Evaluation of Human Factors in Neuronavigated Transcranial Magnetic Stimulation (TMS)

Hubert Chauvat(1,2), Romuald Ginhoux(2), Benjamin Maurin(2)

(1) ECE Paris, 37 quai de Grenelle, Immeuble Pollux, 75015 Paris
(2) Axilum Robotics, 1 place de l'hôpital, 67000 Strasbourg

Introduction

Transcranial Magnetic Stimulation (TMS) is a non-invasive brain stimulation technique where a coil delivering focal, short and high-intensity magnetic pulses is applied to the head [1]. Depending on the targeted cortical area, effects of the locally induced electrical currents have shown to have therapeutic applications for the treatment of drug-resistant depression, auditory hallucinations of schizophrenia or neuropathic pain [2]. The coil being held by hand, TMS is affected by the experience and attention of the operator manipulating it. Human errors in targeting the appropriate area therefore alter the accuracy and repeatability of the delivery of transcranial stimuli. Human factors are of a particular relevance in clinical applications of TMS where current treatment protocols, for instance in depression, involve several thousands repeated stimulations during a session of several tens of minutes, where sessions have to be repeated every day for a few weeks [2].

Computer and robot assistance tools have been developed with the objective to improve the accuracy of the targeting of the stimulations: Neuronavigation allowed to personalize the targeted cortical area based on MR images of the head, improving the accuracy of the transcranial stimulations [4, 5]. Robotic manipulators were introduced taking advantage of neuro-navigation tracking tools to further cancel the head motion during a session, repeat a TMS protocol at the desired positions and make sure the maximal amount of energy is transmitted to the brain by keeping the coil applied to the head [6, 7, 8].

If neuronavigation and robotics contribute to suppress a part of human factors in TMS, however, the human operator still has a key impact on accuracy and repeatability. Indeed, performing the necessary head registration at the beginning of a TMS session requires training and attention from the operator. Head registration is the prerequisite step to any neuronavigated or robotic TMS session and has to be repeated from scratch at any session once the patient is equipped with optical tracking markers. The objective is to put in correspondence the brain in the MR images with the brain of the real patient. Limited data are currently available to understand the influence of human factors on the quality of head registration although it directly affects the quality of coil positioning. In [3], authors evaluated the mean error of head registration in a commercial Nexstim neuronavigation device to 2.5 mm in an overall mean error of their entire system evaluated to 5.7 mm but did not describe the evaluation method. The goal of the paper is to study the influence of human factors on the repeatability of head registration. We propose a systematic framework applicable to commercial neuro-navigation devices and give early results.

Materials

We used a commercial neuronavigation device (Localite TMS Navigator v2.8, Localite, St Augustin, Germany) where head registration consists in 3 main steps: First, as a pre-registration step, the positions of a few anatomical landmarks highlighted on a 3D reconstruction of the skull have to be recorded on the corresponding parts of the real head. For that purpose, the operator equips the patient with optical tracking markers and uses a specific pointing tool (see Fig. 1), containing 3 optical markers, all being in the field of view of a NDI Polaris Spectra camera (NDI, Ontario, Canada). Second, an arbitrary number of additional points have to be recorded freely over the surface of the skin, allowing for a precise surface fitting of the real head. Third, the software computes the final registration and allows to measure offsets between the pointing tool and the 3D head model.

We used a dummy plastic head which went into a CT scanner (Siemens Somatom) to create reference images in DICOM format for loading into neuronavigation devices. The head surface is spanned by about hundred holes, including holes on ears and nose (see Fig. 1). As holes are easily visible in the images, they allow for a precise pointing during registration and provide ground-truth references.

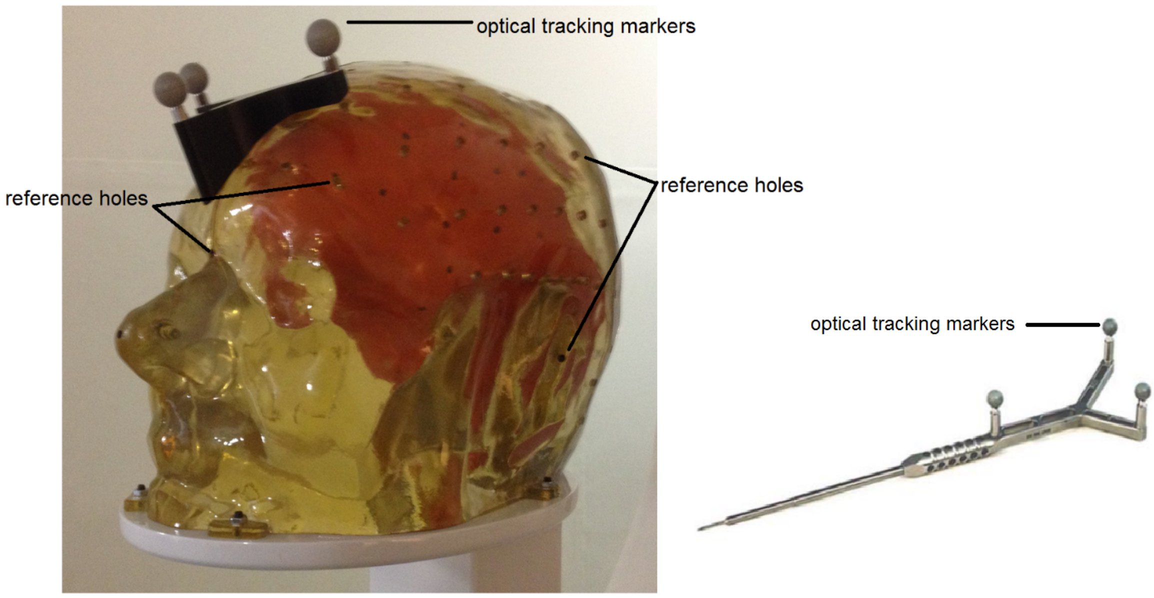

Figure 1 - Dummy plastic head equipped with optical tracking markers (left) and pointing tool (right)

Methods

Three holes of the dummy head were defined as landmarks for the pre-registration step: there were 2 holes in left and right preauricular areas and 1 hole on the nasion. About 100 surface points were recorded during the second registration step. 1 additional hole was used during the final registration step as a verification point: the pointing tool was inserted in the hole and the distance between the tip of the tool and the center of the hole was measured using the neuronavigation software. Head registration is supposed to be perfect when that distance is 0.

Seven operators (male, 23-52 years old) received a training. Each operator had to realize 3 different head registrations: the first one (T1) was designed to be the most accurate. The operator took time to position the pointing tool as precisely as possible and to turn its tracking markers towards the optical axis of the camera to optimize marker detection (the camera's optical axis and the plane formed by the three markers are orthogonal). The goal was to obtain a reference offset for each operator.

Then, we designed two tests to simulate typical error scenarii in order to evaluate how human factors can induce errors at the final step of the registration process. For the second test (T2), the operator kept the pointing tool in the planned holes, but this time, he had to turn it along its axis in order to reach an orientation of its three optical markers where the camera can barely see them: the camera's optical axis and the plane formed by the three markers are almost coplanar. The final test (T3) focused on good orientation of the tool but a bad positioning: the operator voluntarily missed the expected holes by 2 millimeters.

Results & Discussion

Results are shown in Fig. 2. In ideal conditions (T1) where one would expect the reference offset to be close to 0, we measured a mean error of 1.43 mm (min: 0.40 mm, max: 3.00 mm). This shows that head registration is not repeatable from one operator to another, shifting the position of the coil up to 3 mm during a TMS session. The second test (T2) proves that if the pointing tool is not properly oriented towards the camera, the offset error can be multiplied by a factor of 2 (min: 0.80 mm, mean: 2.90, max: 7.00). The third test (T3) shows that if the landmarks are not accurately pointed at during the first registration step, it becomes difficult to reach an error below 2 mm whereas 100 surface points have been recorded (min: 1.40 mm, mean: 3.20, max: 6.20).

These results show that training and attention of the operator affect the repeatability of head registration. T2 and T3 show common human errors which may combine on real patients, leading to large registration offsets. By shifting the coil position on the real head they may weaken the repeatability of TMS.

Figure 2 - Offsets measured with the verification point in the 3 head registration tests.

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