Factors influencing learning to self-regulate brain activity using real-time fMRI: comparison between conscious strategy and contingent feedback

Pradyumna Sepúlveda[1,2], Ranganatha Sitaram[3,4], Mohit Rana[3,5], Tomás Ossandón[6], Marcelo Andía[1,7], Cristián Montalba[1], Sergio Uribe[1,7], Pablo Irarrázaval[1,2], Sergio Ruiz[4,6], and Cristián Tejos[1,2]

[1]Biomedical Imaging Center, Pontificia Universidad Católica de Chile, Santiago, Chile, [2]Department of Electrical Engineering, Pontificia Universidad Católica de Chile, Santiago, Chile, [3]Department of Biomedical Engineering, University of Florida, Gainesville, Florida, United States, [4]Institute of Medical Psychology and Behavioral Neurobiology, University of Tübingen, Tübingen, Germany, [5]Graduate School of Neural & Behavioural Sciences, International Max Planck Research School, University of Tübingen, Tübingen, Germany, [6]Department of Psychiatry, Faculty of Medicine, Interdisciplinary Center for Neuroscience, Pontificia Universidad Católica de Chile, Santiago, Chile, [7]Radiology Department, Faculty of Medicine, Pontificia Universidad Católica de Chile, Santiago, Chile

Target Audience: Neuroscientists, psychiatrists, neurologists, engineers, basic scientists and clinicians interested in neurofeedback or real time fMRI.

Introduction: Technological advances have favored the development of real time fMRI (rtfMRI) neurofeedback (NF) tools, i.e. providing in real time contingent information to a subject about her/his own brain activity so that to teach or facilitate self-regulation of brain functions. Using rtfMRI NF enables subjects (healthy and patients) to self-regulate BOLD signal voluntarily in local and extended brain areas after a training period [1,2]. This last feature has potential therapeutic applications for brain disorders since behavioral changes can be observed after successful neuronal self-regulation. RtfMRI NF can be also used to study brain activity, and hence to observe changes in subject's behavior [4]. However, it is yet to be defined which is the optimal modality to improve self-regulation capacity of individual subjects. Although different factors have been described, whether or not those factors affect the learning process of self-regulation remains an open question. Learning processes can be often affected by giving a "conscious" mental strategy to subjects for self-regulation of particular brain areas. However, if learning how to self-regulate our brain metabolism is purely determined by operant conditioning, thus explicit and conscious strategies may not be necessary [3].

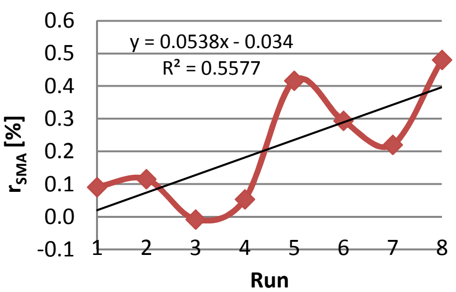

Figure 1. Learning curve for one subject of Group 2 (feedback+strategy). r_{SMA} depicts an increment in SMA BOLD signal during up-regulation blocks in each training run.

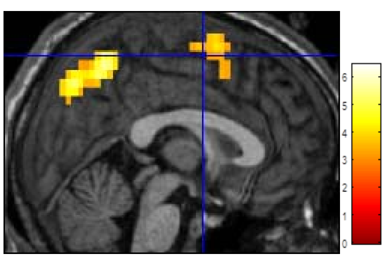

Figure 2. SMA **activation observed in a representative subject during the last training run. The blue cross indicate x=0; y=0; z=60, t-value in bar**

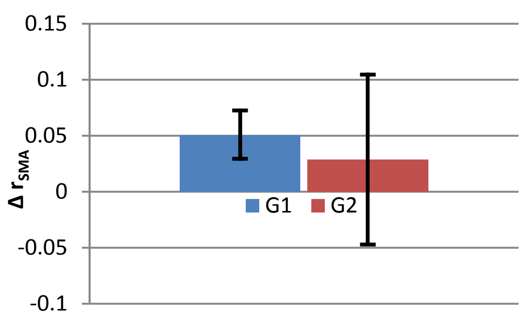

Figure 3. Change in SMA BOLD up-regulation percentage, comparing final and initial runs of NF training for Groups 1 and 2 (red, only feedback; blue, feedback + strategy). Comparison using Δr_{SMA}= Mean ($r_{SMA,8}$;$r_{SMA,7}$)-Mean($r_{SMA,2}$;$r_{SMA,1}$), being $r_{SMA,i}$ BOLD up-regulation increment percentage for individual run i. Group means for Δr_{SMA} and standard error bars depicted.

Purpose: Our aim is to elucidate whether or not adding a potentially useful conscious mental strategy to rtfMRI NF improves self-regulation after a training period. For this we selected a particular region, the Supplementary Motor Area (SMA), for which there is enough evidence that can be self-regulated through rtfMRI NF and is responsive to conscious mental strategies: i.e, motor imagery. So, we designed an experimental setup to compare self-regulation outcomes using purely contingent NF versus NF + conscious mental strategy (CMS).

Methods: Two groups of 5 healthy subjects each (23.1± 1.69 year-old males, right handed) were trained in a NF task to increase BOLD signal in SMA with contingent rtfMRI visual feedback. Group 1 received only feedback, just knowing that it is related to brain activity. Group 2 was additionally oriented from the beginning with a proper strategy (they were suggested to perform motor imagery). Each subject was trained during 2 days with NF or NF + CMS, 4 training runs per day (around 5 minutes each) alternating rest state and up-regulation blocks. Each day, subjects performed two additional runs: functional localizer (to identify SMA) and "transfer runs" (subjects try to self-regulate SMA without receiving NF) before and after the NF training, respectively. Additionally, in a third day subjects performed a motor task (finger tapping) to evaluate possible behavioral changes as a result of self-regulation.RtfMRI system was implemented using an 1.5T Scanner (Philips Achieva, Netherlands) with functional image acquisition using FE-EPI sequence with TR=1500 ms, TE=45 ms, voxel size=3.2x3.3x4 mm^3 and 150 measurements (10 dummy scans). We used a standard PC running Turbo Brain Voyager rtfMRI software (Brain Innovations, Netherlands) and custom MATLAB scripts to generate feedback information. A second PC with Presentation software (NBS, USA) was used to show feedback in an MR-compatible Visual System (NNL AS, Norway). Anatomical T1-weighted images were acquired both days. fMRI images were preprocessed and analyzed using SPM and additional in-house MATLAB scripts, pointing to evaluate BOLD increment in both groups. To evaluate self-regulation success a simple measure is being used: r_{SMA}, the increment percentage of BOLD signal during up-regulation compared to baseline blocks for each run, all in a selected ROI of SMA (MNI coordinates: x: -16, 0; y: -8, 8; z: 52, 68). To measure the success in brain self-regulation we use Δr_{SMA}, which is the difference in r_{SMA} for the last two training runs and the first two, for each subject.

Results: Our results showed that subjects learned to self-regulate SMA using this setup, as exemplified by r_{SMA} variation across training runs in one subject of Group 2 (figure 1). Comparing the data from both groups we observed that the use of a conscious mental strategy does not generate significant improvement with respect to the use of only contingent feedback, considering learning in terms of Δr_{SMA} (figure 3).

Discussion & Conclusion: Adding a conscious mental strategy to the rtfMRI NF has not necessarily a significant impact in learning efficiency, at least in SMA. This appears to be in line with the idea that operant conditioning is a key factor for learning brain self-regulation in human studies on NF, and that conscious process are not required in NF [3]. Additional research work needs to be done to have a deeper understanding of NF learning process and to identify relevant factors and modalities to develop optimal training protocols and potential therapeutic methodology. We are currently using additional tools (e.g. brain pattern analysis) to unravel neural substrates of rtfMRI NF learning.

References: [1]Sulzer et al, NeuroImage,76,2013; [2] Ruiz et al, Biological Psychology, 95, 2014; [3] Sitaram et al, Computational Intelligence and Neuroscience, 2007; [4] Birbaumer et al, Trends in Cognitive Sciences, 17(6), 2013.