A Magnetic Resonance compatible Stepper (MARCOS) for fMRI Investigation of Gait

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Introduction

Recovery of patients with spinal cord injury can only be successful, if patients are not immobile over a long time, because immobility results in a loss of neuronal function. In order to keep the patients mobile, new locomotor training devices (e.g. the LOKOMAT – a robotic gait orthosis manufactured by Hocoma AG, Switzerland) have been developed. However, knowledge about the mechanism leading to a loss of function and about the effects of training on cortical activation patterns is limited, although desired to evaluate and improve rehabilitative training. Functional magnetic resonance imaging (fMRI) techniques are predestined to measure brain activation and its related change during ongoing mobilization training. fMRI measurements should be done during movement execution. Thus, a stepping device has to be developed that generates periodic gait-like leg movements and does neither affect the MR image quality nor is affected by the scanners magnetic fields.

This paper presents the design of a device to produce gait-like movements under the constraints of fMRI measurements. Furthermore, the influence of the used components on fMRI measurements will be measured and evaluated.

Definition of Requirements

The brain activation patterns caused by the execution of exercises with the device must be similar to the brain activation during gait. However, natural gait movements cannot be realized inside a scanner tube due to the limited space, changed gravity conditions, and missing ground contact of the feet. Movements and force interaction have therefore to be adapted and simplified. Made adaptations and simplifications were defined based on a review of the literature: Several studies dealing about cerebral activity during gait (Fukuyama, Ouchi et al. 1997; Hanakawa, Katsumi et al. 1999) and gait-like movements have shown that knee or foot movements cause typical brain activations (Miyai, Tanabe et al. 2001; Luft Andreas R. 2002; Suzuki, Miyai et al. 2004). The corresponding muscle activities can be achieved by moving both legs (Kawashima, Nozaki et al. 2005) and applying a ground reaction force (Dietz, Gollhofer et al. 1992; Dietz, Muller et al. 2002; Ivanenko, Grasso et al. 2002). We conclude that the device must comply with these requirements to achieve gait-like brain activation.

Determination of the influence to MR measurements

To quantify the influence to the magnetic field, we determined the change of the temporal signal to noise ratio (tSNR) of phantom (a bottle filled with water) measurements with and without the device. Imaging was performed at 3.0-T MR system (Philips Medical Systems, Eindhoven, The Netherlands) equipped with an 8 channel SENSETM head coil. For the functional acquisitions a T2* weighted, single-shot, field echo, EPI sequence of the whole brain (TR = 2 sec, TE = 40 ms, flip angle = 82°, FOV = 220 mm × 220 mm, acquisition matrix = 128 × 128, in-plane resolution = 1.7 × 1.7 mm^2, slice thickness = 3 mm) with a SENSE factor of 2 was applied to collect signals from 39 contiguous slices. We first scanned the phantom while the device was not in the scanner room. Second, we put the device in the position of real measurements and scanned the phantom again. Thereafter, the device was completely removed out of the scanner room and the scan was repeated. To get the tSNR we divided the mean of 81data points in the middle of the phantom over 20 time steps by its standard deviation. The difference of the tSNR between a measurement without the device and a measurement with the device running should be below an empirical threshold of 10 % to produce meaningful results.

Results

We decided to realize a kind of on-a-spot stepping movement, because it involves the most important joints as during walking. Hyperextension of the hip is achieved by lifting the pelvis from the bench by a little block and lay the back on a slope. To induce the stepping trajectories each foot is fixed on carriages of a linear guide. The whole device (magnetic resonance compatible stepper MARCOS, Fig. 1 and Fig. 2) can be adapted to different body sizes. MARCOS is driven pneumatically to allow a satisfactory force and position control (Yu, Hollnagel et al. 2008). MARCOS consists of PVC, aluminum and brass. These materials are not sensitive to the magnetic field. Further the parts have only little influence to the magnetic field since the device is placed outside of the scanner bore more than one meter away from the region of interest. The mean of the tSNR with the device is 190 while the mean of the tSNR of the two phantom-scans at the same region is 220 and 186 (Fig. 3).

Discussion and Outlook

The tSNR of the scans with MARCOS running were between the tSNR of the two phantom-scans. We conclude that MARCOS does not affect image quality. In combination with a newly developed head fixation, MARCOS can be used to investigate the recovering process of spinal cord injured patients or stroke patients. It is the only known device, which can produce reproducible movements of the whole leg combined with a controlled force on the foot. We expect MARCOS to give important insights on how a rehabilitative training can be assessed and modified to achieve the best therapeutically outcome for patients.

Fig. 1 Components of MARCOS

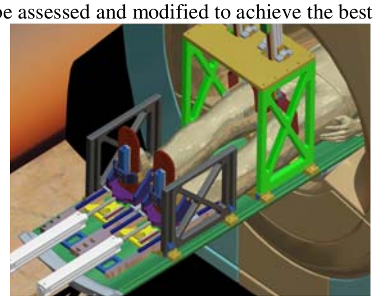

Fig. 2 Animation of MARCOS

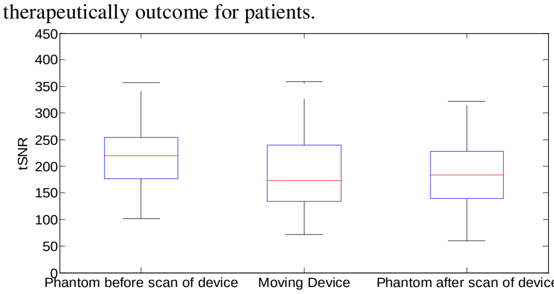

Fig. 3 Results of the tSNR measurements

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