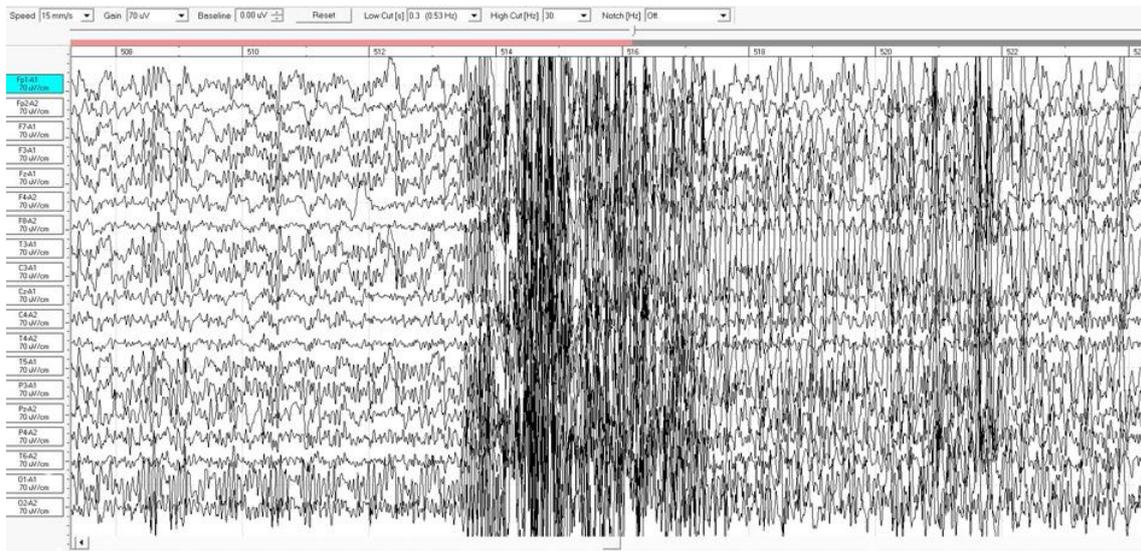


Figure 4 Seizure-like activity of a samatha meditator

One strategy is to analyse segments before, during and after the “seizure” to try to better discriminate cortical activity from physical artefact components. This will be described in more detail elsewhere, covering the experiences of several meditators. For this particular recording, the run-up to the “seizure”, a 52-second segment analysed over 4-second epochs, yields the components and sources shown in Figure 5.

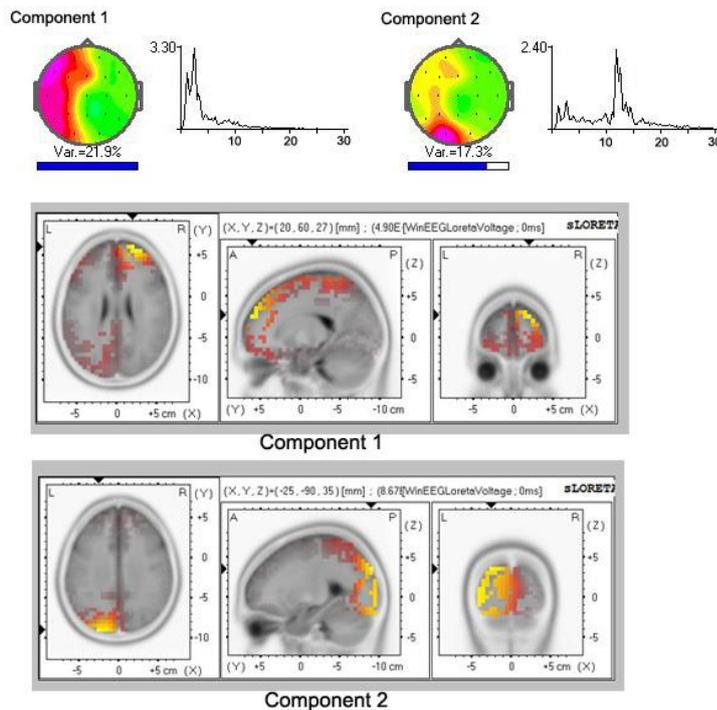


Figure 5 Independent components 1 and 2, pre-“seizure”, and sLoreta sources

Component 1 represents 21.9% of the overall EEG variance, and shows a dominant delta peak around 1.95 Hz, with a corresponding source in Brodmann 10, middle frontal gyrus, right, at MNI coordinates X=20, Y=60, Z=25, extending back medially across the head. Component 2 accounts for 17.3% of total variance, shows a small delta peak, and a strong peak in the high alpha range at 12.2 Hz, with the corresponding sLoreta

source at Brodmann 19, left cunius, coordinates X=-25, Y=-90, Z=35.

In the examples of this type of energisation analysed so far, strong delta activation is always present in the run up to and after the “seizure”. The presence of low frequency activity more generally in samatha meditation we hypothesise performs a slowing down and containing function, suppressing discursive activity and beta activity. The meditator’s subjective experience in arousing this “seizure”-like activity is of a letting go of control and

his sense of “place”, while maintaining a level of pleasant, or at least neutral feeling. So in this example, component 1 may represent the role of strong delta in the default mode network to ground and contain the process of arousing energy, while the strong alpha in component 2 may represent the maintaining of pleasant feeling. The location of this latter component is in the left cunius known to be involved in visuo-spatial processing, visuo-spatial challenge, and motion ((Kaiser Brodmann Atlas), which may fit nicely the meditator’s sense of “letting go” without fear.

Figure 6 shows the same analysis during the “seizure” episode, for an 11-second fragment. Component 1 represents 24.5% of the overall EEG variance, and again shows a delta peak around 1.95 Hz, with a stronger low frequency peak at 5.8 Hz, with a low spread across the alpha band. sLoreta calculates the source for this component in Brodmann 10, middle frontal gyrus, but now more medial than pre-“seizure”, at MNI coordinates X=10, Y=65, Z=25, again extending back medially across the head. Component 2 accounts for 13.7% of total variance, shows a very strong and sharp peak at 5.86 Hz, and a small alpha peak at around 11 Hz, with the corresponding sLoreta source at Brodmann 21, left mid-temporal gyrus, coordinates X=-65, Y=-30, Z=-10.

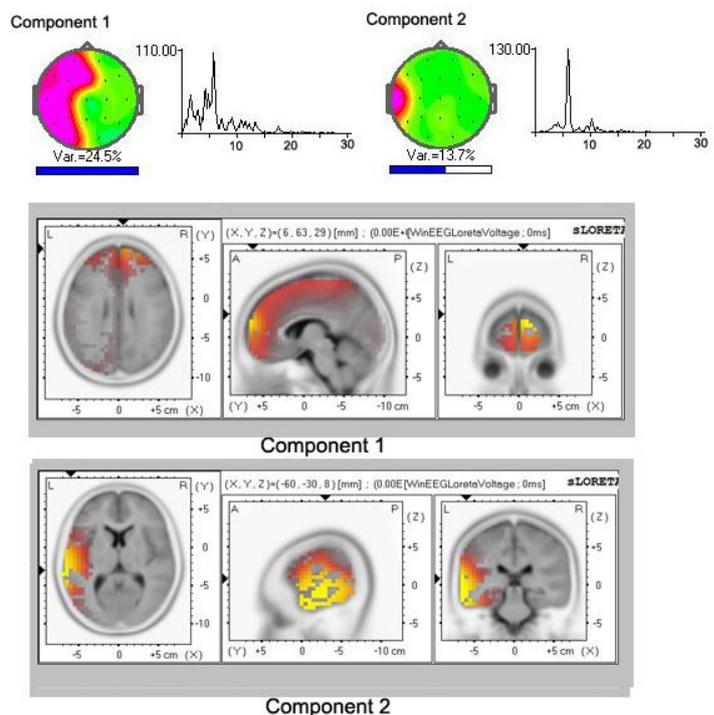


Figure 6 Independent components 1 and 2, during the “seizure”, and sLoreta sources

Compared to pre-“seizure”, low frequency activity appears a little more consolidated in the medial default mode areas, but the big change is the very focused activity in the left temporal lobe, a frequent site for epileptic activity. During the “seizure”, the meditator also exhibits bodily shaking reminiscent of epilepsy. Kitazaki and Griffin (1998) studied the resonant behaviour of the seated human body, and found a main resonant peak at around 5 Hz, as a whole-body mode of predominantly

vertical-plane movement. We consider it likely that the observed spectral peak at 5.86 Hz is made up of a bodily movement resonant component, as well as the underlying cortical activity identified by sLoreta.

Discussion

We are at an early stage in this study, and much work waits to be done, particularly on the more detailed 31-electrode recordings that allow frequencies into the gamma band to be studied. So far the following points bear comment:

- It is very clear to samatha meditators that without the development of pleasant feeling, interest and commitment, that it is impossible to develop attention and concentration to the level of the *jhānas*. Given the similarities of samatha meditation to a neurofeedback

process, this highlights that for traditional neurofeedback, also, the feedback process has to be interesting to the subject, and that it should arouse pleasure and satisfaction to complete the feedback loop. Satisfaction at success when a reward is given is clear, but the whole context can support these requirements to facilitate a pleasant experience. The importance of pleasure is particularly clear with children, for example their very clear pleasure and sense of involvement in being able to make a “noisy” favourite video less noisy during neurofeedback. A century ago Freud (1922) recognised the power of the unconscious drive for pleasure, which no doubt plays a role here.

- Brandmeyer and Delorme (2013) suggested that neurofeedback may help meditators develop their practice more easily. While this may be so for mindfulness practices, we doubt that it would help in more advanced meditation practices such as samatha. Samatha meditation is aimed towards refining the subject-object duality towards a state of absorption and one-pointedness, and the introduction of a separate point of reference would likely interfere with the clarity of the self-directed process in this form of meditation. We would say that the power of the technique lies in the completely inner and self-directed nature of the very personal feedback loop described. However, there may be ways in which insights from the way samatha meditation is very effective in developing inner attention, may have applications to other situations. See below, on epilepsy.
- The steady and progressive development of attention in samatha meditation, and the capacity of experienced meditators to maintain a highly energised and focused concentration parallels the systems-understanding that feedback can provide a great robustness of control. Also in feedback theory, positive feedback can be increased to the point of oscillation, which was the basis for the use of reverberation in early radio tuners. It can also be increased further to the point of instability and runaway behaviour, which is believed by many to be a factor in epilepsy. It may be that the technique of arousing energy in samatha meditation operates on a similar basis of allowing the feedback to shift from a calm balance, into over-emphasising the positive feedback component to the point of seizure.

Whatever the details of the process, what is striking in comparison to epilepsy is that the meditator is able to enter, maintain, and leave the “seizure” state under full control and with no discomfort. We hypothesise that the strongly developed attention and the relative mastery of distraction and disturbance, while maintaining and enhancing pleasant feeling, leads to a robust state where anxiety or fear does not colour the experience of the “seizure”. It would be interesting to explore whether there are aspects of the samatha technique that might help epilepsy sufferers to develop more resilience to the onset of a disturbed state, to prevent it developing into a full-blown episode.

- Relevance for sleep studies. The frequent presence of delta activity, particularly during the earlier phases of samatha meditation, is intriguing. The 31-electrode system we are now using records down to DC, and some meditators show even slower waves of 0.5 Hz or lower while developing the early stages preparing to enter *jhāna*. Such activity is normally only found in stage 3 sleep or pathological states. How does the meditator remain in a highly alert state while exhibiting brain activity so similar to deep sleep? It may be relevant that the meditator does not show sleep spindles, but the significance of this is not yet understood.

Many meditators (and not only with this technique) go through an early phase of struggling with sleepiness. Indeed, on intensive retreats a meditator may repeatedly “nod-off”; one minute drowsy but reasonably alert, the next suddenly jerking fully awake having almost fallen over while sitting, into sleep. It seems that the samatha meditator somehow learns to push through this stage, and the arising of the *nimitta* seems to correspond to a stage of a person’s meditation practice where falling into sleep is no longer a problem.

We believe that EEG studies of the samatha technique show potential towards better understanding the neural processes of attention, have relevance to sleep studies, and may suggest ways to enhance the degree of resilience to seizures in epilepsy sufferers. The study will continue along these lines.

What also seems remarkable, is that developing and using the *nimitta* as an internal “guide” in samatha meditation appears to be a completely natural form of neurofeedback, a powerful process of conscious neuroregulation. And that this naturalistic neurofeedback predates modern scientific experiments in neurofeedback by over two and a half millennia.

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