An MRI Compatibility Study of a Fabric Sensing Glove for Sensory-Motor Brain Activity Exploration

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Abstract

In this work we investigated the compatibility with functional Magnetic Resonance Imaging (fMRI) studies of a fabric sensing glove. The glove is able to monitor hand posture and gesture, and could be fruitfully used in fMRI studies to explore brain activity during specific tactile or motor tasks. A specific compatibility test was performed and results are discussed. Preliminary results of an fMRI experiment on a subject wearing the glove are also reported and reproducibility issues are suitably addressed.

1. Introduction

In this work we report the preliminary results about fMRI compatibility of a strain sensing fabric. This fabric is used to realize a glove for hand posture and gesture monitoring that could be properly used in behavioral and functional studies aiming at investigating both the psychophysical and neural correlates of presence.

The aim of this work is specifically to verify whether the information acquired by a sensing glove could be integrated with the fMRI data in order to explore brain networks involved in the execution of tactile or motor tasks. The monitoring and the characterization of the task performed by a subject during an fMRI experiment is motivated by the need of differentiating the role of brain areas underlying a specific task execution.. fMRI data are indeed modelled using a priori hypotheses about the shape of blood oxygenation level dependent (BOLD) signal changes elicited by the activation of specific brain areas [1] . A detailed description in time of the actual task performed by the subject is required to have a model as precise as possible.

The need for reproducibility, control and monitoring of visuo-motor performances, has led to design fMRI compatible devices **Error! Reference source not found.**[2] ,[3] [4]]. This task represents a technological challenge, given the working conditions of the devices and the safety and compatibility criteria to be satisfied [5] . Their presence in the MR environment may cause artefacts due to large differences as compared to body tissues in susceptibility values, thus causing dishomogeneities in the static magnetic field. Artefacts may be originated by electromagnetic interferences due to electric currents used for the device driving and control. The interaction between conductive materials and time varying electromagnetic fields, such as gradient and radiofrequency (RF) pulses, results in electrical eddy currents which may produce significant local artefacts. Moreover, the scanning sequences used for fMRI studies are gradient echo echo-planar (GE-EPI) that are very sensitive to changes in static magnetic field homogeneity and varying magnetic fields. To assess device compatibility the correct working condition of the device itself must be assessed as well.

2. Material and Methods

2.1. System Description

The prototype here proposed here is a biomimetic sensing glove based on sensorized textile technology. Most of commercial devices are obtrusive, thus strongly affecting the natural movement and gesture of the hand. On the contrary, the glove used here is realized directly on a textile substrate and can be worn for a long time with no discomfort. Sensor networks made by Conductive Elastomer (CE) are integrated into an elastic fabric used to manufacture the sensing glove. CE composites show piezoresistive properties when an external deformation is applied. The sensing glove was realized by directly spread the CE mixture, over a Lycra/cotton fabric (Figure 1) previously covered by an adhesive mask following the technique described in [6] .

Figure 1. Sensorized glove

The mask is designed according to the desired sensor location and connection topology (figure 2). The conductive mixture CE was used for both sensors and conductive paths, thus avoiding the usage of conventional metallic wires adopting a specific and dedicated topology. This new technology allows us to implement sensors to be integrated in usual garments. The conductive CE mixture does not change mechanical properties of the fabric and maintains the wearability of the garment. Lightness, adherence and elasticity of the fabric make the sensorized garments unobtrusive and uncumbersome, and hence comfortable for the subject wearing them. Moreover, an adherent wearable system increases the mechanical coupling with body surface and reduces movement artifacts.

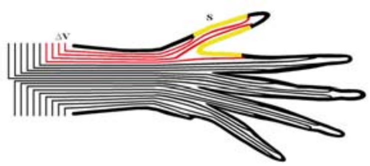

Figure 2. Galley proof used to print the conductive mixture on the fabric glove.

The sensing glove is able to record postures and gestures of the hand recognizing static and dynamic configurations of the fingers. As above mentioned, an innovative aspect of the sensing glove enhancing mechanical performance and fMRI usability, regards the electrical paths, usually made of metallic wires, which connect sensors to the acquisition card. The bold black track, shown in figure 2, represents the set of sensors connected in series and covers the most important joints of the fingers. The thin tracks represent the connection between sensors (S) and the electronic acquisition system. Since connections are realized by the same material adopted for sensors, they undergo a not negligible change in electrical resistance when user moves his hand. For this reason the front-end acquisition unit was designed to compensate connection resistance variation such as described in [7] The sensors current is lower than 50 μA. A copper shielded cable was used to connect the sensing glove to the acquisition electronics in the console room, through a waveguide.

2.2. fMRI Compatibility: tests of the System

2.2.1. Effect of the sensing glove on the images. An fMRI compatibility test was proposed for the system under investigation **Error! Reference source not found.**[8] . The test is about mean differences of image quality indexes between different experimental conditions, i.e. with the device and a control condition without the device (baseline). The images are GE-EPI (TE/TR=40/3000 ms, FA=90, BW=62.5 kHz, FOV=24, 25 5 mm thick Axial Slices) that are sensitive to T2* parameter and are used to detect BOLD signal changes. The images are acquired using a spherical phantom of $CuSO_4$ solution. The indexes proposed are the image signal to noise ratio (SNR), estimated for each image in the time sequence, and the time domain standard deviation (SD), estimated for a group of image voxels (volume elements) in the center of the phantom. Each image sequence is formed by 20 time frames so that 20 estimates of the SNR in each experimental condition are given. The SD is estimated in a 15x15 voxels Region of Interest (ROI), so that 225 estimates are given for each condition. The statistical test is a t-test for the low degree of freedom case of SNR, and a z-test for the higher degrees of freedom of time domain standard deviation. The p critical value, for the bidirectional null hypothesis to be considered unlikely, was chosen to be 0.05. This value leads to a t critical value of ±2.024 and a z critical value of ±1.96.

2.2.2. Effects of the scanning system on the sensing glove. The effect of the imaging system on the signals acquired from the glove was investigated. The signal was acquired with the glove located at the scanner bore entrance, while the scanner was not operating and while system was scanning. Glove signals were acquired when an operator was stretching the glove, by holding the two edges of the elastic fabric, during scanning. A power spectral density (PSD) analysis of the signals was performed.

2.3. fMRI Study description

2.3.1. fMRI Experiment. An fMRI experiment was performed. A 37–year old right handed healthy male gave informed consent for the test. Functional images with a GE-EPI (same scanning parameter as in section 2.2.1) sequence and a spoiled grass 3D T1 weighted anatomical image were acquired with a 1.5 T GE Scanner Excite HD. A first experimental design was a blocked paradigm alternating five times between 20 sec of finger tapping task and 20 sec of rest performed with and without the glove. A second experiment consisted in a self paced finger tapping task: the subject alternated task and rest conditions thus choosing the temporal pattern of finger movement.

2.3.2. fMRI Data processing. The image data were spatially realigned to correct for head movements and spatially smoothed using a 3 mm FWHM gaussian kernel to increase image SNR. A multiple linear regression was performed: the regressor of interest was obtained by convolving the square wave describing the blocked paradigm with a model for the hemodynamic response function as in [9] In the self paced experiment the expected response was obtained from the sensing glove signal: the information retrieved was about the temporal intervals while the subject was actually performing the task or he was still. A t-test on the coefficient of the regression pertaining the stimulus function was estimated. The maps were thresholded using an F-statistics. All the preprocessing steps and the analysis were performed with AFNI [10] . To test the effect of the wearable sensing glove on the fMRI maps, a reproducibility measure [11] was estimated, comparing the blocked design finger tapping task results, obtained with and without the glove. This reproducibility measure is defined as $R^{ij}_{overlap} = 2 * V^{ij}_{overlap} / (V_i + V_j)$, where V_i and V_j are the sizes of activated volumes in the *i*-th and *j*-th scan respectively, while $V^{ij}_{overlap}$ is the size of the volume activated in both scans.

3. Results

3.1 fMRI Compatibility Test Results

3.1.1. Effect of the sensing glove on the images. Test results are summarized in Table 1. The compatibility test showed a mild effect of the system on image quality. These effects are mainly present when the system is powered. Changes in image quality are present in some slices while other seem to be unaffected. Slices labeled with lower numbers are those closer to bore entrance.

Table 1. Glove Compatibility Test results. Critical values: t =±2.024, z = ±1.96). Values above threshold are shown in bold type.

	Slice #1		Slice #5		Slice #10		Slice #20	
Experiment	t SNR	z SD	t SNR	z SD	t SNR	z SD	t SNR	z SD
Baseline vs Glove off	-0.89	0.39	0.25	**2.74**	1.21	0.05	0.59	0.17
Baseline vs Glove on	1.95	**2.11**	1.81	1.3	**2.08**	0.44	0.39	**2.94**

3.1.2. Effects of the scanning system on the sensing glove. In figure 3 the power spectral density of the acquired signal in different experimental conditions are shown These data show that the scanner causes a relevant noise power on the acquired signal. The signal PSD is much larger than the noise for frequencies below 5 Hz.

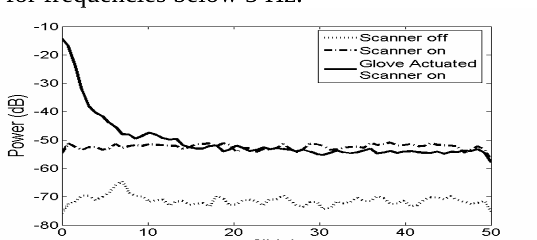

Figure 3. PSD of the signals acquired from the sensing glove in different experimental conditions.

3.2 fMRI Study Results

In figure 4, functional maps of the finger tapping task are shown. In the upper part, the maps of the experiment without the glove are shown, while the lower part depicts the regions activated during the experiment with the glove. The t-statistic regarding the regressor of interest coefficient is shown superimposed on an anatomical image in Talairach space. Only those voxels with p value < 10^{-7} are shown. Significant activations were found in areas that are likely to be involved in the task under examination, in both cases. Activations were found in the ipsilateral and contralateral primary motor cortex and supplementary motor area (SMA). Right and left precuneus and posterior parietal areas were activated as well.

The reproducibility measure was about 60%. In the lower part of figure 5 the raw data acquired from a glove sensor during the self paced finger tapping experiment are shown.

In the upper part of the same figure low pass filtered (LP Equiripple Fir filter, 5Hz cut off frequency) data are shown.

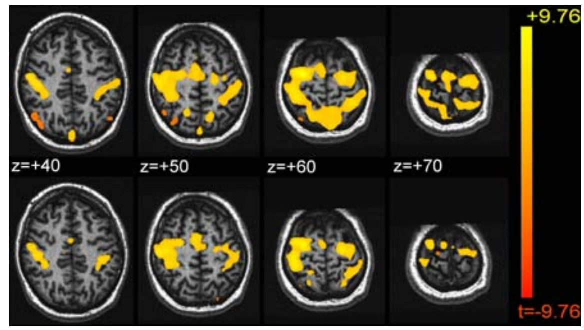

Figure 4. fMRI results (Talairach space). Task: block designed finger tapping (threshold F, p<10^{-7}) without the glove (upper row) and with the glove (lower row)

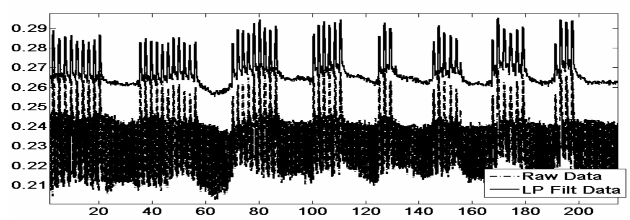

Figure 5. Raw (lower graph) and LP filtered signal acquired from a glove sensing element at the thumb.

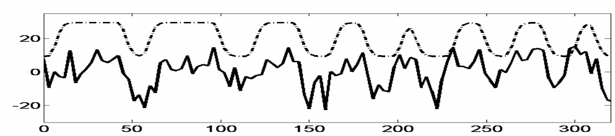

Figure 6. Expected hemodynamic response (upper graph) estimated from the sensing glove info and an actual time series extracted from an activated brain region.

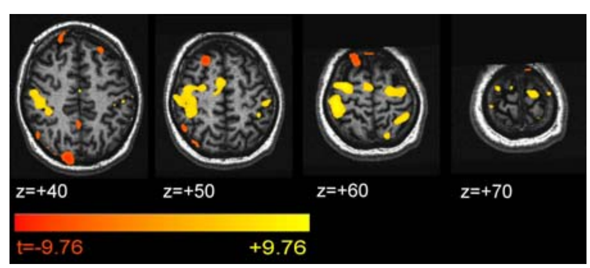

Figure 7. fMRI results in Talairach coordinates. Task: self paced finger tapping (threshold F, p<10^{-5}).

This information was used to determine the regressor of interest used for analyzing fMRI data in this case. The expected hemodynamic response is shown in the upper part of figure 6. The activation maps obtained are shown in figure

7 (Threshold F statistics, $p<10^{-5}$). Ipsilateral and contralateral primary motor cortices and (SMA) and posterior parietal areas were found activated.

4. Discussion

Here we report the preliminary results of a compatibility test for a glove made of strain sensing fabric. This sensing device can be used in fMRI experiments investigating the neural correlates of haptic or motor tasks (e.g. person-to-object or person-to-person interactions) in studies on presence using VR or enhanced mixed scenarios. The information on hand posture and gesture could be correlated with task-related performances or behavioral (i.e. affective) responses that are crucial aspect of presence.

The compatibility test results of the sensing glove showed that the system moderately affects GE-EPI image quality. These effects seem not to be homogeneous and do not affect all the phantom slices. Some improvements may still be applied to the system as an effective shielding of the wires as they are connected to the conductive elastomer. Moreover a shielding of the sensor network may be designed.

The noise introduced by the scanning system is relevant. In this work, a deformation of the strain sensing elements, was applied. These movements were mainly characterized by low frequency components (< 5 Hz). The power of this signal was higher than noise power and the signal shape could be easily retrieved (data not shown). The possibility of retrieving information from the glove of such signal components, without affecting image quality, may allow to employ the system for hand posture and hand gesture monitoring during a functional MRI experiment.

A preliminary experiment with a subject has showed a good compatibility of the system with functional studies. The estimated reproducibility measure indicates a good similarity degree between the activated regions found with and without wearing the sensing glove. It is worthwhile noting that there are many factors that may alter the value of this index, as small differences in the task, habituation and learning phenomena. However, the activated regions found in the experiment with the glove, are consistent with those expected in a blocked design finger tapping experiment. A self paced finger tapping experiment was performed. In this preliminary test only a small part of the available information acquired with the sensing glove was used for fMRI data analysis and used to reconstruct the actual timing of the subject overall movement. We have to highlight that the self paced experiment is not optimal for the statistical power and a lower F statistic threshold is used for displaying of self paced task related results, as compared to the block design. The activated regions are consistent with a pattern found in finger tapping experiments.

5. Conclusions

In this work a good compatibility of the proposed sensing glove with fMRI studies was shown. Further work has to be done in order to improve MRI compatibility of the system. Information acquired from the glove could be fruitfully used to explore in finer detail the brain networks involved in tactile tasks. In addition to hand posture and gesture recognition, next developments aim at enabling the sensing glove to record haptic interaction signals.

Acknowledgements

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