PEOPLE

MARIE CURIE ACTIONS

Marie Curie International Reintegration Grants (IRG)

Call: FP7-PEOPLE-RG-2009

PROPOSAL

"Attention Regulation"

Final Report

December 2014

Introduction:

Mindfulness meditation is a standard form of meditation that intends to enhance qualities of concentration and meta-cognitive monitoring. Mindfulness meditation has been adapted and routinely incorporated in the American and European healthcare systems for the purpose of stress reduction and emotion regulation, particularly among clinical populations with anxiety, depression, and chronic pain. Although the clinical benefits of these interventions have been well documented, the neurobiological mechanisms by which meditation may produce such benefits are still not well understood. The aim of this study was to evaluate the mechanisms of mindfulness meditation within the experimental and methodological framework of cognitive neuroscience (study 1) and epilepsy research (study 2). This research project pertains both to basic and clinical neuroscience. More specifically, study 1 aimed to determine the effect of mindfulness training on the neuroplasticity of cognitive control as measured by meditation-training-related changes in spontaneous electroencephalographic (EEG) oscillatory activity during awake and sleep, and in oscillatory neural correlates of response inhibition and error awareness. Study 2 aimed to determine the regulatory effects of mindfulness meditation on epileptic patients' attention capacity, well-being and on the overall clinical and brain risk factors of seizure.

Methods: During study 1, we measured resting state baseline EEG, and electrical and behavioral response during an auditory Go/No-Go task. This previously published task (Shalgi et al., 2009) measures response inhibition and error awareness. During this task, participants heard auditory stimuli and had to press a button in response to some of the sounds and withhold a button press in response to other sounds. After this task, we collected sleep EEG overnight. We collected 105 non-meditator participants (labeled 'MNPs' for 'Meditation Naïve Participants') through the overall procedure. The MNPs were split into three different groups. Pre and post measures were gathered for a Mindfulness Based Stress Reduction (MBSR) (low-dose group) intervention and an active control intervention named the Health Enhancement Program (HEP). Pre, post and follow up measures (three sessions) were gathered for an MNP waiting list (WL) condition. 130 control participants started with the initial procedure (first session, labeled 'T1'). Additionally, we collected data for 26 long-term meditator (LTM) participants (high-dose group) across three sessions (one baseline measurement, one measure after either a day of mindfulness meditation, labeled 'DOPM' or after a day of compassion meditation, labeled DOPLK'). 31 meditator participants started with T1.

Data collection and Analysis: We have finished analyzing the spontaneous EEG brain rhythms during resting baselines and sleep. We finished analyzing the behavioral data from study 1. The analyses of the brain responses during the response inhibition task are still undergoing. The data collection of study 2 has started in 2014 and is still ongoing.

Main results:

Over all the study 1 revealed:

(i) A trait-related effect of meditation lifelong practice on EEG correlates of oscillatory neural synchrony during NREM sleep (Ferrarelli et al. PLoS One, 2013). We found that LTM had increased parietal-occipital EEG gamma power during NREM sleep. This increase was specific for the gamma range (25–40 Hz), was not related to the level of spontaneous arousal during NREM and was positively correlated with the length of lifetime daily meditation practice. Altogether, these findings indicate that meditation practice produces measurable changes in spontaneous brain activity, and suggest that EEG gamma activity during sleep represents a sensitive measure of the longlasting, plastic effects of meditative training on brain function.

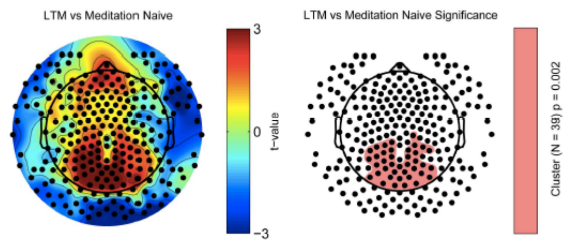
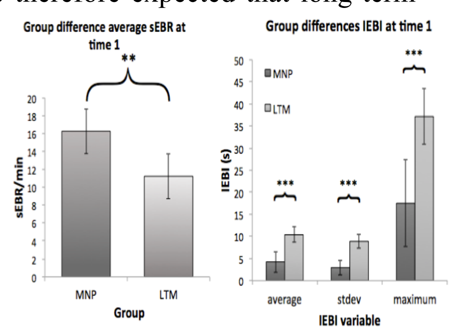


Figure 1: LTM showed a 35% gamma power increase in a parietal-occipital region compared to meditation naives. The pink area in the white topographic plot depicts.

(ii) A trait-related effect of meditation lifelong practice on spontaneous eye-blink activity, a non invasive index of striatal dopaminergic function (Kruis et al. Submission Jan. 2015). We investigated effects of meditation on spontaneous Eye Blink Rates (sEBR), a non-invasive peripheral measure of central dopamine activity. Previous studies have shown a relationship between sEBR and cognitive functions such as mind-wandering, cognitive flexibility, and attention - functions that are also affected by meditation. We therefore expected that long-term meditation practice would alter eye-blink activity. To test this we recorded baseline sEBR and Inter Eye-Blink Intervals (IEBI) in long-term meditators (LTM) and meditation naive participants (MNP) before intervention. We found that LTM not only blinked less frequently, but also showed a different eye-blink pattern than MNP. Moreover, we examined the effects of an 8 week-course of Mindfulness Based Stress Reduction (MBSR) on sEBR and IEBI, compared to an active control group and a waitlist-control group. No effect of short-term meditation practice was found. Finally, we investigated whether different types of meditation differentially alter eye blink activity by measuring sEBR and IEBI after a full day of two kinds of meditation practices. No effect of meditation type was found. Taken together, these findings may suggest either that individual difference in dopaminergic neurotransmission is a self-sel ection factor for meditation practice, or that long-term, but not short-term meditation practice induces stable changes in baseline striatal dopaminergic functioning.



between LTM and MNP during 6 minutes of baseline recording (pre-intervention). ** p<0.01, *** p<0.001.

(iii) *Trait-related behavioral effect of meditation practice on attention control*: Though there were not significant differences by group for overall reaction time (RT) or accuracy to Go or No-Go trials, MNPs and LTMs differed significantly at baseline in their RT to Go trials just prior to a No-Go trial, such that MNPs RT was faster than their

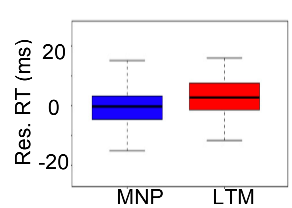


Figure 3: Reaction time (RT) of the Go preceding the NoGo, residualized compared to the overall Go RT.

mean RT while the LTM's was slower. This finding is consistent with MNPs responses becoming more automatic, and thus faster, for repeated Go trials, while LTMs responses slowed reflecting a maintaining of attention (Smallwood, 2011).

(iv) Meditation induced changes in waking EEG. These changes indexe neuroplasticity as revealed by homeostatic dynamics during NREM sleep (Lutz et al. Submitted, Dentico et al. submitted). As a common effect of an intensive day of meditation practice, we found increases in low (≤ 8 Hz) and fast (15-25 Hz) waking EEG oscillations for LTMs only over prefrontal, and left centro-parietal electrodes. There was no significant difference between meditation styles in the long-term meditators as well as no difference between time points in the meditation naïve group. At night, we found also an increase in low-frequency NREM oscillatory activities (≤12 Hz) following the intensive day of meditation practice over similar group of electrodes. Low-frequency NREM sleep changes predicted changes in waking EEG oscillations. The relationship between waking plasticity and sleep can be understood within the theoretical framework of the synaptic homeostasis hypothesis: during a waking episode, learning statistical regularities about the environment relevant for the individual strengthens connections between neuronal ensembles. This strengthening increases the cellular requirement for energy and supplies, and saturates learning. During sleep, spontaneous activity renormalizes net synaptic strength and restores cellular homeostasis, which could explain the benefits of sleep on memory acquisition, consolidation, and integration. EEG sleep studies on motor-learning-related effects on the brain are evidenced by specific, local changes in particular in slow wave activity (SWA; 1-4.5 Hz EEG power) during sleep (18–21). Local changes in slow waves (1-12Hz) during NREM is thought to index homeostatic regulation following neuroplasticity.

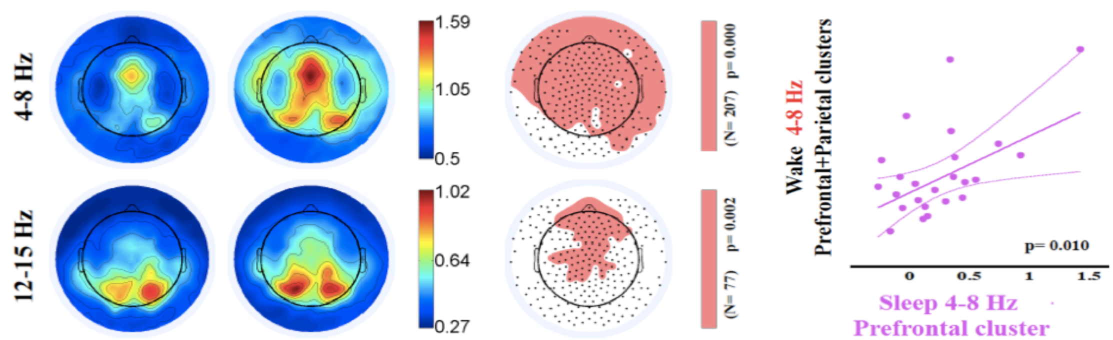


Figure 4: Scalp topographies of average spectral power (μV^2) in theta, and high alpha frequency-bands in resting EEG at baseline session (T1) (left) and on average across the baselines following a daylong training in either mindfulness meditation or compassion meditations for LTMs (2^{nd} column). Significant clusters exhibiting a Training (Meditation interventions vs T1) effects for LTMs only are shown in pink over a white topographical map ($p<0.05$, corrected). Right. Predictive power of prefrontal NREM theta meditation-related changes on meditation-related changes in waking theta activity.

Conclusions:

- We identified novel EEG and psychophysics marker of meditation practices.
- We demonstrated for the first time that acute meditation practice induced neuroplastic changes in brain circuits as indexed by waking and NREM sleep EEG.

Potential socio-economic impact of the project:

- These novel markers could be used to better assess the efficacy of mindfulness-based clinical interventions.
- We also published a summary of our research on the neurobiology of meditation in one article in English in Scientific American (Ricard, Lutz and Davidson, 2014) and two

articles in French in Cerveau & Psycho (Lutz, 2012), and Pour la science (in press, Ricard, Lutz, and Davidson, 2015), which are highly respected outreach scientific magazines in English and in French, respectively.

Bibliography acknowledging the research funding:

MacCoon, D. G., MacLean, K. A., Davidson, R. J., Saron, C. D., & Lutz, A. (2014). No Sustained Attention Differences in a Longitudinal Randomized Trial Comparing Mindfulness Based Stress Reduction versus Active Control. PloS One, 9(6), e97551. doi:10.1371/journal.pone.0097551.

Allen, M., Smallwood, J., Christensen, J., Gramm, D., Rasmussen, B., Jensen, C. G., … Lutz, A. (2013). The balanced mind: the variability of task-unrelated thoughts predicts error monitoring. Frontiers in Human Neuroscience, 7, 743. doi:10.3389/fnhum.2013.00743.

Ferrarelli, F., Smith, R., Dentico, D., Riedner, B. A., Zennig, C., Benca, R. M., Lutz, A., Davidson, R.J, Tononi, G. (2013). Experienced mindfulness meditators exhibit higher parietal-occipital EEG gamma activity during NREM sleep. PloS One, 8(8), e73417. doi:10.1371/journal.pone.0073417.

Lutz A., Dentico D., Bachhuber, D Riedner B., Ferrarreli, F., Tononi G. and Davidson R.J. Meditation-induced changes in waking EEG indexes neuroplasticity as revealed by homeostatic dynamics during NREM sleep (submitted).

Dentico D., Ferrarelli F., Lindstrom M.J., Riedner B.A., Smith R., Zennig C., Tononi G., Lutz A., Davidson R.J. Short meditation trainings reduce self-report negative affect and enhance non-REM sleep low-frequency oscillations (Submitted).