Short-Term Memory Improvement Requires Stable Modulation of EEG Alpha Oscillations

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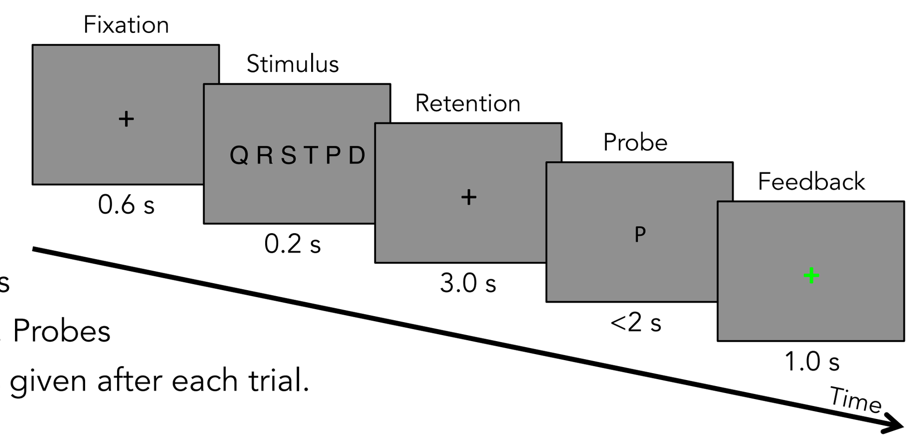
How does increased effort modulate neural activity during short-term memory retention?

Alpha-band (9–13 Hz) oscillations during short-term memory retention are hypothesized to act as a sensory gating mechanism, protecting the contents of memory. The magnitude of these oscillations is observed to increase with memory set size (Bonnefond & Jensen, 2012). To understand the roles that subjects' effort and cognitive control play in this response to increasing task difficulty, we offered a bonus monetary payment on one block of a short-term recognition memory experiment while recording electroencephalogram (EEG).

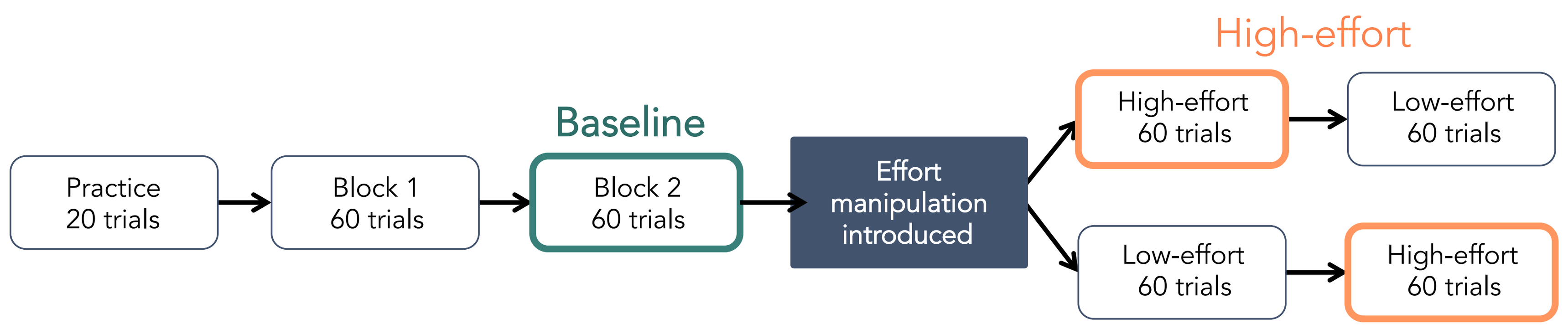
Experimental task and design

In a modified Sternberg short-term memory paradigm, each trial's memory set comprised six consonants. The memory set was presented for 0.2 s, followed by a 3 s retention interval.



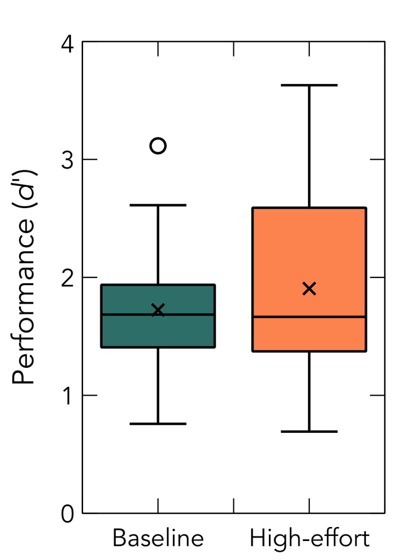
A single probe letter was then presented, and subjects reported whether it was a member of the memory set. Probes had a 50% probability of being targets. Feedback was given after each trial.

Twenty subjects each completed four 60-trial blocks. After the first two blocks, we told the subject that we were interested in how brain activity changed with effort, and that we would ask him or her to exert "low effort" or "high effort" in the next blocks. Post-manipulation block order was counterbalanced across subjects.



High-effort blocks included a monetary bonus ($1 for correct responses) on ten random trials. At the end of a bonus trial, the feedback fixation cross was surrounded by $$ symbols, indicating that the subject had earned (or lost the opportunity to earn) a bonus payment.

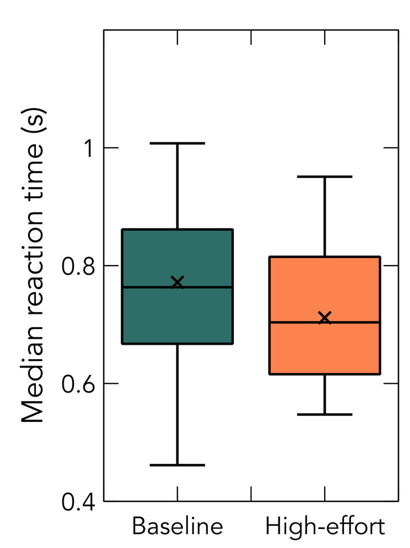
Asking for high effort produces small boost in accuracy



Only 65% of subjects had higher d' scores on the **high-effort** block than on the **baseline** block. The difference between conditions was not significant, $t = 1.20$, $p = .245$.

Subjects have difficulty improving short-term memory performance when offered a random-reward monetary incentive.

Median reaction times were significantly lower in the **high-effort** block, $t = 3.77$, $p = .001$.



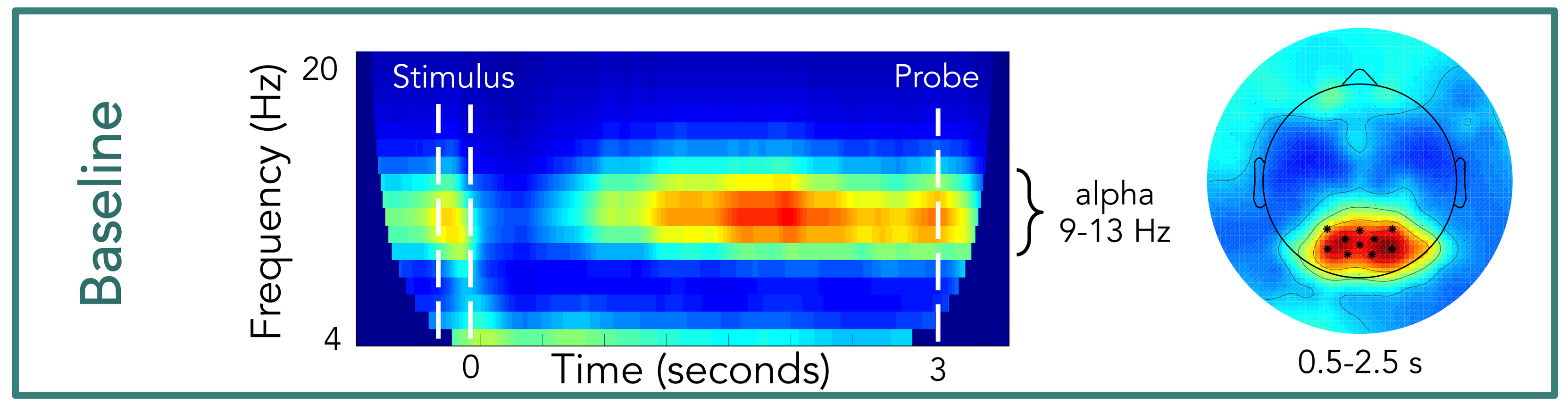
EEG recording and analyses

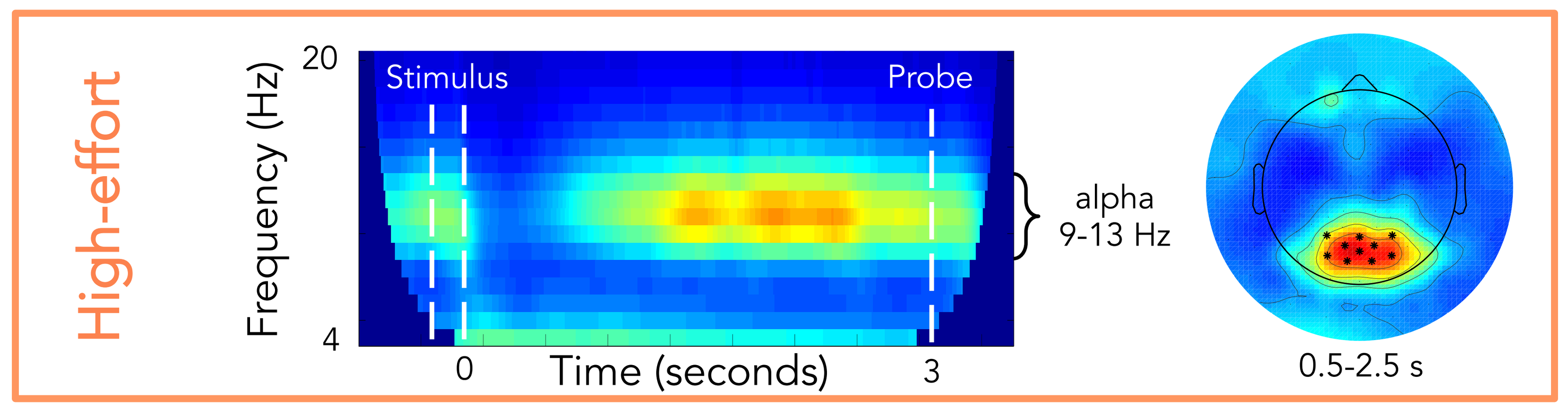
High-density scalp EEG was recorded at 250 Hz for offline analysis. The EEG signal was filtered to between 2 and 100 Hz, and artifacts were removed by visual inspection and ICA analysis.

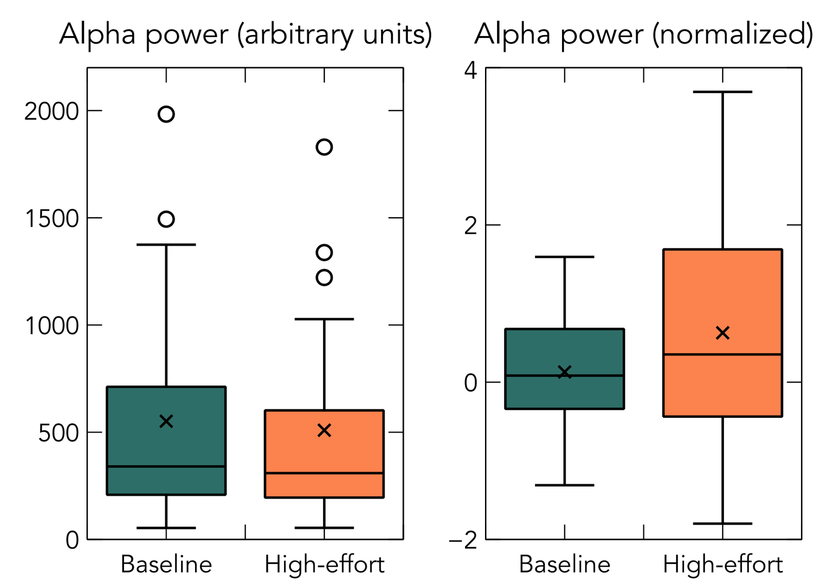
Time-frequency transforms were performed using a Morlet wavelet filterbank on the time window from 0.5-2.5 seconds after stimulus offset.

Retention-period alpha is higher in baseline than high-effort

Average alpha power at an array of 10 parietal electrodes was higher in the **baseline** than in the **high-effort** block.



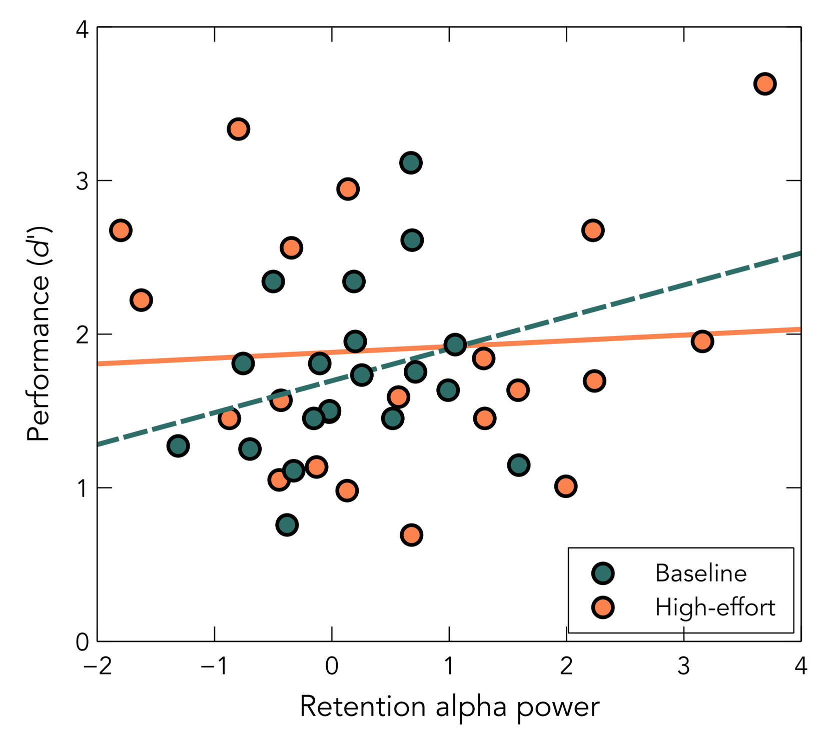




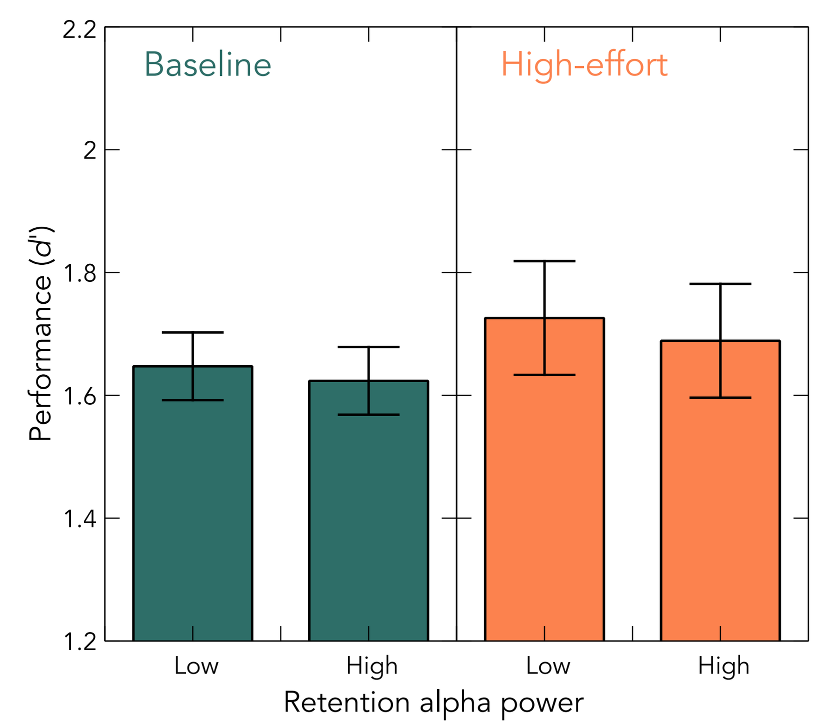
Inter-subject variability in alpha power was very high (two orders of magnitude). Raw differences between conditions were not significant, $t = 0.48$, $p = .640$.

To control for the skewed distribution of alpha signal strength, we normalized the alpha power scores by log-transforming, baseline-correcting, and z-transforming them,. The two conditions were not significantly different after normalization, $t = 0.41$, $p = .687$.

Retention-period alpha power does not predict performance



The relationship between a subject's retention-period alpha power and his or her performance is not significant in either the **baseline** or the **high-effort** condition ($r = .137$, $p = .399$).

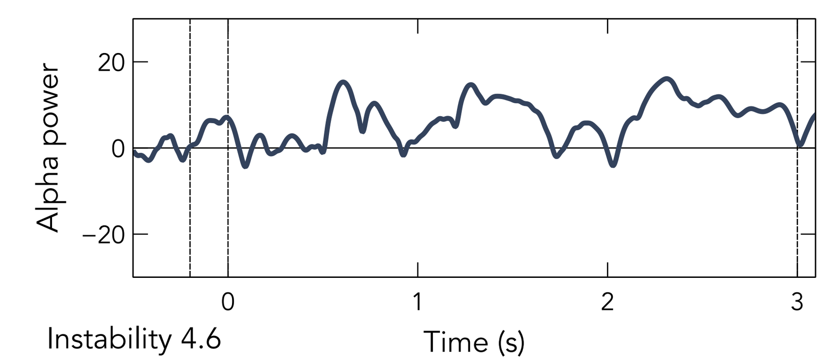


Within subjects, we median-split trials based on retention-period alpha power. There is no significant difference in d' in either the **baseline** or **high-effort** conditions (baseline: $t = 0.22$, $p = .827$; high-effort: $t = 0.51$, p = .614).

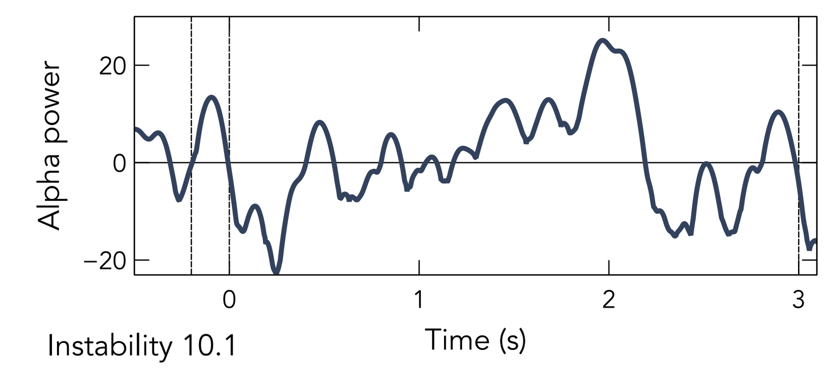
Retention-period alpha stability predicts performance

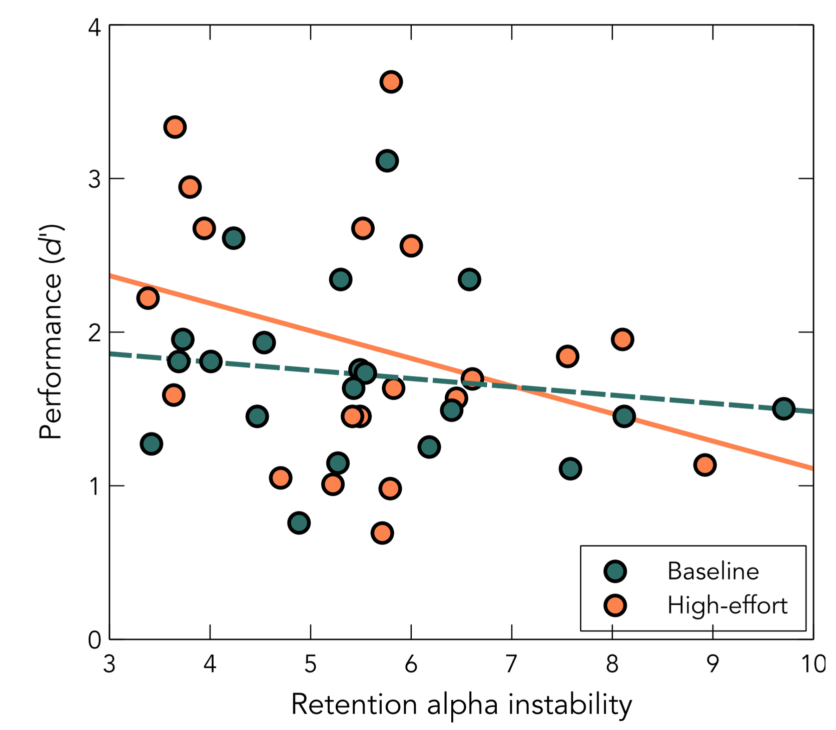
We computed the instability of retention-period alpha power within each trial by taking the SD of normalized alpha power across the time window from 0.5-2.5 s from stimulus offset. Then, for each subject, we computed the mean instability for each condition.

Example low-instability trial:

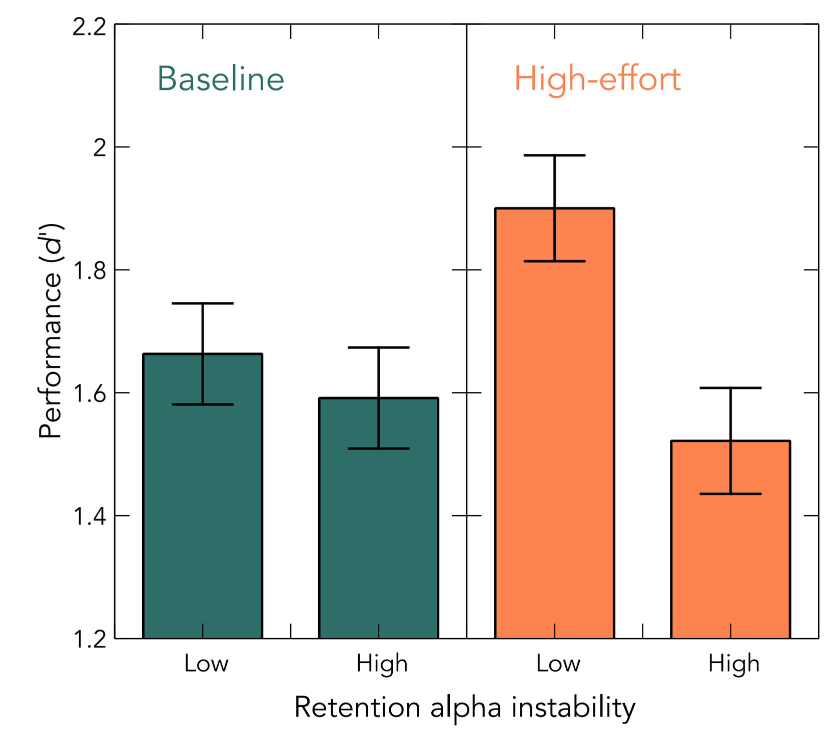


Example high-instability trial:





The relationship between a subject's retention-period alpha instability and his or her performance is significant in both the **baseline** and the **high-effort** conditions ($r = .34$, $p = .032$).



Within-subjects, we median-split trials based on retention-period alpha instability. Instability significantly impairs performance in the **high-effort** condition, $t = 2.25$, $p = .036$.

Attempting to increase effort had minimal overall impact on most subjects' performance.

Instructions to maximize effort improved accuracy for roughly two-thirds of subjects, although most changes were small. Even with monetary reward, successful intentional adjustments in performance are difficult.

Alpha-band neural activity is high during retention in both baseline and high-effort trials.

Subjects consistently display sustained alpha-band activity during short-term memory retention, regardless of effort level, with slightly higher alpha in the baseline condition. However, the average level of such activity does not predict performance, either between subjects or across trials, in either effort condition.

Stable maintenance of alpha-band activity predicts short-term memory retention.

Maintaining a working memory representation requires that it be protected from distractors or other interference. High within-trial instability in the alpha band may reflect failures of such protection. Stability of alpha-band activity during retention could be a marker of cognitive control capacity.

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Bonnefond, M. & Jensen, O. (2012). Alpha oscillations serve to protect working memory maintenance against anticipated distractors. *Current Biology, 22*, 1969-1974.