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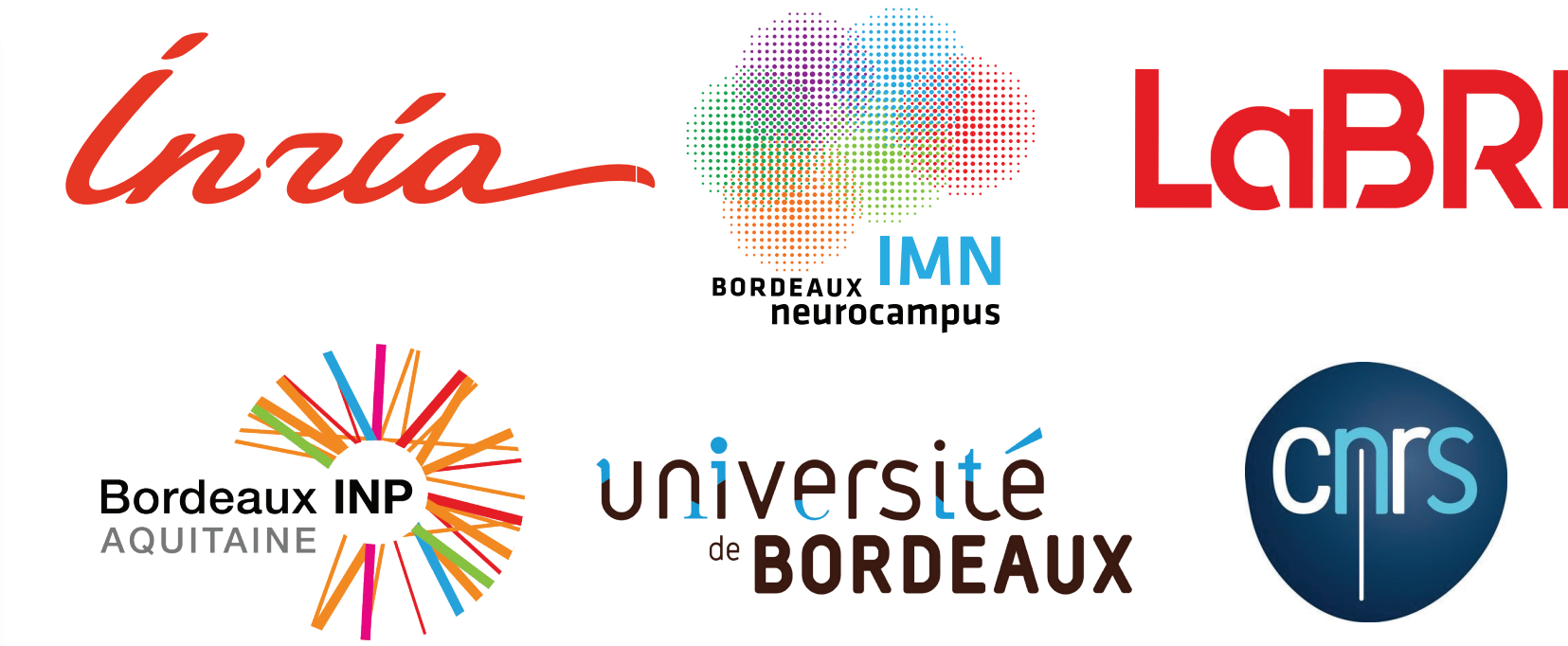
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Contact:
 *subba-reddy.oota@inria.fr
 †nathan.trouvain@inria.fr
 ‡xavier.hinaut@inria.fr

Past Word Context Enables Better MEG Encoding Predictions than Current Word in Listening Stories

S. Reddy Oota^{1,2,3*}, N. Trouvain^{1,2,3†}, F. Alexandre^{1,2,3}, X. Hinaut^{1,2,3‡}

¹Inria, Bordeaux, France
²IMN, UMR 5293, Bordeaux, France
³LaBRI, UMR 5800, Talence, France



Abstract

> Brain encoding is the process of mapping stimuli to brain activity. In this study, we encode brain activity recorded through magnetoencephalography (MEG) to explore the nature of language processing in the brain.

> MEG enables us to precisely examine the timing of language processing during a naturalistic task: 8 subjects listened to 4 independent stories (Gwilliams et al. 2022).

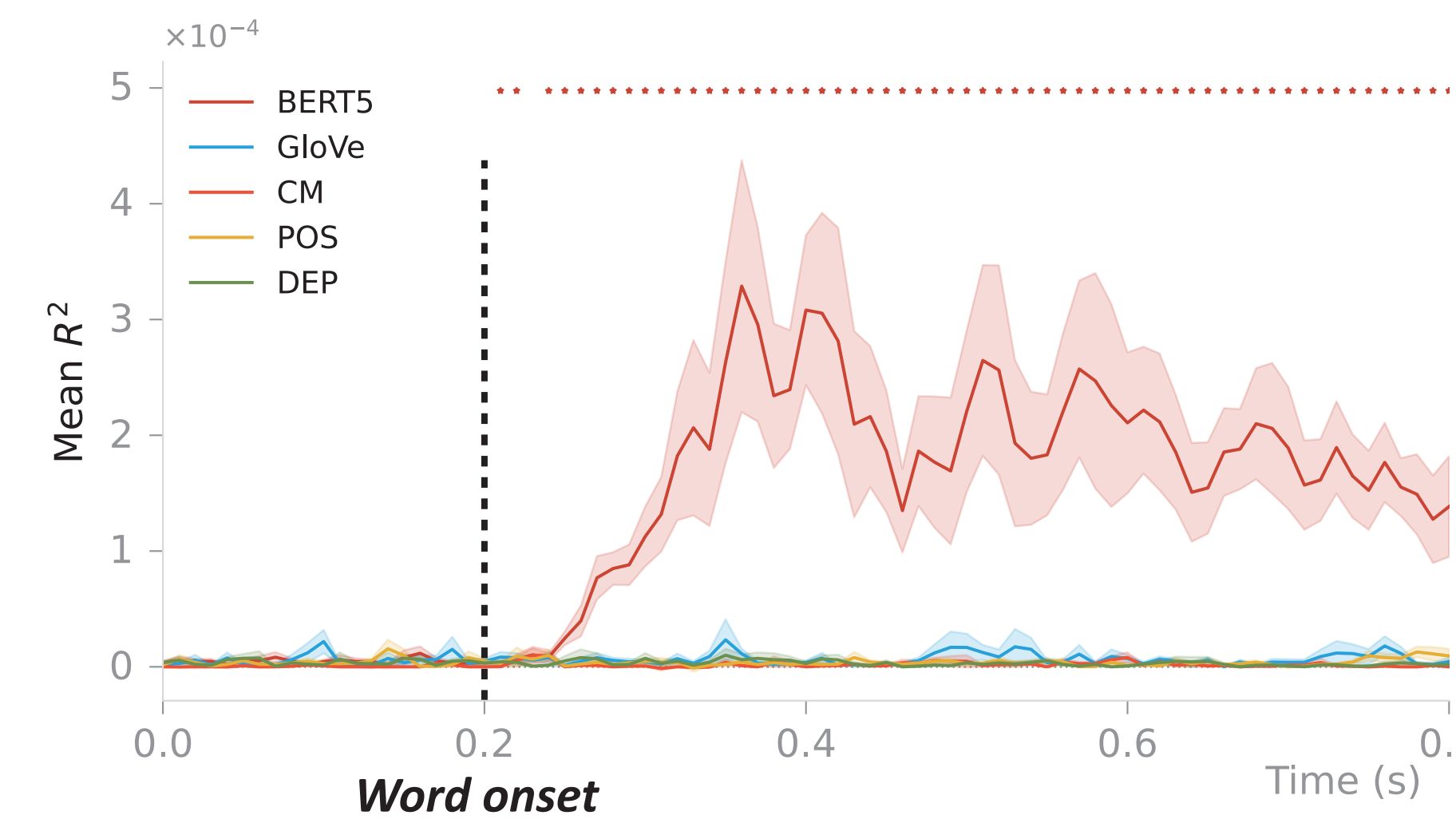
> We parsed or encoded words using several semantic embeddings or features, syntactic parsers, or language models, and predicted MEG activity using these word representations.

> We find that only contextual representations of words significantly predict brain activity at word onset. Moreover, the strong dependence of predictivity on past word context suggests that the brain encodes words in transient representations of their past context.

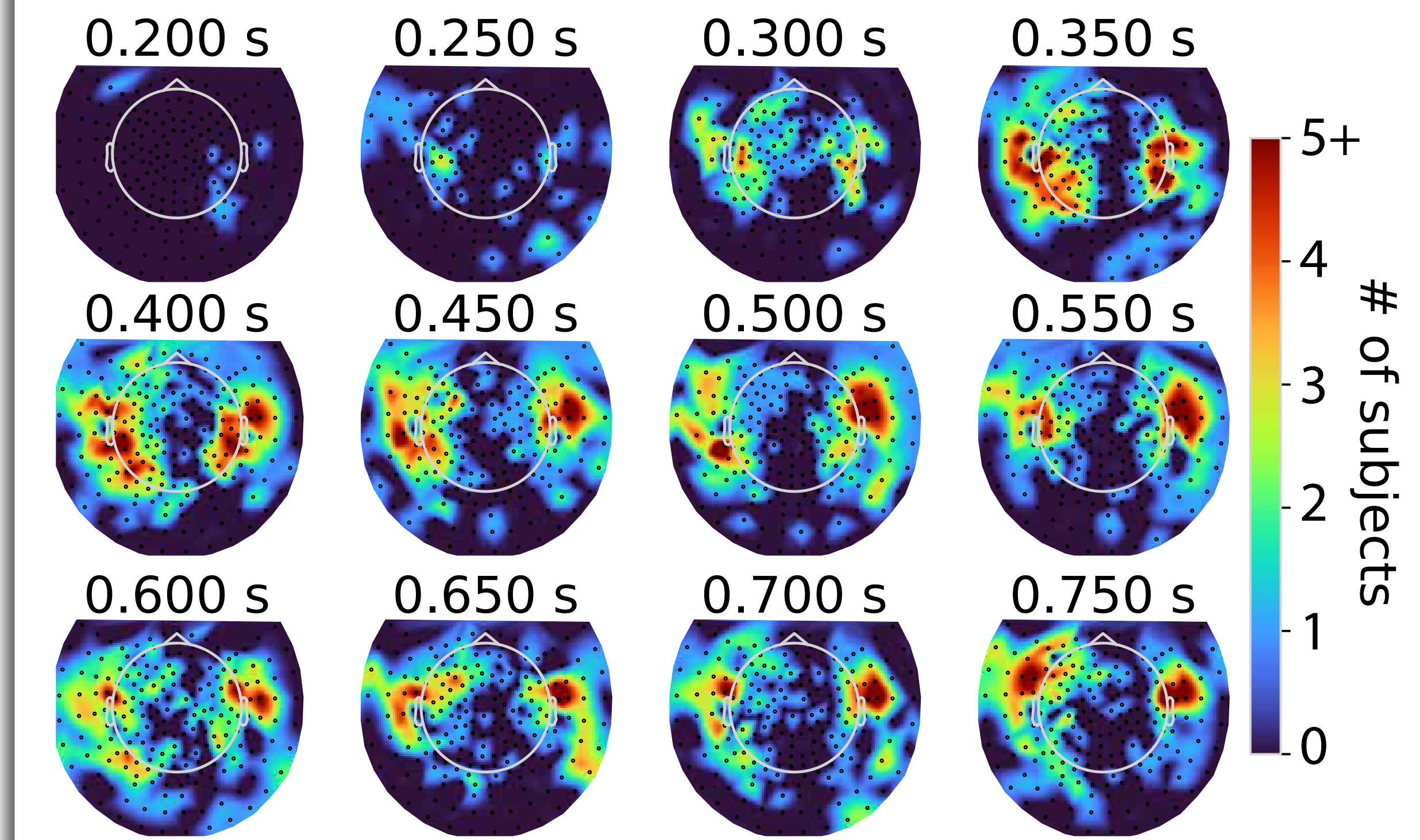
> Those findings are aligned with previous studies on MEG encoding showing past information retention at phonemic scale (Gwilliams et al. 2022), and echo research on bird song production showing a preference for past actions encoding at ambiguous transition points in song in HVC (a song-related brain area in songbirds; Cohen et al. 2020).

Context is all you need

Among all word representations, only contextual representations (BERT) are able to significantly predict MEG activity at word onset. (One sample t-test, $p < 0.05$, FDR correction)

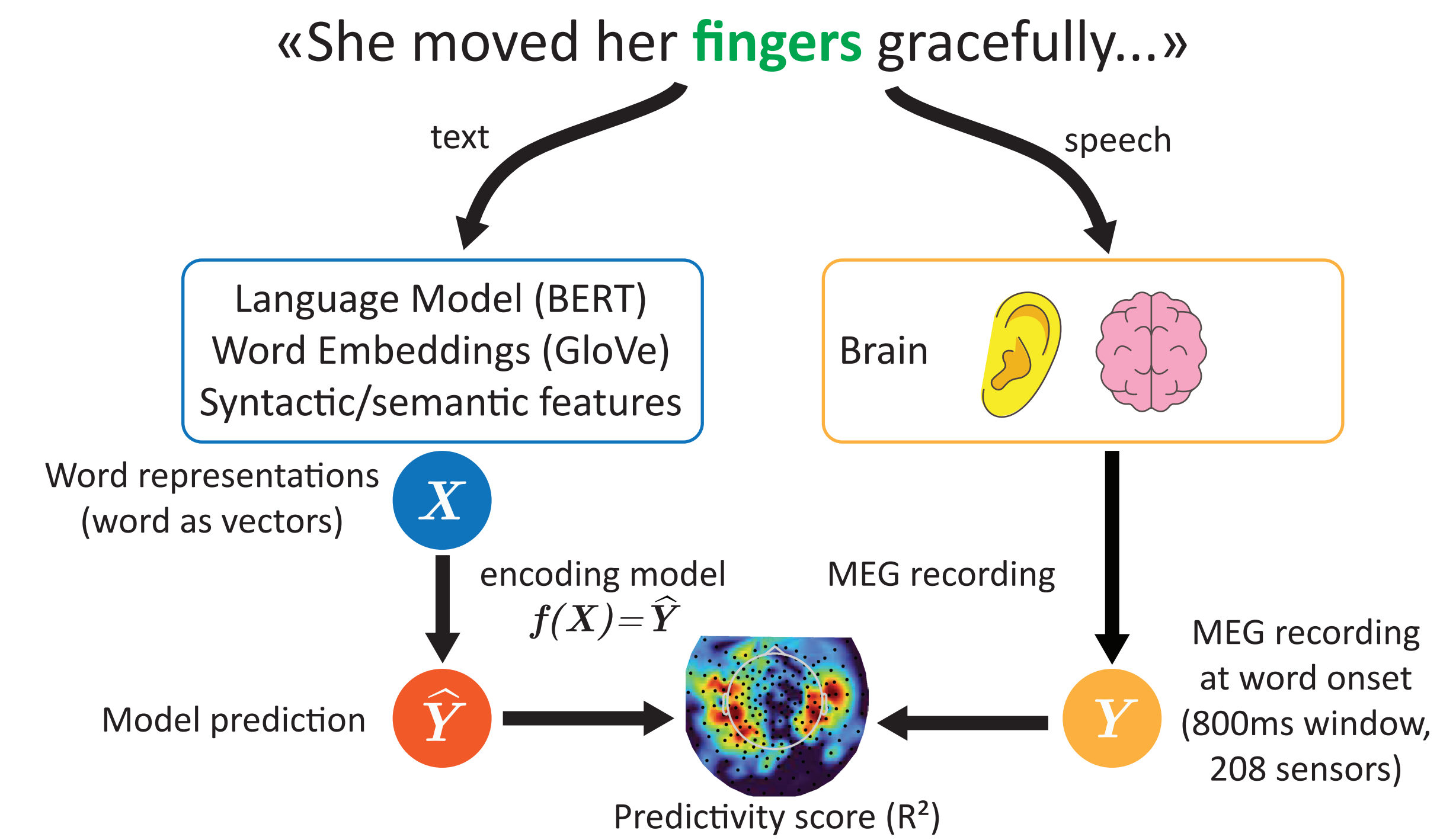


Predictivity is mostly significant in temporal and inferior frontal lobes

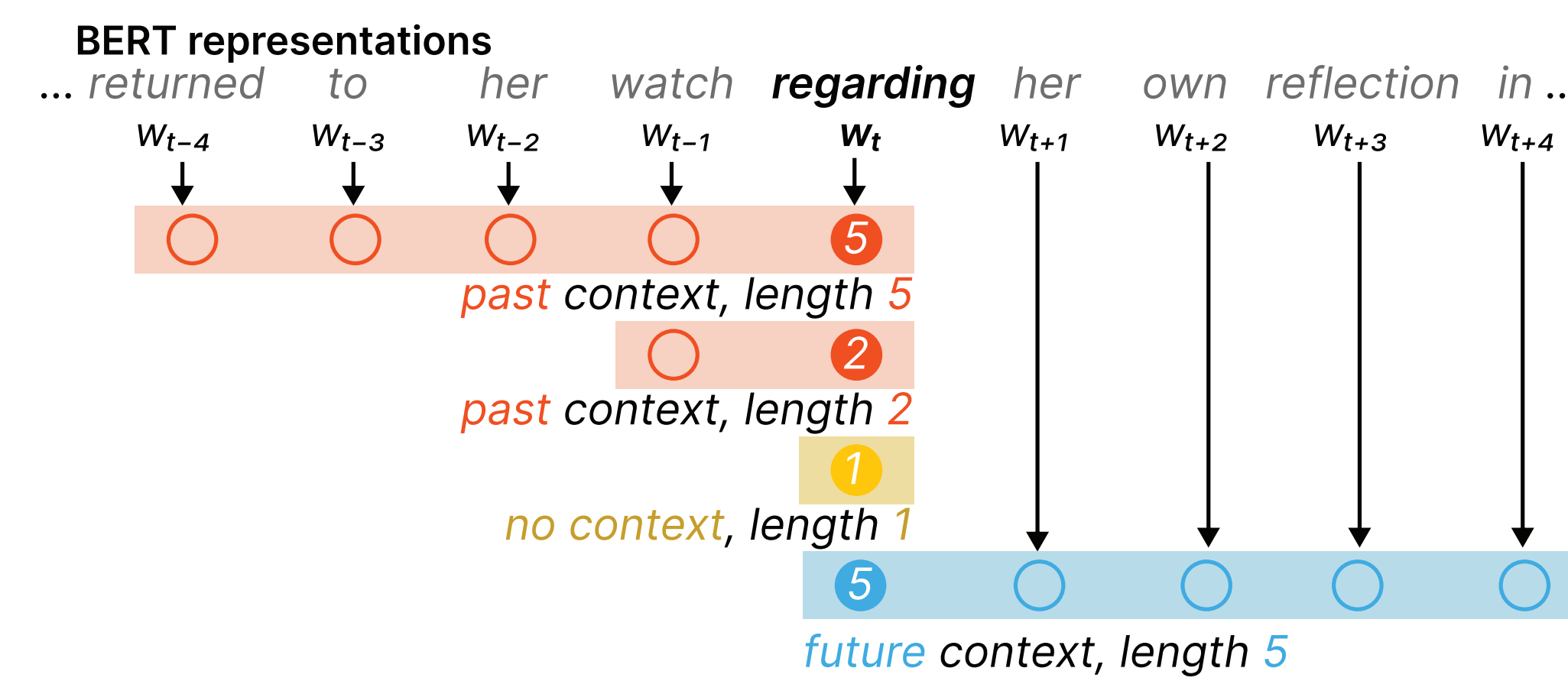


Brain encoding using word representations

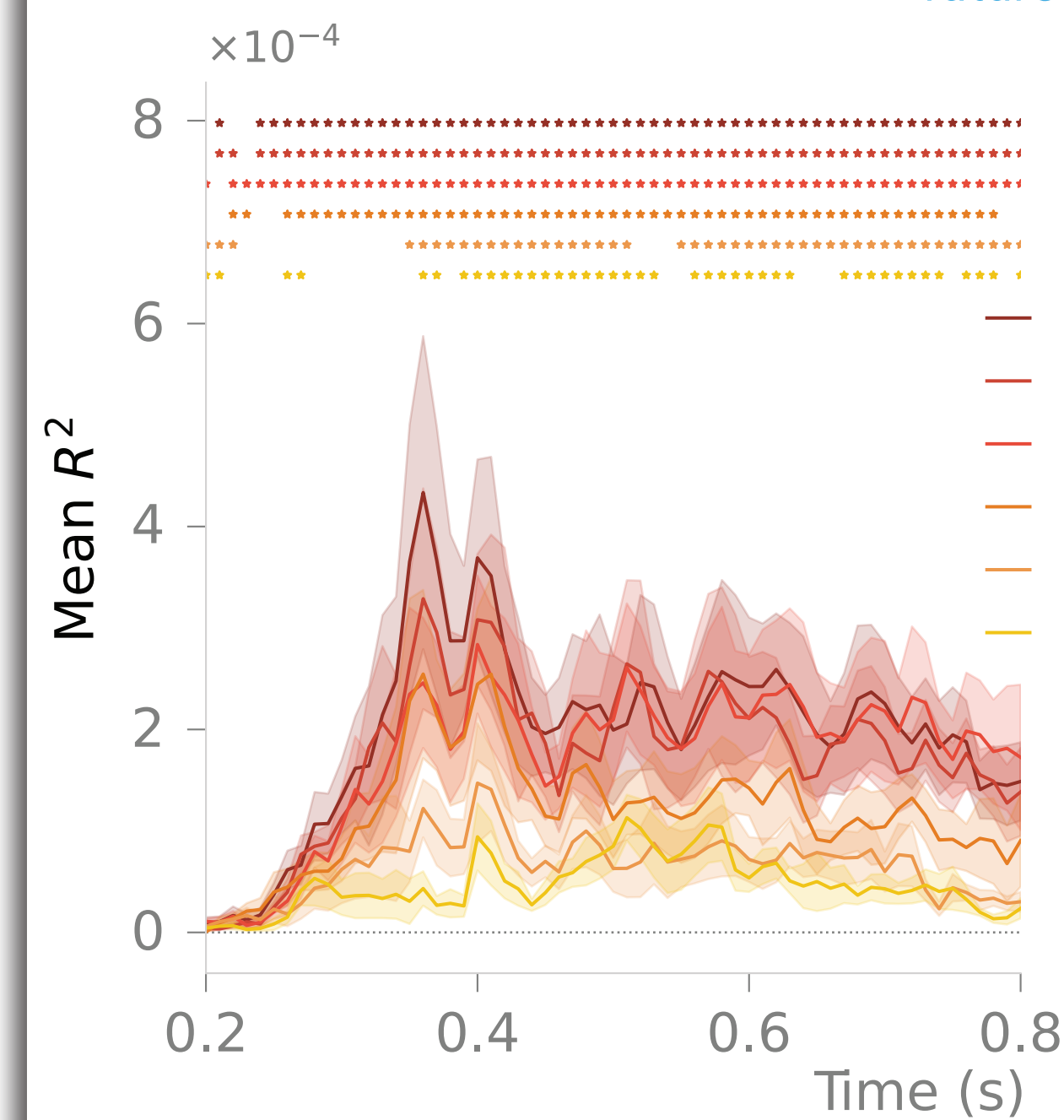
Dataset: MASC-MEG (8 subjects listening to 4 stories)



Predictivity is function of context size and direction

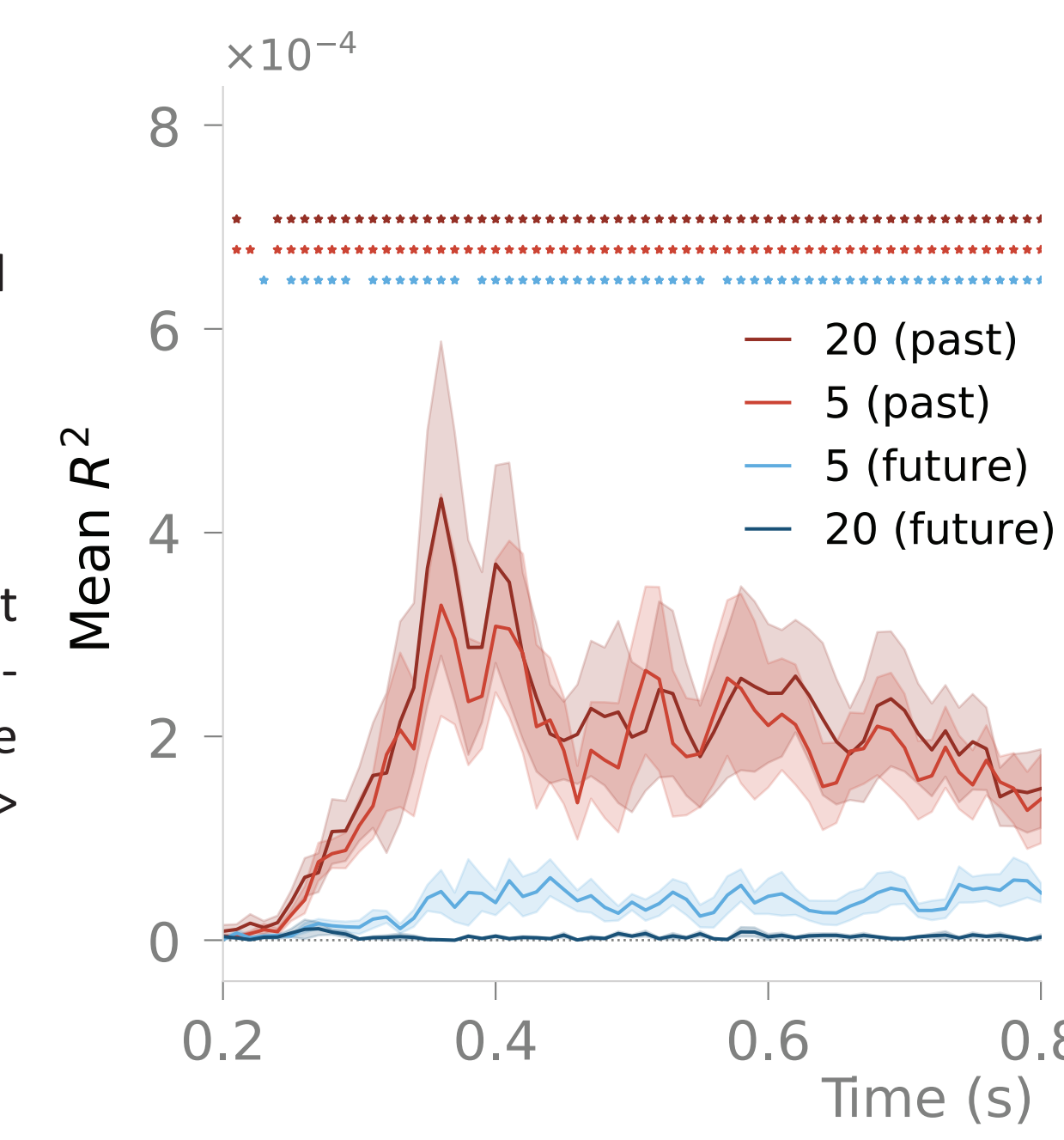


< For each word, BERT representations are built from varying context sizes, e.g. from 1 to 5 words in the past or future, including current word.



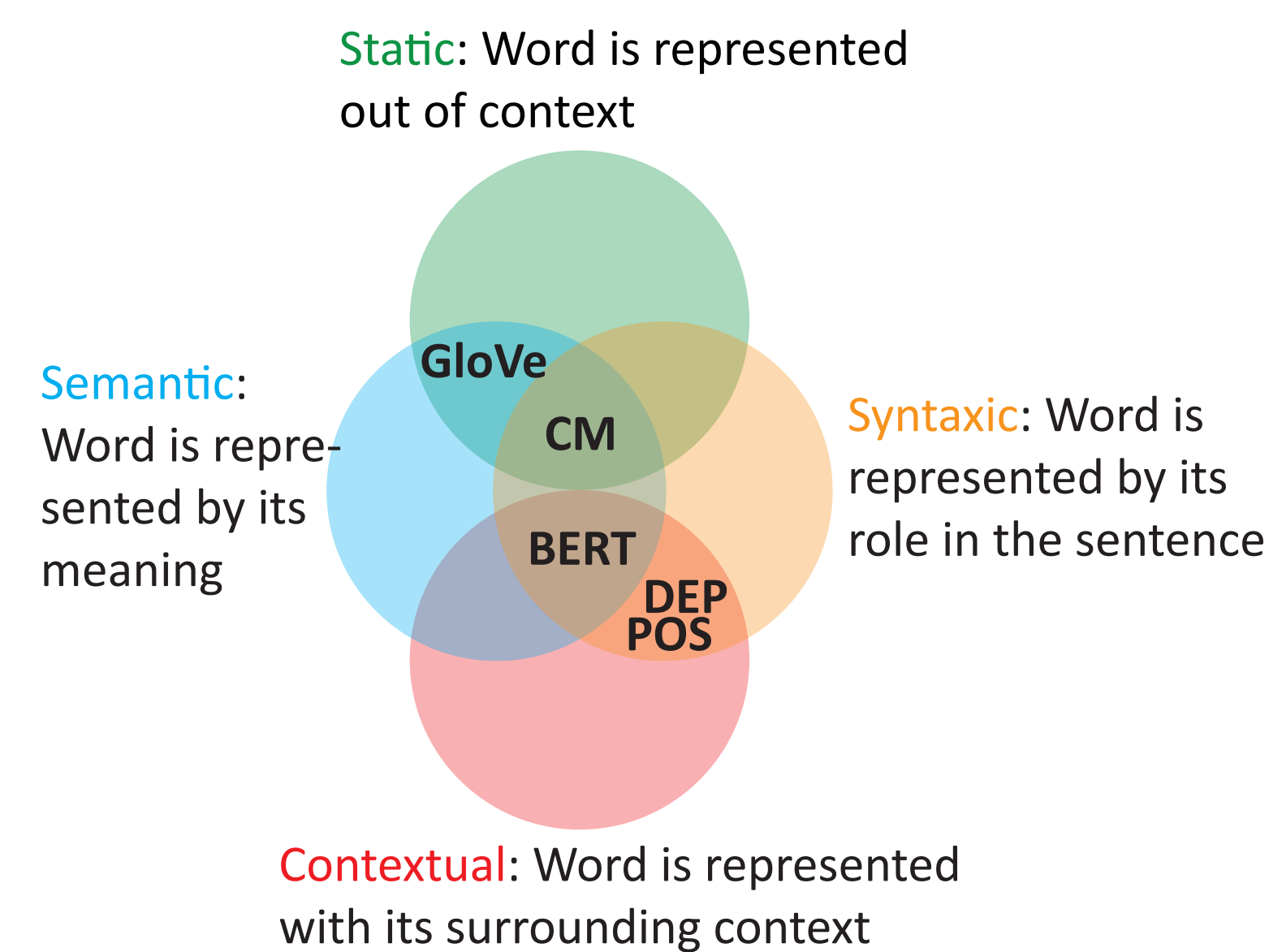
< Predictivity is function of past context size. Peak predictivity of MEG activity is obtained 200 ms after word onset. Representations built using long contexts correlate more to brain activity than using short contexts.

Predictivity is dependent on context direction: Past context is more correlated to brain activity than future context. >

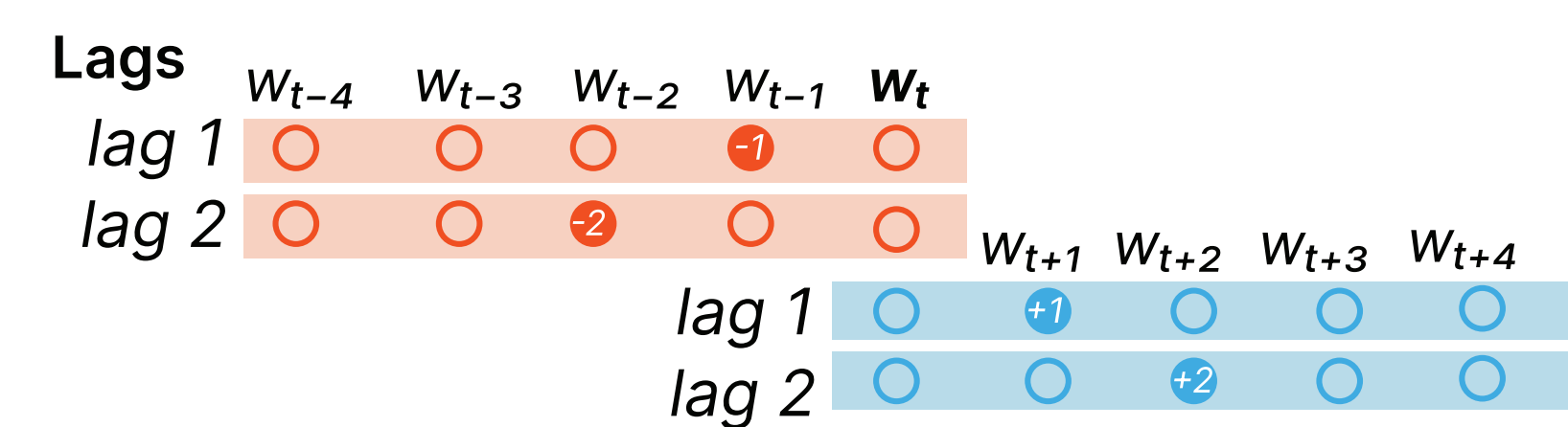


Word representations

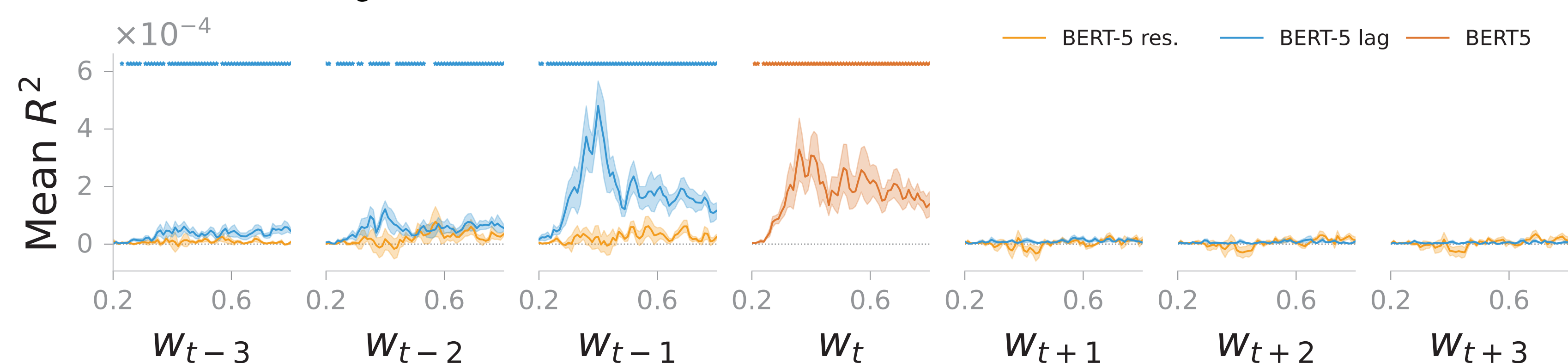
- > Complexity Metrics (CM)
- > Part-of-speech (POS)
- > Dependency tags (DEP)
- > GloVe (one 300-dimensions vector per word, irrespective of word context)
- > BERT (one 768-dimensions vector from the intermediate encoder layer (layer-7) to obtain the embeddings.)



MEG activity is the product of current word information and short-term context



Residuals
 $f_1(1) \approx 5$ $5-1 = 5 - f_1(1)$
 length 1 length 5 residuals 1
 $f_2(2) \approx 5$ $5-2 = 5 - f_2(2)$
 length 2 length 5 residuals 2



Method

> Preprocessing: MEG activity is filtered (0.5Hz-30Hz) and epoched in 800ms windows around word onset (-0.2s before onset, +0.6s after word onset). First 200ms serve as baseline for detrending.

> Encoding models are fitted using linear regression with L2 regularization (regularization parameter found through 10-fold cross validation, for each story and each sensors and timepoints).

> R^2 score significance is assessed using a permutation test (5000 random permutations within each story, FDR corrected using Benjamini-Hochberg method with $\alpha=0.05$)

Conclusion

> Brain activity seems to reflect contextual information. MEG activity is only significantly predicted by BERT contextual embeddings, and predictivity is function of past context size.

> Words encoded with future context show very low predictivity: If predictions are made by the brain, they can not be retrieved using BERT encodings.

> High predictivity with lagged encodings suggests that past context plays an important role in encoding current word information in the brain

> In the speaker's brain, there appears to be an "encoding center of mass" that is responsible for processing long-time dependencies and encoding past actions rather than future actions. This is supported by studies on songbirds, where the brain area involved in managing these dependencies preferentially encodes past actions, particularly during phrases with history-dependent transitions in song. Similarly, research on phoneme representations suggests that past events or actions are held in memory until they are used to disambiguate future events or actions (Gwilliams et al. 2022)

References

L. Gwilliams, G. Flick, A. Marantz, L. Pylkkanen, D. Poeppel, and J.-R. King, "Meg-masc: a high-quality magneto-encephalography dataset for evaluating natural speech processing," *arXiv preprint arXiv:2208.11488*, 2022.
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