Development of a MEG compatible method to study the interaction of sensory and motor cortex in humans

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Problem

The fine graded usage of the hand is a remarkable skill of humans. Even other primates are not able to use their hands in a similar skilled fashion. The ability to use the fingers with high precision is thought to require close interaction between the motor and the sensory systems. In humans, unlike in other mammals, the layer V pyramidal cells of the primary motor cortex controlling hand muscles project monosynapticly onto the spinal motor neurons. However, it is still not fully understood, how sensory feedback modulates motor commands in demanding sensory-motor tasks. This is due to the fact, that there is no approach for investigating the sensory-motor cortical interaction in sufficient detail. The fast and precise communication between the sensory and motor systems which is reflected in the close topographic proximity of both cortical regions requires measurements of cortical activity with high temporal and spatial resolution. Magnetoencephalography (MEG) is capable of both, and is therefore the method of choice to validate or falsify network models. However, to take advantage of MEG an experimental paradigm capable of simultaneously recording functional responses and calculating response latencies in both cortices is necessary. Such a sensory-motor paradigm does not currently exist. In our previous studies, we showed that robust sensory responses can be generated by repetitive tactile stimulation. Further, robust responses of the motor cortex can be generated by active periodical increase and decrease of muscle tone. Utilizing both of these observations we have designed an MEG-compatible prototype of a stimulator. The stimulator consists of a rotating disk with an elevation on the otherwise flat surface such that subjects sense with his/her finger the speed of the disk. With the force applied by the finger onto the disk, the subject can control its speed. During the experiment the subject is asked to keep the speed of the disk constant while the driving torque of the motor is systematically manipulated. In a pilot study, we could show that a detailed analysis of the sensory motor network is principally possible when using this prototype in an MEG recording. In contrast to existing paradigms this setup allows separate time-locked analysis of the sensory and motor component independently and therefore the calculation of latency parameters for both systems. Combining these results with diffusion MR imaging, which allows reconstruction of the white matter fibres, results in a functional and structural characterisation of the sensory-motor network.}

Reference

P. J. Broser and C. Braun. Hydraulic Driven Fast and Precise Nonmagnetic Tactile Stimulator for Neurophysiological and MEG Measurements. IEEE Trans Biomed Eng, 59(10): 2852-2858, 2012.

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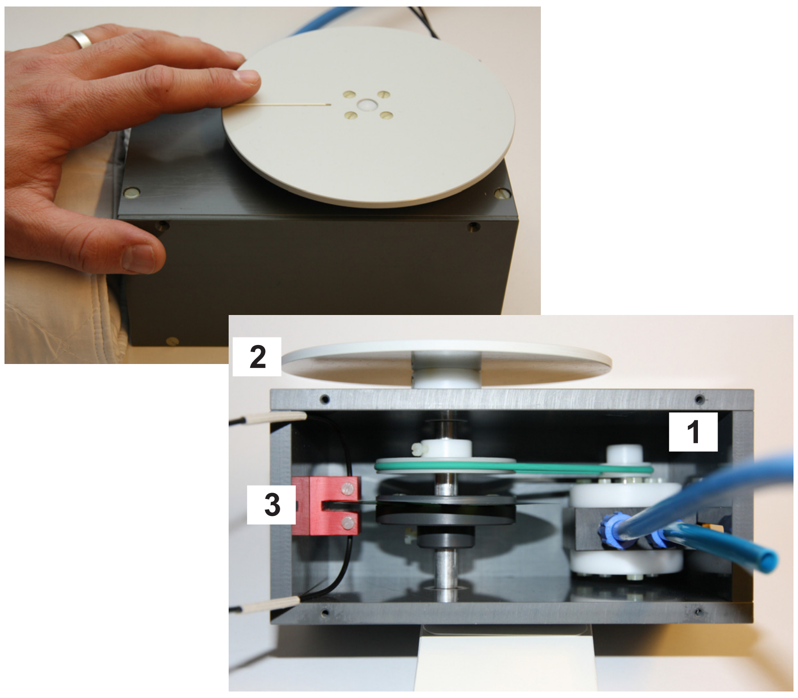
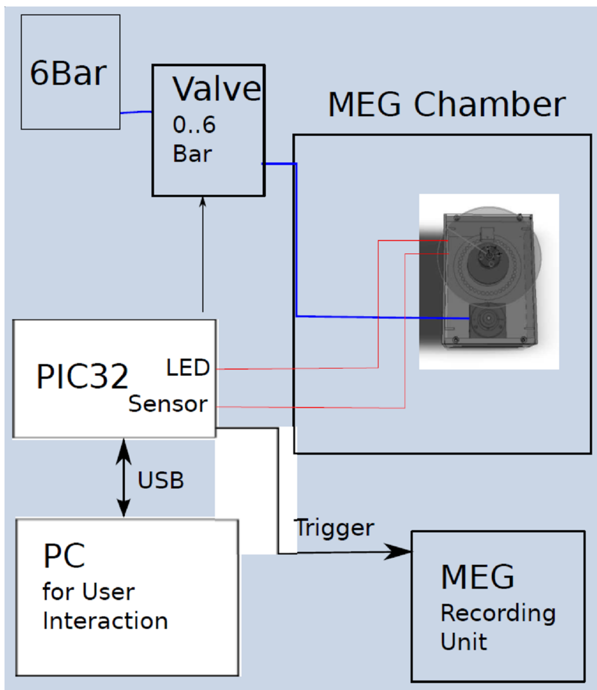
Principle and Build Up

Core element of the stimulator device is a rotating disk with one small, radially oriented elevation on the disk. During the experiment, the subject is asked to place the tip of his index finger onto the rotating disk. The subject is capable of sensing the speed of the rotating disk by feeling the number of times the elevation passes his finger. Using this stimulator we could show that triggering a response of the primary sensory system is possible. In contrast to existing methods, the rotating disk stimulator can be used to design paradigms that show the activity of the motor and sensory cortex independently and further can be used to measure latencies for the sensory and motor cortex.

The development of this prototype was challenging in several aspects: The first challenge was to develop an MEG proof engine. Engines available on the market are typically electric engines, combustion engines, or pneumatic / hydraulic engines made of steel. We designed and built a pneumatic engine completely free of ferromagnetic components. The torque of the engine can be regulated by a proportional valve. The second challenge is the sensing of the precise angular position and rotating speed of the disc. To this effect we have designed a light barrier system and controller system based on a PIC-32 micro-controller, capable of determining the relevant disc parameters in the submillisecond time scale and controlling the valve with high precision. To our knowledge this is the only system available. **The ability to time lock the analysis independently for the activity in the sensory and motor cortex gives us the unique ability to measure the processing latency for both systems.**





Data Analysis

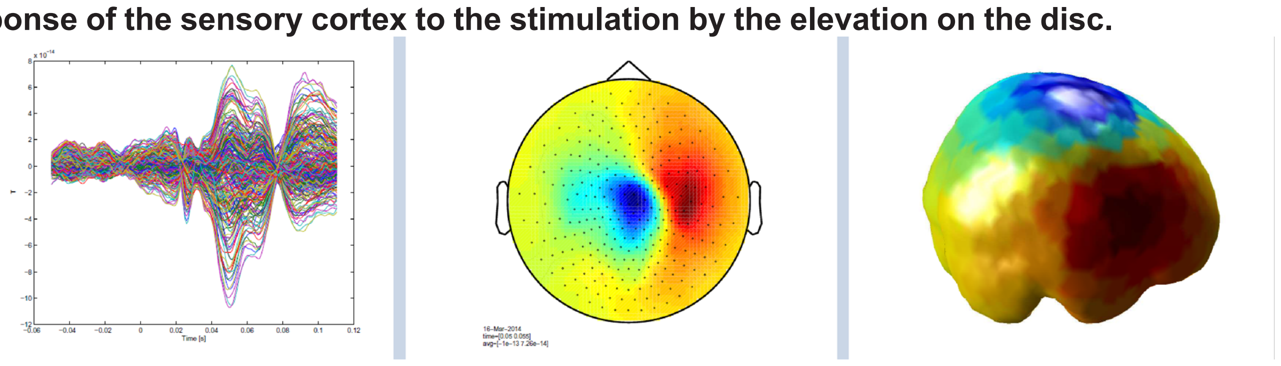
The experiments with the rotating disk stimulator are executed as follows: The subject is sitting in the MEG chamber and its brain activity is measured continuously by the MEG apparatus. The rotating disk stimulator is placed such that the subject puts the tip of his index finger onto the rotating disk.

Task: The subject has to keep the rotating speed at a constant velocity in a given range $(l < \frac{d\phi}{dt} < h)$ by pushing with his finger onto the disk to counter the engines torque.

Setup: The torque generated by the stimulator is stepwise cycled between high and low torque.

Analysis: Time locked average, locked to the modulation of the torque yielding the periodic activity of the primary sensory and primary motor cortex. Second level analysis shows the phase shift from the activity of the sensory to the activity of the motor cortex.

Response of the sensory cortex to the stimulation by the elevation on the disc.



Activity in the motor cortex during the task.