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Measurement of Background Noise on Magnetic Stimulation Coil

by
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Abstract

Transcranial magnetic stimulation is a non-invasive technique that can directly stimulate the human brain. The effects of magnetic stimulation are dependent on the stimulus frequency, number of stimuli, and stimulus strength. There is also evidence that the intensity of the magnetic stimulus can modulate the effect of the stimulus frequency. Thus, investigating the relationship between the magnetic stimulation strength and stimulus frequency is important for use of transcranial magnetic stimulation in humans. However, background noise by the measurement system, such as from the cable, can make it difficult to accurately measure magnetic stimulation strength. Therefore, we developed a method for measurement of background noise during the measurement of magnetic stimulation intensity. Spherically, magnetic stimulation strength was analyzed via the magnetic flux density using a dedicated probe. For magnetic stimulation, biphasic magnetic stimulation was used with a pulse width of 320 µs. The stimuli were 10 pulses and 35% － 85% intensity. The measurement points were 19 mm above the stimulation coil, while the measurement range was ±50 mm in the long axis direction and ±50 mm in the short axis direction from the center of the stimulation coil. The mean magnetic flux density for each level of magnetic stimulation was approximately 62 mT at 35% intensity, 64 mT at 45% intensity, 67 mT at 55% intensity, 70 mT at 65% intensity, 72 mT at 75% intensity, and 75 mT at 85% intensity (all significantly different compared with the 35% intensity; $p < 0.001$). By contrast, there were no differences in the magnetic flux density at the measurement points compared with the center of the stimulation coil for each strength. These results suggest that background noise is independent of the measurement location at 19 mm above the stimulus coil for transcranial magnetic stimulation in the brain. This study showed that the background noise during the measurement of magnetic flux density may be removed using a simple measurement device.

Key Words : Transcranial magnetic stimulation, Background noise, Magnetic flux density, Magnetic stimulation intensity

1. Introduction

Transcranial magnetic stimulation (TMS) is a non-invasive technique that can facilitate or inhibit the excitability of the human cerebral cortex [1-3]. This modulation of excitability occurs via stimulation of the brain tissue by the eddy current. The magnetic stimulation is not affected by the scalp, skull, or hair [3, 4]. In addition to magnetic stimulation, non-invasive brain stimulation methods have included the use of an electrical stimulator (e.g., transcranial electrical stimulation [TES]) [5]. Although transcranial magnetic stimulation and TES were reported to have similar effects in the motor cortex [3], they have different mechanisms of action [6].

Importantly, transcranial magnetic stimulation provides painless stimulation because it is not affected by the high impedance of the scalp and skull. Furthermore, the localization of the cortical stimulus with TES is not as sharp as that with transcranial magnetic stimulation [7]. For transcranial magnetic stimulation, the stimulus localization can be regulated using a figure-of-eight coil, which has a stimulus resolution of approximately 5 mm [8, 9]. Stimulus localization is useful for clinical therapy and brain function research. Clinically, transcranial magnetic stimulation is used to treat or alleviate symptoms of brain and psychiatric disorders, including in Parkinson's disease and depression [10-13]. Furthermore, transcranial magnetic stimulation is used to examine higher brain functions, such as sensory organs and language function (e.g., in the visual cortex, somatosensory cortex, Broca's area, and Wernicke's area, and for memory) [14-19].

Transcranial magnetic stimulation at the supra-motor threshold can be used to evoked facilitatory or inhibitory brain responses depending on the stimulation frequency. Generally, a low frequency stimulation at 1 Hz is considered to inhibit cerebral cortical excitability, while a high frequency stimulation at 5 Hz facilitates cortical excitability [3]. However, at the sub-motor threshold, low frequency stimulation at 1 Hz actually facilitated cerebral cortex excitability [20-22]. These findings suggest that the magnetic stimulation intensity can regulate the effects of magnetic stimulation on brain activity. Therefore, it is

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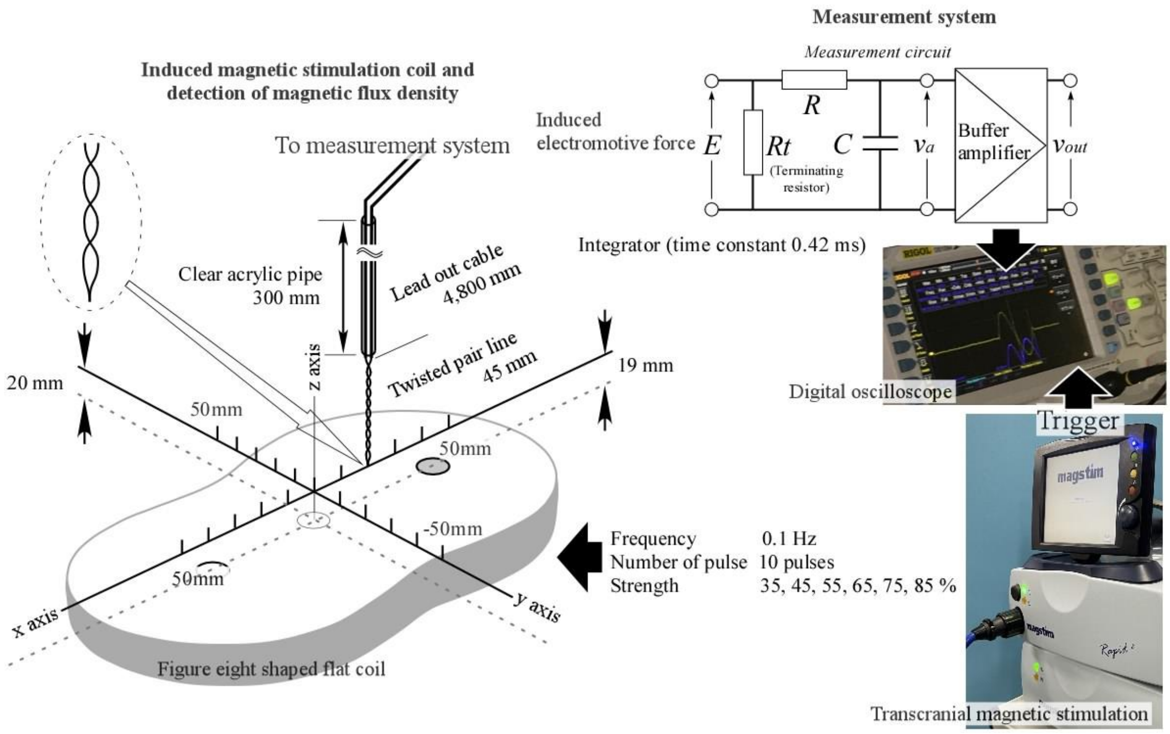

Figure 1. Experimental design. The study was designed to determine the magnetic flux density (background noise) detected by the twisted pair cable and lead-out cable without a sensor coil. The distance between the source of the magnetism and the measuring system was separated by a long distance by the lead-out cable. The tip of the twisted pair cable was short-circuited, and the opening surface connecting to the lead-out cable was parallel to the magnetic flux. The time constant (τ) of the integrator was τ >320 μs (magnetic stimulation pulse width) to avoid the measurement error. A space of 19 mm was assumed for the presence of the scalp, the skull, the cerebrospinal fluid, and a sensor for measuring the magnetic flux density [23-25].

important to determine the detailed energy dynamics of transcranial magnetic stimulation in the cerebral cortex to understand the mechanisms underlying the effects of transcranial magnetic stimulation.

However, there are very limited relevant studies because of the difficulties in accurately measuring magnetic stimulation strength caused by background noise introduced by the measurement system (e.g., from the cables). In a prior study using a magnetic flux density measurement at 75% TMS power, and a magnetic flux density at the center of the magnetic stimulation coil of approximately 250 mT, the magnetic flux density of the background noise was approximately 61 mT [23]. Thus, approximately 25% of the measured magnetic flux density values were related to background noise. As such, it is important to assess the contribution of background noise during measurements of magnetic flux density measurement. The aim of the present study was to assess the background noise generated during the measurement of magnetic stimulation intensity using a simple system that measures background noise on the stimulation coil.

2. Methods

2.1 Experimental design

A schematic of the experimental design for measuring background noise on a magnetic stimulation coil is shown in Figure 1. Background noise was measured at 19 mm above the magnetic stimulation coil [23-25]. The magnetic flux density was measured using a probe consisting of a twisted pair cable (cable length: approximately 45 mm) and a lead-out cable (cable length: approximately 4,800 mm). Polyurethane copper wire (outer diameter of 0.6 mm) was used for the twisted pair cable. An acrylic pipe (300 mm) was used to keep the cable straight. The induced electromotive force (E) detected by the probe was fed to the resistor-capacitor (RC) integrator in the measuring system. The output voltage (v_{out}) passing through the buffer amplifier was recorded by a digital oscilloscope (DS1054Z; Rigol Technologies Co. Ltd, Suzhou, China). The RC integrator consisted of a resistor (R; 4.217 kΩ) and a film capacitor (C; 0.09967 μF), which were measured by an inductance–capacitance–resistance meter (LCR-1983; Mothertool Co., Ltd., Nagano, Japan) at 1 kHz. The magnetic flux density (B) was

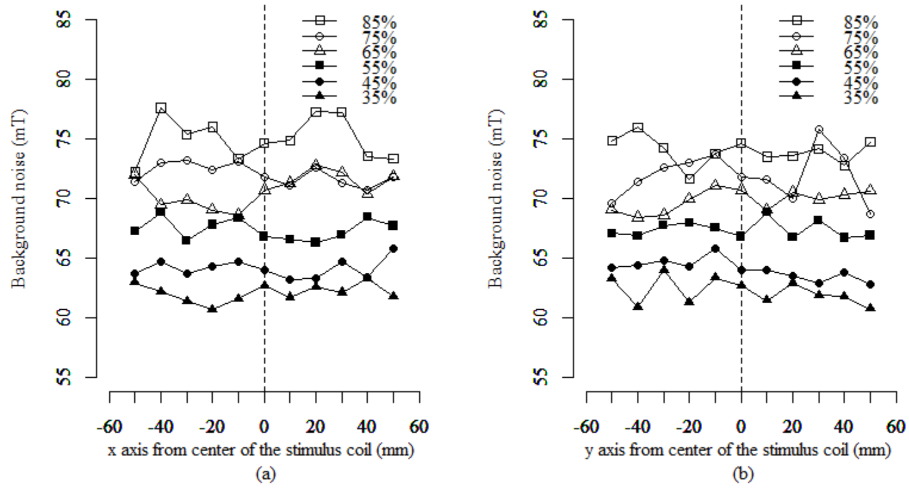

Figure 2. Relationship between the magnetic flux density (mean) and measurement position on the stimulus coil. (a) The magnetic flux density on the *x*-axis. (b) The magnetic flux density on the *y*-axis. The dashed line indicates the 0.0 mm position in the center of the figure eight-shaped flat coil.

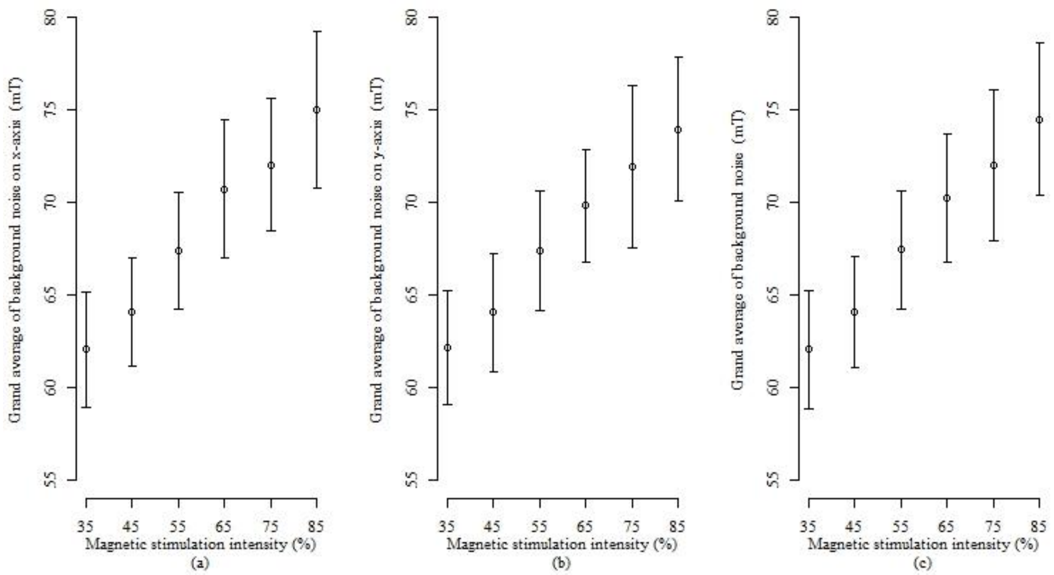

Figure 3. Relationship between magnetic flux density (mean ± standard deviation) and magnetic stimulation intensity. (a) Mean ± standard deviation of the magnetic flux density on the *x*-axis on the stimulation coil. (b) Mean ± standard deviation of the magnetic flux density on the *y*-axis on the stimulation coil. (c) Mean ± standard deviation of the *x*- and *y*-axes on the stimulation coil.

calculated using formula (1). *S* indicates the area of the sensor coil. In this study, a one-turn ($N = 1$) sensor coil with a diameter of 8 mm was assumed [10].

$$\boldsymbol{B} = \frac{1}{NS}\int E\,dt \simeq \frac{RC\,v_{out}}{NS} \qquad (1)$$

Measurement points of the background noise were placed every 10 mm from the center of the stimulus coil to ± 50 mm on each *x*- and *y*-axis. The measurement data were analyzed using R (Welch *t*-test).

2.2 Transcranial magnetic stimulation

A super rapid stimulator (Magstim Co. Ltd, Whitland, Carmarthenshire, UK) and a magnetic stimulation coil (P/N 4102-00; diameter of 70 mm; Magstim Co. Ltd) were used for magnetic induction. Magnetism was generated by transcranial magnetic stimulation with 10 pulses of a 320 μs pulse width. The stimulation frequency was approximately 0.1 Hz, and the magnetic intensity was 35%, 45%, 55%, 65%, 75%, and 85% of the magnetic stimulator output.

3. Results

The mean values of the magnetic flux density on the *x*-axis (a) and *y*-axis (b) of the figure-eight coil at each magnetic stimulation intensity are shown in Figure 2. At the 0.0 mm position (the intersection of the *x*- and *y*-axes), the magnetic flux density at 85% intensity was 74.646 ± 3.611 mT, at 75% was 71.811 ± 3.282 mT, at 65% was 70.715 ± 2.989 mT, at 55% was 66.777 ± 3.011 mT, at 45% was 63.968 ± 3.785 mT, and at 35% was 62.655 ± 1.651 mT. There were no differences in the magnetic flux density of each measurement position compared with the magnetic flux density at the 0.0 mm position for all magnetic stimulation intensities on the *x*- or y axes.

The mean ± standard deviation of the magnetic stimulation intensity on the *x*-axis (a) and the *y*-axis (b) are shown in Figure 3. For the *x*-axis, the magnetic flux density was 75.038 ± 4.221 mT at 85% intensity, 72.040 ± 3.567 mT at 75% intensity, 70.735 ± 3.715 mT at 65% intensity, 67.386 ± 3.176 mT at 55% intensity, 64.094 ± 2.941 mT at 45% intensity, and 62.050 ± 3.102 mT at 35% intensity. By contrast, for the *y*-axis the magnetic flux density was 73.980 ± 3.864 mT at 85% intensity, 71.955 ± 4.375 mT at 75% intensity, 69.825 ± 3.078 mT at 65% intensity, 67.372 ± 3.238 mT at 55% intensity, 64.046 ± 3.211 mT at 45% intensity, and 62.171 ± 3.097 mT at 35% intensity. There was a significant different in the magnetic flux density compared with 35% of magnetic stimulation intensity for each the *x*- and *y*-axis ($p < 0.001$). However, there were no differences in the magnetic flux density of *x*-axis and *y*-axis, except for at 65% intensity (vs. 35%: $p = 0.7727$, 45%: $p = 0.9068$, 55%: $p = 0.9734$, 65%: $p = 0.0490$, 75%: $p = 0.8745$, 85%: $p = 0.0540$). The overall (*x*-axis and *y*-axis) mean ± standard deviation each magnetic stimulation intensity is shown in Figure 3(c). The mean magnetic flux density was 74.495 ± 4.131 mT at 85% intensity, 72.017 ± 4.059 mT at 75% intensity, 70.236 ± 3.485 mT at 65% intensity, 67.439 ± 3.226 mT at 55% intensity, 64.080 ± 3.015 mT at 45% intensity, and 62.056 ± 3.201 mT at 35% intensity. There was a significant difference in the mean magnetic flux density compared with that at 35% intensity ($p < 0.001$).

4. Discussion

Previous studies have used a probe to measure the magnetic flux density on the stimulus coil during transcranial magnetic stimulation. This probe consists of a one-turn sensor coil, a twisted pair line, and a lead-out cable. These measured values also include the magnetic flux density (background noise) detected by the twisted pair cable and the lead-out cable [23]. However, this background noise affects the accuracy of the magnetic flux density measurement. Thus, in the present study, we developed a simple measurement system to subtract the background noise generated by transcranial magnetic stimulation.

The magnetic flux density is modulated by different measurement positions on the figure-eight flat coil [23]. Therefore, we predicted that the background noise value would depend on the measurement position on the stimulus coil. We found that the magnetic flux density of the background noise was reduced by low intensities of magnetic stimulation. Specifically, background noise decreased by approximately 5% at magnetic stimulation intensities of 75% and 65%, by 10% at 55% intensity, and by approximately 15% at 45% and 35% intensities when compared with 85% magnetic stimulation intensity. Thus, the background noise value depended on the magnetic stimulation strength. However, these results suggest that for each strength, the background noise value remains constant regardless of the measurement position, such as on the *x*-axis or the *y*-axis. Note that there was a significant difference in background noise between the *x*- and *y*-axes at 65% intensity, which may be due to measurement error.

It was previously reported that the subtraction process requires an off-line measurement to measure the magnetic flux density and background noise [23]. The present findings suggest that the magnetic flux density at the center position on stimulus coil and background noise at far from center position on stimulus coil can be measured simultaneously. Thus, the measurement position of the background noise does not have to be the same as that for the sensor coil. Nevertheless, simultaneous measurement can cause interference between the two probes. As such, measurement of the magnitude of each effect is required.

5. Conclusion

We investigated the background noise generated during measurement of magnetic flux density using a sensor coil. The background noise was detected using a twisted pair line and a lead-out cable, without a sensor coil. Therefore, we utilized a dedicated probe to evaluate the background noise on the stimulation coil during transcranial magnetic stimulation. We found that the background noise value was dependent on the magnetic stimulation strength, but not the measurement position. This may help solve the problem of background noise during the measurement of magnetic flux density.

Acknowledgments

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