Language-brain entrainment: a crossmodal comparison of spoken and signed languages.

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Signed and spoken languages use the visual and acoustic modalities, respectively, for the transmission of linguistic information. The modality used deeply influences the temporal organization of the linguistic signal: in spoken language, information is presented in a predominantly sequential fashion, while sign language is characterized by a multi-layered and parallel presentation of information (Sandler, 2018). The temporal structure of speech is characterized by quasi-periodic components both at the level of production and perception (Walsh & Smith, 2022; Meyer, 2018). This is reflected in language processing as well: language-brain entrainment refers to the synchronisation of the neural activity with the incoming speech signal (Obleser & Kayser, 2019). This phenomenon is widely studied in the acoustic modality, and seems to support language comprehension through the decoding of the linguistic information from the physical signal (Doelling at al., 2014). In this study we investigate whether this phenomenon is specific to spoken language, or whether it extends to a language expressed and perceived through the visual modality, such as sign language.

To characterize the temporal regularities of the visual sign language signal we used motion tracking. A custom-built Kinect setup allowed us to record videos of signers while tracking multiple points on the body and face (see figure 1). We used this motion tracking system to record videos of models signing several short (one-minute long) texts in their native language. These motion tracking data were used to extract the speed vectors of various articulators, including the hands, the head, the right (dominant) shoulder and the torso during sign language production, and thus to characterize the kinematic and temporal properties of the sign signal. These motion-tracked recordings were used as stimuli in the following experiment.

We used magnetoencephalography (MEG) to record the neurophysiological activity of two groups of hearing participants – 15 expert signers and 15 individuals with no knowledge of sign language – while they watched videos of short narrative texts in a familiar spoken language (Spanish), an unfamiliar spoken language (Russian), a familiar sign language (LSE - Spanish Sign Language) and an unfamiliar sign language (RSL - Russian Sign Language). Expert signers self-rated their proficiency in LSE on a scale from 1 to 5 (mean rating 4.64, SD 0.5). This design allows us to investigate the effect on entrainment of language modality, on the one hand, and language familiarity, on the other. Each participant saw ten video texts for each language, five of which were by a male model, and five by a female model (except for RSL, for which both models were male). An orthogonal probe recognition task was used to ensure that participants paid attention to the videos (after each video participants saw two 5-second clips and had to decide which one had appeared in the video); performance on this task was good (over 70% accuracy) except for one participant from the sign-naive group, who was excluded from the analysis.

To evaluate phase synchronization between brain activity and the linguistic signal, we calculated coherence between the preprocessed MEG data and the speech envelope (for spoken language) or the speed vector of the right hand (for sign language). Based on the previous literature on entrainment in signed (Brookshire et al., 2017) and spoken languages (Bourguignon et al., 2013; Gross et al., 2013; Molinaro & Lizarazu, 2018) and a visual inspection of coherence plots, we selected two frequency bands of interest for our analysis: delta band (0.5 - 2.5 Hz) and theta band (4 - 7 Hz). To assess whether there were statistical differences in coherence values for a specific frequency band across experimental conditions, we performed cluster-based permutation tests (Maris & Oostenveld, 2007). (This nonparametric permutation analysis allows us to avoid the problem of multiple comparisons among the high number of sensors of the MEG.)

The results of this study show that entrainment takes place during signed language processing as happens with spoken language. For speech, our results replicate the typical findings of previous work: synchronisation in delta and theta frequency bands located in bilateral temporal regions (Ding, Melloni, et al., 2017; Bourguignon et al., 2013; Keitel et al., 2017). In sign language entrainment is conditioned by the specific properties of sign's temporal structure: entrainment is restricted to the delta frequency band, in line with the slower periodicity of the visual signal, and localised over right parietal areas, associated with motion processing. We find stronger entrainment in spoken languages compared to sign languages, but in both modalities familiarity with a language impacts the extent to which entrainment occurs. These findings show the interplay between language modality, structure and processing. Despite the differences in temporal structure between sign and speech, the brain leverages temporal regularities in the signal to process language.

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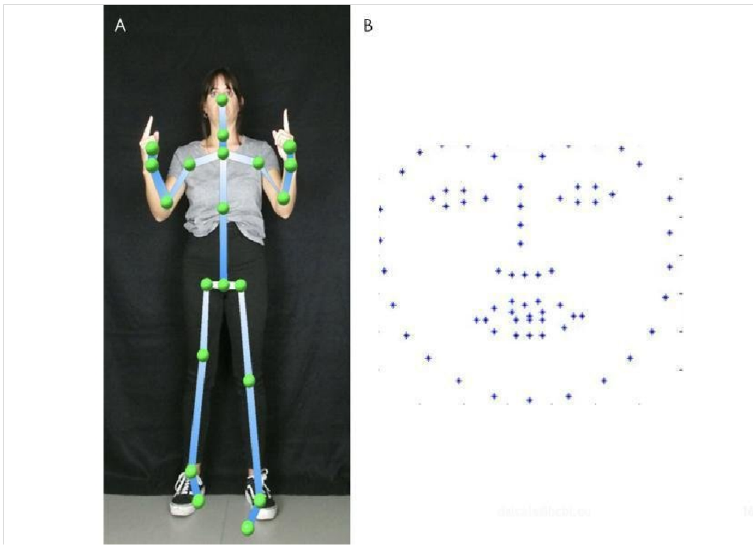

Figure 1. Body (A) and face (B) points tracked by the custom-built Kinect system.