Functional MRI for Validating Neuronavigation of Transcranial Magnetic Stimulation

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Introduction

Transcranial magnetic stimulation (TMS) and functional magnetic resonance imaging (fMRI) have become established methods in cognitive neuroscience for studying cortical information processing. The combination of both methods offers new opportunities to investigate cortical functions in single subjects. The idea presented here is to navigate the magnetic coil to those brain regions which are involved in specific functions as identified by fMRI.

The general correspondence between the location of fMRI activity in the motor cortex and the region where a motor response can be evoked was demonstrated by several motor mapping studies with resolutions of up to 1 cm[1].

For a precise positioning of the TMS our TMS group adapted an optical tracking based neuronavigational system to guide the coil to the desired cortical area and to monitor its position online during the stimulation procedure. To evaluate the navigational system we examined the spatial relation between i) the cortical activation in fMRI during a motor task and ii) the cortical region at which a corresponding motor response could be evoked by TMS.

Methods

Neuronavigation: A neuronavigational system used in neurosurgery, the "Surgical Tool Navigator" (STN, Zeiss), was adapted to the requirements of TMS. The system is based on frameless stereotaxy with a 3D-camera system detecting infrared light emitting diodes (LED) which were mounted on the subjects head and on the magnetic coil (MagPro, Dantec). A line perpendicular through the midpoint of the figure-8-coil, which is supposed to be the maximum of the induced electric field, was visualized as a vector relative to the anatomical brain image on the computer screen (Fig. 1a). With the STN it is possible to guide the magnetic coil to the desired area for focused stimulation. We checked the precision of the system to be about 2 mm.

Functional MRI: Five healthy subjects (3f, 2m, age 21-34) performed a rhythmic 1,5 Hz movement of the right thumb repeatedly interrupted with rest as control conditioin in a Magnetom Vision 1,5 T MR-Scanner (Siemens; TE/TR/FA 91/6000 ms/90°, Matrix 128x128, 32 slices, 2.0 mm slice thickness without gap). The fMRI data were analysed by cross correlation, fused with the images of a structural T1-weighted MR (voxel size 1x1x1 mm) using a special software (STP4, Zeiss Leibinger) and visualized by the navigator (Fig. 1a).

Stimulation: The motor threshold (MS) was defined as the lowest stimulation intensity that evokes in at least 3 of 6 stimulations a magnetic evoked potential (MEP) of at least 50 µV recorded by a surface EMG (Keypoint Portable, Medtronic) of the right M. abductor pollicis brevis. The stimulations were performed with 120% of the MS, in two subjects additionally with 110%. The magnetic coil was held with the handle in the lateral position and guided on a 5x5 mm grid surrounding the region of the activated area. The subjects were stimulated at each point of the grid one time. The amplitudes of the evoked motor responses were registered. Each stimulus triggered the registration of its coil position coordinates.

Data analysis: The analysis of the mapping coordinates and corresponding amplitudes was performed in Statistica (StatSoft) using XYZ-Scatterplots. Regression planes were calculated (Fig. 1b) in which each stimulation is marked with a colored dot representing the relative amplitude. The mean of the three maximal amplitudes was defined as 100% and the amplitudes were divided in four groups: amplitude=0, 1-30%, 31-60%, >60%. A mean coordinate of the coordinates with the amplitudes >60% ("MEP-center") was calcuated and visualized in the map as well. Additionally, the coordinate with the center of gravity of the fMRI ("fMRI-center") was marked. It was calculated as mean coordinate of the centers of regions with functional activation in the motor cortex given in the anatomical slices visualized in the navigational system.

Results

In all five subjects we obtained motor responses from the M. abductor pollicis brevis when stimulating the activated area as visualized by fMRI in the precentral gyrus of the frontal cortex. Motor responses were also obtained with high interindividual variability at distances of up to 30 mm anterior from the center of gravity of the fMRI activation signal, with the magnetic coil held from the lateral side and with a stimulation intensity of 120% MS.

The distance between the center of gravity of the functional activity and the mean coordinate of the maximal amplitudes was 9 mm (mean) with a range of 4-13 mm in the regression plane. In three of the five subjects the "MEP-center" was located prominently anterior of the "fMRI-center". The mean distance in the y-axis, calculated from all subjects, was 7 mm with a range of -2 to 13 mm. The stimulations with 110% intensity showed a smaller region of evoked motor responses, again the MEPs were anteriorly (in the y-axis 5 and 12 mm) to the center of the fMRI.

The neuronavigational procedure was comfortable and reliable. We did not observe serious stimulation related side effects during and after the stimulation sessions.

Discussion

Our results show a good overall spatial correspondence in single subjects between functional motor activity in fMRI and TMS evoked motor function. However, the center of the evoked maximal amplitudes was anteriorly to the center of fMRI activation. This might origin from different locations of blood oxygenation changes, detected by fMRI, and sensibility to electric field changes, which is the basis for EMG responses to TMS.

We conclude that the combination of neuronavigated TMS and fMRI is a useful method to guide the magnetic coil to functionally defined cortical areas and to monitor its position online with high spatial resolution. However, the exact relation betwen the center of fMRI activation and the optimal location of stimulation requires further studies examining different coil positions and different stimulation intensities. This is most important when TMS is used to modulate cortical functions in cognitive neuroscience[2] or in clinical applications, e.g. TMS-treatment of depression[3] or hallucinations[4].

References

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