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An MEG compatible system for measuring skin conductance responses

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HIGHLIGHTS

- ▶ Magnetoencephalography compatible low-cost system for monitoring skin conductance responses in the magnetically shielded room.
- ▶ The system allows high quality simultaneous recordings of SCRs and MEG signals.
- ▶ Its implementation calls for limited knowledge in electronics due to its simplicity.

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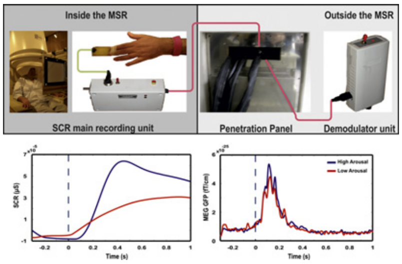
GRAPHICAL ABSTRACT



ABSTRACT

We present the design of a low-cost system for recording galvanic skin conductance responses (SCRs) from humans in a magnetically shielded room (MSR) simultaneously to magnetoencephalography (MEG). Such a system was so far not available to the MEG community. Its availability is of utmost importance for neuroscience, since it will allow the concurrent assessment of the autonomic and central nervous system activity. The overall system design optimizes high signal to noise ratio (SNR) of SCRs and achieves minimal distortion of the MEG signal. Its development was based on a fiber-optic transformer, with voltage to optical transduction inside the MSR and demodulation outside the MSR. The system was calibrated and tested inside the MEG environment by using a 151-channel CTF whole head system (VSM MedTech Ltd.). MEG measurements were recorded simultaneously to SCRs from five healthy participants to test whether the developed system does not generate artifacts in the MEG data. Two measurements were performed for each participant; one without the system in the MSR, and one with the system in the MSR, connected to the participant and in operation. The data were analyzed using the time and frequency domains in separate statistical analysis. No significant differences were observed between the two sessions for any statistic index. Our results show that the system allows high quality simultaneous recordings of SCRs and MEG signals in the MSR, and can therefore be used as routine addendum to neuroscience experiments.

Abbreviations: SCRs, skin conductance responses; MSR, magnetically shielded room; SNS, sympathetic nervous system; ERPs, event-related potentials; MR, magnetic resonance; RF, radio-frequency; PSD, Power Spectral Density; SK, spectral kurtosis; VCO, voltage-controlled oscillator; EOG, Electrooculographic; ECG, electrocardiographic; MTM, Multitaper Method; GFP, global field power; IAPS, International Affective Picture System; PHA, pleasant and high arousing; PLA, pleasant and low arousing; UHA, unpleasant and high arousing; ULA, unpleasant and low arousing; SAM, Synthetic Aperture Magnetometry; IPF, inferior parietal lobule; TP, temporal pole; MNI, Montreal Neurological Institute.

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1. Introduction

In response to different kinds of stimuli, part of the human sympathetic nervous system (SNS) is activated filling up the palmar and plantar sweat glands and as a consequence resulting in alterations of the human skin electrical properties (Boucsein, 1992). These skin conductance changes, termed skin conductance responses (SCRs), can easily be recorded via a pair of electrodes usually placed on the hand digits of a human participant. The temporal features of the SCR are well characterized with an onset latency of 1.5 s and a rise in skin conductivity thereafter that is proportional to the degree of synchronization of sweat gland secretions (Lim et al., 2003). SCRs are frequently used in neuroscience research as an indirect measure of human's emotional arousal (Bernat et al., 2006; Ohira et al., 2006; Lithari et al., 2010), level of attention (Critchley et al., 2000), or learning (MacIntosh et al., 2007).

Neuroscience studies of concurrent central and autonomic activity are considered useful in elucidating the relationship between central and autonomic responses. Traditionally, SCRs have been studied in conjunction with event-related potentials (ERPs) recorded by electroencephalography (EEG) that provide excellent temporal but limited spatial resolution.

Over the years, magnetoencephalography (MEG) has proven to be a reliable neuroimaging tool in studying electro-magnetic activity in the cortex (Hamalainen et al., 1993) offering – under favorable circumstances – a good spatial resolution of few millimeters (Yamamoto et al., 1988; Moradi et al., 2003; Papadelis et al., 2009, 2011) in addition to its sub-millisecond temporal resolution. MEG measures the weak (10 fT–1 pT) magnetic fields produced by neuronal currents in the human brain. Since the brain neuromagnetic signals are extremely weak compared with ambient magnetic-field variations, MEG requires the measurements to be performed within specially designed magnetically shielded rooms (MSRs). This technical requirement makes problematic the use of electrical devices placed in the MSR and thus the simultaneous recording of MEG signal and SCRs. Electronic devices need to be shielded, since otherwise will generate severe technical artifacts distorting the MEG signal.

Since now, there is no well-established methodological framework allowing the simultaneous acquisition of SCR with MEG. The literature reporting such kind of measurements is limited to only a single study (Seth et al., 2006), in which technical issues are not addressed in detail. This article addresses the technical aspects of monitoring SCR on human participants in the MSR during MEG measurements. The work presented here realizes in part the ideas and directions set in collaboration between the Laboratory of Medical Informatics, School of Medicine, Aristotle University of Thessaloniki and the Laboratory for Human Brain Dynamics at the Brain Science Institute, RIKEN (1998–2009) and its continuation at the AAI Scientific Cultural Services Ltd. in Cyprus. The principal goal of this collaboration was the design and implementation of a cheap and accurate measure of SCR that can be used both in studies with expensive state of the art MEG and fMRI equipment and in studies with simpler instrumentation, notably few-channel EEG. The system is therefore ideal for studies of affect and emotion, serves the growing battery of neurophysiological measurements required and the human–computer interaction that may accompany it (Bamidis et al., 2004). It is also ideal for measurements with children and patients under stressful tests where subtle features of the EEG response (Ioannides and Sargsyan, 2012) must be studied together with indices of arousal and anxiety levels.

To achieve these goals, we developed a low cost MEG-compatible system able to record SCRs with high signal to noise ratio (SNR) while not adversely distorting the MEG recordings. The design of our system was partially based on a device proposed by Shastri et al. (2001) for monitoring SCRs in a clinical magnetic resonance (MR) scanner during functional imaging. This functional magnetic resonance imaging (fMRI)-compatible device was initially built and tested in a MEG experimental setup. It was found to be non-MEG compatible, since it generated severe technical artifacts in the recorded MEG signal. To overcome this problem, a second MEG-compatible unit was designed and built employing an optical isolation serving to the signal transduction between the recording unit placed inside and the transforming unit placed outside the MSR. The special feature of our system is the optical isolation between the two units one placed inside and the other outside the MSR, which does not allow radio-frequency (RF) artifacts to pass through the acquisition cable and interfere with the MEG recordings. A fiber-optic system for recording skin conductance – similar to ours – was first proposed by Lagopoulos et al. (2005). However, this system was designed for use in fMRI serving its needs and not in an MEG setup. The main problem somebody faces when attempts to record electrophysiological data inside the MRI room and transmits these data outside, is the powerful alternating magnetic field environment that prohibits placing metallic cables and electrical components in close proximity to the magnetic bore (Lagopoulos et al., 2005). Powerful RFs, which are present in the MRI room, affect severely any conductive cable placed inside the room that acts as a RF antenna. By placing a conductive cable in the MRI scanner room in order to simultaneously record SCR, you (i) introduce artifacts in the MRI scanner, that severely compromise the quality of the acquired images, and (ii) introduce strong artifacts to the recorded SCR signal from the magnetic gradients. The difficulties somebody faces when he/she would like to record SCR signals simultaneously with MEG recordings are different. The presence of a conductive cable inside the MSR that transmits the data in an external computer can bring RFs inside the room canceling the main purpose of the MSR to eliminate RFs radiation, which would degrade SQUID performance. Yet, the presence of any metallic and electrical component in close proximity to the SQUIDs can severely affect the quality of the recorded MEG signal. In both setups, the optical isolation will not allow RF artifacts to pass through the acquisition cable and interfere with the MEG recordings and distort the MRI images respectively. Additionally, the optical fiber in the MRI setup – compared to metallic cabling – is insensitive to the magnetic field of the scanner that may generate severe artifacts in the SCR signal.

The development, calibration, and testing of our system are described and discussed here by using techniques such as skewness and kurtosis, Power Spectral Density (PSD) and the average spectral kurtosis (SK). Once the overall operation reached the required performance level the system was used in an experimental paradigm assessing the emotional processing of healthy human participants.

2. Materials and methods

2.1. Design of the MEG-compatible SCR system

The principal idea for measuring SCRs is to impose a constant DC voltage across two Ag/AgCl electrodes and to measure the changes in the flow of current as a result of the skin conductivity alterations. The MEG-compatible SCR system consists of five integrated circuits (Fig. 1). These were implemented within two separate units: the main recording unit placed inside the MSR and the demodulator unit that is placed outside the MSR. The main recording unit records, amplifies, filters and finally modulates the SCR data to optical signal, while the demodulator unit converts the optical signal to voltage. Both units are powered by batteries. The two units are connected through a fiber optic connection in order to eliminate the transfer of RF from outside the MSR inside distorting the MEG signal with technical artifacts. The fiber-optic cable exits the MSR