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Research article

StimTrack: An open-source software for manual transcranial magnetic stimulation coil positioning

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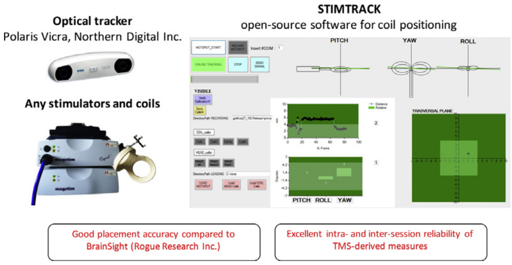
HIGHLIGHTS

- StimTrack is an open-source software for TMS coil positioning over the motor cortex.
- StimTrack is both accurate and reliable.
- StimTrack can be used to trigger external devices (e.g. TMS stimulators).

GRAPHICAL ABSTRACT



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ABSTRACT

Background: During Transcranial Magnetic Stimulation (TMS) experiments researchers often use a neuronavigation system to precisely and accurately maintain coil position and orientation.
New method: This study aimed to develop and validate an open-source software for TMS coil navigation. StimTrack uses an optical tracker and an intuitive user interface to facilitate the maintenance of position and orientation of any type of coil within and between sessions. Additionally, online access to navigation data is provided, hereby adding e.g. the ability to start or stop the magnetic stimulator depending on the distance to target or the variation of the orientation angles.
Results: StimTrack allows repeatable repositioning of the coil within 0.7 mm for translation and <1° for rotation. Stimulus-response (SR) curves obtained from 19 healthy volunteers were used to demonstrate that StimTrack can be effectively used in a typical experiment. An excellent intra and inter-session reliability (ICC > 0.9) was obtained on all parameters computed on SR curves acquired using StimTrack.
Comparison with existing method: StimTrack showed a target accuracy similar to that of a commercial neuronavigation system (BrainSight, Rogue Research Inc.). Indeed, small differences both in position (~0.2 mm) and orientation (<1°) were found between the systems. These differences are negligible given the human error involved in landmarks registration.

Abbreviations: AUC, area under the curve; CI, confidence interval; EMG, electromyography; GUI, graphical user interface; ICC, intraclass correlation coefficient; MEP, motor evoked potential; MEP_{pp}, peak-to-peak MEP amplitude; M_{max}, maximal evoked response; MRI, magnetic resonance imaging; MSO, Maximum stimulator output; MT, motor threshold; SR curve, stimulus-response curve; RF, reference frame; TA, tibialis anterior; TMS, transcranial magnetic stimulation.

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Conclusions: StimTrack, available as supplementary material, is found to be a good alternative for commercial neuronavigation systems facilitating assessment changes in corticospinal excitability using TMS. StimTrack allows researchers to tailor its functionality to their specific needs, providing added value that benefits experimental procedures and improves data quality.

1. Introduction

Transcranial magnetic stimulation (TMS) is a non-invasive and painless technique to stimulate the human brain with an electromagnetic coil placed on the scalp. TMS is widely used as a tool to assess corticospinal excitability, a commonly used marker for corticospinal plasticity (Hallett, 2000). With the coil placed over the primary motor cortex a twitch in a contralateral muscle can be elicited, which when measured using electromyography (EMG) is named a motor evoked potential (MEP) (Rossini et al., 2015). Frequently, MEPs are recorded with the coil held steady over the position at which the greatest MEPs for the muscle studied may be elicited. The position and orientation of the coil over this 'motor hotspot' needs to be accurately maintained within and between sessions as they both affect the magnitude of the evoked response (Conforto et al., 2004; Laakso et al., 2014; Mills et al., 1992).

Traditionally the motor hotspot is marked either directly on the scalp or on a swim cap and coil positioning over the hotspot is performed manually (Devanne et al., 1997; Herwig et al., 2003). With this method, the capability to accurately maintain (within-session) and replicate (between-session) coil position and orientation is limited. As a result, rigid holders or mechanical arms have been used to aid and maintain coil placement during long TMS sessions (Chronicle et al., 2005; Schubert et al., 1997; Taube et al., 2008). However, this solution requires the participant to keep the head as still as possible. To help participants, researchers have attempted to fix the head with respect to the coil using a head resting frame (Richter et al., 2013) or by strapping coil to the head (e.g. (Barsi et al., 2008)).

Neuronavigated TMS is commonly employed to reduce variability in coil position and orientation in space and over time (Herwig et al., 2001). Navigated TMS makes use of anatomical or functional magnetic resonance imaging (MRI) data and an optically tracked frameless stereotaxic system. This allows the researcher to maintain the stimulation site with millimetre accuracy (Schönfeldt-Lecuona et al., 2005). Furthermore, when using navigated TMS, stimulation sites can be maintained <2 mm from the target among 20 repeated trials, compared with 60 mm for non-navigated TMS (Julkunen et al., 2009).

Although neuronavigation systems provide accurate and precise coil placement, this technique is still underutilised. Neuronavigation systems typically suggest using a (participant specific) MRI, that are often not available or not required to locate the motor hotspot. Indeed, the size of the MEP response and the induced movement are important hints that can be used to determine the hotspot location. In addition, current neuronavigation systems do typically not provide the investigator with online access to the coil position and orientation data, only providing the ability to use data offline. This is potentially important in trials when the coil might be expected to move with respect to the head (e.g., during walking) (Barthélemy et al., 2012). Online access to the coil position and orientation would allow for better control of stimulation delivery which could then allow one to stop stimulation automatically should the coil move with respect to the scalp.

The aim of this study was to develop a user-friendly open-source software tool providing a platform for online monitoring of the position and orientation of any type of TMS coil. This software tool (StimTrack) assists with maintaining coil position and orientation with respect to the participant's head, recalls previous coil positions for comparison over multiple sessions, and interrupts the stimulation when the coil is placed incorrectly. Three experiments were performed to test correct functioning of StimTrack: we assessed (1) the repeatability in hotspot finding by using a custom-built testing platform; (2) the accuracy of the stimulation site by comparing StimTrack to a commercial neuronavigation system; and (3) the test-retest reliability of TMS-derived measures by collecting TMS data from 19 healthy participants.

2. Methods

2.1. StimTrack

An optical tracking system (Polaris Vicra, Northern Digital Inc.) and two passive tools fitted with spherical, retro-reflective markers, on the participant's forehead and on the coil handle (Fig. 1), are used to monitor the relative pose between the coil and the participant's head.

To set up StimTrack for monitoring any coil's position and orientation two steps need to be taken:

1) Definition of the coil and head local reference frames (RFs)

Coil and head local RF are constructed based on specific sites pointed out on the coil and head using a pointer. To define the coil local RF, four sites on the coil are selected (Fig. 1A): three points describe the transversal plane, while the fourth defines the origin. To build the head local RF, three landmarks are selected (Fig. 1B): the nasion (defined as the origin) and the left and right tragus. When the pointer is correctly placed on each landmark, the operator presses the corresponding button in the Graphical User Interface (GUI) (Fig. 2A). When all the points are selected, the coil and head local RFs are constructed (${}^{coil}T_{coil\_tool}$ and ${}^{head}T_{head\_tool}$, respectively). If the participant has been previously involved in a TMS session, it is possible to compare the position of the 3 landmarks on the head with those already saved.

2) Hotspot identification

When the coil is placed over the hotspot, the homogeneous transformation matrix between the coil local RF and the head local RF (${}^{hotspot}T_{head}$) is stored when the 'Record Hotspot' button is pressed (Fig. 2A). The GUI also allows to load a previously identified hotspot.

Once local RFs and hotspot are defined, StimTrack is set up to provide continuous feedback about coil position and orientation with respect to the hotspot. At each time step, the rotation matrix ${}^{hotspot}T_{coil}$, defining the position and orientation of the coil local RF with respect to the hotspot, is computed as follows:

$$ {}^{hotspot}T_{coil} = {}^{hotspot}T_{head}\,{}^{head}T_{head_{tool}}\left({}^{coil_{tool}}T_{head_{tool}}\right)^{-1}\left({}^{coil}T_{coil_{tool}}\right)^{-1} \quad (1) $$

where ${}^{coil_{tool}}T_{head_{tool}}$ is directly provided by the tracking system.

The translation vector and the orientation angles derived from ${}^{hotspot}T_{coil}$ are fed back online and represent the error of the coil pose with respect to the hotspot previously stored.