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N2pc-based decoding of covert visual spatial attention is independent of stimulus predictability

C. Reichert[1*], S. Dürschmid[1], F. Tittel[2], H. Hinrichs[1,2]

[1]Leibniz Institute for Neurobiology, Magdeburg, Germany; [2]Otto-von-Guericke University, Magdeburg, Germany

*Brenneckestr. 6, 39118 Magdeburg, Germany. E-Mail: christoph.reichert@lin-magdeburg.de

Introduction: Recently, it has been shown that visual stimuli presented simultaneously in the periphery of the left and right visual hemifield are suitable to control a brain-computer interface (BCI) by shifting attention to a target stimulus with no requirement of eye movements [1]. In the electroencephalogram (EEG), parieto-occipital channels typically record stronger negative deflections around 220ms after onset of targets contralaterally presented compared to ipsilateral ones. The N2pc is defined as the difference of these contra- and ipsilateral EEG deflections. This phenomenon permits to decode the side of target presentation even though it is only covertly attended. Despite a huge body of literature on the effects of stimulus characteristics on the N2pc, the impact of stimulus predictability on decoding is not known. Here we investigate three facets of predictability of target stimuli on decoding accuracy and on EEG wave forms: presentation speed, temporal predictability and spatial predictability.

Methods: Twenty participants were asked to perform a visual search task in which they covertly attended a peripherally presented, colored target item. In each trial, a series of ten stimuli was shown, where the target and nontarget item were presented in opposite visual hemifields. In eight runs we combined different stimulus characteristics. We presented the items with shorter (600ms) and longer (800ms) stimulus onset asynchrony (SOA), with constant or jittered (0–250ms were added) SOA, and in a random or predictable (alternating between hemifields) order. We quantified the N2pc as difference between contralateral and ipsilateral event-related potentials, averaged between 180ms and 250ms and across channels P3, P7, PO3, PO7 and P4, P8, PO4, PO8, depending on the side of target presentation and compared these values using a paired t-test. Most importantly, we compared the decoding accuracies obtained by decoding the attended item from parieto-occipital EEG channels using an approach based on canonical correlation analysis [1], by means of Wilcoxon signed-rank tests.

Results: All three tested stimulus characteristics resulted in comparably high decoding accuracies, showing no statistically significant differences (random order: 90.3%; predictable order: 88.3%; short SOA: 90.0%; long SOA: 90.1%; constant SOA: 89.5%; jittered SOA: 89.2%). However, due to the faster stimulus, the information transfer rate (ITR) was significantly higher with short SOA (5.2 bit/min) than with longer SOA (4.0 bit/min). Waveform investigation resulted in a significantly higher N2pc amplitude with longer SOAs compared to shorter SOAs ($t(19)=5.14$, $p=0.0001$) and in random stimulus order compared to predictable stimulus order ($t(19)=3.96$, $p=0.0008$). No variation of the N2pc was found in jittered SOA compared to constant SOA.

Conclusion: Although the N2pc amplitude, as a marker of visual spatial attention, was significantly modulated when stimulation speed and spatial predictability was varied, no differences were found in decoding accuracy. The independence of temporal and spatial stimulus predictability shows that the N2pc represents a robust signal which can be used to control gaze-independent BCIs. While the higher ITR achieved with shorter SOAs suggests that the SOA could be further reduced, the length of the SOA is limited due to the subject’s cognitive capabilities and the time course of attention-based brain potentials.

References

[1] Reichert C, Tellez Ceja IF, Sweeney-Reed CM, Heinze HJ, Hinrichs H, Dürschmid S. Impact of stimulus features on the performance of a gaze-independent brain-computer interface based on covert spatial attention shifts. *Frontiers In Neuroscience.*, 14:591777, 2020.