Understanding and improving neurofeedback-guided self-regulation

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1. Summary

While the major focus of previous neurofeedback work lay on observing changes in the neurofeedback target or task-specific psychological outcome variables, only a much smaller part of research has been dedicated to study the general mechanisms of self-regulation and learning in the context of neurofeedback. To contribute to an understanding of how the brain responds to neurofeedback, this thesis focused on the mechanisms contributing to neurofeedback-guided self-regulation across different neurofeedback tasks and time.

In chapter 2, we focused on whether neurofeedback performance and psychological effects of neurofeedback are influenced by different training styles. Specifically, we investigated the effects of providing an initial neurofeedback task with assumed lower task demands before switching to the main training. Participants underwent three real-time fMRI neurofeedback-training sessions, in order to learn to regulate activation of the anterior insula (aINS) to three different target levels, either by performing the identical emotion regulation task over the whole training (constant training style group: CON), or by first training to reach three target levels with motor-imagery-driven neurofeedback from the supplementary motor area (SMA; changing training style group: CHA). While achieving fine-grained control over the fMRI-signal level was more feasible for participants receiving SMA in comparison to aINS neurofeedback during the initial training, both groups were able to significantly improve their aINS regulation performance over the subsequent sessions. Although both groups did not

differ in their ability to stabilize the neurofeedback signal at a certain target level, the group initially obtaining neurofeedback experience through training with a motor-imagery task showed an increased tendency to up-regulate the neurofeedback signal, which correlated with more effective training outcomes with regard to post-training positive affect. Findings were supported by participants' self-evaluation on personal neurofeedback regulation abilities and motivation. Overall, the results of chapter 2 support that neurofeedback guided emotion regulation is associated with subjective experiences of emotion. While differences between training styles are subtle, the overall pattern of group differences suggests that different training styles modulate self-regulation and psychological outcomes of a neurofeedback training.

In chapter 3, we focused on the neural basis of neurofeedback guided self-regulation and how it changes over time. By comparing brain activation between the two different mental tasks described in chapter 2 (SMA and aINS neurofeedback), we could replicate recent findings on involvement of a domain-general network in neurofeedback (Emmert et al., 2016) and in addition revealed differential activation in task-specific regions selectively involved in emotion regulation and motor imagery. Across both neurofeedback tasks, neurofeedback target regions showed significant increases in connectivity to the rest of the brain. Significant connectivity clusters of the two different target regions (SMA and aINS) overlapped with brain activation shared between both tasks, supporting the domain general function of the involved network. During the subsequent sessions of aINS neurofeedback training, activation remained largely constant, with a trend for increased striatum activation for the CHA group that was not present in the CON group. Connectivity between the target region and several cortical regions was significant during all sessions, particularly to regions that have been shown to be activated (lateral prefrontal, parietal, insular) or deactivated (hubs of the default mode network, DMN) across different neurofeedback tasks (Emmert et al., 2016). Additionally, connectivity between the target region and the anterior striatum was only observed during the last session. Overall, the results of this chapter support the notion, that during neurofeedback a defined network is recruited reliably. They suggest, that regions of this network synchronize their activation with the neurofeedback target, while especially the striatum could be implicated in learning effects in response to neurofeedback.

In chapter 4, we focused on the neural basis of feedback processing during neurofeedack guided self-regulation. For this matter, we compared fMRI activation across different mental tasks involving gradual self-regulation with and without providing neurofeedback. Participants freely chose one self-regulation task and underwent two training sessions, one with and one without receiving neurofeedback. Neurofeedback signals were provided based on activity in task-related, individually defined target regions. Whole-brain analysis revealed, that a network of cortical control regions as well as regions implicated in reward and feedback processing were activated during neurofeedback compared to rest. Self-regulation with feedback was accompanied by stronger activation within the striatum across different mental tasks. Additional time-resolved single-trial analysis revealed that neurofeedback performance was positively correlated with a delayed brain response in the striatum that reflected the accuracy of self-regulation.

2. General Discussion

2.1 Task-general effects of neurofeedback

The reliable activation of a network of prefrontal control areas (aINS, ventrolateral and dorsolateral prefrontal cortex (vl/dlPFC) and anterior cingulate cortex (ACC)) across various neurofeedback tasks (chapter 3 and 4, see also Emmert et al. (2016)) suggests that during neurofeedback a network is trained, which exerts control over a wide range of cognitive and affective processes. That the recruited network is involved in many different mental tasks suggests that it is not narrowly dependent on a particular task setting. It seems therefore likely that this network will exert its influence also in other mental tasks outside the neurofeedback setting. Studies on emotional self-regulation without neurofeedback support this notion: The aINS, vlPFC, dlPFC and ACC have been shown to be involved in endogenous generation of emotional states of positive as well as negative valance, and across different mental imagery modalities (Engen, Kanske, & Singer, 2016). Additionally, the aINS, vlPFC, dlPFC and ACC appear to be crucial in down-regulating negative emotions: Dörfel et al. (2014) could show that across emotional down-regulation strategies the dlPFC, ACC and aINS were reliably recruited, while vlPFC activation was particularly pronounced during reappraisal. The transfer from neurofeedback training effects in this network