Integration between fMRI and motion capture system to evaluate changes in cortical activations after rehabilitation in hemiplegic patients.

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Abstract

After-stroke hemiplegia is not a static phenomena, motor function can be partially regained along with a process of cortical reorganization. fMRI allows to investigate brain activation but hemiplegic subjects may not perform correctly the task paradigm. The aim of the study is to combine MRI with a motion capture system in order to provide a method to quantitatively correlate the cortical images with the executed movement. A specific protocol of ankle dorsal-plantar-flexion was defined and used to evaluate the experimental setup and the rehabilitation effect on a post-acute hemiplegic patient. After one month of rehabilitation no more activations in the patient’s premotor cortex were found during the execution of the movement.

1 Introduction

Hemiparesis resulting after stroke is not a static phenomena. It foresees some degrees of recovery which depend considerably on the severity of the stroke and on the choice of rehabilitation treatment. Part of the initial restoring is imputable to the resolution of local edema and reperfusion of the penumbra. It has been verified that functional recovery occurs at the same time with a dynamic process of cortical reorganization that begins after the acute phase of stroke [1]. Actually, functional Magnetic Resonance Imaging (fMRI) is the most suitable technique to evaluate which areas are activated in the brain when performing a motor or cognitive task.

While performing an fMRI exam on hemiplegic patients, clinicians have to deal with the difficulty of patients in performing the required selective motor task. Indeed, task could be not correctly carried out and involuntary movements occur, such as the mirror movements, i.e., unintentional, simultaneous replication on the healthy side of the intended movements performed by the plegic side. The goal of this study was to develop a new setup which combines a functional magnetic resonance imaging system with a motion capture system. This integrated setup will be crucial to evaluate changes in motor cortex of hemiplegic patients after rehabilitation correlating activation maps with kinematics data that characterize the movement performed by the patient.

2 Method

2.1 Integrated experimental setup

Fig. 1 A scheme of the integrated set-up developed for acquisitions.

MRI was performed on a 1.5 T scanner (Cv/I™, GE). A motion capture system (Smart μg™, BTS) was used to measure kinematics of subject’s feet.
Two cameras were put inside the RF shield in the MR room; cables connecting cameras and CPU passed across a waveguide (see Fig. 1). A third camera outside the MR room, captured an active infrared LED used to synchronize the fMRI protocol and the kinematics acquisition. The integrated setup validation was conducted on a phantom and then on a healthy subject, not described in this contribution.

Patient’s anatomy was acquired with a 3D spoiled gradient echo sequence weighted on T1 with a preparatory impulse of 450 ms; TE=6.9 ms; automatic TR around 15.9 ms; flip angle=15 °; bandwidth=10.87 kHz; matrix 256x256 with excitatory impulse NEX; field of view (FOV)=26 cm; voxel size=1x1x0.8 mm. Two functional acquisitions were performed, one while moving the paretic foot and one for the healthy one. A gradient EPI sequence weighted on T2 has been used with a preparatory impulse of 450 ms; TE=50 ms; TR=3 s; flip angle=90 °; automatic bandwidth; matrix 96x96 with excitatory impulse NEX; FOV=24 cm; voxel size=2.5x2.5x4 mm. Each functional acquisition comprised 100 volumes of 22 images, for a total of 2200 scans.

2.2 Patient

After giving her written informed consent, one patient was recruited from the Villa Beretta Rehabilitation Centre. She was 48 and suffered an ischemic stroke 15 weeks before the hospitalization. Lesion was located on the right hemisphere and covers insula, temporopolar cortex, capsule and lenticular nuclei. fMRI acquisition was performed at the hospitalization and after a month of rehabilitation therapy. She underwent to standard rehabilitation (passive and active movement), 20 Functional Electrical Stimulation (FES) cycling sessions and functional orthopaedic surgery.

2.3 Motor task

The activation task was self-paced repeated active dorsal-plantar-flexion of the foot. The fMRI paradigm consisted of 5 epochs of activation alternating with 5 resting periods. Each period lasted 30 s, thus the trial duration was 300 s. Patient was instructed to keep eyes closed. She was trained outside the MRI till she had acquired confidence with the protocol. Head’s movements were minimized with rubber pads and straps. She wore earphone and microphone to communicate with the operator. Knees were bent and legs lied on pillow to ensure minimum transmission of movement to the head, across the spine.

2.4 Kinematics data

Kinematics data were acquired at a frequency of 60 Hz by an optoelectronic motion capture system using passive markers. Ankle angle was approximated with the angle \( \alpha \) formed by the line passing for the two markers placed on the tibia and the line joining the marker on the toe and the projection of malleolus on the line passing for the two markers placed on the tibia (see Fig. 2). For each acquisition the following parameters were computed: the mean amplitude and frequency of \( \alpha \) during the dorsal-plantar-flexion movement; the standard deviation of \( \alpha \) (SD) during activation epochs for the foot not performing the task (relying on values found for the healthy subject, movements were considered significant when SD>2°); correlation (R) between the angles at the two ankles to assess if the involuntary movement was a mirror movement (R>0.5).

2.5 Functional images pre-processing and statistical analysis

Functional images were processed with SPM5. Images were realigned, normalized on the MNI (Montreal Neurological Institute) standard brain and smoothed with a gaussian kernel homogeneous in the 3 directions with Full Width Half Maximum 6 mm. Task paradigm was built in the design matrix considering the effective time periods performed by the patient, obtained from kinematics data. Parameters were estimated with the Classical method and statistical analysis was conducted (p-value < 0.001, Family Wise Error correction, extent threshold=100 voxels) [2]. Two Regions Of Interest (ROI) were defined, each one representing the area of ankle in the primary motor cortex for an hemisphere. To estimate inter-hemispheric balance, weighted laterality index (wLI) was calculated following [3]

\[
\text{wLI} = \frac{\sum t_c - \sum t_I}{\sum t_c + \sum t_I}
\]

where \( t_c \) are t-values of voxels lying in the controlateral hemisphere and \( t_I \) are those of voxels
Fig. 3  kinematics recorded for both the feet (panel (a)) when performing the task with the paretic foot at the hospitalization and related activation map (panel (b)); kinematics recorded for both the feet (panel (c)) when performing the task with the paretic foot one month later and related activation map (panel (d)).

lying in the ipsilateral hemisphere. The more wLI is close to 1 the more the activation is controlateral.

3 Results

At the hospitalization (Fig 3 panel (a)) the paretic limb performed a dorsi-plantar-flexion of 18.7 °±5.0 ° at a frequency of 0.41 Hz±0.04 Hz. The resting limb produce an SD of 4.3 °± 1.3 ° and R between the 2 angles was 0.68±0.06 (indicating the presence of mirror movements). In the brain map active voxels were located in primary motor cortex, Brodmann’s area 5 and 7 and premotor cortex of both hemispheres. wLI = 0.82. After one month of rehabilitation, for the same limb, the amplitude of the movement was 9.0  ±2.9 ° performed at a frequency of 0.36 Hz ± 0.03 Hz. The resting limb produced an SD of 0.5°± 0.1° with correlation 0.54 ± 0.14. Activations were registered in primary motor cortex and Brodmann’s area 5 and 7, wLI = 1, confirming the evident reduction of mirror movements. A good fulfill of task temporal sequence was achieved in both the trials.

4 Discussion

The goal of the study was to combine MRI with a motion capture system to correlate effective movements executed by the patient and cortical activations in order to evaluate the effects of rehabilitation. Both at the hospitalization and after one month, besides in the primary motor cortex, activations were localized in areas (like Brodmann’s 5 and 7) that in healthy subjects are active only when performing complex tasks involving many joints [4]. In the post-rehabilitation fMRI exam no activation in the pre-motor cortex was recorded. This result may indicate a return to physiological distribution. Anyway, the reduction of the amplitude of the task (=19 ° pre, =8° post) could partly justify the differences. Indeed the size and intensity of activated areas depend on the movement characteristics [5]. wLI values showed mostly controlateral activation in both the exams. The higher value in the post exam confirm the loss in significance of the parasite movements of the resting leg, observed on kinematics data.

5 Conclusion

The presence of a motion capture system inside the MR room allows to evaluate the presence of mirror movements and to verify the correct execution of the motor task. Moreover, the quantitative measure of movement amplitude and frequency might allow clinicians in making stronger hypothesis about the cortical activations associated to the task, and to evaluate the efficacy of the therapy on cortex reorganization.

6 Literature