Prefrontal tuning in mnemonic chunking in a spatial self-ordered search task

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Introduction

1. Mnemonic chunking, the ability to group information held in mind, improves working memory (WM) capacity, but the neural mechanisms that reorganize mnemonic information remain unclear.

2. Neurons in primate dorsolateral prefrontal cortex (DLPFC) encoded WM information in visuospatial WM task, and spatial tuning decreased when sequencing strategies were used (Chiang & Wallis, 2018).

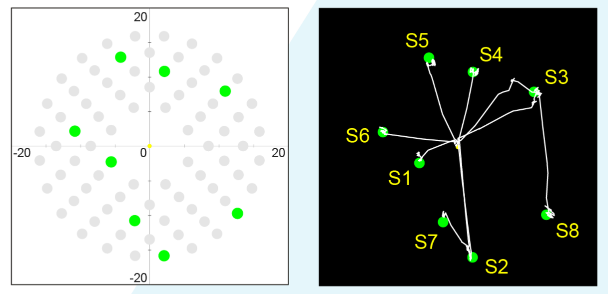
3. Evidence from neural network models and human fMRI studies indicate that neural representations of chunked items merge together, in some cases based on spatial proximity.

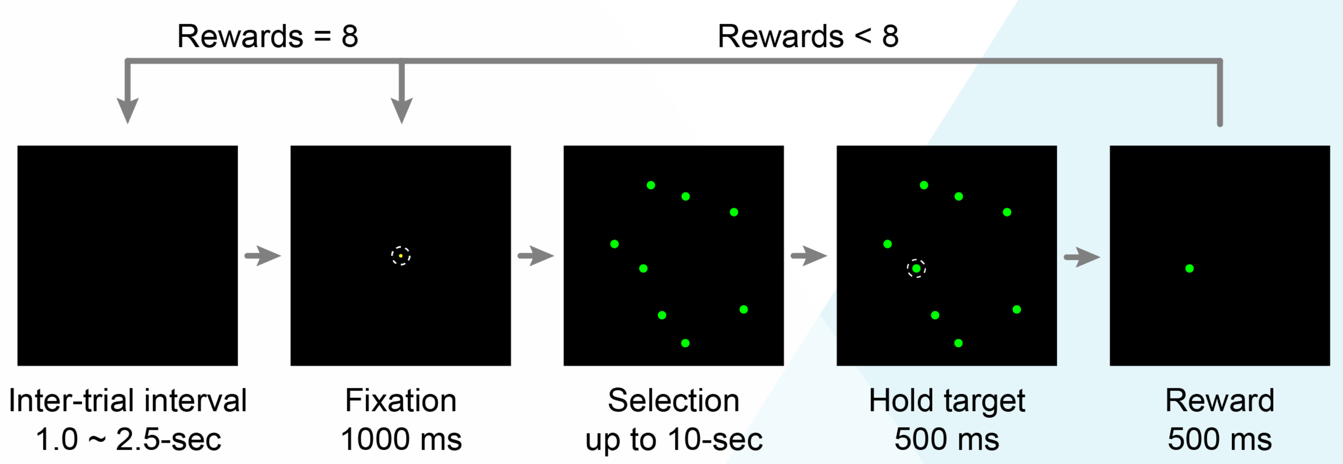
4. Therefore, our hypothesis is that WM representations in DLPFC may merge together when targets are part of the same chunk.

Methods

NHPs performed a spatial self-ordered search task

1. Task designs:
- 8 identical targets per trial
- target configurations generated pseudorandomly
- same configuration for blocks of 40 trials
- 6 blocks with different configurations per session



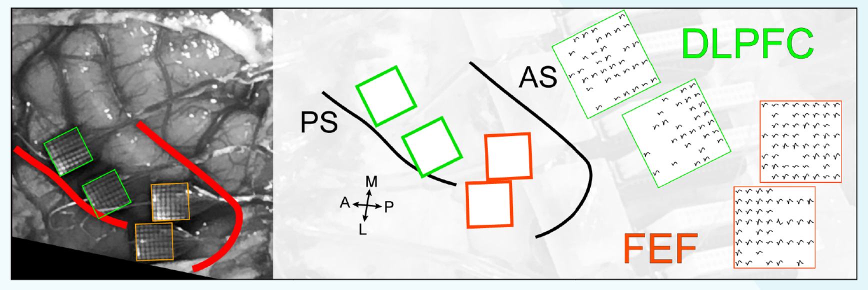


2. Monkeys select all reward targets one at a time with any order by using eye saccades. Targets revisited within a trial were counted as an incorrect saccades and not rewarded. Reward contingencies reset when all targets have been visited, following an inter-trial interval. Therefore, monkeys must use WM to maintain and update visited targets in order to collect all rewards.

3. The color matrix shows how often each target was selected first, second, etc. Common selection patterns in the same configuration were defined by selection frequency in a block of 40 trials.

Large-scale recording

1. Four 64-channel Utah arrays were implanted dorsal to the principle sulcus (PS) and anterior to the arcuate sulcus (AS). Here we report DLPFC data from 15 recording sessions.



Spatial decoding

Ridge regressions with 10-fold cross validation decoded target locations (x and y coordinates) Astrand et al. (2016)

Chunking index

$$MI = \frac{1}{2m}\sum_{i,j}\left[A_{ij} - \frac{k_i k_j}{2m}\right]\delta(c_i, c_j)$$

A_{ij}: transition matrices.

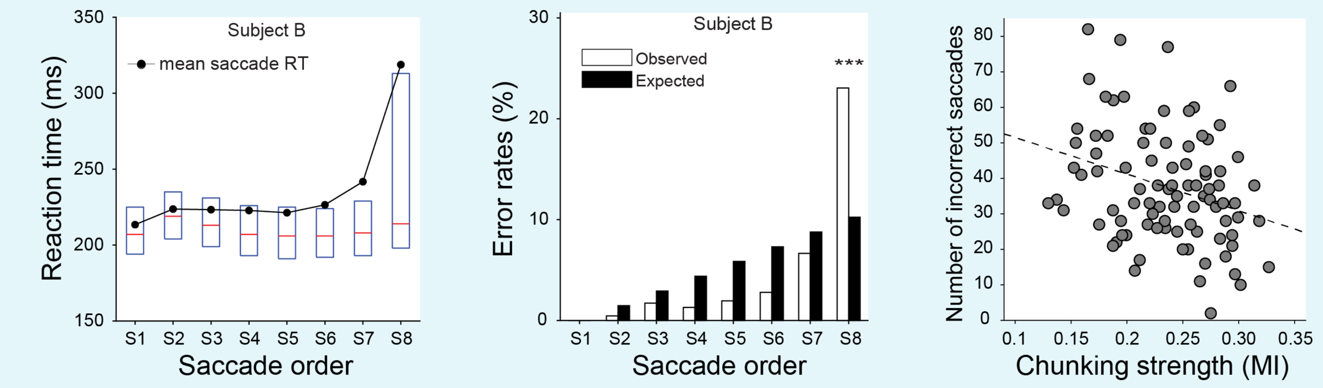
MI: measures of chunking pattern with a block of trials.

Blondel et al, 2008, J. Stat. Mech.

Behavioral results

1. Saccade reaction times and error rates increased with saccade order, suggesting increased WM load across saccades (3458 trials in 15 recording sessions, *** p < 0.001).

2. Graph theory used transitions between target selections to identify groups of targets consistently selected together, operationally defining chunks. A community index (MI) quantified the strength of chunking per block. Incorrect saccades decreased as a function of MI, indicated that chunking improved WM performance (90 behavioral blocks in 15 recording sessions, *** p < 0.001).



Summary

1. Chunking strategies improved working memory performance in spatial self-ordered search task.

2. Neural ensembles in DLPFC represented target locations and updated reward information for planning the next target selection.

3. Evidence for merging representations in DLPFC was observed in the first two target selections, which were frequently selected together.

4. Further analyses will determine how this merging representation changes according to behavioral strategies such as chunking.

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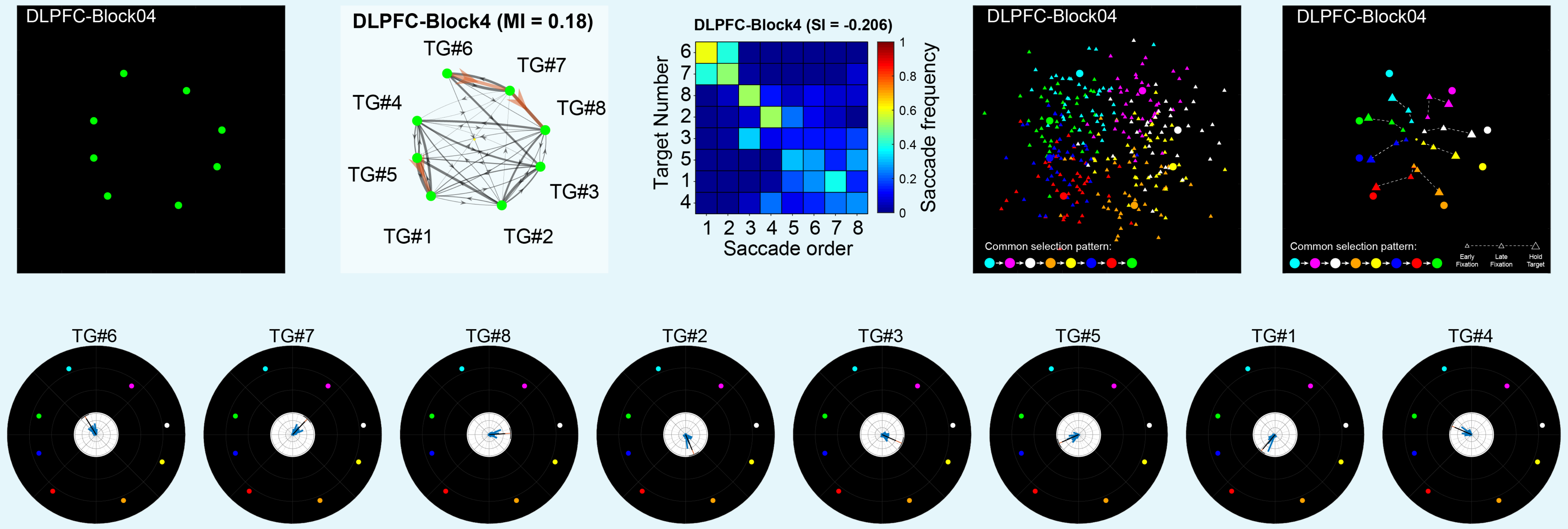
Lower level of chunking behavior with no merging representation

1. Two example configurations: Low MI (0.18) vs. High MI (0.28)

2. Common selection patterns were configuration-dependent

3. Target locations were decoded from 97 simultaneously recorded DLPFC neurons (triangle symbols) during the hold target epoch. Colors = selected reward targets.

4. Centroid of decoded location clusters moved toward from the fixation to selected targets across time.



5. The resultant vectors computed from decoded locations for each target indicated that neural representations in DLPFC specified directional information about selected targets

6. Evidence for merged representations was quantified as a shift in resultant vectors toward a non-selected target. This bias was observed when monkey selected two targeted together more often.

Higher level of chunking behavior with merging representation