Investigating Midfrontal Theta Signal and Learning

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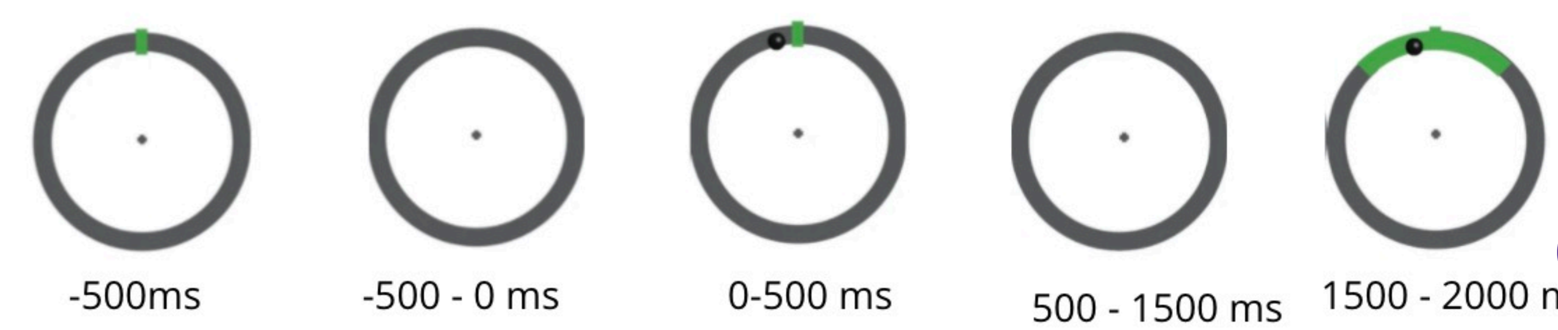
Motivation

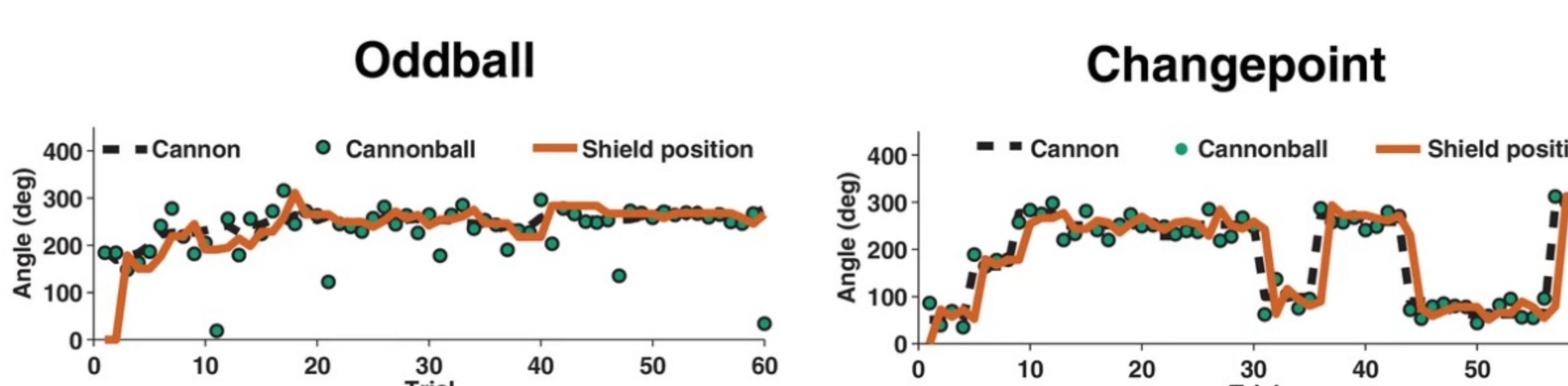
An increase in midfrontal theta signal in the brain (4-7 Hz) has previously been observed during surprising situations requiring learning, leading to the proposal that theta may be a learning signal (1). Conversely, the theta signal could also relate to latent states, hidden structures which inform the brain about the current context and help us make decisions accordingly. To determine whether theta relates to learning or latent state representation, we re-analyzed EEG data from a predictive inference task.

Computer Task Overview



(2)

Participants were told that there was a cannon in the middle of the circle, and a cannonball was released on each trial from the cannon. The angle of the cannon was unknown to participants. Participants were asked to move a green shield to the location on the circle where they predicted the cannonball would be fired to maximize their chance of blocking the cannonball.



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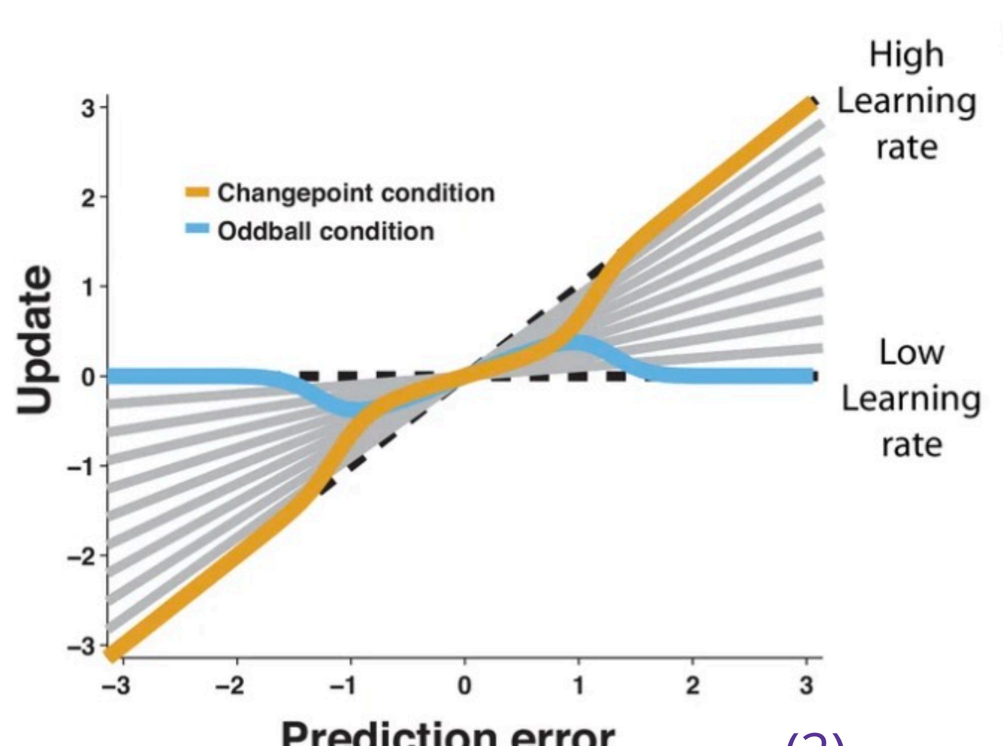
Participants experienced two statistical contexts which helped inform their predictions: one in which changes in cannonball location were persistent (changepoint), and one in which changes were transient (oddball).



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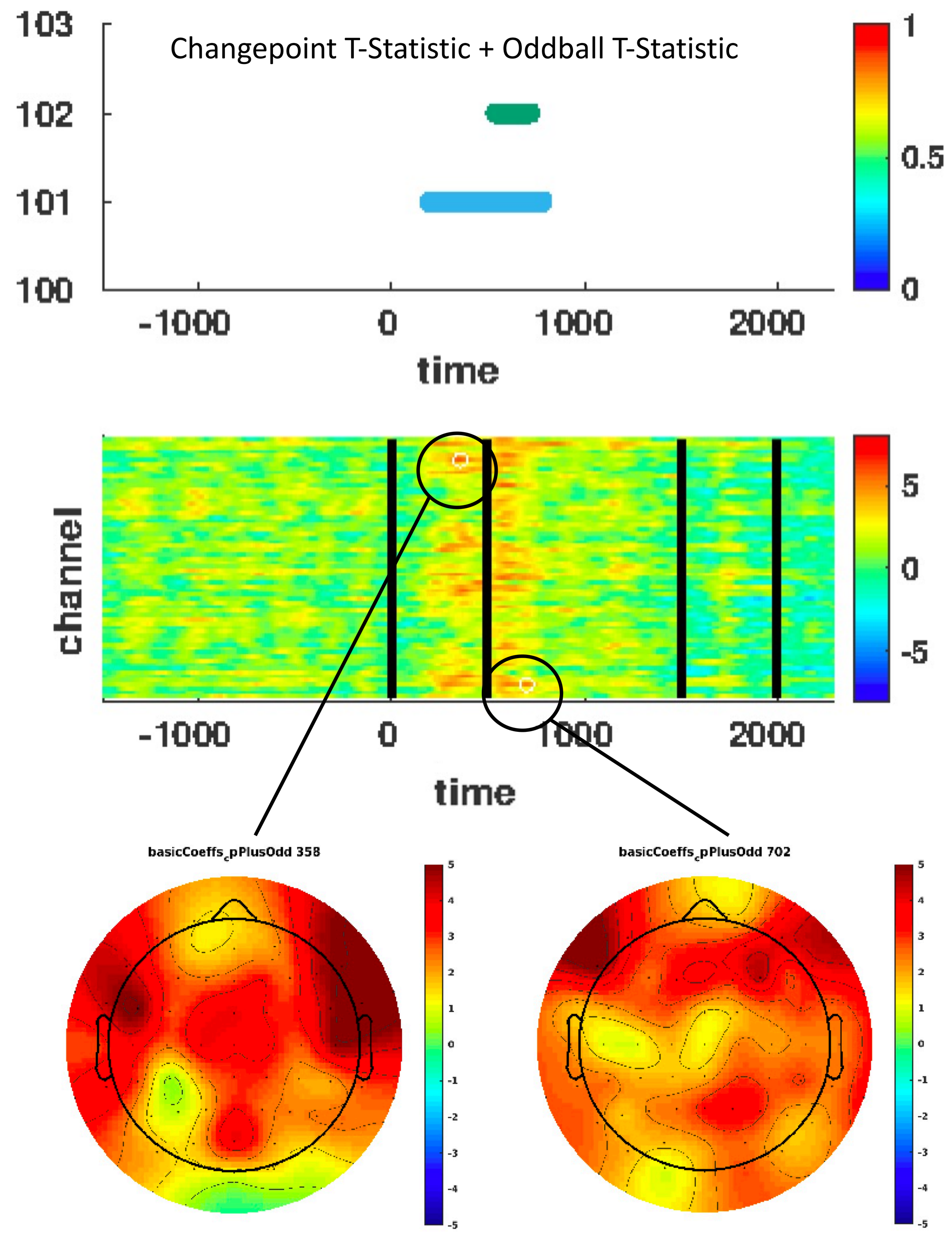
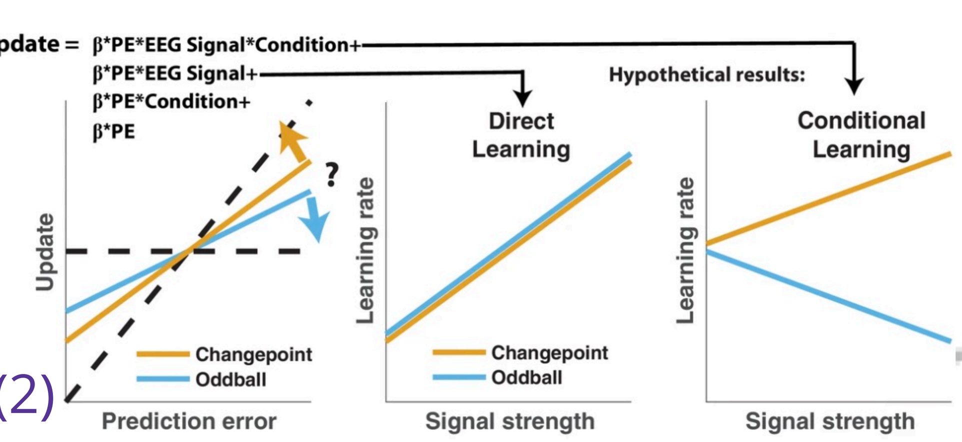
In the behavioral model, prediction error leads to different behavior in different contexts. The sign of prediction error and update indicates whether errors and updates were made in the clockwise or counterclockwise direction on the circle.

Theta Response to Surprise



After finding the sum of the T-statistics for theta signal during changepoint and oddball trials, we identified two clusters of time after stimulus onset (which occurs at 0 ms) during which theta signal peaks during both oddball and changepoint trials. Topoplots show the spatial distribution of the theta signal in the brain at the two peak time points.

Theta Signal and Learning Rate



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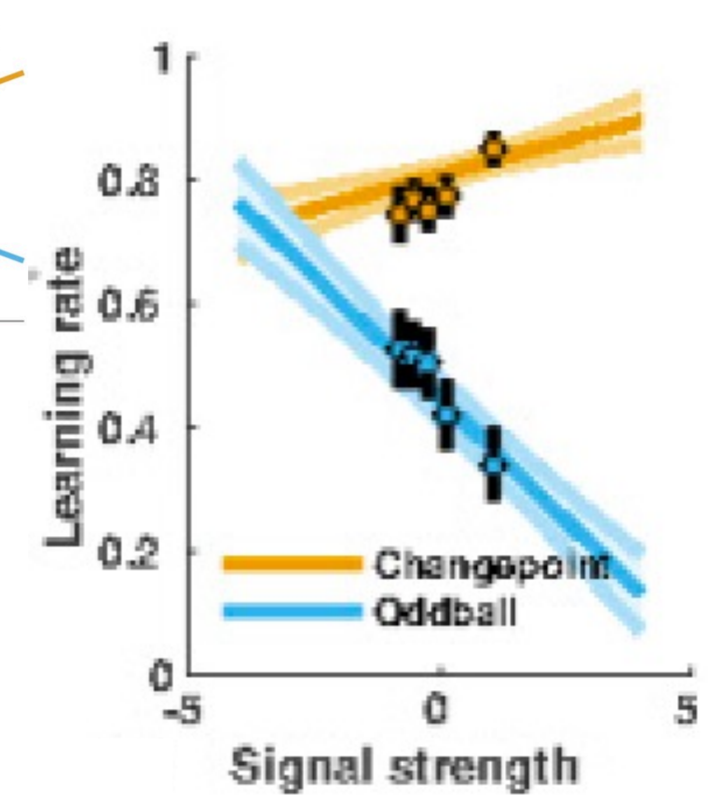
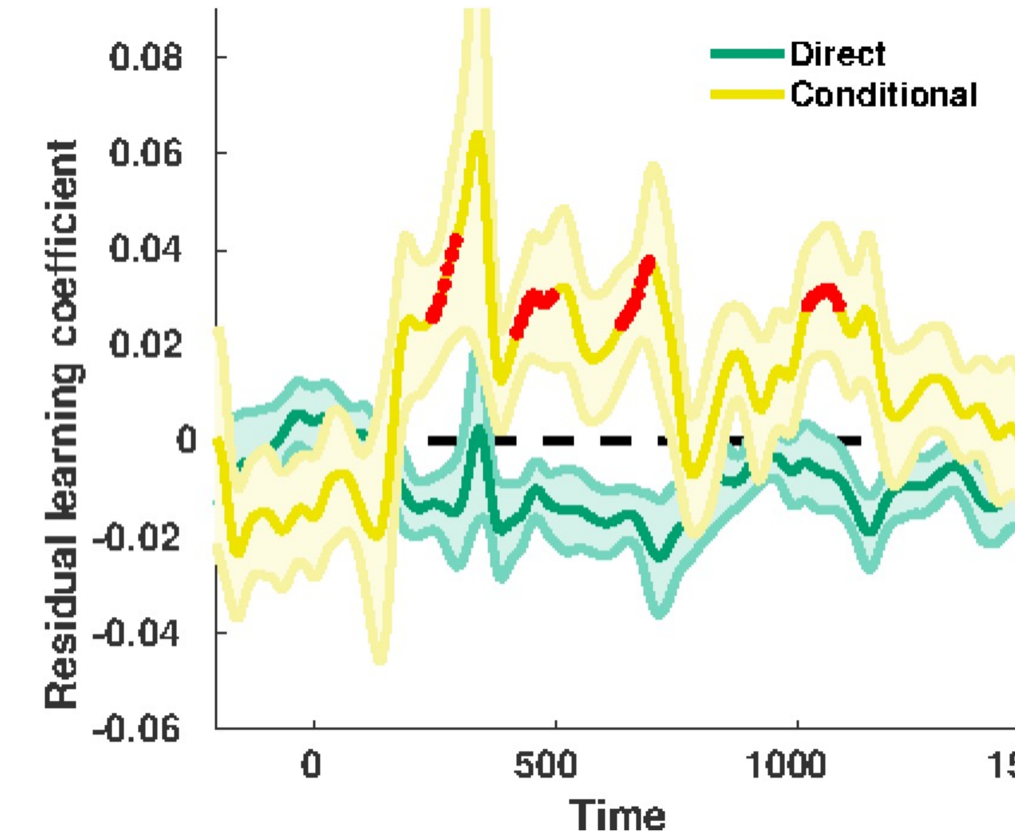
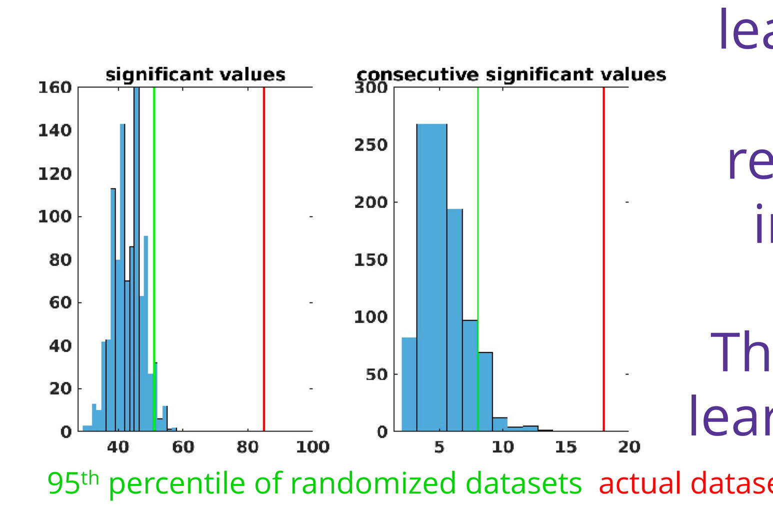


The above schematic illustrates two hypotheses for the relationship between theta and learning. If theta and learning are directly related, we expect to see the same relationship between theta and learning during both statistical contexts. If theta and learning are conditionally related, we expect to see a positive correlation during changepoint contexts and negative correlation during oddball contexts. Our results (at right) show the latter.

Theta Relationship to Learning

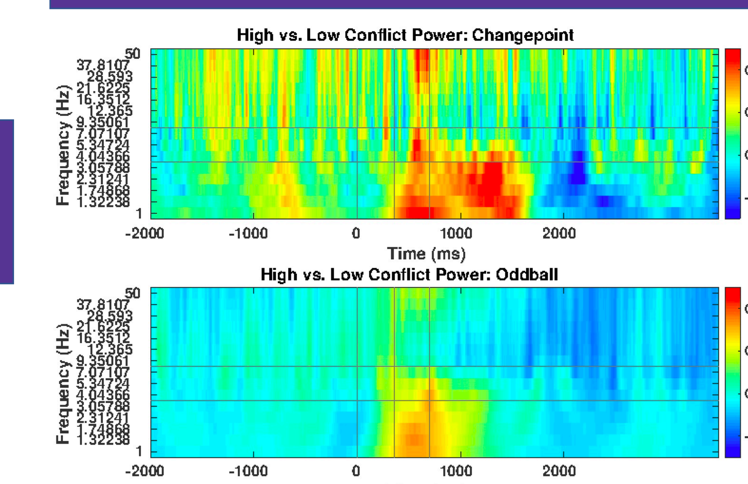


Direct:
ß*Coefficient*Theta Signal
Conditional:
ß*Coefficient*Theta Signal*Condition



After performing a regression which included a behavioral model of learning, we found no direct relationship between learning and theta signal. However, we identified a positive conditional relationship (significant points marked in red). A permutation test confirmed the significance of this relationship. Thus, theta is positively correlated with learning during changepoint conditions, but not during oddball conditions.

Activity Across Other Frequencies



Our most recent analysis determines activity across different frequency bands ranging from 0-50Hz. We found that the observed peak in theta signal is not specific to theta.

Conclusions and Future Directions

These results suggest that theta is not a direct learning signal as previously speculated, but rather may play a role in modulating latent state representation as it is present in both changepoint and oddball contexts. Our most recent analysis shows that these basic relations between theta and learning are not exclusive to theta but extend across other frequency bands such as delta as well, which we are currently investigating.

Acknowledgements

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References

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2. Nassar MR, Bruckner R, Frank MJ. Statistical contexts dictates the relationship between feedback-related EEG signals and learning. *eLife* 2019;8:e46975. doi:10.7554/eLife.46975