The Role of Alpha Band Activity During Retrieval of Perception-Action Features – How Top-Down Attentional Control Prevents Inadequate Retrieval

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Background: Human cognition is fundamentally geared toward action control, i.e., the ability to respond efficiently to environmental demands. A core mechanism supporting this function is the episodic retrieval of previously formed perception-action bindings. When individuals encounter features of prior experiences, these bindings can be automatically reactivated, enabling fast and often unconscious action responses. Nevertheless, such automatic retrieval can be maladaptive if contextual demands differ, which underscores the importance of simultaneous attentional control. This thesis systematically investigates how alpha band activity (ABA) serves as a neural marker of this attentional regulation while retrieving integrated perception-action features.

Research questions: The overarching research question if attentional control is a modulator for retrieval efficiency is subdivided into three more specific ones:

(i) Is attentional control, observable as pronounced ABA, reflecting retrieval of previous bound features, and not just to focused responding in general?
Objectification: Within-subject, ABA is significantly higher during responses that are influenced by retrieval processes compared to responses that are not.

(ii) Is increased attentional control, observable as more pronounced ABA, reflecting improved episodic retrieval?
Objectification: Within-subject, ABA is significantly higher for improved retrieval, i.e., less overlap costs, compared to typical retrieval. Vice versa, within-subject ABA is less or not at all pronounced, when retrieval is less or not at all improved.

(iii) Are general deficits in attentional control linked to detrimental retrieval and a failed modulation of ABA?
Objectification: Individuals with known general deficits in attentional control, i.e., individuals with attention-deficit-(hyperactivity) disorder (AD(H)D) show simultaneously detrimental retrieval, i.e., more partial overlap costs, and lower ABA compared to individuals without general deficits in attentional control.

An additional explorative research question is of great value: Which brain regions are involved in modulations of ABA during episodic retrieval? To this end, source-localization will be applied for significant differences in ABA in each empirical study.

Methods: To address the respective research question, binding effects were examined in four EEG studies with different paradigms and samples:

(i) an embedded response paradigm including action plan withholding and discarding within a sample of healthy adults to investigate the distinction between retrieval and non-retrieval conditions
(ii) a distractor-response binding paradigm including two degrees of predictability within a sample of healthy adults to investigate variations in retrieval efficiency
(iii) a distractor-response binding paradigm including two degrees of predictability within a sample of healthy (pre-)adolescents to investigate variations in retrieval efficiency
(iv) a conflict Go/Nogo task including overlapping and non-overlapping stimuli within a sample of children and adolescents with AD(H)D to investigate the role of attentional dysfunctions.

In all studies time-frequency transformed data was analyzed with focus on ABA. When significant differences in ABA were observed, source-localization in form of Dynamic Imaging of Coherent Sources beamforming was applied for the respective time intervals. Additionally, an effective connectivity analysis was applied in one study as well as a multi variate pattern analysis in another study.

Results: Findings consistently show that stronger and more precisely timed ABA modulations are linked to more efficient retrieval. ABA was significantly higher in conditions that should initiate retrieval compared to ones that do not, and was even higher when retrieval performance was improved. Conversely, delayed or attenuated ABA, particularly in individuals with attentional vulnerabilities (children and adolescents with AD(H)D), predicts reduced retrieval performance. The specific brain regions involved varied depending on additional cognitive demands, such as motor inhibition or contextual updating. The effective connectivity analysis revealed that when retrieval was significantly improved, ABA was not only elevated within the same brain regions as were involved in unimproved retrieval, but the connectivity between

those brain regions shifted. In summary, ABA modulation emerged as a general, task-independent mechanism.

Discussion and implications: ABA's consistent engagement across paradigms and sensitivity to attentional dysfunction suggest that it is a reliable neural marker of top-down attentional control during retrieval. Alpha oscillations likely facilitate attentional "shielding": suppressing irrelevant features while enhancing task-relevant memory traces. This enables the brain to manage the sensory complexity of everyday environments by filtering episodic content in a goal-directed manner. Importantly, the thesis also provides clinical insights, showing that in AD(H)D, the timing but not the strength of ABA is disrupted, leading to premature or inappropriate responses. These results point to novel directions for targeted interventions, such as neurofeedback to enhance ABA regulation. The convergence of findings across paradigms and populations strengthens the central claim that ABA modulation plays a crucial role in shaping adaptive retrieval – independent of the brain regions involved. Thus, this thesis advances our understanding of how the brain balances flexibility and stability in action control, paving the way for new approaches to target attentional and action control deficits.