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FINAL PROGRESS REPORT - August 2011

Cortical Oscillations and Altered States of Consciousness: The Study of Meditative States and Functional Brain Connectivity (grant #74-08)

This is the final report of our 2-year project #74-08 that started in August 2009. We enclose the financial report as well. What follows is a summary of the main findings.

The purpose of our research is to study the coordinated (collective) cortical activity derived from magnetoencephalographic (MEG) recordings during the practice of meditation. Some recent publications in the field demonstrated that there was an enhancement of gamma band frequencies during meditation, as well as an increase in synchrony at those frequencies (>30 Hz), in experiments carried out using scalp electroencephalographic (EEG) recordings (Lutz et al., PNAS 101(46), 16369-16373). However other recent empirical results have cast some doubt in these results; specifically, those studies that showed that gamma activity inferred from whole head scalp EEG recordings could be, to a large extent, the result of increased tone in head muscles that closely associates with brain function and whose activity is precisely high in the gamma range (see for example Whitham et al., 2008, 'Thinking activates EMG in scalp electrical recordings', Clin. Neurophysiol. 119, 1166-1175; Also Whitham et al., 2007, Clin. Neurophysiol. 118, 1877). In this project, we explored the consequences of this activity to the case of meditation combining magnetoencephalography (MEG) and electromyography (EMG), to help dissociate contributions from muscle activity and neural sources.

The main objective proposed in the grant was the study the coordinated cortical activity (quantified as phase synchronization) derived from the MEG recordings in expert practitioners of meditation, and to compare the results to those obtained with novices, performing two main types of meditation: focused attention (also known as calm abiding, or samatha) and insight mediation (vipassana). The neurophysiological activity (MEG signals) is analysed in terms of phase synchronization at different frequency bands, from 4 to 35 Hz, thus covering other frequency bands that were not studied in the aforementioned study of Lutz et al. Meditation is conceived here as a "clean" model of cognitive state, one that also correlates with notable alterations of the regular baseline power in several frequency bands, and thus may be a good model for stable and reproducible patterns of synchronized activity. For instance, long-term practitioners of meditation can generate more reproducible mental states than untrained subjects and they can also describe these states more accurately than naïve subjects.

Methods

Our proposed specific objectives in the original application were two: 1- To study the coordinated brain activity, in terms of phase synchronization, derived from neurophysiological recordings in expert practitioners of meditation and compare their synchrony patterns to those of novices, performing two types of meditation: focussed attention (one-pointed) and insight; 2- To assess whether muscle activity in the scalp may be responsible, in part, for the observed synchrony patterns.

To this end, we have recruited 8 expert meditation practitioners and 3 beginners. Recruitment has been difficult because of lack of interest of the many places that we contacted where mediation is practised regularly. More than 20 meditation centres in Toronto were contacted, of which only 3 expressed some interest in helping us with volunteers. In addition, a good number of those "expert" volunteers who came were not really experts. Here "experts" are defined as those with more than 5 years of (continuous) experience in meditation. Hence, 8 participants who had an average of 16 years of experience were used as experts, whereas the novices had been practising under 1 year and, as well, their account to us of their meditation practice informed us that they in fact could be considered novices. The mean age of the participants was 45.8 ±9.

The whole-head electromagnetic activity was recorded using our MEG set-up, and, simultaneously, electromyographic (EMG) recordings were taken to assess scalp muscle activity. EMG electrodes are placed on frontalis, temporalis, trapezius and sternocleidomastoids muscles. One EMG sensor was also placed on the arm to verify whether or not the possible enhanced gamma scalp muscle activity during meditation occurs in other muscles in the body. The meditation-MEG experiments take place in a magnetically shielded room, and the recordings are obtained using 151 gradiometers (MEG sensors) at a sampling rate of 625 Hz (Omega, CTF Systems Inc.), as described in the original grant proposal. To measure phase synchronization, the standard procedure introduced in Mormann et al. (2000), is used, described in our article Garcia Dominguez et al., 2005, Journal of Neuroscience, 25(35), 8077-8084 (also in Perez Velazquez et al., 2009, Correlations of cellular activities in the nervous system: physiological and methodological considerations, in *Coordinated Activity in the Brain: measurements and relevance to brain function and behaviour*, J.L. Perez Velazquez and R. Wennberg, eds., Springer). Synchrony is defined as the quantification of the degree of phase locking between two signals, and phase locking occurs when there is a constant phase difference during a given period of time between two oscillating signals. The phase that is considered here is the instantaneous phase of the signals extracted using the Hilbert transform.

During the experiment, MEG recordings are taken of participants first during a 10 minute control period, then 15 minutes of one-pointed (samatha) meditation and finally a third period of 15 minutes of insight (vipassana) meditation. During the control period, five minutes were spent with eyes opened and five minutes were spent with eyes closed so as to disambiguate any potential alpha rhythms that resulted from closed eyes in the subsequent meditation sessions. After the experiment, first-person reports (the subjective account of the experience) were obtained with regards to the extent to which participants were able to achieve the desired meditative state as well as the subjects upon which they meditated. Data analyses were conducted in MATLAB.

Results

The EMG signals of scalp sensors positioned as described above, of both experts and novices showed that, on average, muscle activity was higher in frequencies below 10Hz and between 15 and 25 Hz (Figure 1 below), but that there was no increase in power during meditation in the expert group, hence these results do not support our hypothesis of a possible enhancement of muscle activity during meditation practice. However, an increase in the novice group at some frequencies, <5 Hz and 22-25 Hz, was noted (see Discussion below for data interpretation).

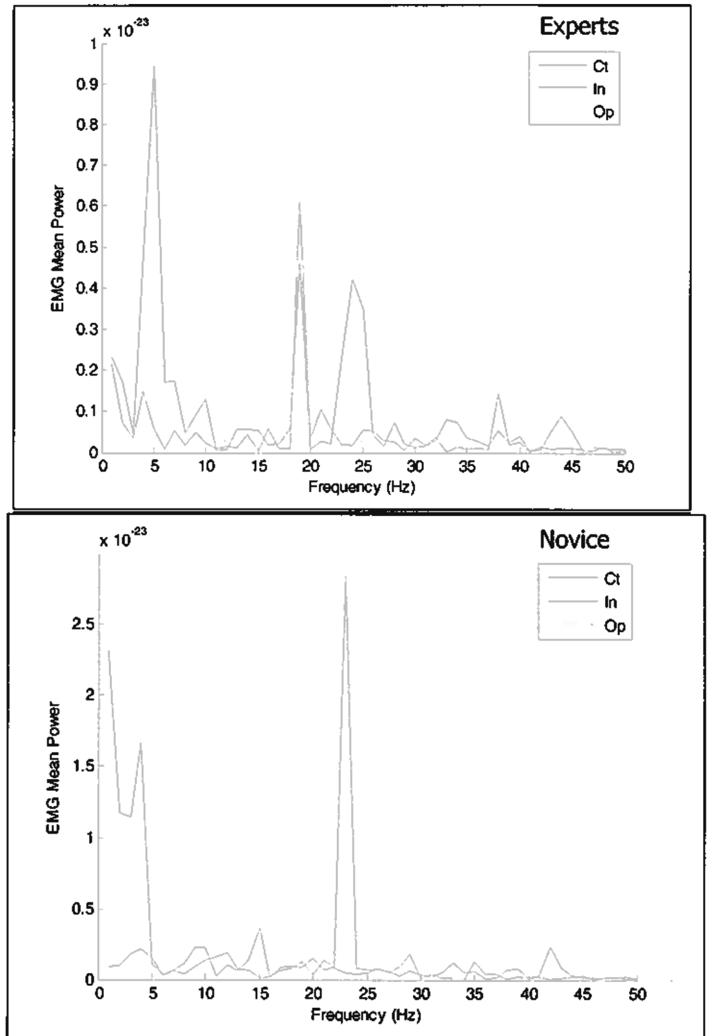

Fig1—Average Power of scalp muscle Signals

Figure 1. Power spectra of scalp EMG signals in novices and expert meditation practitioners, in three conditions: Control (Ct), one-pointed (Op) and insight (In) meditation

Phase synchrony amongst MEG sensors has been evaluated at five frequency bands (with ±2 Hz window), with centre frequencies are 4, 10, 15, 22 and 35 Hz. Mean phase synchrony values, denoted as R in the figures, are calculated for every signal versus another. There are three groups corresponding to R values obtained from the running phase synchrony algorithm on MEG versus MEG signals (R_{MEG}), and as well the synchrony between EMG signals (which are mostly scalp muscle signals) was evaluated (R_{EMG}). Figure 2, below, depicts average R_{MEG} values, showing that synchrony among MEG channels across the brain is subsequently lower in higher frequencies. Scalp muscle signals (EMG) show an abrupt drop in synchrony after 4±2 Hz (Figure 3), implying that the higher activity observed in certain frequency bands in the novices' EMG sensors (figure 1) is not synchronized during meditation as compared to the control period.

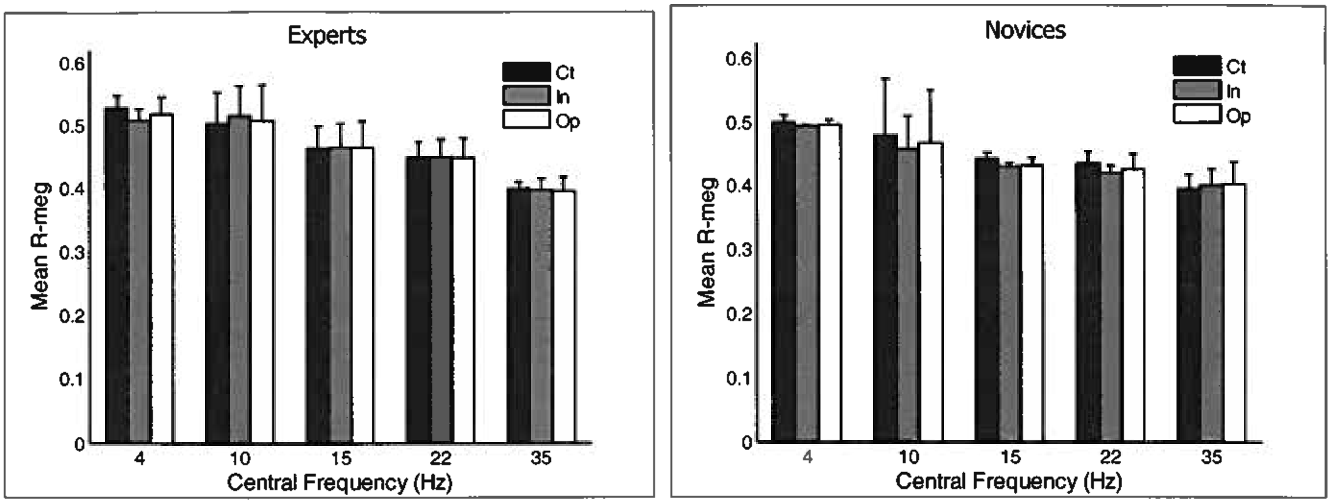

Figure 2. Mean values of the synchrony index R amongst MEG sensors. The three conditions are as in figure 1: Control (Ct), one-pointed (Op) and insight (In) meditation.

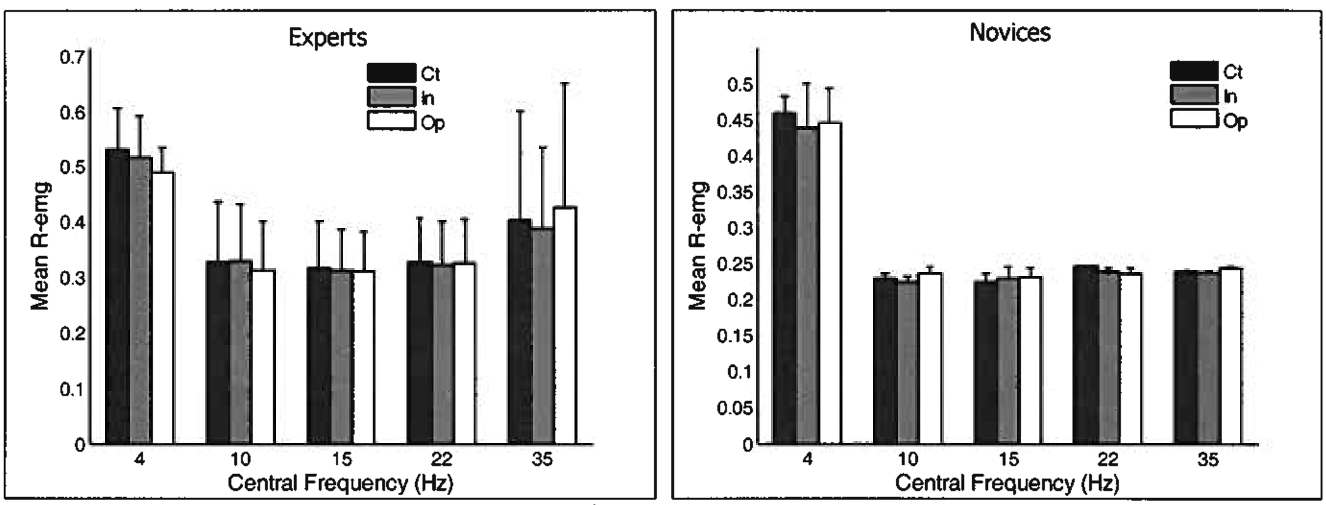

Fig3—Average R_{EMG}

Figure 3. Mean values of the synchrony index R between EMG sensors (right and left frontalis/temporalis). The three conditions are as in figure 1: Control (Ct), one-pointed (Op) and insight (In) meditation.

A notable trait here is that for each frequency band, the R values in the control period are very similar to those of meditation; in other words, meditation does not seem to induce higher synchrony neither among brain signals nor among signals in the scalp muscles. Another trait is that higher synchrony is normally exhibited at the lowest frequency band, at 4±2 Hz. Ignoring this first frequency band, the overall average R value of experts in comparison to the novices, shown in figure 4, is 0.0233 higher in the brain signals and 0.0986 higher in muscle signals, but the differences are not significant ($P>0.05$).

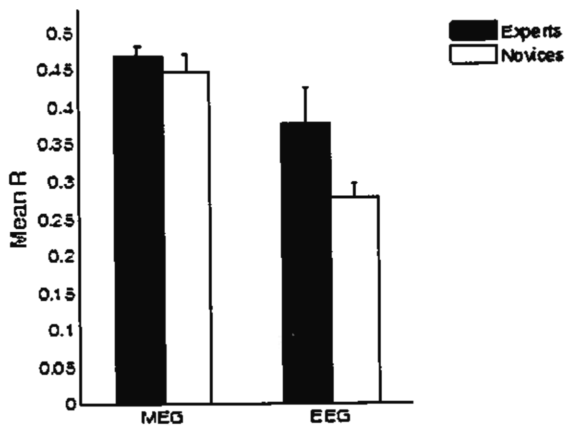

Figure 4. Comparison between the mean synchrony index in MEG (left bars) and EMG (right hand-side bars) signals in experts and novices

Discussion

The result of assessing the power of scalp muscle oscillatory activity indicate that there are no major changes during meditation as compared with the resting, control state. The enhancement of the power at some frequencies in the novices, as shown in figure 1, is not too surprising because increased scalp muscle activity is known to occur during cognitive task performance or intense cogitation, therefore considering that for the novices the practice of meditation constitutes a mental effort and that expert practitioners are used to it, then it is not surprising to observe the increased scalp muscle activity in the beginners.

No significant changes in synchronization amongst the MEG sensors was noted, hence we could not reproduce the data of the paper mentioned in the introductory paragraphs. This could be due to several factors: we used MEG and not EEG (EEG uses a common reference and that poses problems when assessing synchrony); our subjects performed other types of meditation (the volunteers in the Lutz et al. study practised loving-kindness meditation); and finally, they used monks, hence their level of expertise is probably higher than that of our participants.

We plan to continue analysing these data, specifically one of our next objectives is to determine, using principal component analysis, whether the MEG signals are contaminated by scalp muscle activity. Another objective we plan to pursue is to investigate whether there could be changes in synchrony but restricted to specific MEG sensors covering different cortical areas, as the results here reported used a grand average of the synchronization amongst all 151 MEG sensors covering the whole extension of the cortex.