The vulnerability of working memory to distraction is rhythmic

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Background

Recent research has shown that the cognitive system samples target stimuli rhythmically at frequencies ~3–8 Hz [e.g., 1–3].

Although evidence for rhythmic sampling comes mainly from the visual modality, there is also some evidence for rhythmic sampling of auditory objects [4].

Besides encoding of targets, a key cognitive function is the protection of working memory from distractor intrusion.

Research question: Is the vulnerability of working memory to distraction rhythmic?

Approach: We employ behavioural markers (memory recall) and neural markers (N1 ERP amplitude) of distractor intrusion in working memory and test whether these are periodically modulated by distractor onset time.

Methods

Participants: N = 23 in main experiment; N = 6 in follow-up experiment.
Task: Irrelevant-Speech Task in main experiment [5]; visual match-to-sample task in follow-up experiment. Distractor presentation during working memory retention.
Distractor stimuli: Short spoken sentences in main experiment; broad band (0.1–5 kHz) noise of 1-s duration in follow-up experiment.
Distractor onset manipulation: randomly drawn from uniform distribution [1.035; 1.835 s] relative to encoding offset in main experiment; 24 linearly spaced time points in the interval 0.5–1.5 s relative to offset of memory encoding in follow-up experiment.
Analysis of periodic modulation: Linear mixed-effects models (Fig. 2A–C) with sine- and cosine-transformed distractor onset time as predictors [6].

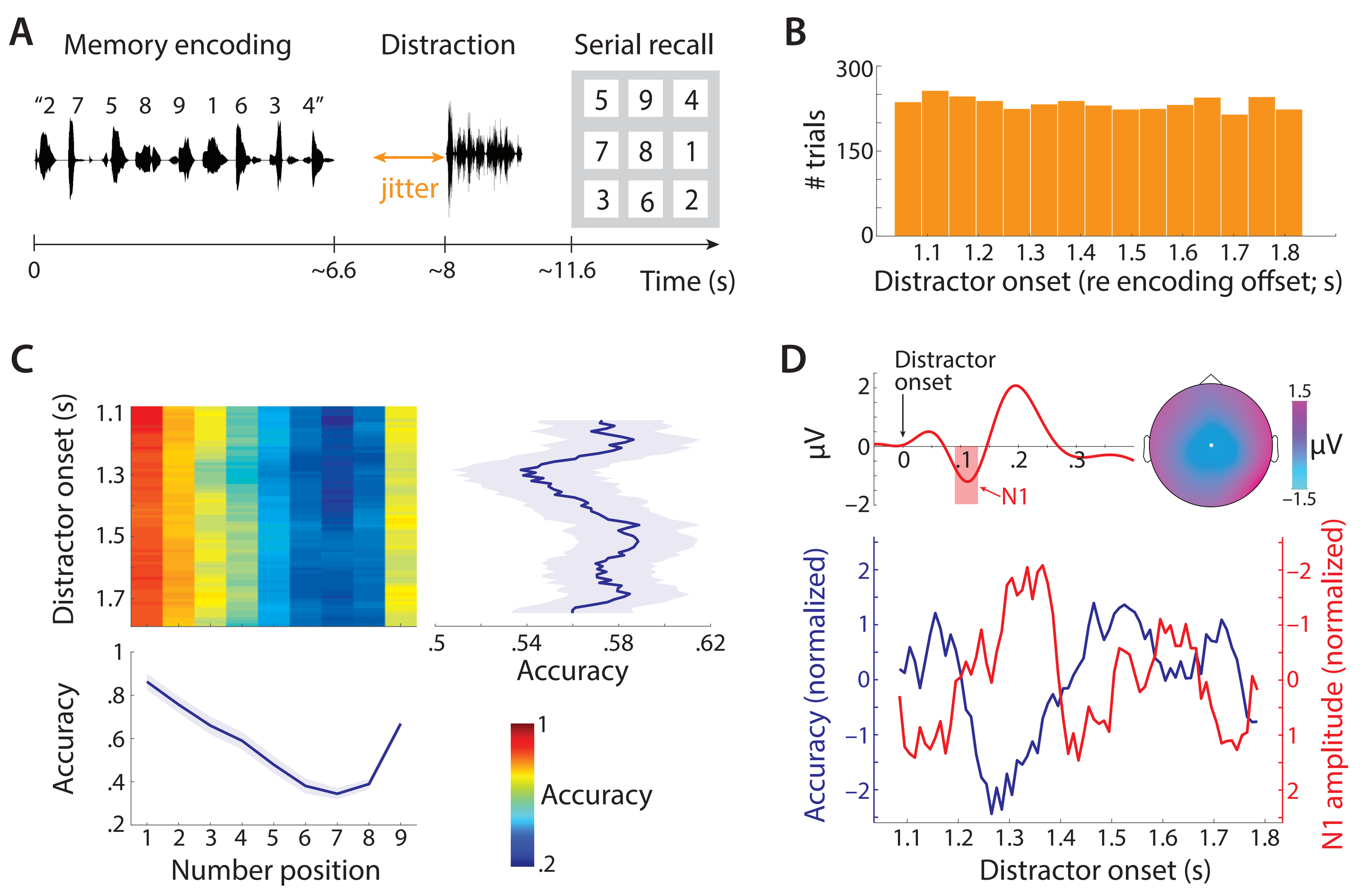

Figure 1. (**A**) Irrelevant-Speech Task. During retention of numbers in memory, participants were distracted by a task-irrelevant spoken sentence. At the end of each trial, participants had the task to select the numbers from a visual display in the order of presentation. (**B**) Histogram of distractor onset times across all (N = 23) participants. (**C**) Heatmap shows average recall accuracy as a function of number position (x-axis) and binned distractor onset time (y-axis). Blue lines show marginal means. Shaded areas show ±1 between-subject standard error of the mean (SEM). (**D**) Top: Grand-average distractor-evoked event-related potential (ERP) at electrode Cz. The topographic map shows the N1 component in the time window .09–.13 s after distractor onset (red shaded area). Bottom: Lines show z-transformed grand-average proportion correct (blue) and N1 amplitude (red) as a function of binned distractor onset time. Note that negative N1 amplitude values (referring to stronger distractor encoding) are plotted upwards.

Distractor onset periodically modulates memory recall

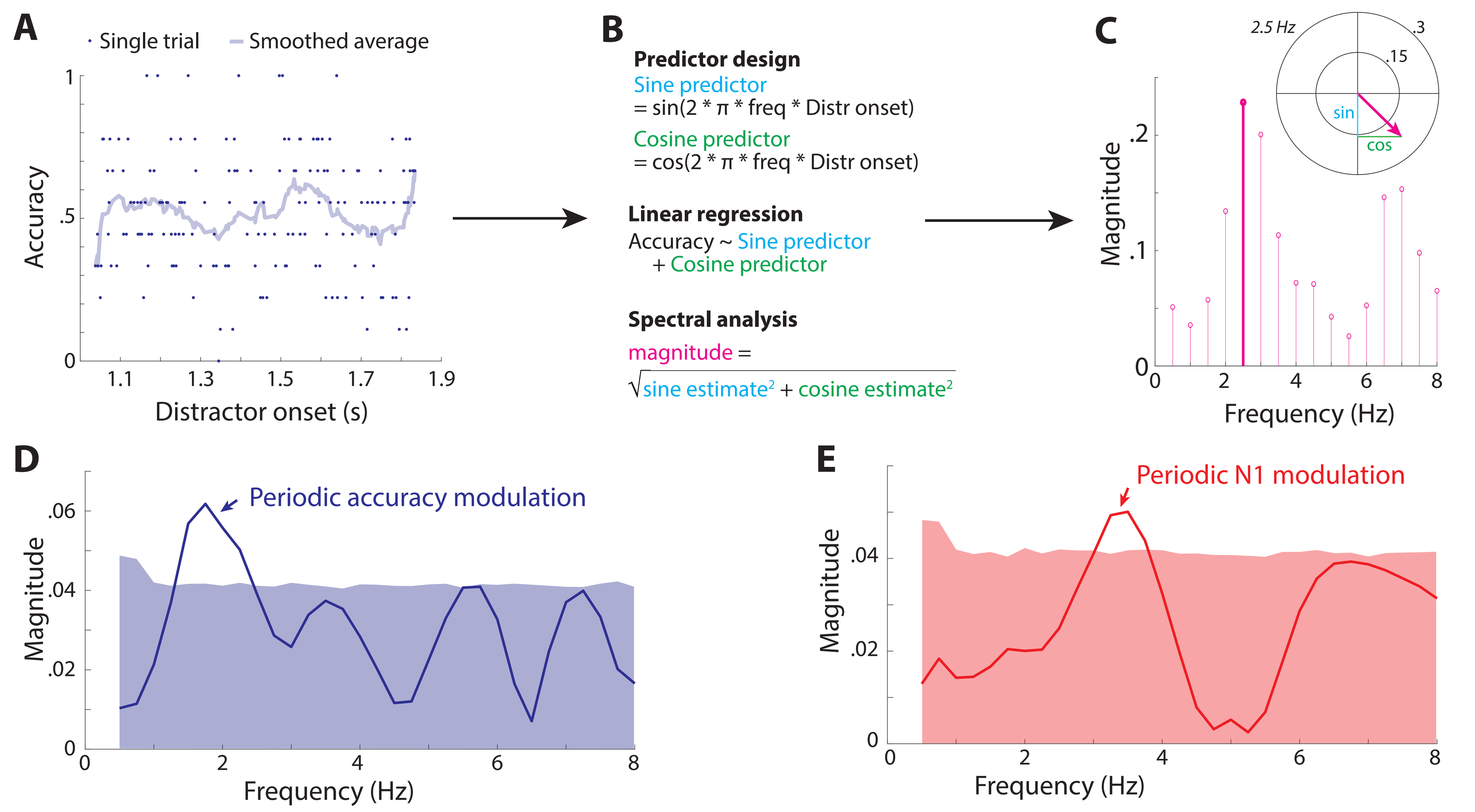

Figure 2. (**A–C**) Analysis procedure for periodic modulation of single-trial measures of distraction. (**A**) Dots show single-trial accuracy as function of distractor onset for one participant. The shaded line shows accuracy averaged across twenty neighbouring distractor onsets. (**B**) For statistical analysis, sine- and cosine-transforms of distractor onset time were used as predictors in a linear regression to model single-trial accuracy. Spectral magnitude was calculated as the square root of the sum of squared sine and cosine estimates. (**C**) Spectral magnitudes derived from multiple linear models for frequencies 0.5–8 Hz. The unit circle shows sine/cosine estimates and spectral magnitude (length of pink arrow) for a frequency of 2.5 Hz. (**D**) Solid line shows spectral magnitude of periodic modulation of single-trial accuracy by distractor onset (derived from linear mixed-effects models). Shaded area shows the 95th percentile of surrogate spectra (derived from 5,000 permutations of single-trial distractor onset time within single participants). (**E**) Same as D but for periodic modulation of N1 amplitude.

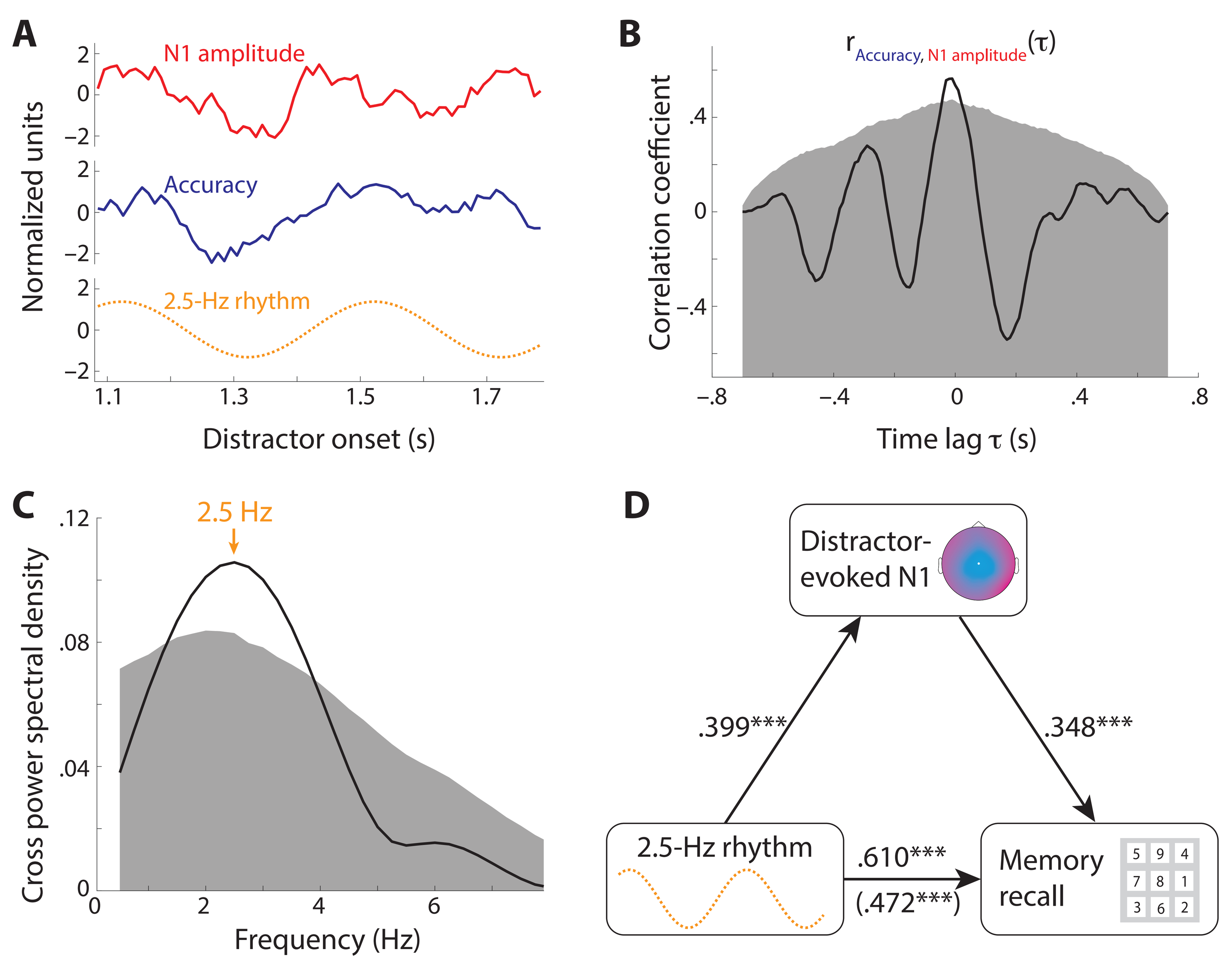

Figure 3. (**A**) Average N1 amplitude (red), accuracy (blue), and the 2.5-Hz rhythm (orange) extracted from the mixed-effects model to regress single-trial accuracy on 2.5-Hz sine- and cosine-transformed distractor onset time. (**B**) Cross-correlation of average recall accuracy and N1 amplitude. (**C**) Cross power spectral density of average recall accuracy and N1 amplitude. Shaded areas in B&C show 95th percentile computed on surrogate data (derived from 5,000 permutations of single-subject distractor onset times). (**D**) Mediation analysis. Numbers at arrows show beta-coefficients of linear regression models. The total effect of the 2.5-Hz rhythm on memory recall accuracy (.610) was weakened when N1 amplitude was controlled for (direct effect= .472), resulting in a significant partial mediation via N1 amplitude (indirect effect = .139). *** p<.001.

Replication in a visual match-to-sample task

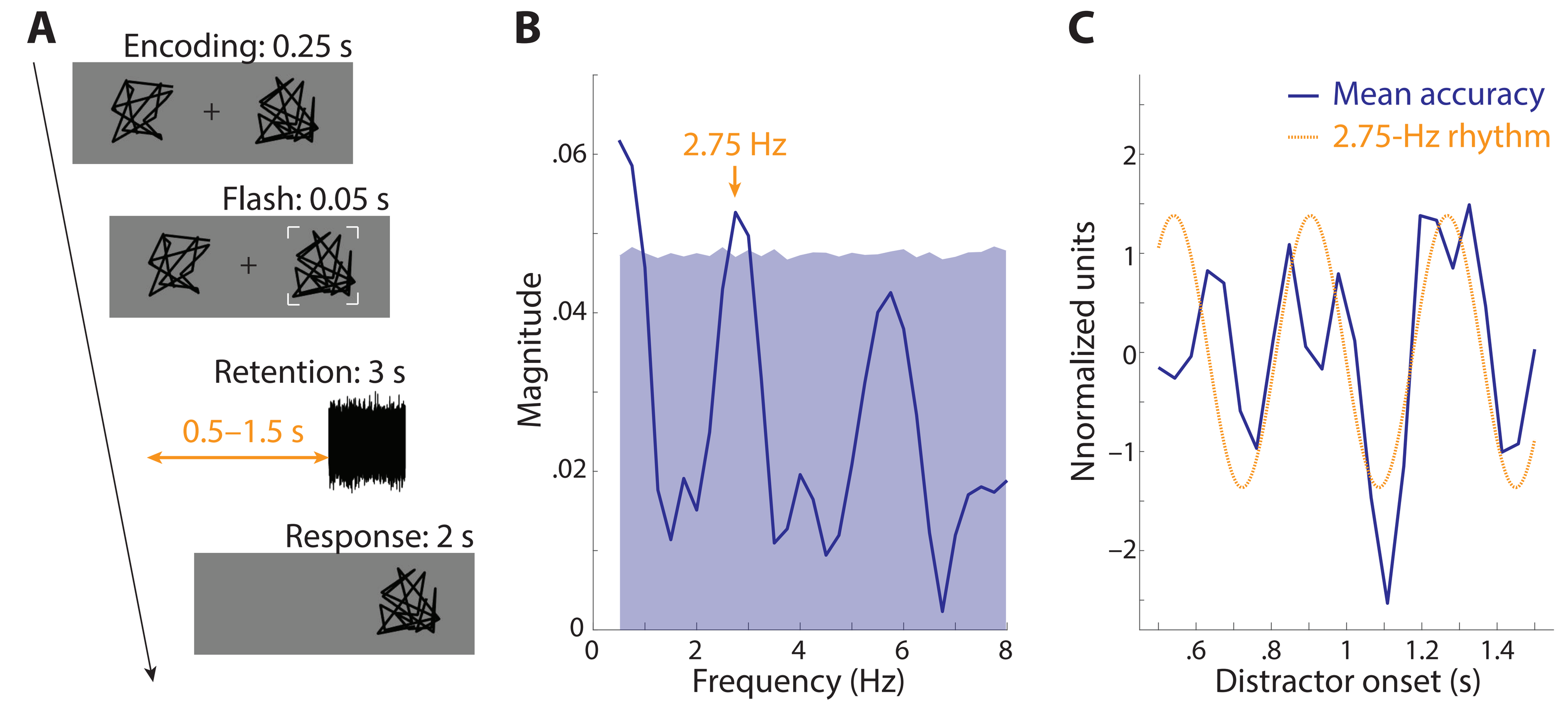

Figure 4. (**A**) Design of behavioural follow-up experiment. Participants (N = 6) encoded two line-figures, before one of them was highlighted by a flash event. During the ensuing 3-s memory retention period, an auditory distractor was presented at one of 24 linearly spaced delays between 0.5 and 1.5 s. In the end of a trial, participants had to indicate whether the probe figure matched the one presented on the same side during encoding (response timeout: 2 s). (**B**) Line shows spectral magnitude of periodic modulation of single-trial accuracy by distractor onset. Shaded area shows the 95th percentile of surrogate spectra (derived from 5,000 permutations of single-trial distractor onset time within single participants). (**C**) The blue line shows average accuracy (which was temporally smoothed, detrended, and z-transformed for purpose of visualization). The orange line shows the 2.75-Hz rhythm derived from the mixed model to regress accuracy on sine- and cosine-transformed distractor onset time.

Conclusions

While previous research has shown that the attentional sampling of exogenous target stimuli [1&2] and target stimuli retained in working memory is rhythmic [3], we demonstrate here that the vulnerability of working memory to distraction is rhythmic at a frequency of ~2.5 Hz.

Since target sampling and distractor suppression have recently been shown to be largely independent neuro-cognitive processes [e.g., 7&8], it is well conceivable that rhythms of different frequency orchestrate the dynamic sampling of target stimuli at ~3–8 Hz versus suppression of distractors at ~2.5 Hz.

The follow-up experiment shows that memory distractibility fluctuates rhythmically even when no rhythmic sensory stimulation precedes working memory retention. This supports the notion that the observed ~2.5-Hz rhythm is a spontaneous, internal rhythm underlying memory function.

References

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