Technical and safety aspects in concurrent TMS/fMRI

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Introduction: Transcranial magnetic stimulation (TMS) is an important method for cognitive neuroscience research in noninvasive stimulation of the human cortex for probing brain connectivity, combined with fMRI. Concurrent TMS-fMRI holds great promise to supplement our understanding about the immediate and rapid changes TMS can evoke in cortical networks. The high magnetic field strength of modern MRI scanners imposes several limitations and challenges for its simultaneous combination with TMS, which was first performed by Bohning et al. [1,2]. Our goal was to investigate technical and safety aspects in concurrent TMS/fMRI: 1) temperature characterization of the TMS coil, 2) synchronization procedure for TMS stimulation in concurrent TMS/fMRI. **Methods:** In our study we used a "MagPro Magnetic" stimulator from the Medtronic Company combining with the certified TMS-coil MRI-B88 from the MagVenture Company, a MR-compatible figure-of-eight TMS-coil with a diameter of 90 mm certified for MRI scanner up to 4 Tesla. We used a MedSpec® 4T, Bruker Biospin MRI scanner (Siemens MAGNETOM electronics, Sonata Gradients). For the temperature characterization we used a Luxtron m3300 Biomedical Lab Kit and four optical sensors with 10 meters extensions. The stimulator was positioned outside the scanner room and the TMS line was appropriately filtered through the Faraday cage to not induce RF pickup artifacts during MRI. **1)** For the temperature characterization the TMS coil was positioned in the scanner isocenter without the head coil, and the four probes were positioned on the surface of the TMS coil (figure 1) adding a thin gel film that warranted the thermal contact. The TMS coil was on the patient table with the axis parallel with the y-axis of the scanner. During this part of the experiment we did not run sequences on the scanner, and we stimulated the TMS coil with two different protocols (table 1) and with different stimulator intensity, taking in account to wait 6 hours before to start a new stimulation in order to warranty the right coil cooling. The four fiber optic sensors were connected to a converter and we registered the temperature by means of a RS232 connection on an external PC. At the same time was measured the temperature of the coil with the internal temperature sensor. All the temperature measurements were normalized at the room temperature. The TMS coil controlled the internal temperature and disabled automatically the stimulator at 40°C.
2) In the synchronization procedure, we have implemented a hardware/software system, in order to eliminate the risk of sync stimulus in concurrent TMS/fMRI. In fact, an important risk for patient is to receive both RF stimulus from scanner and from the TMS at the same time, and an important risk for the MRI hardware is to receive the TMS stimulus when the Head Coil is in receiver mode. In the first case we were no more able to control the exposure limits for the patient, and in the second case we could compromise the radiofrequency chain of the scanner. In order to eliminate both of these problems we implemented a setup using a National Instruments (NI) board, the TTL trigger volume form the scanner and a Matlab script. The setup is showed in figure 2. The external PC controlled the NI board. The volume trigger was acquired with the NI board, and with a Matlab code we were able to create the right and controlled delay for the TMS stimulator. The delay was of 2330 msec in accordance with the EPI design. We run 10 single-shot EPI sequences, with 64x64x64 matrix, a voxel size of $3x3x3mm^3$, TR=3s, TE=35ms, 37 slices and 280 volumes and a delay in TR of 670 msec.

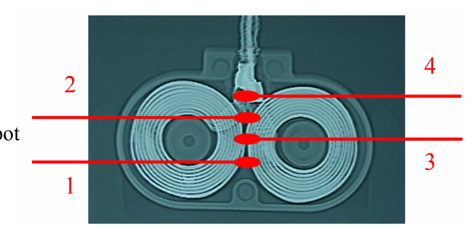

Figure 1: On an X-ray picture are overlapped the positions of the 4 temperature sensors corresponding to the hot spot of the TMS coil [3]. The number 3 is over the crossing cable connecting the two coils

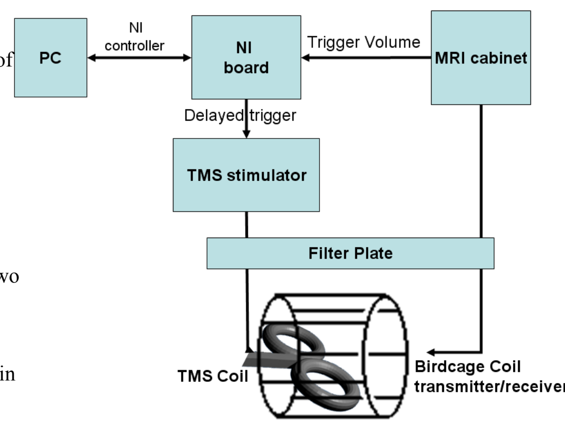

Figure2: Block diagram of the synchronization setup for concurrent TMS/fMRI

	PROTOCOL A	PROTOCOL B
	9Hz, 5pulses, 348 trains, 2 sec internal interval	1Hz, 1pulse, 1 train, 2 sec internal interval
Stimulator intensity	80%	50%
	60%	60%
	100%	70%

Table 1: the two different TMS protocols with the stimulator intensity used in the study

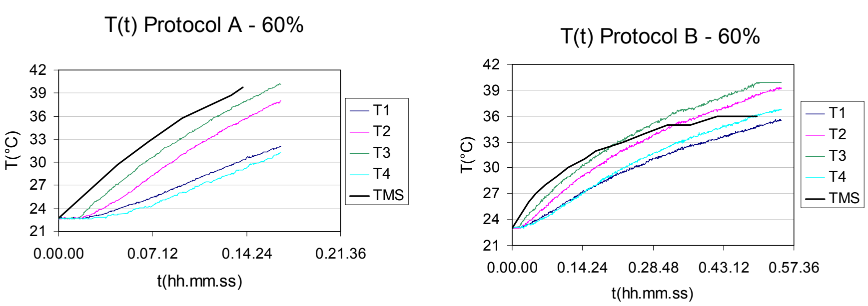

Figure 3: in the two plots the temperature measurements in the two protocols, only referred to the 60% stimulator intensity to show the different response of the internal temperature sensor

Results: 1) The four sensors were able to characterize our coil with the thermal measurement. Weyh et al. [4] showed similar results, but in our study we observed a drastic difference for different protocols. The internal control system temperature of the TMS coil was not completely reliable. Using a hard protocol (protocol A) the temperature in the coil was conservative respect the temperature of the four sensors on the external surface (as showed in figure 3), that means an anticipated stop of the stimulator. But in case of a less stressful protocol like the B one, we observed a more high temperature on the surface respect the internal temperature. That means an unrealistic temperature measurement then a not conservative prediction of the stop limit at 40°C. **2)** The synchronization system warranties 10 repetitions of the EPI without overlapping of the two stimulations (TMS together with fMRI). Using shorter delay in TR (less than 670 msec) we lost one pulse in the train. A concurrent monitoring of the trigger volume and TMS stimulation trigger helped to identify the overlapping status. **Conclusions:** The temperature measurement is a right and necessary instrument to characterize the TMS coil before a TMS/fMRI study. The patient protection in terms of overheating is improved. The study showed as with a 1 Hz, single pulse, 60% stimulation protocol, the temperature could reach on the surface 39°C, 3° more than internal temperature value of the TMS coil showing an unrealistic measurement. The implementation of the thermal curve can help the planning of the TMS/fMRI protocols. The external control trigger is recommended in all the concurrent TMS/fMRI study. The work proposes systematic methods for testing the safety, for patient and for the scanner, of protocols that will be used. **Acknowledgements:** Support for this research was provided in part by the government of the Provincia Autonoma di Trento, Italy, the private foundation Fondazione Cassa di Risparmio di Trento e Rovereto, and the University of Trento, Italy. **References**: [1] Bohning DE et al.. Invest Radiol 1998;33(6):336-340. [2] Bohning DE et al. Biol Psychiatry 1999;45(4):385-394. [3] Ferrari et al, ISMRM09 proceedings. [4] T. Weyh et al. Clinical Neurophysiology 116 (2005) 1477–1486.