Journal of Neuroscience Methods 294 (2018) 34–39

Contents lists available at ScienceDirect

Journal of Neuroscience Methods

journal homepage: www.elsevier.com/locate/jneumeth

Short communication

Improving the quality of combined EEG-TMS neural recordings: Introducing the coil spacer

K.L. Ruddy[a], D.G. Woolley[a], D. Mantini[a,b], J.H. Balsters[a], N. Enz[a], N. Wenderoth[a,*]

[a] Neural Control of Movement Lab, ETH, Zurich, Switzerland
[b] Movement Control and Neuroplasticity Research Group, KU Leuven, Leuven, Belgium

HIGHLIGHTS

- Combined TMS-EEG produced significant contact artifacts in Delta and Theta range.
- The coil spacer is a simple solution providing a platform between TMS and EEG cap.
- Design files are available for other groups to 3D print and customize the coil spacer.

ARTICLE INFO

Article history:
Received 1 August 2017
Received in revised form 22 October 2017
Accepted 1 November 2017

Keywords:
Combined
TMS
EEG
Artifact

ABSTRACT

Background: In the last decade, interest in combined transcranial magnetic stimulation (TMS) and electroencephalography (EEG) approaches has grown substantially. Aside from the obvious artifacts induced by the magnetic pulses themselves, separate and more sinister signal disturbances arise as a result of contact between the TMS coil and EEG electrodes.
New method: Here we profile the characteristics of these artifacts and introduce a simple device – the coil spacer – to provide a platform allowing physical separation between the coil and electrodes during stimulation.
Results: EEG data revealed high amplitude signal disturbances when the TMS coil was in direct contact with the EEG electrodes, well within the physiological range of viable EEG signals. The largest artifacts were located in the Delta and Theta frequency range, and standard data cleanup using independent components analysis (ICA) was ineffective due to the artifact's similarity to real brain oscillations.
Comparison with existing method: While the current best practice is to use a large coil holding apparatus to fixate the coil 'hovering' over the head with an air gap, the spacer provides a simpler solution that ensures this distance is kept constant throughout testing.
Conclusions: The results strongly suggest that data collected from combined TMS-EEG studies with the coil in direct contact with the EEG cap are polluted with low frequency artifacts that are indiscernible from physiological brain signals. The coil spacer provides a cheap and simple solution to this problem and is recommended for use in future simultaneous TMS-EEG recordings.

1. Introduction

There has been a recent surge in the number of publications reporting simultaneous transcranial magnetic stimulation (TMS) and electroencephalography (EEG) recordings. This amalgamation of methods has introduced valuable new ways to probe and measure the brain, such as with TMS evoked responses (e.g. Ferreri et al., 2011; Miniussi and Thut, 2010; Bonato et al., 2006) and TMS induced oscillations (eg. Paus et al., 2001). While the vast majority of studies have focused on post-TMS EEG signals, emerging theories on state-based stimulation make the claim that differences in ongoing neural oscillations at the moment when brain stimulation occurs likely impact outcome measures (see Thut and Pascual-Leone 2010). For these investigations, the EEG signal measured *before* the TMS pulse contains critical information.

Considering the immense methodological challenges posed by the application of high intensity magnetic pulses during the recording of delicate low amplitude EEG signals, it is not surprising that the focus of most attempts to improve combined TMS-EEG pro-

* Corresponding author at: Neural Control of Movement Lab, Department of Health Sciences and Technology, ETH Zurich, Y36 M12, Winterthurerstrasse 190, Zürich, 8057 Switzerland.
E-mail address: nicole.wenderoth@hest.ethz.ch (N. Wenderoth).

https://doi.org/10.1016/j.jneumeth.2017.11.001

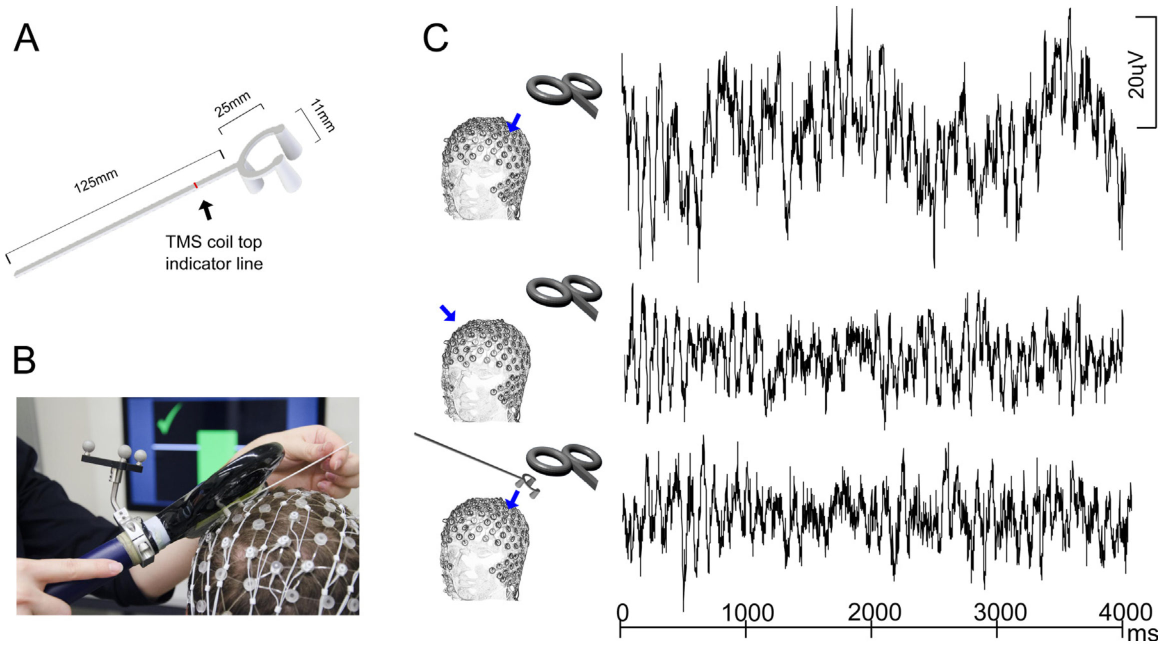

Fig. 1. Combined TMS-EEG using the Spacer. The spacer design (A) and an image of the spacer in use during an experiment (B). EEG recordings from a representative subject of one 4000 ms epoch in each condition (C): Blue arrows indicate the location of the electrode from which recordings are displayed. In the upper panel, the TMS coil is placed directly on top of the EEG cap over the left hemisphere motor hotspot during recording. The mid panel depicts the same epoch of data but recorded from the corresponding electrode on the right hemisphere while the TMS coil is on the left hemisphere. The lower Panel shows the left hemisphere hotspot recording when the spacer is placed between the TMS coil and the EEG cap. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

tocols has been on the substantial signal disturbances caused in the immediate interval following the pulse. In this regard, much progress has been made (Veniero et al., 2009; Virtanen et al., 1999; Mutanen et al., 2013; Rogasch et al., 2013; Julkunen et al., 2008), but there remains another less obvious source of artifact that has received little attention and is crucial to the study of pre-TMS brain states. This is the signal disturbance that arises simply from contact between the TMS apparatus and the surface of the EEG cap. In the absence of a dedicated investigation comparing signals with and without this disturbance, the extent of the artifact and its impact upon resulting interpretations of data remains unknown. Movement artifacts are in the frequency range of bioelectric events, making them particularly difficult to discern from true brain signals, posing a high risk of polluting the EEG in a way that is disguised as viable physiological data. Here we focus specifically on the artifact associated with direct contact between the TMS coil and electrodes during simultaneous EEG recording, and introduce a simple solution to improve the quality of such recordings for future investigations.

2. Methods

2.1. Participants

Six healthy volunteers (age: 22–29, 3 male, 3 female) participated in the study. All gave informed consent to procedures. The experiments were approved by the Kantonale Ethikkommission Zürich, and were conducted in accordance with the Declaration of Helsinki (1964).

2.2. Experimental setup and procedure

Subjects sat in a comfortable chair with both arms and legs resting in a neutral position supported by foam pillows. Surface electromyography (EMG, Trigno Wireless; Delsys) was recorded from right First Dorsal Interosseous (FDI) and Abductor Digiti Minimi (ADM). EMG data were sampled at 2000 Hz (National Instruments, Austin, Texas), amplified and stored on a PC for off-line analysis.

2.3. Combined TMS-EEG

TMS was performed with a figure-of-eight coil (internal coil diameter 50 mm) connected to a Magstim 200 stimulator (Magstim, Whitland, UK). Prior to application of the EEG cap, the 'hotspot' of the right FDI was determined as the location with the largest and most consistent MEPs, and was marked directly onto the scalp with a skin marker. The TMS coil was hand held over this location with the optimal orientation for evoking a descending volley in the corticospinal tract (approximately 45° from the sagittal plane in order to induce posterior-anterior current flow). Once the hotspot was established, the EEG cap (Electrical Geodesics Inc. (EGI), Oregon, USA) was applied and electrodes were filled with gel. Through the EEG cap, the previously marked position of the FDI hotspot was located visually and the TMS coil was applied directly over this point. With the coil directly resting on the EEG cap, the lowest stimulation intensity at which MEPs with a peak-to-peak amplitude of approximately 50 μV were evoked in at least 5 of 10 consecutive trials was taken as Resting Motor Threshold (RMT). The procedure to establish RMT was repeated again with the introduction of the coil spacer between the cap and the TMS coil.

2.4. The coil spacer

The coil spacer (Fig. 1A & B) is a plastic circular tripod (1.1 cm in height) with a 12.5 cm handle, which was 3D printed (Ultimaker 2, design files available online at https://3dprint.nih.gov/discover/3dpx-007789) and can be customized to virtually every EEG cap and TMS coil available. The three conical feet attached to the circular ring are wider at the bottom than the top, to spread pressure widely over the scalp area and avoid discomfort. The circular ring is hollow in the middle to allow direct vision for positioning the