# ENTRAINMENT OF THE ALPHA RHYTHM DURING FLICKER STIMULATION IN HUMAN EEG AND MEG RECORDINGS

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**Abstract: It is known that repetitive visual stimulations by external flickering light lead to an entrainment of the alpha rhythm in EEG recordings in humans. This effect is also called photic driving, and is used as an activation method in clinical routine. The objective of our study was to perform flicker stimulation adapted to a specific range of individual alpha rhythm. The effects of this stimulation were studied by simultaneously recorded EEG and MEG on healthy volunteers, investigating both topological and time-varying characteristics of the resulting alpha entrainment. It can be shown that the effect of frequency entrainment is more pronounced in the MEG recordings in all investigated volunteers. Furthermore, the alpha entrainment shows topological and time-varying properties, and is dependent on the ratio of the flicker frequency to the individual alpha rhythm.**

## Introduction

Electrophysiological experiments have shown that repetitive visual stimulations by external flickering light lead to an entrainment of the alpha rhythm in EEG recordings [1, 2]. Neurons in the human visual cortex synchronize their firing to the frequency of flickering light, leading to EEG responses showing the same frequency as the flicker stimulus [3]. The investigated entrainment effect is also called photic driving and is used as an activation method in clinical routine [4, 5]. Electroencephalographic properties of the alpha rhythm during photic driving have been extensively investigated, e.g. with respect to histological correlations in the visual cortex [6], phase relationships [7], and the preservation of the alpha rhythm shortly after photic driving [8]. Topographic aspects of photic driving in the EEG can be found in [9]. Furthermore, it is known that the human alpha rhythm behaves in a non-linear fashion due to neural oscillators constituting an non-linearly coupled system [10].

The aim of our investigation was to perform a flicker stimulation adapted to a specific interval of individual alpha rhythm (ranging from 0.4 of alpha frequency to 1.6 of alpha frequency). For the first time the effects of such an alpha entrainment are investigated and compared in simultaneously recorded EEG and MEG in healthy volunteers (n=10). Topological as well as time-varying properties of the alpha entrainment in the EEG and MEG recordings are quantified using classical, parametric, as well as time-varying, FFT-based spectral measures.

## Materials and Methods

The investigation was carried out in a group of 10 healthy volunteers (aged 22 to 40 years, 5 male; 5 female). Simultaneous EEG and MEG recordings (closed eyes, sampling frequency 1000 Hz, low pass filter 300 Hz) were performed using 32 electrical channels (Neuroscan; enhanced 10-20 system with a 10-10 system over the occipital region), and 31 corresponding magnetical channels (Philips; digital 3-D position tracking system ).

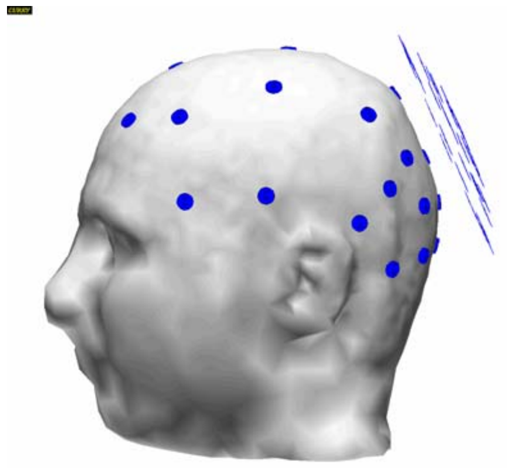

Figure 1: Positions of electrical electrodes and magnetic coils during the simultaneously performed EEG and MEG recordings.

Because of the large inter-individual differences of the alpha frequency which are related to age and memory performance [11], an initial resting condition of 60 seconds was recorded to define the individual alpha rhythm of each volunteer. The measured individual alpha frequency of all investigated volunteers ranged from 9.5 Hz to 11.8 Hz. After this period, flicker stimulations were conducted for 15 fixed frequencies

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with an alpha ratio (flicker frequency/individual alpha) of 0.4 to 1.6 in each volunteer. The chronological order of performed stimulations are shown in Table 1:

Table 1: Chronological order and alpha ratio (flicker frequency / individual alpha) of the stimulations.

| order | alpha ratio |
|---|---|
| 1. | 0.40 |
| 2. | 0.70 |
| 3. | 0.45 |
| 4. | 0.60 |
| 5. | 1.40 |
| 6. | 0.55 |
| 7. | 1.05 |
| 8. | 0.90 |
| 9. | 1.00 |
| 10. | 1.20 |
| 11. | 0.50 |
| 12. | 0.80 |
| 13. | 1.10 |
| 14. | 0.95 |
| 15. | 1.60 |

Resting periods (30-60 s) were recorded between the stimuli. Each stimulation frequency was presented by a sequence of 20 trains. A single train contained 40 flashes, and was separated again by a resting period (4 s). A processing scheme of the complete experimental design is given in Figure 2:

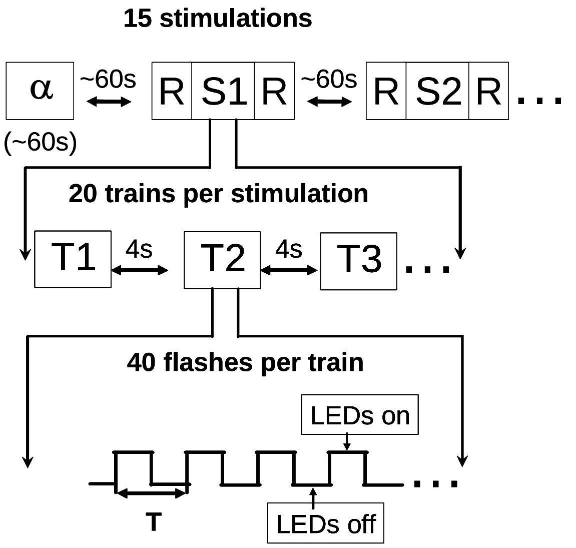


Figure 2: Experimental design of the study. “R” denotes resting periods, “S” periods of flicker stimulation, and “T” single trains during stimulation.

Simultaneous recordings were analysed using 4 EEG ($P_3$, $O_1$, $O_z$, $O_2$) and 4 corresponding MEG (M16, M18, M1, M10) channels. Original traces of the investigated MEG (M18) and EEG ($O_1$) channels in volunteer #5 are given in Figure 3.

Shifts in the alpha-peak were investigated by performing a FFT based spectral analysis (2 s interval, starting with the onset of stimulation) for each frequency and each train. The power spectra of the 15 different stimulation frequencies were averaged over the 20 available trains, and the maximum peaks of the resulting power spectra were detected.

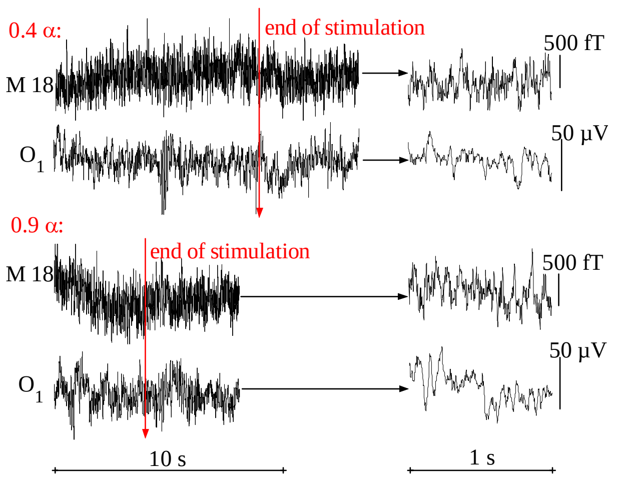


Figure 3: Original traces (MEG: M18 / EEG: $O_1$) of volunteer #5 during stimulation with 0.4 alpha and 0.9 alpha. One complete train of stimulation (left) and a one-second-section from the beginning of the train (right) are displayed.

For the time-varying approach, short-term FFT and parametric spectral analysis based on an AR-modeling adapting a Kalman filter [12] were perfomed for all frequencies and each train with a time resolution of 0.5 s. Time-frequency representations of the 15 different stimulation frequencies were averaged over the 20 available trains.

## Results

A frequency entrainment of the individual alpha rhythms occurred in the MEG as well as the EEG of all investigated volunteers with a more or less distinct characteristic. Two of the ten investigated volunteers showed only weak entrainment effects. The alpha entrainment was much stronger in the MEG than in the EEG recordings (Figure 5 and Figure 6) and showed time-varying characteristics (Figure 7).

Figure 4 demonstrates the alpha entrainment effect in one EEG channel and its corresponding MEG channel of volunteer #5.


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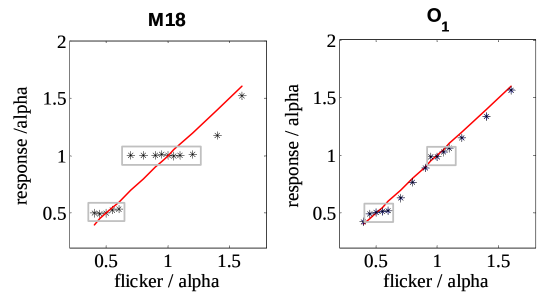


Figure 4: Entrainment effect in one MEG and one EEG channel of volunteer #5. The ratio of flicker/alpha is plotted against response (max. peak of spectra)/alpha producing black horizontal lines of stars indicating entrainment (highlighted by light-grey box). The red, diagonal line indicates no entrainment.

In the MEG of volunteer #5, flicker stimulations ranging from an alpha ratio of 0.4 to 0.6 produced an entrainment effect resulting in a frequency of nearly twice the stimulation frequency whereas stimulations in the range of 0.7 to 1.2 alpha produced an entrainment effect resulting in a frequency similar to the stimulation frequency. In the EEG, these regions were reduced to 0.45 to 0.6 alpha and 0.95 to 1.1 alpha (Figure 4).

The mean alpha entrainment effects over all investigated volunteers (error bars of mean $\pm$ standard deviation) are presented in Figure 5 and Figure 6. The results of all analysed EEG channels and the corresponding MEG channels are given. The more distinct characteristic of entrainment effects in the MEG as well as topological differences in the MEG and EEG recordings are evident.

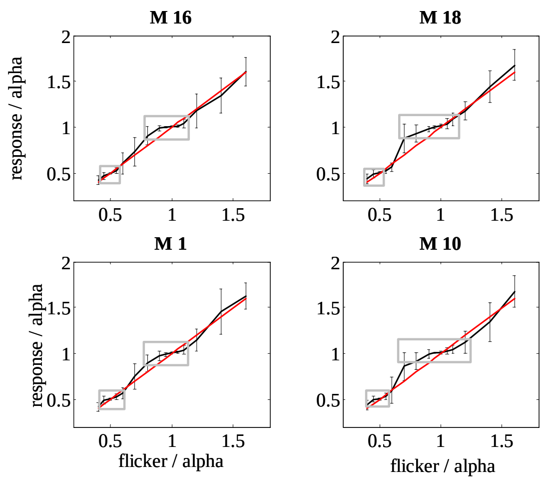


Figure 5: Mean entrainment effect (mean $\pm$ standard deviation) over all volunteers in all investigated MEG channels. The ratio of flicker/alpha is plotted against response (max. peak of spectra)/alpha producing black horizontal lines depicting entrainment (light-grey boxes). The red, diagonal line indicates no entrainment.

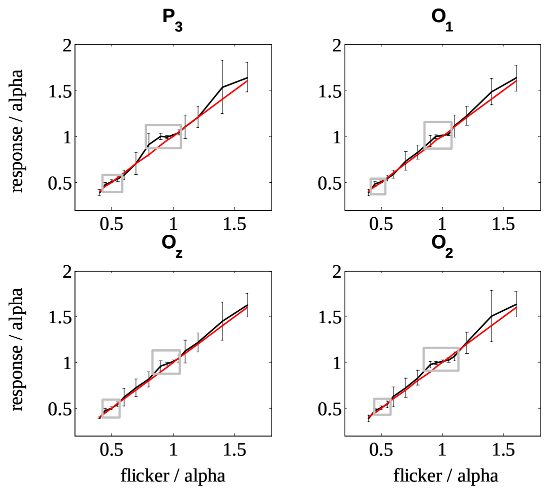


Figure 6: Mean entrainment effect (mean $\pm$ standard deviation) over all volunteers in all investigated EEG channels.

The time-varying investigations of the entrainment effects revealed the appearance of alpha entrainment within 0.5 s after the onset of stimulation.

Figure 7 shows an exemplarily spectral time-frequency representation of averaged trains during a stimulation frequency of 0.4 alpha in the MEG recording M1 and the EEG recording $O_1$ of volunteer #5 (stimulation frequency: 4.4 Hz; individual alpha frequency: 11 Hz). The individual alpha frequency changed from 11 Hz to about 13 Hz (three times the stimulation frequency) in M1 and $O_1$. In M1, another spectral peak occurred around 9 Hz (two times the stimulation frequency). The strength of alpha entrainment varied over the whole stimulation time and remained effective even after the end of stimulation (Figure 6).

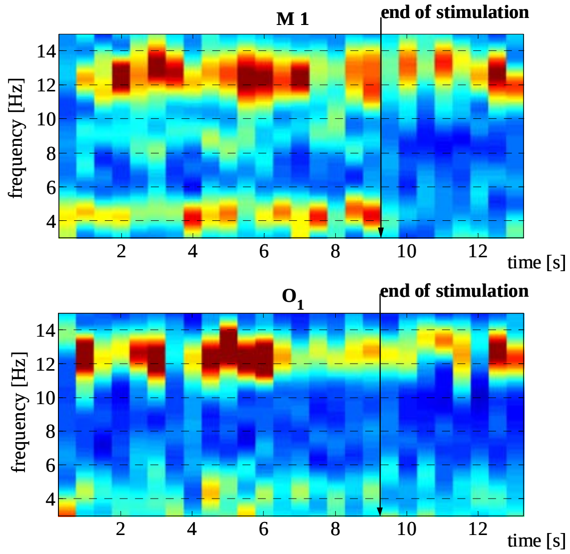


Figure 7: Spectral time-frequency representation (short-term FFT of M1 and $O_1$ in volunteer #5) of averaged trains during a stimulation frequency of 0.4 alpha. Red colour indicates high spectral amplitudes.


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## Discussion

For the first time the EEG and the MEG of ten healthy volunteers were simultaneously recorded and analysed while undergoing repetitive visual stimulations by external flickering light.

Eight (or 80%) of our investigated volunteers showed a moderate to strong alpha entrainment effect whereas two (or 20 %) of the volunteers revealed only weak stimulation effects. This corresponds to the demonstrability of photic driving used in clinical routine [4].

Alpha entrainment appears to be dependent on the ratio of the flicker frequency to the individual alpha rhythm [13]. A flicker stimulation with a frequency pattern between 0.4 to 0.6 and 0.9 to 1.1 of the individual alpha rhythms seems to be most effective.

The MEG recordings, in comparison to the EEG recordings, showed more distinct alpha entrainment effects. Topological as well as time-varying characteristics could be quantified.

Previous investigations of the human alpha rhythm have suggested non-linear properties [10]. Our results showed harmonic as well as subharmonic resonance peaks leading to the conclusion that the involved oscillators constitute a non-linearly coupled system.

## Conclusions

It could be shown that the effect of frequency entraiment is more pronounced in the MEG than the EEG recordings of all investigated volunteers. Furthermore, the alpha entrainment shows topological and time-varying properties, and is dependent on the ratio of the flicker frequency to the individual alpha rhythm.

In further follow up studies, source dipole modeling and extensive time-varying spectral investigations should be performed, to glean more insight into the precise mechanisms and processes of alpha genesis.

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