**Improving attention through network-based neurofeedback training**

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**Introduction:** Real-timefMRI neurofeedback allows participants to see and learn to voluntarily control their own brain activity (1). Most real-time fMRI neurofeedback studies so far have trained participants control over single regions, although most mental functions are associated with functional networks. For example, neuroimaging research has identified the sustained attention network (SAN), which becomes active during attention-related tasks (2). Conversely, mind-wandering is associated with reduced activity in the SAN, and increased activity in the default mode network (DMN) (3,4), so this anticorrelation reflects competition between sustaining attention and interference from task-irrelevant thoughts. Here we propose to modulate this competition using a novel network based neurofeedback approach to simultaneously increase SAN and decrease DMN activity. If successful, this approach might provide a promising tool to enhance sustaining attention.

**Materials and Methods:** 11 healthy young adult volunteers participated in this experiment. Data was acquired on a 3T Philips Achieva MR scanner, using a T2\*-weighted EPI sequence with 240 repetitions per run (TR=2s, 37 slices, matrix size 80x80, voxel size 3x3x3mm3, TE=22ms). Real-time fMRI processing was done using a customized Matlab-based toolbox on a high-performance computer, and included real-time spatial realignment, spatial smoothing, coregistering of the ROI masks, head movement correction, suppression of spikes and high frequency noise using a modified Kalman filter, and signal normalization (5). Before and after the neurofeedback training, 150 volumes of resting fMRI data with the same parameters were acquired to search for differences in connectivity. The 3 SAN ROIs were defined as 6-mm spheres at clusters derived from a meta-analysis (2). The 3 DMN ROIs were individually defined by an ICA analysis from the resting-data acquired before training. These 6 ROIs plus the entire SAN and the entire DMN were considered for the connectivity analysis. Neurofeedback training took part on three days and consisted of 2-4 runs per day. Every run consisted of a 60s baseline block to compute the baseline for both networks, followed by five 60s up-regulation blocks interleaved with four 30s down-regulation blocks. The feedback signal corresponded to the differential activation between SAN-DMN and was provided in the form of a thermometer display projected in the scanner. To facilitate learning, we suggested the use of maintaining attention and refocusing strategies to up-regulate SAN and down-regulate DMN, and mind-wandering to achieve the opposite. Before and after training, participants performed self-regulation in the absence of feedback (transfer runs) as well as standardized attention tests (i.e. Continuous Performance (CPT), Psychomotor Vigilance (PVT), Switcher, and Stroop tasks).

**Results and discussion:** With the help of neurofeedback, participants learned to voluntarily control both the SAN and DMN (positive betas training runs, p<0.0008). Once learned, the ability to self-regulate these networks remained even without neurofeedback (last transfer run, p<0.003). Successful self-regulation was positively correlated with self-report scores of how they felt they were in control of the feedback signal, and how much they focused during training (all ps<0.02). Also, the improvement in the Stroop reaction time test for congruent stimuli after compared to before neurofeedback training was positively correlated with training success (r=0.70/p=0.02), but not for neutral (r=0.59/p=0.06) and incongruent stimuli (r=0.51/p=0.11). Supplementary motor area was less positively connected (p=0.0002) to right middle frontal gyrus and less negatively connected (p=0.04) to precuneus after training, what is contrary to the initial hypothesis of more anticorrelated networks after training, but this could mean instead more fatigue after training compared to the first resting-data acquisition.

**Conclusion:** Using differential neurofeedback, it is possible to modulate the relative dominance of two competing brain networks through training, namely the SAN and the DMN. Shifting this dominance requires effort and concentration, and might lead to improved attention.

**References: [**1] Sitaram R et al., Nat Rev Neurosci 18: 86–100, 2017; [2] Langner R et al., Psychol Bull 139(4): 870–900, 2013; [3] Raichle M et al., PNAS 98(2): 676–82, 2001; [4] Mason MF et al., Science 315(5810): 393–5, 2007; [5] Koush Y et al., Neuroimage 59(1): 478–89, 2012.