Parallel real-time fMRI with two connected high-field scanners (3T, 7T)

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Introduction

Compared to typical fMRI experiments where data acquisition and data analysis are separated, real-time fMRI (rtfMRI) provides new and unique experimental setups. Most important is the feedback of the own activation to the volunteers which enables training of the tasks, and therefore developing and optimizing own strategies to increase the BOLD response [1, 2]. Another exciting setup is the real-time interaction with the presented environment, which may change depending on localization and strength of the activation. However, many real world actions involve communication between several partners (such as in economics), where highly non-linear interactions can usually not been foreseen, and therefore not be planed in advance in static environments. We therefore developed a new software-system that connects two (or more) MR scanners in real-time, feeds back the activation of both volunteers to each of them while additionally providing the capability to change virtual reality paradigms depending on the activation patterns of both volunteers. We tested the setup with a competition paradigm thereby connecting a 3T and a 7T scanner. This new setup will enable completely new applications involving mutually depending activation patterns and behaviour strategies. Compared to other approaches such as NEMO [3] our system integrates the control of the scanners as well as the presentation and data analysis, enabling to adapt the paradigm according to the activation patterns e.g. to increase attention or to modify a virtual reality environment.

Methods

A custom-made MATLAB-based real-time fMRI software system was used to control stimulus presentation, data analysis, and communication with the scanner system [4]. The software was extended to allow a centrally controlled connection of two MR scanners. Experiments were performed involving a 3T and 7T MRI scanner (Siemens, Erlangen, Germany). Timing and communication of both scanner systems were defined in a central XML file. We used a modified EPI-BOLD sequence to support real-time export of the functional images. The software processes the data and sends the results of the online data classification [5] and the currently measured parameters such as the BOLD signal to a central SSH server. This server can be accessed by both scanner environments. Parallel rtfMRI was performed with four healthy volunteers (m, 22-28 years) after giving written consent according to the local ethics committee. Measurement parameters were: TR 2000ms, TE 21ms (7T)/ 29ms (3T), matrix size 64x64, 31 slices (3T)/ 7 slices (7T), resolution of 3.4 x 3.4 x 3 mm³ (3T) / 3.3 x 3.3 x 4.6 mm³ (7T), flip angle 90°. Motor tasks (real and imaginary finger tapping, both paced by spoken words "start", "stop") were used for the experiment which consisted of two parts: (1) an initialization measurement where the individual activation patterns for the defined task were semi-automatically identified; and (2) the parallel rtfMRI experiment. A block design (4sec baseline – 6sec active – 14sec baseline) was used for both tasks (5 runs for the initialization measurement, 20 runs for the parallel rtfMRI). Each volunteer was told to maximize the BOLD response in the previously determined brain areas, and to reach higher activation scores than the volunteer in the other MRI scanner. During each single run we used the BOLD signal averaged over the previously identified activated regions as a measure for the activation level. It was (1) presented directly to the volunteer as a coloured bar, and (2) served for the progression of the volunteers virtual sphere (the larger the activation, the larger the progression). At the same time each volunteer saw the sphere of the opponent. To account for 3T vs. 7T signal differences both signals were scaled to 0 to 1 based on the BOLD responses of the initialization measurements**.** For motivational purposes they could increase their final financial reward if they were able to "win the race" with constantly higher BOLD responses than their opponent. (Fig.1). Financial rewards, positions of the spheres, and colour of the bar were updated after each run (24secs) but the software allows also for continuous updates.

Results and Discussion

The described experiments were successfully conducted. The connection between two MRI scanners could successfully be established. The transfer of the results of the online data analysis, classification of activation patterns, and extraction of the BOLD response via SSH took below 100ms. Because of 2000ms TR and the delay of the BOLD response the transfer solution seems suitable for the exchange of online determined parameters between the involved scanner environments. As expected the increase of the financial reward as well as the competition with a second volunteer kept the motivation on a high level so that the level of BOLD responses became more stable over all runs during each experiment. The synchronization of both scanners and their analysis environments raised no problems although two firewalls had to be tunnelled. The result visualization was updated correctly after each run with the latest activation scores. Nevertheless the sequences have to be started simultaneously to enable synchronous scanning with shorter repetition times. The presented system is ideally suited to perform neuro-economic experiments.

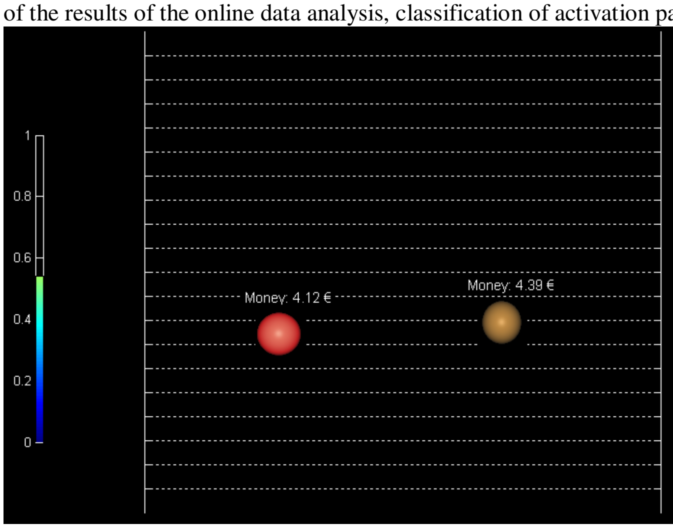

Fig. 1 - The actual BOLD response of one volunteer is depicted as the coloured bar on the left side (scaled to 0 to 1). The volunteer can see his own and the opponents' total scores and rewards of the current measurement indicated by the virtual spheres.

References

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