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Rare events tend to be missed: can we predict behavioural errors using their neural signatures?

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Introduction

- When people monitor for rare targets, they are slower to respond and more likely to miss those targets especially in later stages of the task [1-3].

- There are many real-life situations where it can lead to tragic consequences such as in Ladbroke Grove Rail Crash, 1999.

- We asked, if we could detect what changes in the brain prior to a lapse in vigilance, could we prevent misses?

- To address this question, we built upon the extant literature of neuroimaging studies of vigilance [4] in three major ways:

  * We designed a novel Multiple-Object Monitoring (MOM) paradigm presenting simultaneously moving objects simulating railway monitoring

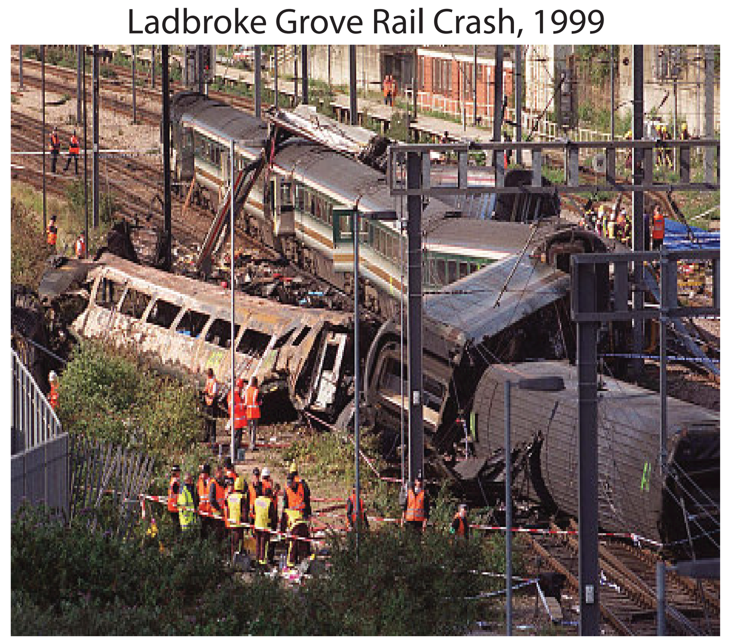
  * We used Magentoencelography (MEG), which provides high temporal resolution

  * We used Multi-Variate Pattern Analyses (MVPA) and our recent "Error" data analyses [5], to predict behavioural errors

BRIEF COMMUNICATIONS

Rare items often missed in visual searches
Jeremy M. Wolfe, Todd S. Horowitz & Naomi M. Kenner

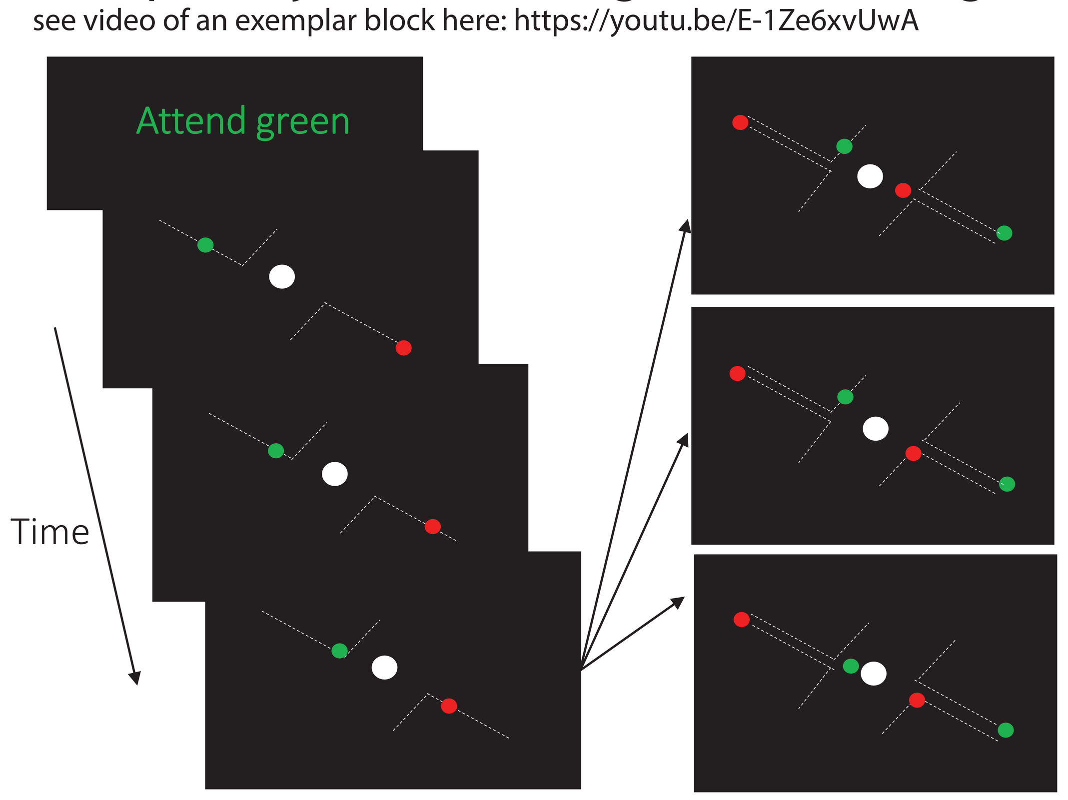
Ladbroke Grove Rail Crash, 1999



Methods

Multiple Object Monitoring (MOM) Paradigm

see video of an exemplar block here: https://youtu.be/E-1Ze6xvUwA



Distractor: no response needed
Active: 50% of uncued dots
Monitoring: 6% of uncued dots

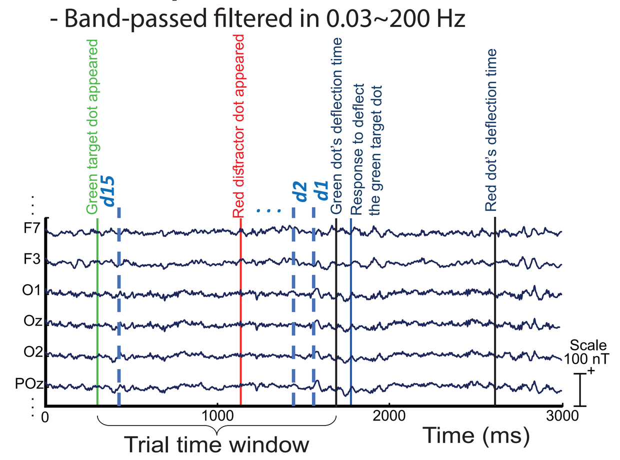
Event: no response needed
Active: 50% of cued dots
Monitoring: 94% of cued dots

Target: press button to prevent collision!
Active: 50% of cued dots
Monitoring: 6% of cued dots

MEG Setup

Sample MEG data

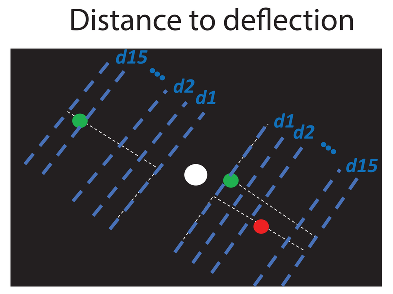
- Band-passed filtered in 0.03~200 Hz



- Using MVPA, we extracted information about dots' distance from the defletion point (all possible pairs of 15 distances) and dots' direction of approach (right vs left).

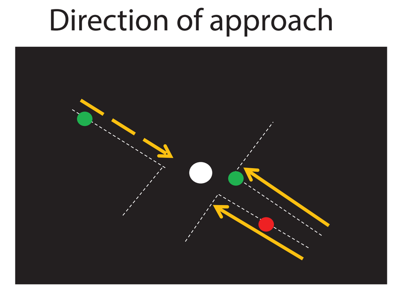
Types of information decoded

Distance to deflection



Trial time window was split into 15 sub time windows corresponding to 15 distances from the deflection point

Direction of approach



All samples within the trial time window were used in the analyses

Bayes factor analysis was used for statistical tests

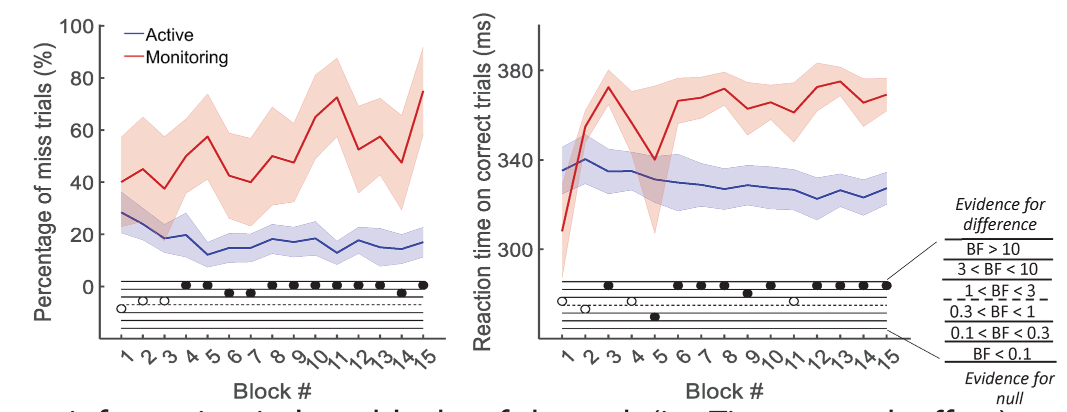
Statistical comparison	Null hypothesis	Alternative hypothesis
Decoding against chance	No difference	Difference exists
Decoding/RT/Miss rate across conditions	No difference	Difference exists

Strong evidence for alternative	BF > 10
Moderate evidence for alternative	3 < BF < 10
Insufficient evidence for alternative	1 < BF < 3
Insufficient evidence for null	0.3 < BF < 1
Moderate evidence for null	0.1 < BF < 0.3
Strong evidence for null	BF < 0.1

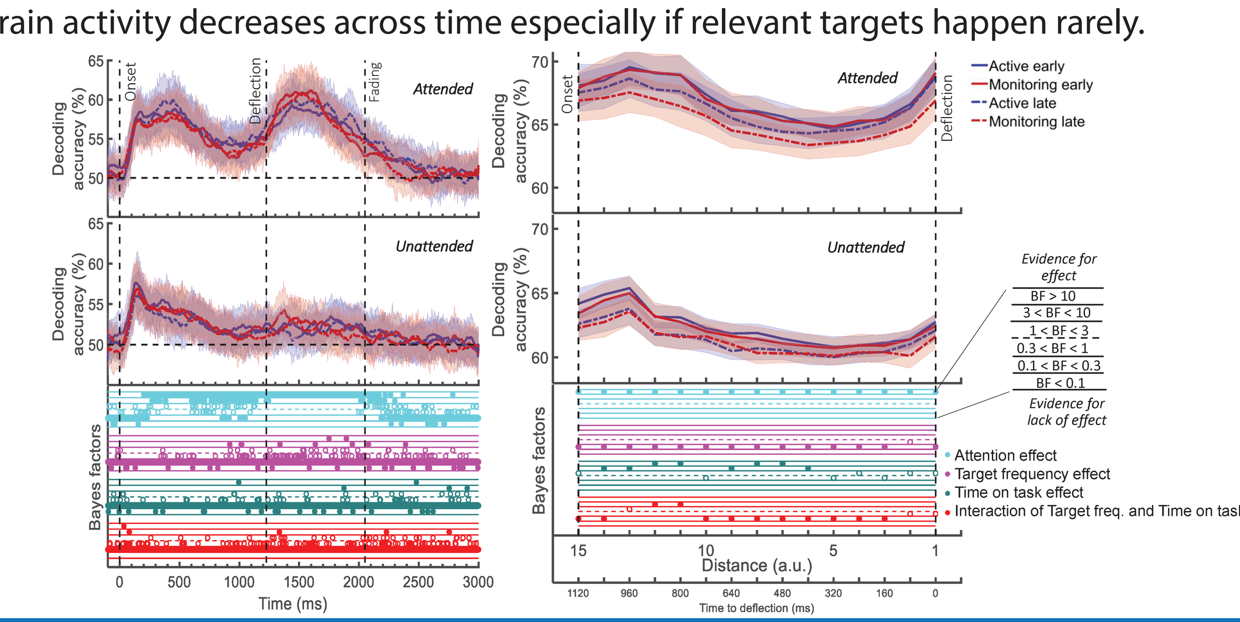
Results

Behavioural and neural effects of vigilance decrement evoked by the MOM task

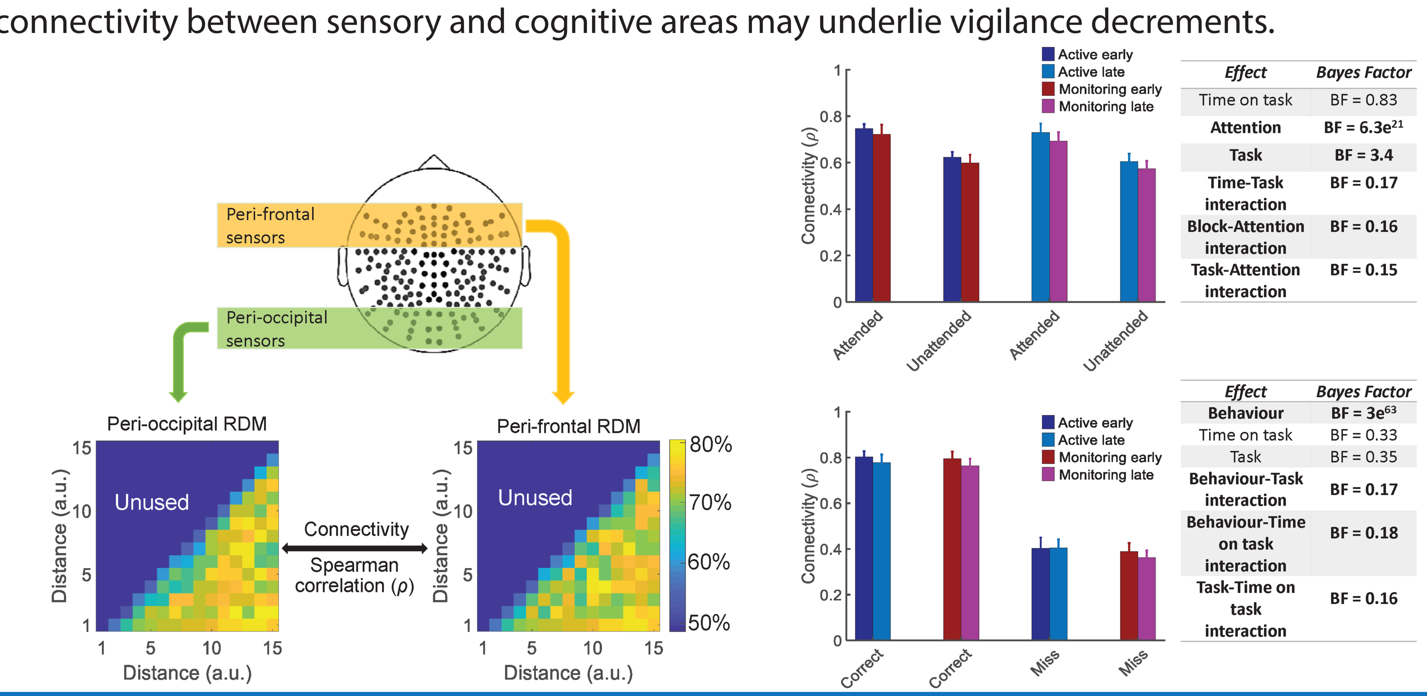
Deteriorating behavioural performance (i.e. increasing misses and reaction times) for the Monitoring vs Active condition shows that the MOM task evokes vigilance decrements successfully.



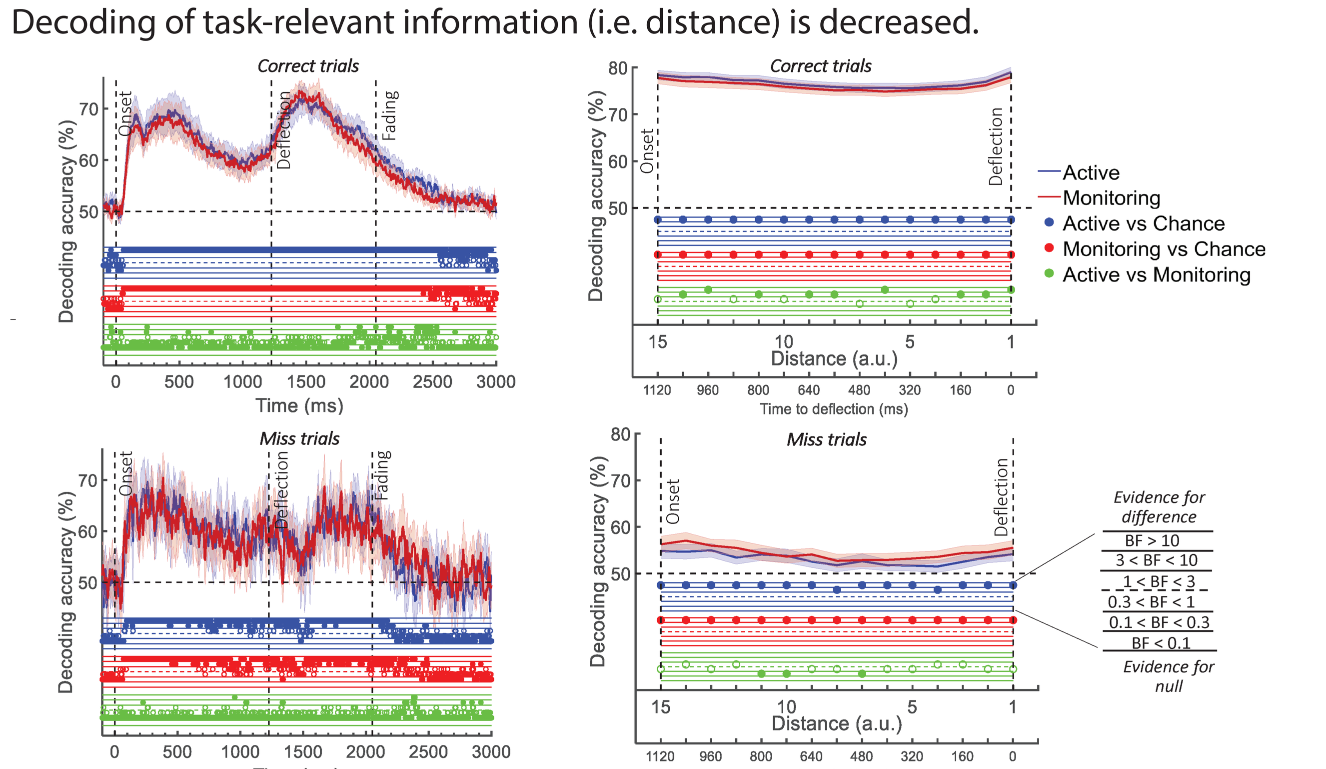
Decreased distance information in later blocks of the task (i.e. Time on task effect) and its interaction with Target frequency provides neural correlates for behavioural vigilance decrements: information decoding from brain activity decreases across time especially if relevant targets happen rarely.



Informational connectivity [6] decreased between Peri-occipital and Peri-frontal brain areas under Monitoring condition (vs Active) and when subjects missed (vs hit) the target. The weakened connectivity between sensory and cognitive areas may underlie vigilance decrements.

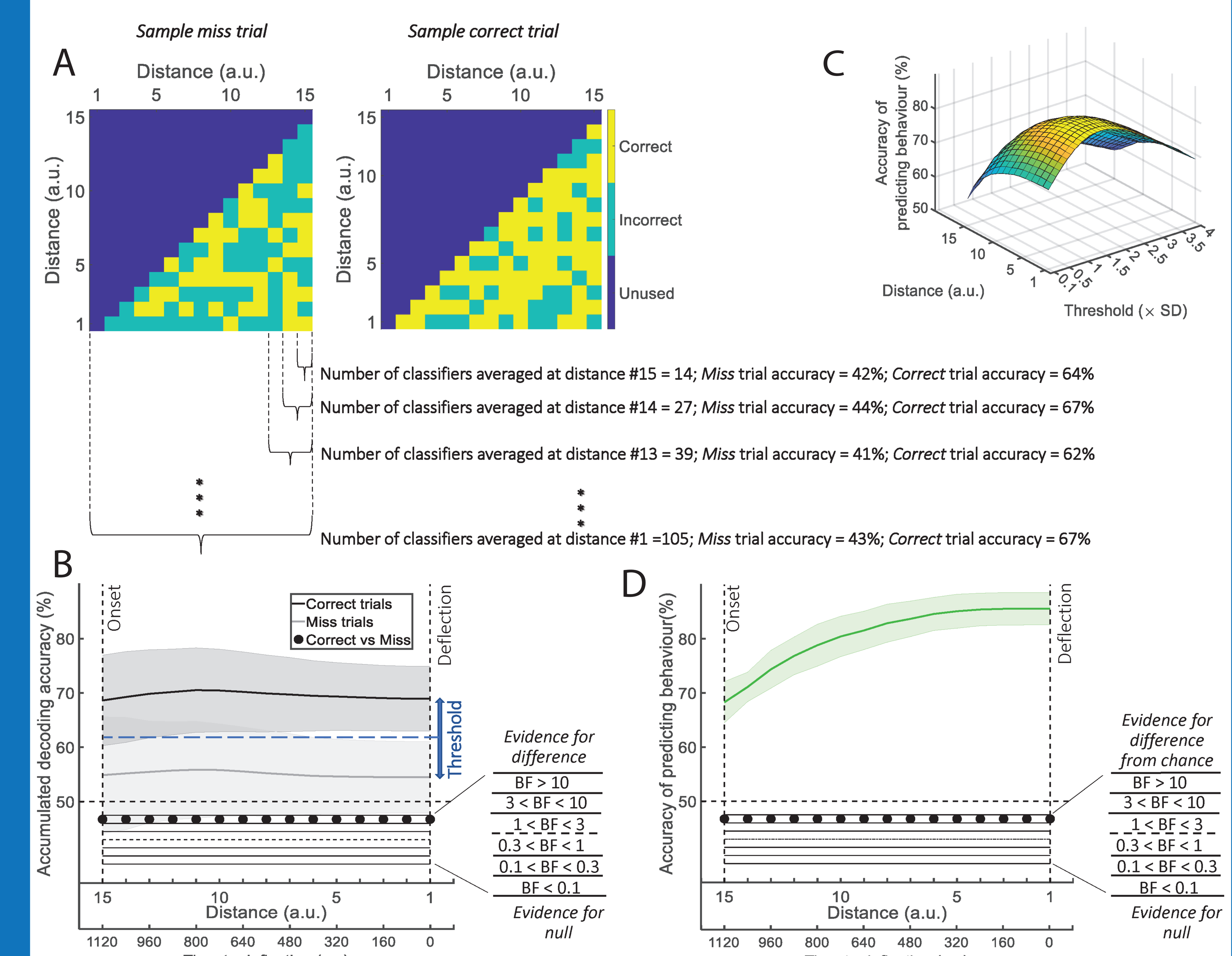


On miss (vs hit) trials:
Decoding of task-irrelevant information (i.e. direction of approach) is noisier, but not decreased.
Decoding of task-relevant information (i.e. distance) is decreased.



Prediction of behavioural miss/correct trials using decoding of distance (task-relevant) information

The difference in information decoding rates between the correct vs miss trials allowed prediction of the outcome of the trial:
1. We trained 15 classifiers (per distance) using MEG data from correct trials and tested them using data from both correct and miss trials (A). The testing decoding rates were higher for correct vs miss trials (B).
2. In a second-level classification, we defined a threshold (B) that allowed the categorization of correct vs miss trials in the testing phase (C).
3. The thresohld was calculated from the categorization rates of other subjects and was applied to the left-out subject.
- The results show accuracte (~80%) prediction of miss/correct trials ~800 ms prior to the response time.



Summary

- Neural representation of task-relevant information decreases in brain activity with time on the task, especially when targets are infrequent.

- On miss trials, the decoding rates of task-relevant information decreases in the brain.

- We used these observations to predict behavioural outcome of individual trials with ~80% accuracy around 800 ms before the action was needed.

- These results provide new insights about how vigilance decrements are reflected in neural information decoding and offer an avenue for predicting behavioural errors using novel neuroimaging analyses.

References

1) Wolfe, J. M., Horowitz, T. S., & Kenner, N. M. (2005). Nature, 435(7041), 439-440.
2) Rich, A. N., Kunar, M. A., Van Wert, M. J., Hidalgo-Sotelo, B., Horowitz, T. S., & Wolfe, J. M. (2008). Journal of Vision, 8(15), 15-15.
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5) Woolgar, A., Dermody, N., Afshar, S., Williams, M. A., & Rich, A. N. (2019). bioRxiv, 673681.
6) Goddard, E., Carlson, T. A., Dermody, N., & Woolgar, A. (2016). Neuroimage, 128, 385-397.

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