# The spatio-temporal dynamics of speech feature encoding in aging and aphasia

**Jill Kries**
**(jill.kries@stanford.edu)**
Department of Psychology, Stanford University

**Pieter De Clercq**
**(pieter.declercq@kuleuven.be)**
Laboratory for Experimental ORL,
Department of Neurosciences, KU Leuven

**Maaike Vandermosten**
**(maaike.vandermosten@kuleuven.be)**
Laboratory for Experimental ORL,
Department of Neurosciences, KU Leuven

**Laura Gwilliams**
**(laura.gwilliams@stanford.edu)**
Department of Psychology, Stanford University

**Abstract:**

**During successful speech comprehension, phonetic features are encoded in a dynamic neural pattern that evolves over time. Here we tested whether individuals with comprehension difficulties exhibit altered neural dynamics of speech encoding. We recorded EEG responses from older adults and individuals with aphasia during natural story listening. We tested for how long phonetic features are decodable, their speed of evolution across neural populations, and which EEG sensors encode phonetic information, across groups. The analysis revealed that phonetic processing is robustly encoded in EEG responses of older adults. Individuals with aphasia were matched in speed of neural pattern evolution, but showed shorter (~50%) duration of phonetic encoding. Speech impairments in aphasia may therefore implicate failure to maintain lower-order information long enough to recognize lexical items.** **Keywords: speech processing; aphasia; EEG; decoding**

## Introduction

Comprehending natural speech entails rapidly converting continuous acoustic input into discrete units, like phonemes and words (Mesgarani et al., 2014). When young, healthy adults listen to natural speech, the properties of phonemes ("phonetic features") are encoded in a dynamic neural pattern, whereby different neural ensembles are recruited across time (Gwilliams et al., 2022). Prior work with MEG has related the duration of phonetic encoding to resolving lexical uncertainty, and the speed of dynamics with the speed of incoming inputs.

Some disorders of language processing, such as post-stoke aphasia, lead to decreased phoneme identification performance (Kries et al., 2023), and correspondingly, weaker encoding of acoustic features of speech and phoneme onsets (Kries et al., 2024). Here, we test the hypothesis that the language difficulties experienced in aphasia can be explained by altered dynamic processing of phonetic features, compared to the changes regularly experienced during healthy aging (Kries & Gillis et al., 2023).

Our first question is whether the robust phonetic decoding shown by Gwilliams et al. (2022) - which recorded 2 hours of MEG during story listening in young adults - can be reproduced in older adults, using a more clinically accessible neural recording technique, namely EEG, with just 25 minutes of recording time. Second, we ask whether the dynamics of phonetic processing, in terms of duration and evolution speed, are different in people with aphasia versus age-matched controls. Finally, considerable functional and structural reorganization occurs during the first few months after onset of stroke-induced aphasia. We therefore test whether individuals with aphasia show an altered decoding topography compared to healthy controls.

## Methods

39 individuals with aphasia in the chronic phase after stroke (> 6 months after onset) and 24 age-matched healthy control participants listened to a narrative for 25 minutes while EEG data was recorded. The narrative was annotated for phonetic features, allowing us to apply time-resolved decoding of phonetic features from the EEG signals. All decoding was performed using one-versus-all logistic regression and 5-fold shuffled cross-validation. We apply this to 18 phonetic features, across manner, place, voicing, roundness and front-back-ness of consonants and vowels. Results are reported on the average across features.

## Results

To test whether phonetic features can be decoded in healthy older adults using EEG data, we fit the logistic regression classifier at each millisecond locked to phoneme onset, and assess significance using a cluster-level temporal permutation test across subjects. Phonetic features were decodable above chance from -

0.01 to 0.26 seconds (p<.001) relative to phoneme onset (fig.1B, yellow line). Thus, phonetic features are decodable for a span of 0.27 seconds in older adults, which is approaches the 0.3 seconds reported for younger adults using MEG data (Gwilliams et al., 2022).

Next, we tested whether individuals with aphasia show an altered duration of decodability. We compared the aphasia group to the control group using a cluster-level permutation test, and found significantly lower decoding accuracy in the aphasia group compared to the control group between 0.08 and 0.25 seconds relative the phoneme onset (p<.001; fig.1B). Individuals with aphasia thus encode the phonetic information for a shorter amount of time.

To test how long phonetic information is maintained within a same neural population, we extracted the train time lags that showed no significant group difference in decoding accuracy, i.e., between 0 and 0.08 seconds (lilac bar in fig.1A). We tested the duration of generalization across test times, and found no significant difference between groups (fig.1C). Average generalization time was 70ms in the aphasia group and 85ms in the control group. The speed of spatial evolution of phonetic encoding in individuals with aphasia is highly overlapping with healthy controls.

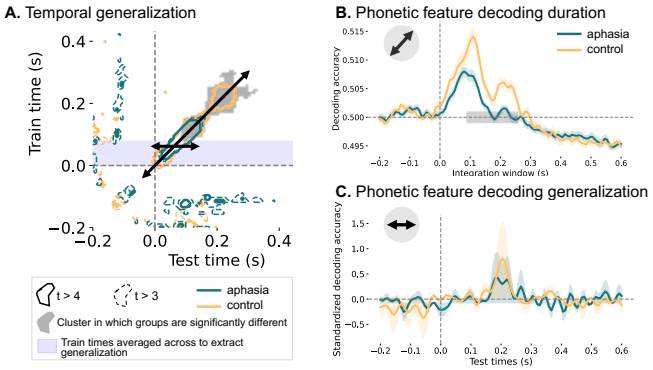


Figure 1: Decoding phonetic features from EEG data. A. Temporal generalization pattern. Decoding duration and generalization are extracted from it for group comparison. B. Higher decoding accuracies for controls between 0.08 and 0.25 seconds. C. No group difference in generalization of phonetic encoding.

Finally, we determined the spatial encoding of phonetic information by fitting the logistic regression on the timecourse of activity at each EEG sensor separately. We submitted the decoding performance of each sensor across subjects and groups to a mass-univariate independent samples t-test (Brodbeck et al., 2023) to analyze topographical differences of phonetic feature decoding between the aphasia group and the control group (fig.2A). With a cluster-forming p-value threshold of p<.001, we identify a cluster of 22 EEG sensors (p<.001; fig.2B) over which individuals with aphasia had lower decoding accuracy than healthy controls. The sensors primarily localized to left auditory cortex and posterior sensors bilaterally.

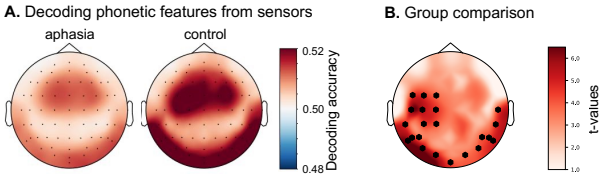


Figure 2: Decoding phonetic features at EEG sensors.

## Discussion & Conclusion

Robust encoding of phonetic features was reproduced in older adults and using an EEG dataset, which replicates a prior MEG study with younger adults (Gwilliams et al., 2022).

Comparing decoding dynamics between groups, we find that individuals with aphasia encode phonetic features for a shorter duration than the control group (fig.1B). Early during processing (0 to 0.08 seconds), no significant difference between groups was found; the difference emerges from 0.08-0.25 seconds. It is possible that the first peak in decoding reflects sensory processing, and the second peak reflects recognition of lexical items (Gwilliams et al., 2022), whereby only the latter is impaired in people with aphasia.

In terms of the dynamics of population encoding, we find that the neural pattern evolves at the same rate for both groups (fig.1C). Specifically, the neural pattern completes a full evolutionary cycle every 70 to 85 ms - similar to the duration of the phonemes in the narrative.

The sensor-level decoding analysis shows that while similar sensors encode phonetic information across groups (fig.2), there is stronger encoding in healthy controls, which is most pronounced over left auditory sensors. While the stroke lesion in the left hemisphere might influence the decoding accuracy, this possibly reflects functional reorganization in the left hemisphere. A third control group consisting of stroke patients with a right-hemispheric lesion without aphasia could help to disambiguate whether the effects that we see are due to structural or functional changes in the brain.

Overall, we find that phonetic processing is robustly encoded in EEG responses of older adults. The primary marker of aphasia was shorter duration encoding, rather than absence of encoding. This suggests that speech impairments in aphasia may be driven by difficulties maintaining lower-order information long enough to recognize lexical items.

## Acknowledgements

Thanks to all the participants and collaborators of the bigger scope of this project. Research of Jill Kries was supported by the Luxembourg National Research Fund (FNR; AFR-PhD project reference 13513810). Pieter De Clercq was financially supported by the Research Foundation Flanders (FWO; PhD grant: SB 1S40122N). Furthermore, this study was financially supported by the FWO grant No. G0D8520N.

## References

Brodbeck, C., Das, P., Gillis, M., Kulasingham, J. P., Bhattasali, S., Gaston, P., Resnik, P., & Simon, J. Z. (2023). Eelbrain, a Python toolkit for time-continuous analysis with temporal response functions. *ELife*, *12*. https://doi.org/10.7554/eLife.85012

Gwilliams, L., King, J. R., Marantz, A., & Poeppel, D. (2022). Neural dynamics of phoneme sequences reveal position-invariant code for content and order. *Nature Communications*, *13*(1). https://doi.org/10.1038/s41467-022-34326-1

Kries, J., Gillis, M., Vandermosten, M., & Francart, T. (2023). Neural tracking of linguistic and acoustic speech representations decreases with advancing age. *NeuroImage*, *267*. https://doi.org/10.1016/j.neuroimage.2022.119841

Kries, J., De Clercq, P., Gillis, M., Vanthornhout, J., Lemmens, R., Francart, T., & Vandermosten, M. (2024). Exploring neural tracking of acoustic and linguistic speech representations in individuals with post-stroke aphasia. *Accepted in Human Brain Mapping.*

Kries, J., De Clercq, P., Lemmens, R., Francart, T., & Vandermosten, M. (2023). Acoustic and phonemic processing are impaired in individuals with aphasia. *Scientific Reports*, *13*(1). https://doi.org/10.1038/s41598-023-37624-w

Mesgarani, N., Cheung, C., Johnson, K., & Chang, E. F. (2014). Phonetic Feature Encoding in Human Superior Temporal Gyrus. *Science Mag*, *343*.