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Disentangeling working memory load – finding inhibition and updating components in EEG data

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Introduction: Recently, passive BCIs have been used for the estimation of working memory load – a quantity describing the used amount of an individual's memory capacity. A well-known theory by Miyake et al. [1] distinguishes three executive functions (updating, shifting and inhibition) as differential factors imposing load onto working memory's central control structure. Most BCI-related research, however, considers working memory load as a unitary construct. The closer investigation of the individual workload components in terms of their neural signatures and the feasibility of their EEG-based classification was addressed by this work. The focus was on two functions updating and inhibition.

Material, Methods: A dataset consisting of EEG recordings of 22 subjects performing an n-back task with the simultaneous presentation of flanker-items formed the basis of the analysis (Scharinger *et al.* [2]). The n-back task imposes demands on updating, whereas the flanker task imposes demands on inhibition. The n-back was performed on sequentially presented strings of seven letters, to which the subjects had to respond with a button press. 'Yes' – the central letter of the string equals the central letter presented *n*-steps before (with three different levels of n manipulating updating demands: 0, 1 and 2) or 'No' the letter is not equal. The flanker accompanying the central letter for the n-back task consisted of six identical letters, three presented on the right, three on the left side of the central letter. The six letters could either be the same (congruent flanker: no inhibition demands) or different (incongruent flanker: inhibition demands) to the central letter. No reaction concerning the flanker was required by the subject. Features in the time and frequency domain have been evaluated for all correct updating and inhibition trials (correct button press). A support vector machine with a linear kernel and a 10-fold cross-validation was used for classification. In the time domain, the one second time frames of all correct trials (from stimulus onset) and all midline EEG channels (*1, *2, *3, *4, *Z positions) were used for classification. In the frequency domain, power spectra between 4-13 Hz for the same set of EEG channels were used. The calculation of the power spectra was done via Burgs maximum entropy method using a modelorder of 32.

Results: Classification on time domain features did not provide good results, which is why no values are reported. Classification based on the power spectra were more promising as can be seen in Table 1. Inhibition vs Baseline (and Updating vs Baseline) was tested in a 10-fold cross-validation to evaluate if the component can be differentiated from baseline trials in which the component was not required. Additionally, Updating vs Inhibition was tested to find out whether both workload components can be distinguished from each other (also cross-validated). The two individual classifiers (vs Baseline) were also tested on trials containing only the opposing component to evaluate if they share strong similarities, which would be an indicator for working memory as a unitary construct instead of a construct based on distinguishable functions.

Table 1. *Classification accuracy averaged over all 22 subjects. Upd. (Updating) refers to all trials in the 1-back condition with congruent flanker. Inh. (Inhibition) to trials in the 0-back condition with incongruent flanker. BL (Baseline) refers to 0-back trials with a congruent flanker. 2- vs 1-back and 2- vs 0-back were also evaluated but are not reported here due to shortage of space.*

Trainset	Inh. vs BL	Upd. vs BL	Upd. vs Inh.	Upd. vs BL	Inh. vs BL
Testset	Inh. vs BL	Upd. vs BL	Upd. vs Inh.	Inh.	Upd.
Accuracy	72.07 %	65.36 %	71.66 %	59.75 %	55.12 %

Discussion: The results indicate that inhibition and updating demands can be classified with accuracies sufficient for the use in passive BCI applications. They corroborate the hypothesis that workload consists of different components, which can be distinguished by their neural signatures. The fact that a classifier trained on either of the two components does not perform well on a dataset containing only the opposing component sustains the assumption that updating and inhibition are two different processes. Confounds due to task design and stimulus presentation can be ruled out as the two functions were executed simultaneously in one experimental setup. For the detection of workload the combination of different classifiers specialized on the individual executive functions might therefore be a good alternative to using one general workload classifier.

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