**Optimizing frontal-sensory alpha-band synchrony to improve attention:
a commentary on Mishra et al. (2021)**

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Introduction

During everyday life, we are continuously subjected to an enormous amount of information. Given the limited capacity of our brain, we cannot process all incoming stimuli simultaneously, and must therefore engage in some selection process. Commonly referred to as “attention”, this process involves making a distinction between goal-relevant and distracting information (Posner, 1980). For example, in vision, we can direct our attention to particular locations in space, or focus on specific (combinations of) stimulus features such as color and shape. This typically enhances visual perception, such that attended stimuli or features can be identified more accurately and more quickly (Posner, 1980).

Numerous studies have investigated the neuronal mechanisms underlying this visual selection process. An often-reported finding is that visual attention is linked to neuronal oscillations within the ~8-14 Hertz alpha band (see Klimesch (2012) for a review). Magneto-/electroencephalography (M/EEG) research has shown that these alpha oscillations originate mostly from posterior brain regions, and that their power is inversely related to visual detection performance (Ergenoglu et al., 2004). Neuronal alpha oscillations thus seem to have a primarily suppressive role (Klimesch, 2012).

Besides revealing activation in the visual system, functional magnetic resonance imaging (fMRI) research has also implicated several higher-level areas in visual attention. Notably, the Dorsal Attention Network (DAN) is involved, including frontal areas such as the Frontal Eye Fields (FEF) and parietal areas such as the Intra-Parietal Sulcus (IPS) (for a review see Scolari, Seidl-Rathkopf, and Kastner (2015)). fMRI signals in both FEF and IPS predicted visual cortex activation during stimulus anticipation (Bressler, Tang, Sylvester, Shulman, & Corbetta, 2008), and especially frontal areas seemed to top-down modulate lower-level sensory areas (De Graaf, Roebroek, Goebel, & Sack, 2010). Given these findings, the question arose whether the communication between these higher-level frontal areas and lower-level sensory areas can be

optimized, to positively affect attention processing in healthy individuals and those with attention deficits.

What exactly should be optimized?

Mishra et al. (2021) recently addressed this question by measuring EEG to calculate alpha-band synchrony between mid-frontal and visual ventral stream areas ('frontal-sensory synchrony', FSS) during attention task performance. In their task, an audiovisual cue was followed by a visual grating stimulus with one of five possible shapes and one of two possible orientations. On each trial, participants indicated whether the stimulus was a target (as designated at the beginning of each experimental block) or a non-target. Crucially, FSS was assessed specifically during the time interval between the attention cue and the visual grating stimulus, thereby isolating the stimulus anticipation (i.e., attentive) process. In their first experiment, the authors found a negative correlation between FSS and task performance. Although anticipatory alpha power in visual ventral stream areas significantly correlated with FSS, there was no significant correlation between alpha power and task performance.

In light of previous findings, the absence of a significant correlation between anticipatory alpha power and task performance might seem surprising (Barne, de Lange, & Cravo, 2020). Furthermore, a recent study found a *positive* correlation between anticipatory alpha-FSS and task performance (Lobier, Palva, & Palva, 2018). Possibly, these discrepancies can be explained by methodological differences and the exact attention mechanism being investigated. Firstly, the attention cue used by Mishra et al. (2021) had an auditory component, which might desynchronize alpha activity in the visual system (Feng, Störmer, Martinez, McDonald, & Hillyard, 2017). Secondly, Lobier et al. (2018) investigated spatial attention (or 'orienting') effects, as target stimuli appeared in either hemifield and preceding cues provided spatially predictive information. By contrast, Mishra et al. (2021) investigated 'alerting' effects, as target stimuli always appeared in the same location and preceding cues were thus temporally but not spatially

informative. Looking ahead, this is especially relevant for potential clinical applications, as children with attention deficit hyperactivity disorder (ADHD) have been shown to display weaker alerting but not orienting ability compared to typically developing children (Mullane, Corkum, Klein, McLaughlin, & Lawrence, 2011). Another important methodological difference is that Mishra et al. (2021) combined task accuracy and reaction times into a single ‘task efficiency’ score, while previous studies typically focused on reaction times (Lobier et al., 2018). The type of task and the quantification of task performance might ultimately determine which neuronal mechanism seems most relevant for optimization (or, in other words, correlates best with task performance). In the specific case of Mishra et al. (2021), this translated into the goal of decreasing anticipatory alpha-FSS to improve attentional alerting.

How to optimize frontal-sensory alpha-band synchrony?

Mishra et al.’s (2021) second experiment involved 10 sessions of neurofeedback during the attention task described previously. Participants were healthy adults, with one group receiving neurofeedback of their own anticipatory alpha-FSS (‘active’ group) and the other group receiving sham neurofeedback (‘inactive’ group). Participants’ goal was to achieve a certain ‘target’ neurofeedback score, which was based on their anticipatory alpha-FSS in a baseline session and was adapted throughout the experiment based on task performance. Only the ‘active’ group improved task performance across sessions. With more consecutive successful trials (i.e., trials in which the ‘target’ FSS was reached), participants in the ‘active’ group learned to reduce their anticipatory alpha-FSS. Interestingly, alpha-band stimulus-evoked responses were higher for targets than for non-targets only in the ‘active’ group, indicating enhanced signal-to-noise ratio (in line with the improved task performance). Neurofeedback benefits were not limited to the training task, but transferred to a sustained attention task. In sum, Mishra et al. (2021) provided compelling evidence for the feasibility and efficacy of rapid alpha-FSS neurofeedback during a cognitive task.

It would be worthwhile to investigate whether the efficacy of alpha-FSS neurofeedback training can be further improved. Besides, neurofeedback might be rather demanding for some individuals, for instance those with neurocognitive deficits. As a potential addition to or alternative for neurofeedback training, transcranial alternating current stimulation (tACS) could be employed (Antal & Paulus, 2013). This non-invasive brain stimulation method can be used to target alpha activity in a brain area (e.g., de Graaf et al., 2020), but also to modulate alpha synchrony between areas (van Schouwenburg, Zanto, & Gazzaley, 2017). Based on the results from Mishra et al. (2021), one would expect that asynchronous alpha-tACS of frontal and visual ventral stream areas (to decrease alpha-FSS) would lead to further attention task performance improvements. It remains to be investigated whether this is indeed feasible and effective.

Though not observed by Mishra et al. (2021), it is possible that there is a limit to the neurofeedback training benefits, such that decreasing alpha-FSS below a certain threshold no longer improves performance. This is analogous to the finding that increasing medication dosage is not always beneficial in ADHD (Stein et al., 2005). The exact threshold might differ across individuals, which makes it essential to personalize training/treatment strategies. For instance, it would be interesting to assess how much Mishra et al.'s (2021) alpha neurofeedback training might benefit from targeting individualized EEG frequencies (Bazanov & Aftanas, 2010).

Why is it relevant to optimize frontal-sensory alpha synchrony?

In a third experiment, Mishra et al. (2021) investigated whether their neurofeedback training could be successfully applied to children with ADHD. As expected, alpha-FSS decreased, task performance increased, and sustained attention task performance increased on average with training. Not all children showed this effect, further highlighting the fact that neurofeedback might not be suitable for everyone. Though the specificity of neurofeedback training effects needs to be established by including an age-matched control group, Mishra et al.'s (2021) findings are promising, as they show that rapid cognitive neurofeedback can be beneficial for at

least some children with ADHD. Their findings might furthermore be applicable to clinical populations that show altered alpha synchrony and suffer from attention deficits, such as stroke patients with spatial neglect (Sasaki et al., 2013).

Besides potential clinical applications, Mishra et al.'s (2021) findings are informative for fundamental research as well. For instance, their attention task required the detection of two features, while previously used attention tasks often only involved the detection of a single, low-level feature (e.g., Schuhmann et al. (2019)). This is why the authors selected visual ventral stream areas in temporal cortex, rather than even lower-level sensory areas in (early) visual cortex. This aligns well with a recent opinion paper, which argued that attentional selection might indeed not occur within early visual cortex, but higher up the visual hierarchy (Peylo, Hilla, & Sauseng, 2021). As a final example, Mishra et al.'s (2021) findings might help solve the long-standing debate whether alpha rhythms enable attentional selection solely by enhancing targets, or also by suppressing irrelevant stimuli (for a review see Foster and Awh, 2019). Specifically, stimulus-evoked responses to targets versus non-targets (i.e., irrelevant stimuli) could be compared before and after neurofeedback, across (non-)active groups. It could then be evaluated whether changes in alpha synchrony following neurofeedback lead to changes in the processing of targets versus irrelevant stimuli.

Conclusion

Mishra et al. (2021) are the first to demonstrate that rapid, anticipatory alpha-FSS neurofeedback is feasible and can improve attention beyond the training task. Their paradigm and findings may be used to improve treatment strategies for individuals with attention deficits, and can help shed light on unanswered fundamental neuroscientific questions. Future studies could explore whether the efficacy of alpha-FSS neurofeedback can be further improved by combining it with tACS and/or by targeting individualized EEG frequencies.

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