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Emotionally Charged Visually Evoked Magnetic Fields

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Electroencephalography is a neuroimaging technique sensitive to emotional states, a feature widely utilized in neuropsychology. Magnetoencephalography, as a technique complementary to electroencephalography, also has the potential to be applied to cognitive and neuroscience. Nevertheless, magnetoencephalography systems based on superconducting quantum interference devices are expensive to operate, limiting their use to mainly exploratory research. Optically pumped magnetometers are small single-unit sensors offering some advantages over superconducting quantum interference devices. Their properties are important in the measurements of subtle brain responses and indicate the possibility of magnetoencephalography becoming widely used in the near future. We used both existing types of magnetoencephalography systems, those with superconducting quantum interference devices and those with optically pumped magnetometers, to study magnetic brain responses to emotional stimuli. We examined the early components of visually evoked fields in five healthy subjects exposed to emotionally charged pictures. Both magnetoencephalography systems revealed a consistent negativity bias, known from electroencephalography, with stronger responses to negative stimuli compared to positive ones. These findings suggest that magnetoencephalography, especially with optically pumped magnetometers due to their ease of use, may play a significant role in neuropsychology.

topics: magnetoencephalography (MEG), superconducting quantum interference device (SQUID), optically pumped magnetometer (OPM), neuropsychology

1. Introduction

Electroencephalography (EEG), a neuroimaging technique based on the electrical activity of the brain, is highly sensitive to a variety of brain states, including emotional processing. Emotions can significantly influence EEG recordings as they modulate brain activity across different frequency bands and brain regions. This feature is widely applied in neuropsychology [1–3].

Magnetoencephalography (MEG), a technique complementary to electroencephalography that measures magnetic fields generated by neuronal electrical activity in the brain, also has the potential to be applied in cognitive and neuroscience [4, 5].

MEG measurements are contactless, so the difficulties associated with the use of electrodes, as in EEG, are avoided. Magnetoencephalography with *superconducting quantum interference devices* (SQUID) is a well-established technique to study brain function [6]. Nevertheless, due to the need for liquid helium cooling, SQUID-based systems are not only geometrically inflexible, but are also expensive in operation, which is the main reason for the MEG experimental-only character.

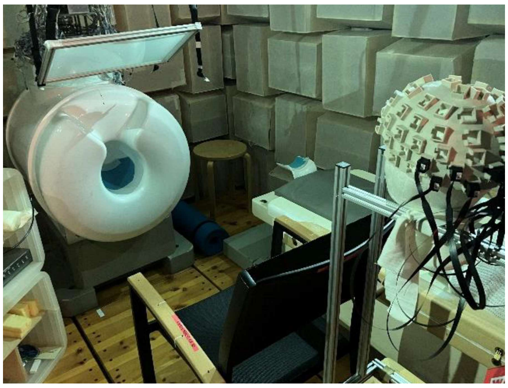

Fig. 1. Setup for magnetoencephalography with optically pumped magnetometers. OPMs are inserted in a MRI-derived 3D-printed sensor holder (right side of the photo). Participants are sitting in a chair and watching images on the tilted screen (left side of the photo).

Developed within the last decade, room-temperature *optically pumped magnetometers* (OPM) are small single-unit sensors with flexible wiring, offering some advantages over SQUID

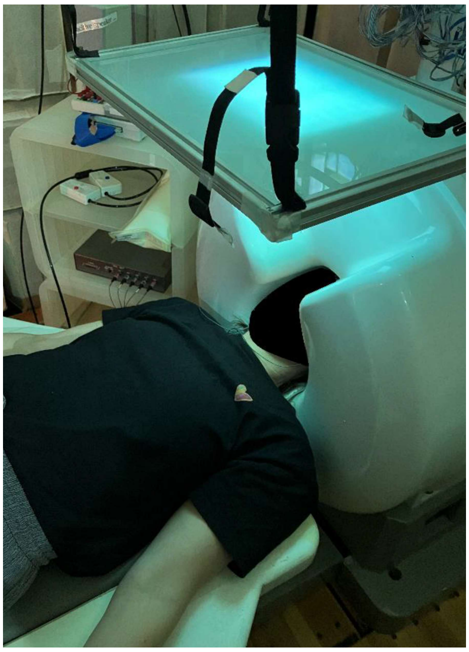

Fig. 2. Subject during SQUID-MEG. Subjects are in a supine position watching images on the screen.

systems [7, 8]. Their properties are important in measurements of subtle brain responses and indicate the possibility of magnetoencephalography becoming widely used in the near future [9, 10].

It is well known that late components of evoked responses reflect higher-order processing and cognitive evaluation of the content. Negativity bias was found in EEG studies for both P200 response [11] (occurring 200 ms after stimulus onset) and in the early range (76–128 ms) [12]. Our aim was to determine whether early MEG components are sensitive to emotional stimuli. The paper presents magnetic brain responses induced by visual stimulation.

Visually evoked magnetic fields (VEF) generated in cortex were measured using both SQUID-MEG system and an array of optically pumped magnetometers. The OPM- and SQUID-MEG signals were recorded in sequence as subjects performed a passive watching of emotionally charged pictures.

2. Materials and methods

Five test subjects (2 female, 3 male) participated in the study. All subjects were ophthalmologically normal, with no history of neurological or any other medical disorders that might have influenced the measurements of visually evoked magnetic fields.

The study was performed in accordance with the principles of the Declaration of Helsinki. Legal institutional approval restricts research to healthy volunteers and strictly non-invasive methods. Measurements were performed in July and August 2024.

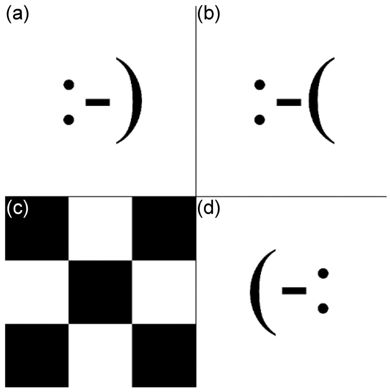

Fig. 3. Pictures used in stimulation: happy (a) and sad (b) emoticon, 3×3 chessboard (c), and inverted emoticon (d). In one block (a), (b), and (c) were repeated 250 times each, and (d) was presented 5 times to keep subject's attention.

For each subject an individualized anatomy-derived OPM sensor holder was prepared. Head surface was extracted from anatomical magnetic resonance images (obtained with clinical 3 Tesla scanner Verio, Siemens Healthcare, Munich, Germany) and used to prepare a subject-specific vector model. Head-cast CAD model was 3D-printed with flexible PLA filament and used for measurements of evoked brain responses [13].

The OPM- and SQUID-MEG measurements were performed in a two-layered Ak3b magnetically shielded room (Vacuumschmelze GmbH & Co. KG, Hanau, Germany) at Physikalisch-Technische Bundesanstalt, Institut Berlin, with a static magnetic field below 20 nT in the measurement volume.

Magnetoencephalography with optically pumped magnetometers was performed in a sitting position (Fig. 1). The subject put on the sensor holder with sensors inserted into the slots. Sensors array was located on the occipital area, covering a region from T5 and T6 across O1 and O2 of the international 10–20 EEG electrode placement system. The sensors were pushed to touch the head surface and minimize sensor-to-signal source distance. Ten dual channel commercially available OPMs (Gen-2 QZFM: QuSpin Zero-Field Magnetometer, QuSpin Inc., Louisville, USA) were used for the measurements [14].

During SQUID-MEG, subjects were lying on a bed with their head surrounded by a helmet-shaped dewar (Fig. 2) of a 128-channel gradiometer Yokogawa system (MEGvision type, Yokogawa/Ricoh, Kanazawa, Japan [15]).

Three types of figures were presented to the participants:

1. happy emoticon (smiley);
2. sad emoticon (frown);
3. 3×3 chessboard — as a reference for visual stimulation.

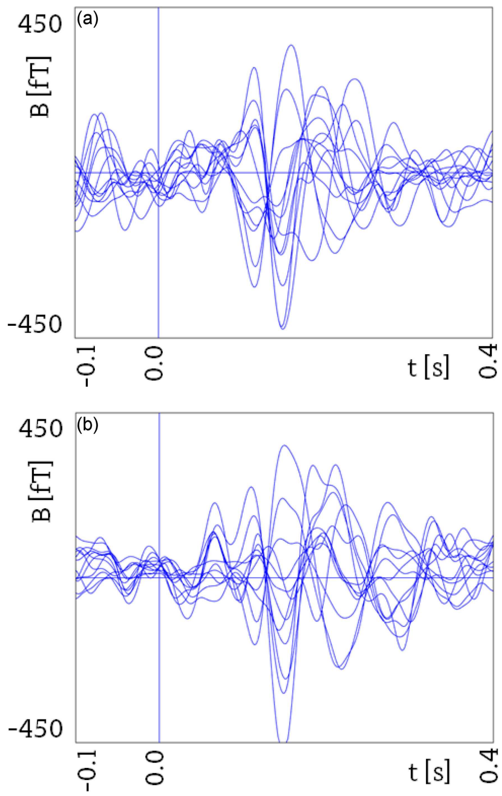

Fig. 4. Superimposed OPM-MEG sensor time-series (butterfly plot) of visually evoked brain responses to positively- (a) and negatively-charged (b) pictures. The amplitude of prominent early response to sad emoticon recorded with optically pumped magnetometers was 13% higher compared to happy emoticon stimulation.

Both icons were horizontal, as used in a written text (see Fig. 3), consisting of colon, hyphen, and right or left parenthesis for each facial expression, respectively. Pictures were presented randomly for 350 ms with 250 repetitions each. *Inter-stimulus interval* (ISI), during which no picture was displayed (black screen), was randomized in a range from 500 to 750 ms. Additionally, after 150 presentations (50 of each type of figure), an inverted emoticon was presented to keep participant's attention. One block of the paradigm lasted 13 min and was presented twice for each measurement method with a short break between. PsychoPy software was used for the visual stimulation [16].

Obtained datasets were analyzed, and the visual brain responses were determined. The evoked fields were calculated by averaging the trials using the specific trigger signal associated with pictures and recorded simultaneously to the MEG.

Data were high-passed with 5 Hz and low-passed with 35 Hz Butterworth filter to eliminate background noise and external magnetic field fluctuations. Data processing relied partially on FieldTrip [17] toolboxes based on MATLAB^{TM}.

3. Results

During the passive watching of emotionally charged figures both types of MEG systems, i.e., SQUID and OPM based, showed a prominent visually evoked response 130–150 ms after the stimulus onset (Figs. 4 and 5).

Visual magnetic brain responses to negatively-charged pictures (sad emoticon) were higher than to positive stimuli (happy emoticon) for four out of five subjects (80%). This pattern was consistent in both OPM- and SQUID-MEG recordings. The amplitude of visually evoked fields reached up to 480 fT in OPM-MEG and 215 fT in the SQUID-based system when the subject was stimulated with a sad emoticon. These values were up to 13% and 17% higher, respectively, compared to the brain responses elicited by positive stimulus (happy emoticon) for each MEG system.

The fifth subject's evoked responses were higher for positive-valence pictures compared to negative-valence ones.

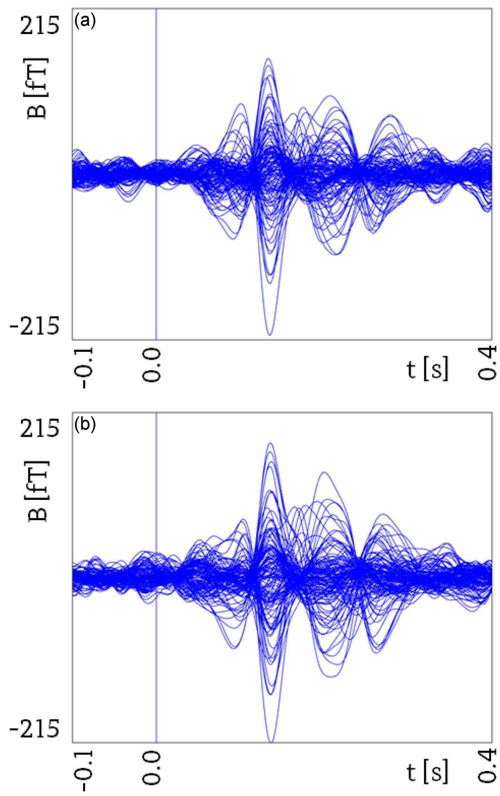

Fig. 5. Superimposed SQUID-MEG sensor time-series (butterfly plot) of visually evoked brain responses to positively- (a) and negatively-charged (b) pictures. The amplitude of prominent early response to sad emoticon recorded with SQUID-MEG system was 18% higher compared to happy emoticon stimulation.

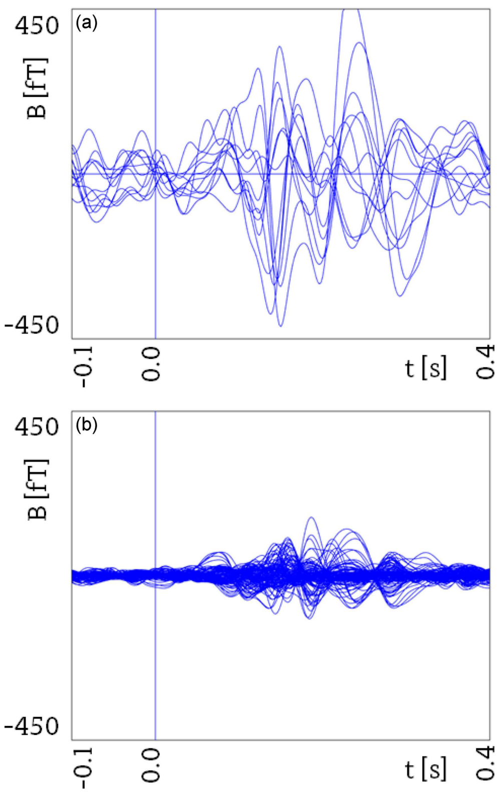

Fig. 6. Superimposed OPM- (a) and SQUID-MEG (b) sensor time series of visually evoked brain responses to the reference stimuli (3×3 chessboard). The prominent response present in SQUID-MEG 200 ms after the stimulus onset was three times lower compared to OPM-MEG results. Different pattern of visual response comparing to emoticon stimulation (Figs. 4 and 5) is related to the different visual parameters of the stimulus (brightness, histogram etc.).

Visually evoked fields obtained with optically pumped magnetometers had two to three times higher amplitude comparing to SQUID-MEG within each subject (Fig. 6).

4. Conclusions

Magnetoencephalography is a well-established neuroimaging technique. However, traditional SQUID-based MEG systems are limited in use as they require expensive cooling and lack geometric adaptability.

Recent technological advancements introduced optically pumped magnetometers, which offer several advantages over SQUID systems. These room-temperature sensors can be placed directly on the scalp, allowing for greater proximity to brain sources and, consequently, higher amplitudes of the measured responses.

Optically pumped magnetometers provide new opportunities for MEG research that are still being explored and are expected to play a significant role in the future of magnetoencephalography and neuropsychology.

In our study, we used magnetoencephalography to investigate if and how emotions affect visually evoked magnetic fields. The data showed a strong early response (130–150 ms after stimulus onset) in all subjects. The negativity bias was observed in four out of five participants (80%), with increased responses to negative (sad emoticon) images, consistent across both OPM and SQUID-MEG recordings. One participant revealed a different pattern, with a sad emoticon eliciting lower responses than a smiley.

The observed magnetic negativity bias requires further investigation. Extended research on a larger and representative population is needed to validate individual response patterns and assess their generalizability.

Despite the much lower channel count of 20 in our OPM-MEG compared to the 125 channels in the SQUID-MEG, the difference between the stimulus categories is reproduced. This means that the OPM placement around O1 and O2 is meaningful and should be used in a planned larger study.

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