CONNECTIVITY-BASED NEUROFEEDBACK: DYNAMIC CAUSAL MODELING FOR REAL-TIME FMRI.

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Introduction: Neurofeedback based on real-time fMRI is an emerging technique that can be used to train voluntary control of brain activity. Such brain training has been shown to lead to behavioral effects that are specific to the functional role of the targeted brain area. Recent studies even demonstrated therapeutic effects in specific patient populations. However, neurofeedback so far was limited to training localized brain activity within a region of interest. Here, we propose to overcome this limitation by developing connectivity-based neurofeedback. This was accomplished by adapting dynamic causal modeling (DCM), which provides a measure of effective connectivity between brain regions, for real-time purposes.

Methods: First, we optimized the trade-off between DCM model convergence precision and computational speed, by integrating DCM into the real-time pipeline, and by generating a feedback signal from the results of a Bayesian model comparison between two model alternatives. The two models that we compared represented covert shifts of visual-spatial attention to the left or right visual field, i.e. they consisted of the interconnected left visual and parietal cortices and the interconnected right visual and parietal cortices. What differed between the models was the modulating input of attention, which should be stronger on the left parietal cortex (PC) and on the connectivity between the left visual cortex (VC) and the left PC when attention is covertly shifted to the right visual field (model M_{aR}), and stronger on the right PC and on the connectivity between right VC and the right PC when attention is covertly shifted to the left visual field (model M_{aL}). The regions of interest were first localized using standard functional localizer runs (flickering visual checkerboard and covert shifts of attention, respectively). In 3 subsequent neurofeedback runs, we then tested the ability of participants (3 male, 4 female, 27.7±3.3 yrs) to voluntarily control the DCM-based feedback signal by covertly shifting their visual-spatial attention. Each of the 3 neurofeedback runs consisted of 8 neurofeedback trials. Each neurofeedback trial consisted of 5 baseline blocks interleaved with either 4 blocks of attention to the right or to the left (all blocks were 10s; attention left/right conditions alternated). The attention conditions were indicated by changes in the fixation point, i.e. participants were informed whether attention to the left or attention to the right will be most effective in order to control the feedback signal. Each neurofeedback trial was followed by a 60s block of resting state acquisition (during this time the feedback signal was computed) and a 5s block during which the feedback signal was presented to the participant. The feedback signal corresponded to the Bayes factor which resulted from the Bayesian model comparison of M_{aL} and M_{aR}. All experiments were performed on a Siemens 3T Trio scanner, using a single-shot gradient-echo T2*-weighted EPI sequence with 630 and 1315 repetitions (TR = 1000 ms, 16 slices volumes, matrix size 64 x 64, voxel size = 3 x3 x 3.75 mm^3, flip angle α = 77°, bw = 2.23 kHz/ pixel, TE = 30 ms).

Results: We found that a trial of 4 blocks of shifting attention interleaved with 5 baseline blocks (total duration 90s) was sufficient to compute a reliable connectivity-based feedback signal. The participants in our experiment were able to control such a feedback signal. Specifically, the group Bayes factors were significantly greater than zero (Fig. 1; sign one-tailed test, z = 1.93, p = 0.027, sign = 97; median = 0.8, first quartile = -10.5, interquartile range = 25.6).

Discussion & Conclusion: Our new approach goes beyond previous neurofeedback studies that only trained voluntary control over activity in specific ROIs. By adapting state-of-the-art connectivity measures such as DCM for neurofeedback, it is now possible to learn voluntary control over functional brain networks. Because most mental functions and most neurological disorders are associated with changes in network activity rather than with activity changes in single ROIs, this novel approach is an important methodological innovation in order to more specifically and directly target such brain networks.

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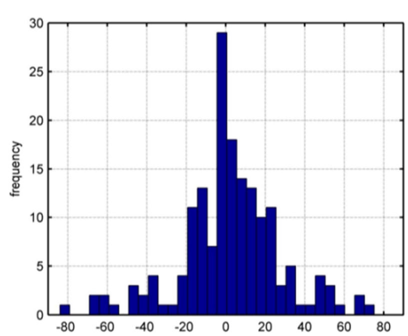

Figure 1: Voluntary control over the connectivity-based feedback signal. Successful control of the feedback signal is reflected by positive feedback signal values, i.e. logarithmic Bayes factors. Collapsing across all participants and trials, the joint logarithmic Bayes factors were significantly greater than zero, which indicates that participants had control over the feedback signal.