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Transcranial magnetic stimulation—a sandwich coil design for a better sham

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Abstract

Objective: To improve the quality of TMS studies by developing a new sham condition.
Methods: We describe a novel and easily arranged TMS set-up of two standard TMS coils and a magnetic shield, stacked like a sandwich. In a first step we compare the magnetic field in the sham and verum conditions. In a second step we ask six subjects to rate the stimulation intensity.
Results: The magnetic field in the sham mode is reduced to about one eighth of that during verum stimulation. The attenuation of the magnetic field is not limited to the actual stimulation site but also effective at neighbouring brain areas, avoiding direct and indirect stimulation via connected neural pathways. This also minimizes stimulation of the skin, but as a consequence allows subjects to distinguish between verum and sham conditions when these are contrasted directly. The position of the coil system and the acoustic sensations are indistinguishable between sham and verum condition. Subjects are not able to discriminate TMS position and condition by external cues.
Conclusions: The proposed TMS setup is simple and allows verum and sham TMS without interaction of the researcher. If used with the magnetic shield, the magnetic field in the brain is attenuated most.
Significance: With the sandwich TMS coil system it is possible to improve the quality of TMS studies.

Keywords: TMS; Transcranial magnetic stimulation; Sham; Placebo; Coil

1. Introduction

Transcranial magnetic stimulation (TMS) allows alteration of brain physiology and is being evaluated in several clinical conditions (for reviews, see Haraldsson et al., 2004; Lisanby et al., 2002; Schonfeldt-Lecuona et al., 2002; Sommer and Paulus, 2003; Wassermann and Lisanby, 2001).

TMS is based on the principle of electromagnetic induction (Roth et al., 1991). By passing a brief strong electric current (pulse duration of ~0.2 ms) through an insulated coil, a rapidly changing magnetic field is generated. Approximately 2 tesla magnetic field strength can be reached. When the coil is placed over a person's head, the magnetic field can penetrate scalp and skull without attenuation. It induces a secondary electric current in the brain which is sufficient to cause a depolarisation of the neurons in the superficial layers of the brain. Currently, direct stimulation of brain tissue deeper than about 2–3 cm from the scalp is not possible, because of the rapid decrease in magnetic field strength (very close to the coil center the magnetic field decreases as the inverse of the distance from the coil and at large distances as the inverse of the forth power of distance).

Despite these limitations, TMS is widely used in neuroscience as a tool to study the cortical excitability and inhibition. Studies utilizing TMS often deliver conflicting results (Martin et al., 2003). These can be partly explained by differing stimulation parameters (such as the

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frequency, intensity, duration and location of stimulation), coil forms or total number of stimuli.

One of the major concerns in TMS experiments, however, is the lack of a reliable placebo (sham) condition. Without such a condition, it is not possible to differentiate between placebo and treatment effect. In depression studies, for instance, these can reach up to 50 percent of the effects of verum TMS (Wassermann and Lisan by 2001). Variability in therapeutic effects across studies may therefore often be related to differences in the sham conditions (Kaptchuk et al., 2000; Lisanby et al., 2001; Loo et al., 1999). Thus, the development of a good sham condition is a prerequisite to assess the therapeutic properties of TMS.

Loo et al. (1999); Lisanby et al. (2001) defined the following criteria for good sham stimulation:

1. Sham TMS should not stimulate the cortex.
2. Position of sham and verum TMS should not differ.
3. The acoustic sensation should not differ.
4. The sensation on skin should not differ.

In this paper, we describe an economical and technically easy sandwich TMS coil design that can be realized utilizing equipment available in most TMS laboratories.

2. Methods and materials

2.1. Coil design

The basic idea was to construct a TMS coil system in which the magnetic field in the sham condition is negligible in comparison with the verum condition not only at the local stimulation point, but also in neighbouring brain areas to avoid an indirect stimulation via connected neural pathways.

This was realized by combining two figure-of-eight coils in a sandwich like way as displayed in Fig. 1 (Magstim Company, Double 70 mm Coil, P/N9925-00; each wing with 9 windings, inductance $L = 16.35$). With a joint between the handles the two coils were arranged to cover congruently. The backsides of both coils were adjacent. Between the wings of the coils we inserted a magnetic shield consisting of 2 mm thick mu-metal (160 mm × 90 mm × 2 mm, the relative permeability is about 80,000 for the static field and decreases with increasing frequency, for $T \approx 0.2$ ms pulse duration it is $\mu_r \approx 5000$, resistivity $\rho \approx 0.55 \times 10^{-6}$ Ωm. A thinner mu-metal sheet can be used, but deformation of mu-metal should be avoided, as it's properties will change). It was fixed with hard plastic spacers so that the distance between each coil and the magnetic shield amounted to 2 cm. The wings of the complex were wrapped with small stripes of one to two layers of adhesive tape. This made the complex stable without restricting the natural convection. The vibrations from one coil were transmitted through the spacers and the mu-metal sheet to the other coil. The coil next to the subject's head was used for verum stimulation, the other one for sham stimulation. Thus, both verum and sham TMS could be obtained without moving or tilting the coil complex.

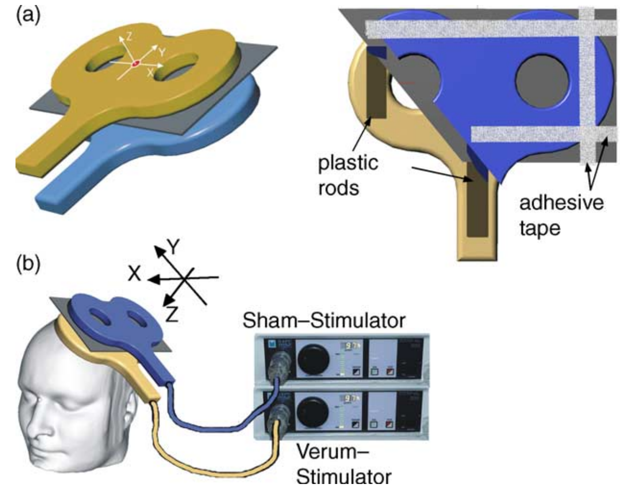

Fig. 1. (a) Verum-Sham-Coil-Complex. Two figure-of-eight coils are combined with their backs adjacent, congruently covering each other. Between the two coils a magnetic shield consisting of 2 mm thick mu-metal is inserted. Beige defines the verum-side and blue the sham-side of the coil complex. The point we refer to as center of the coil is marked in red. It is also the origin of the displayed coordinate system (fixed to the verum-side). (b) For sham-stimulation the upper stimulator (connected to the blue coil) and for verum-stimulation the lower stimulator (connected to the beige coil) is triggered. Since the position of the coil complex does not change for either sham or verum stimulation, subjects are not able to discriminate between both conditions simply by differing coil positions. With masked stimulator displays and a computer controlled set-up, not only the subject but also the operator can be blinded to stimulation type, making it possible to perform double blind TMS studies (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

2.2. Magnetic field of verum and sham TMS

To verify that the magnetic stimulation in the sham mode is negligible in comparison to the verum mode (i.e. the ratio of sham:verum is small compared to 1), we measured a correlate of the magnetic field in both conditions. The magnetic stimulator used was a Magstim Rapid with two booster modules (Magstim Company) producing biphasic TMS pulses.

The induced voltage components U_x and U_y were measured with a pair of wire-loops (each with a circumscribed area of 1.0 cm^2) oriented perpendicular to the TMS-coil plane. They were placed as close to the front of the verum coil as possible ($z \approx 0$, compare coordinate-systems in Figs. 1 and 2). U_x and U_y refer to the voltages induced by the change of the B_x and B_y component.

The wire-loops were attached to two channels of an oscilloscope, and as the induced voltage is proportional to the change of flux density ($U_{ind} = \partial(\underline{BA})/\partial t = (\partial \underline{B}/\partial t)\underline{A}, \underline{B} = \mu_0 H$, air as medium, U_{ind}: induced voltage, A: area of