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Functional Magnetic Resonance Imaging of the human sensorimotor cortex before and after 48 hours of Dry Water Immersion

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INTRODUCTION Studying the sensorimotor system with functional Magnetic Resonance Imaging (fMRI), we have shown recently, that afferent electrical stimulation of the left hand below the sensory threshold can augment cortical brain activity during a motor task in the specific contralateral and ipsilateral motor and sensory areas of the frontal and parietal lobes /1/. Probably, we depolarized the large afferents from the hand's intrinsic muscles and thus proprioceptive input to the brain changed. The aim of this stud was to deprivate the brain from proprioceptive input and thus to evaluate the effects of simulated microgravity or immobilization on cortical activation patterns of the sensorimotor cortex.

MATERIALS AND METHODS All experiments were performed on a 1.5 Tesla whole body scanner (Magnetom VISION, Siemens, Germany) with a conventional circular polarized head coil (FoV=250mm). T2* weighted images were acquired with a single shot echo planar imaging (EPI) sequence /2/ allowing the simultaneous measurement of 15 slices with 2 sec (TR/TE/α=4sec/64ms/90°). To avoid artifacts due to involuntary head motions, a dedicated, self-developed device was used to provide a rigid head fixation within the head coil. The 15 images were positioned to cover the entire sensorimotor cortex, parallel to a line crossing the anterior and the posterior commissure. The on/off motor paradigm was a monitored fist clenching with the left hand pressing a grip with a pneumatic tube connected to a blood pressure monitoring device. Before starting the experiment, the subjects trained themselves by visual feedback to perform the fist clenching with a constant clenching rate of 2 Hz and a constant clenching pressure of 60 mmHg. Series of 10 images at rest (condition A) and 10 images performing fist clenching (condition B) were alternatively acquired up to a total amount of 60 images (time series: ABABAB). The temporal resolution was 4 sec.

The experimental setup consisted of a baseline fMRI examination (test motor task, TMT) before the 48 hours of sensory deprivation, a conditioned fMRI examination immediately after the sensory deprivation (conditioned motor task, CMT) and the third fMRI examination one week after the second one. The experiments were performed with four healthy male volunteers (age range 24-30 years) who gave informed consent. The experimental protocol was approved by the local ethic committee.

Prior to statistical analysis, the image data sets were corrected for involuntary subject motions with the Woods algorithm /3/. For the calculation of the activation maps, we used cross correlation analysis /4/. Finally, we transformed the activated foci into Talairach space /5/.

RESULTS The base-line fMRI examinations revealed bilateral activation within the primary motor (MI) and the primary sensory cortex (SI). Since this primary activation focus covers the precentral as well as the postcentral region without demarcation, we consider this activation focus as the unique MI/SI activation focus. Activation within the secondary sensory cortex is summarized as SII activation. In addition, the base line fMRI examination reveals activation bilateral within the supplementary motor area (SMA) and the premotor area (PM). After 48 hours of sensory deprivation, we observed extensive changes of the cortical brain activity. Table 1 summarizes the data of all four studied objects for regional cerebral blood flow (rCBF) changes determined by the number of activated pixels within the bloc of 15 slices. There is a consistent profile of changes between the studied cortical brain areas of the MI, the SI, the PM, the SMA and the SII. Another phenomenon, that we observed, was new activation within the ipsilateral Globus Pallidus (GP) in CMT, SMA showed increased activation more than 100% after sensory deprivation in all of the four subjects. Secondly, there was an increase of more than 70% of activation within the ipsilateral PM in CMT. Changes in contralateral PM were not definitely seen. Increase of activation was also seen bilaterally within the MI/SI activation focus with emphasis on the ipsilateral hemisphere. The same was true for the SII, where the contralateral increase of activation was less pronounced. Further CMT

Table 1: Number of activated pixels during first clenching of the left hand before/after 48 hours of sensory deprivation. There is an increased number of activated pixels within the supplementary motor area (SMA), the ipsilateral premotor area (PM), the ipsilateral Globus Pallidus (GP) in 3 of the 4 subjects, the left and right primary motor and primary somatosensory area (MI/SI) and the secondary somatosensory area on both hemispheres (SII).

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m = male, R = right hemisphere, L = left hemisphere

showed new activation within the ipsilateral GO in 3 of th 4 subjects (table 1). Performing another fMRI experiment one week after the CMT, these changes disappeared, and the same activation pattern as in the TMT but with little variance was observed.

CONCLUSIONS Dry Water Immersion (DWI) modifies the organization of afferent sensory information which is involved in motor regulation. Following this sensory deprivation, we found a significant increase in activity in higher motor control areas compared to the pretest baseline. Probable explanations include:

1. It is known, that due to the reduced afferent feedback during immobilization and sensory deprivation the motor system cannot be regularly updated by information and recalibrated. The body scheme is altered and it takes more effort to achieve the accurate execution of even a simple motor task. Post immersion the involvement of higher motor control centers are necessary to reestablish programs for the performance of known preprogrammed movements, to get additional information from other sensory systems and to estimate errors in execution. With regard to optimal rehabilitation of patients with focal brain injuries and stroke, our results support proprioceptive stimulation during long-term bed rest and immobilization.
2. It is known from experiments in real and simulated weightlessness that short-term exposure to microgravity (7 days) decreases threshold of vibrosensitivity as well as threshold of the T- and H-reflex and the direct muscle response. Thresholds are declining progressively beginning on the first day of exposure and thus leading to proprioceptive hyper-reactivity and increased excitability of central motoneurons during the adaptive reorganization of motor coordination /6,7/.

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Functional Magnetic Resonance Imaging of the human sensorimotor cortex before and after 48 hours of Dry Water Immersion

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MATERIALS AND METHODS All experiments were performed on a 1.5 Tesla whole body scanner (Magnetom VISION, Siemens, Germany) with a conventional circular polarized head coil (FoV=250mm). T2* weighted images were acquired with a single shot echo planar imaging (EPI) sequence /2/ allowing the simultaneous measurement of 15 slices within 2 sec (TR/TE/=4sec/64ms/90°). To avoid artifacts due to involuntary head motions, a dedicated, self-developed device was used to provide a rigid head fixation within the head coil. The 15 images were positioned to cover the entire sensorimotor cortex, parallel to a line crossing the anterior and the posterior commissure. The on/off motor paradigm was a monitored finger-to-thumb tapping (motor sequence test) with the left hand. Before starting the experiment, the subjects trained themselves by visual feedback to perform the sensorimotor task. Series of 10 images at rest (condition A) and 10 images performing fingertapping (condition B) were alternatively acquired up to a total amount of 60 images (time series: ABABAB). The temporal resolution was 4 sec.

The experimental setup consisted of a baseline fMRI examination (test motor task, TMT) before the 48 hours of sensory deprivation with dry water immersion (DWI, fig.1), a conditioned fMRI examination ten minutes after the sensory deprivation (conditioned motor task, CMT) and a third fMRI examination one week after the second one. The experiments were performed with four healthy male volunteers (age range 24-30 years) who gave informed consent. The experimental protocol was approved by the local ethic committee.

Prior to statistical analysis, the image data sets were corrected for involuntary subject motions with the Woods algorithm /3/. For the calculation of the activation maps, we used cross correlation analysis /4/. Finally, we transformed the activation foci into Talairach space /5/.

RESULTS The baseline fMRI examinations revealed bilateral activation within the primary motor (MI) and the primary sensory cortex (SI). Because this primary activation focus covers the precentral as well as the postcentral region without any demarcation, we consider this activation focus as the unique MI/SI activation focus. Activation within the secondary sensory cortex is summarized as SII activation. In addition, the baseline fMRI examination reveals activation bilateral within the supplementary motor area (SMA) and the premotor area (PM). After 48 hours of sensory deprivation, we observed extensive changes of the cortical brain activity. Table 1 summarizes the data of all four studied subjects for regional cerebral blood flow (rCBF) changes determined by the number of activated pixels within the bloc of 15 slices. There is a consistent profile of changes between the studied cortical brain areas of the MI, the SI, the PM (fig. 2), the SMA (fig. 3) and the SII (fig. 4). Another phenomenon observed was the new activation within the ipsilateral Globus Pallidus (GP) in CMT (fig.5). SMA showed increased activation of more than 100% after sensory deprivation in all of the four subjects (fig. 3a,b). Secondly, there was an increase of more than 70% of activation within the ipsilateral PM in CMT (fig. 2a,b). Changes in contralateral PM were not definitely seen. Increase of activation was also seen bilaterally within the MI/SI activation focus with emphasis on the ipsilateral hemisphere (fig. 2a,b). The same was true for the SII (fig. 3a,b), where the contralateral increase of activation was less pronounced. Further, CMT showed new activation within the ipsilateral GP (fig. 5a,b) in 3 of the 4 subjects (table 1). Performing another fMRI experiment one week after the CMT, these changes disappeared, and approximately the same activation pattern as in the TMT was observed (fig. 2c, 3c, 4c, 5c).

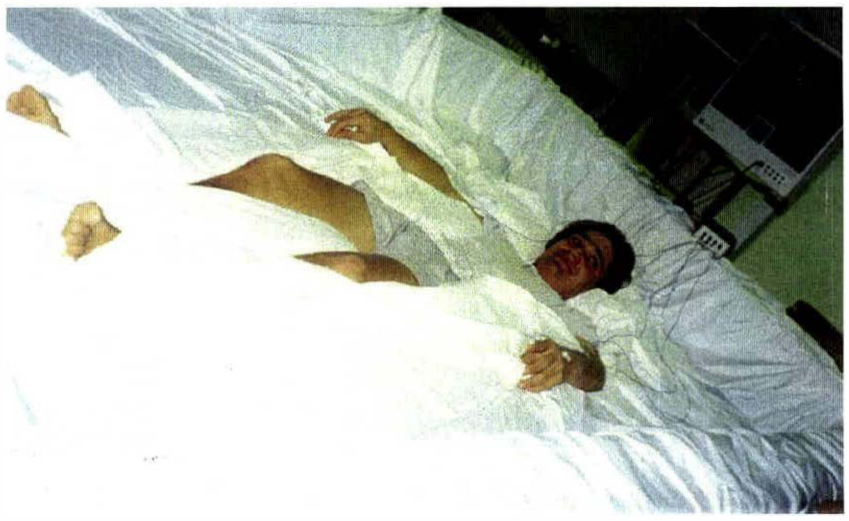

Fig.1: Dry Water Immersion: For 48 hours the subject remained within a basin covered with a plastic layer to simulate microgravity.

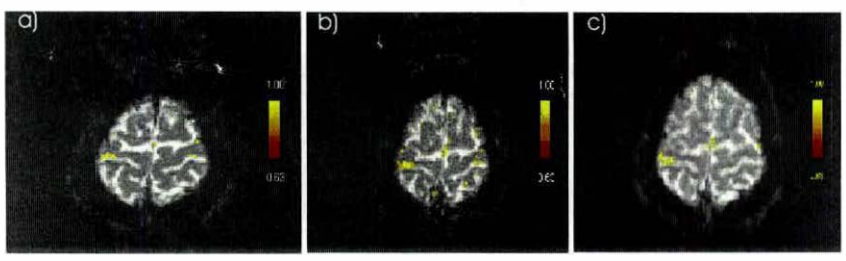

Fig.2: Cortical activation within the primary motor and the primary sensory area MI/SI a) prior to DWI, b) immediately after DWI and c) one week after DWI. An increase of activation is seen bilaterally within the MI/SI and ipsilaterally to the tapping hand within the premotor area PM. One week after DWI the changes of activation signal in CMT study disappeared and an activation pattern similar to the baseline study was found.

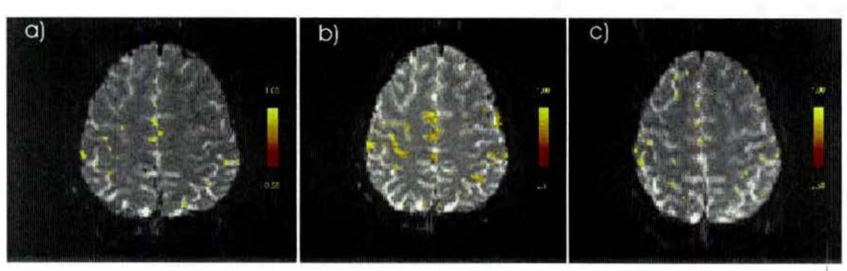

Fig.3: Cortical activation within the anterior and posterior SMA a) prior to DWI, b) immediately after DWI and c) one week after DWI. There is an increase of cortical activation of more than 100% in anterior as well as posterior SMA. The third examination one week after DWI shows reduction of activation to approximately baseline values.

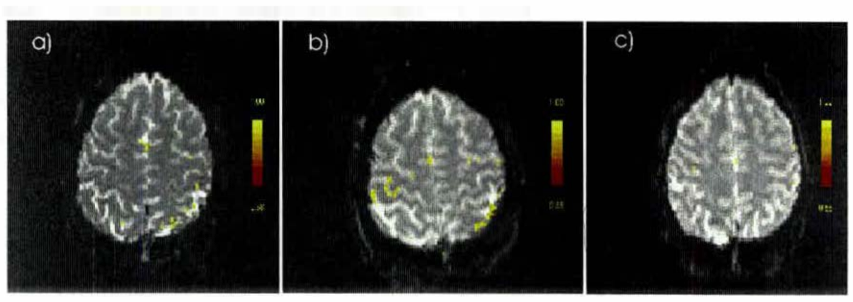

Fig.4: Cortical activation within the secondary somatosensory cortex SII a) prior to DWI, b) immediately after DWI and c) one week after DWI. The baseline study shows weak SII activation ipsilaterally to the tapping left hand, immediately after DWI, two sharply delineated SII activation foci can be seen, which disappear again one week after DWI.

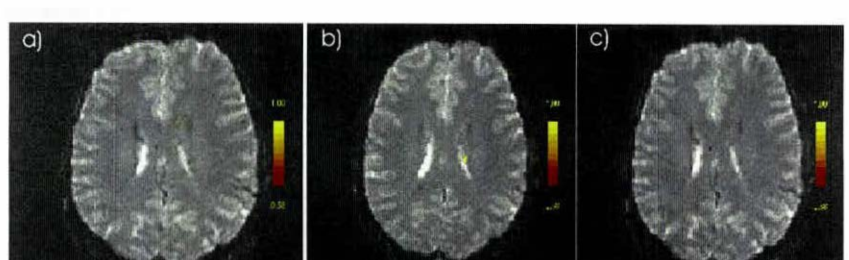

Fig.5: Cortical activation within the Globus Pallidus GP a) prior to DWI, b) immediately after DWI and c) one week after DWI. In CMT study, a small but sharply delineated activation focus within the medial GP ipsilaterally to the tapping left hand can be discovered, which is absent in first and second test motor task TMT.

Table 1: Number of activated pixels during fingertapping of the left hand before/after 48 hours of sensory deprivation. There is an increased number of activated pixels within the supplementary motor area (SMA), the ipsilateral premotor area (PM), the ipsilateral Globus Pallidus (GP) in 3 of the 4 subjects, the left and right primary motor and primary somatosensory area (MI/SI) and the secondary somatosensory area on both hemispheres (SII).

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Table 1: Number of activated pixels during fist clenching of the left hand before/after 48 hours of sensory deprivation. There is an increased number of activated pixels within the supplementary motor area (SMA), the ipsilateral premotor area (PM), the ipsilateral Globus Pallidus (GP) in 3 of the 4 subjects, the left and right primary motor and primary somatosensory area (MI/SI) and the secondary somatosensory area on both hemispheres (SII).

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