Oscillations in the alpha frequency range (8 – 12 Hz) are believed to shape the functional architecture of the brain by exerting inhibitory control over neuronal information processing (Klimesch et al., 1999; Klimesch et al., 2007; Jensen and Mazaheri, 2010). This is accomplished by attenuating the processing of irrelevant information, thereby increasing the efficiency of high priority tasks (Jensen et al., 2014; Bonnefond and Jensen, 2015; Gips et al., 2016). Accordingly, alpha oscillations have been linked to perceptual as well as cognitive performance (Ai and Ro, 2014; Linkenkaer-Hansen et al., 2004; Baumgarten et al., 2016; Vernon et al., 2009). Special training protocols have been developed, enabling participants to learn how to volitionally regulate alpha oscillations (Kamiya, 1971; Sterman, 1981). Such neurofeedback trainings have been implemented with great success to enhance cognitive and perceptual performance along with personal well-being (Hanslmayr et al., 2005; Zoefel et al., 2011; Nan et al., 2013; Gruzelier et al., 2014; Okazaki et al., 2015; Hsueh et al., 2016).

So far, it remains elusive whether learning processes would similarly benefit from increased oscillatory alpha activity and whether neurofeedback training could be applied to control learning efficiency. To attend to this matter, a short-term neurofeedback protocol was implemented to up- and down-regulate somatosensory alpha oscillations. Immediately afterwards, a passive, training-free perceptual learning paradigm was applied, by means of repetitive sensory stimulation (Ragert et al., 2008). This particular type of stimulation has been shown to induce reliable tactile acuity increases to the fingertip, accompanied by reorganizational changes in the somatosensory cortex (Pleger et al., 2001; Dinse et al., 2003b; Pleger et al., 2003; Höffken et al., 2007; Heba et al., 2017; Schmidt-Wilcke et al., 2018). The extent of stimulation-induced reorganization occurring has been shown to reflect the extent of tactile acuity improvement on a behavioral level. After only 20 min of stimulation, sufficient perceptual learning is induced, to be measurable on behavioral level (Ragert et al., 2008).

In the present study, it was demonstrated in two separate experiments that short-term neurofeedback training can be successfully applied to up- and down-regulate somatosensory alpha power. This in turn controls subsequent stimulation-induced perceptual learning. In particular, participants who increased somatosensory alpha power via neurofeedback training displayed increased perceptual learning efficiency compared with control participants. By contrast, neurofeedback-induced down-regulation of somatosensory alpha oscillations disrupted the learning process. The relationship between somatosensory alpha oscillations and
Abstract

Perceptual learning efficiency was especially pronounced in neurofeedback groups, explaining up to 59% of the perceptual learning outcome and markedly reducing interindividual learning variance.

Furthermore, analysis of cortical processing mechanisms during repetitive sensory stimulation revealed distinct patterns for neurofeedback groups. Heightened alpha power levels were maintained throughout the whole duration of stimulation. Additionally, participants who increased somatosensory alpha power showed sustained activation in the stimulated frequency (20 Hz) in between stimulation trains. Participants who decreased somatosensory alpha power revealed increased lower beta (14 – 19 Hz) activation after completion of neurofeedback training. The interaction of both neural processes was directly connected to the extent of alpha power changes during neurofeedback training and the extent of stimulation-induced perceptual learning. Accordingly, both factors represent possible mediators for the effect of alpha oscillations on perceptual learning efficiency.

Alpha neurofeedback training is a promising procedure with high potential for the application in clinical, rehabilitational and pedagogical environments, as well as in daily life.