Age and Language Experience Modulate Predictive Processing in the Visual Modality

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Across the lifespan, the human brain undergoes functional reorganization that reflects both developmental adaptation and experience-dependent change. One of the central goals of neuroscience is to understand how the brain anticipates and adapts to structured input. Predictive processing frameworks suggest that the brain continuously generates expectations about incoming sensory data: thus, perception is shaped not only by incoming stimuli, but also by top-down expectations grounded in past exposure. Language comprehension, as a high-level cognitive function, provides a natural domain in which to examine such predictive mechanisms.

Sign languages offer a unique testbed for studying experience-dependent predictive processing in the visual modality, independent of auditory processing. Deaf signers acquire language through vision and develop highly tuned sensitivity to temporal dynamics of visual motion. Native Deaf signers allow us to examine how structured, dynamic visual input over a lifetime affects cortical organization. Signed language signal consists of a highly structured visual stream, where timing and kinematics are tightly linked to linguistic meaning [1]. Understanding how the brain changes processing of visual cues for predictive processing over the lifespan is crucial for modeling predictive mechanisms in computational neuroscience.

We used EEG recordings from Deaf native signers of Austrian Sign Language (ÖGS) to examine how predictive neural dynamics vary with age and language experience. Participants (N = 24, age range 28–68) viewed natural signed sentences and time-reversed non-linguistic motion controls (temporal reversal preserves low-level motion statistics while disrupting multi-scale linguistic structure). We conducted two complementary analyses (Figure 1). First, spectral complexity metrics (entropy, flatness, centroid) characterized general EEG signal properties indicative of functional connectivity during task performance. These revealed age-related changes in neural organization, but no effect of stimulus type. This indicated that only age affected baseline functional connectivity. Second, we computed coherence between EEG and optical flow in the stimuli, quantifying how neural activity tracked the temporal dynamics of visual motion. Machine learning feature selection identified coherence features most diagnostic of linguistic versus non-linguistic processing (496 initial features reduced via cross-validated classification, achieving 94% accuracy).

Within these stimulus-discriminative coherence features, age effects emerged that were modulated by brain region and stimulus condition: in non-linguistic reversed videos, older participants exhibited delayed entrainment in frontal regions, suggesting difficulty integrating unpredictable sensory input with internal models (Figure 2A). Conversely, in the sign language condition, age was positively associated with posterior coherence strength, particularly at low frequencies associated with phrase or sentence-level timescales (Figure 2B). This finding points to a refinement of predictive mechanisms with lifelong language experience.

Our findings support the hypothesis that life-long language experience refines predictive coding in the brain [2]. The transition from sensory-driven to model-driven inference appears to be reflected in frequency-specific coherence dynamics, particularly in frontal and posterior regions. These results expand current models of predictive processing by showing how sensory modality and linguistic experience shape cortical aging trajectories.

This page serves for Tables, Figures, and References.

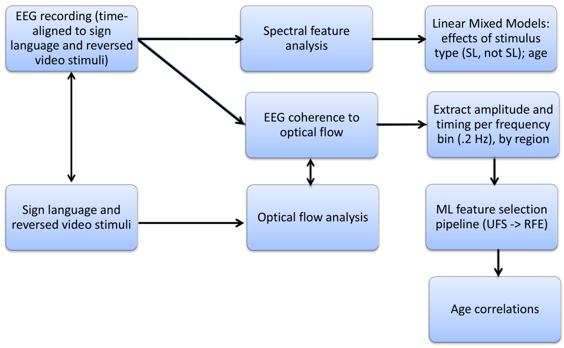
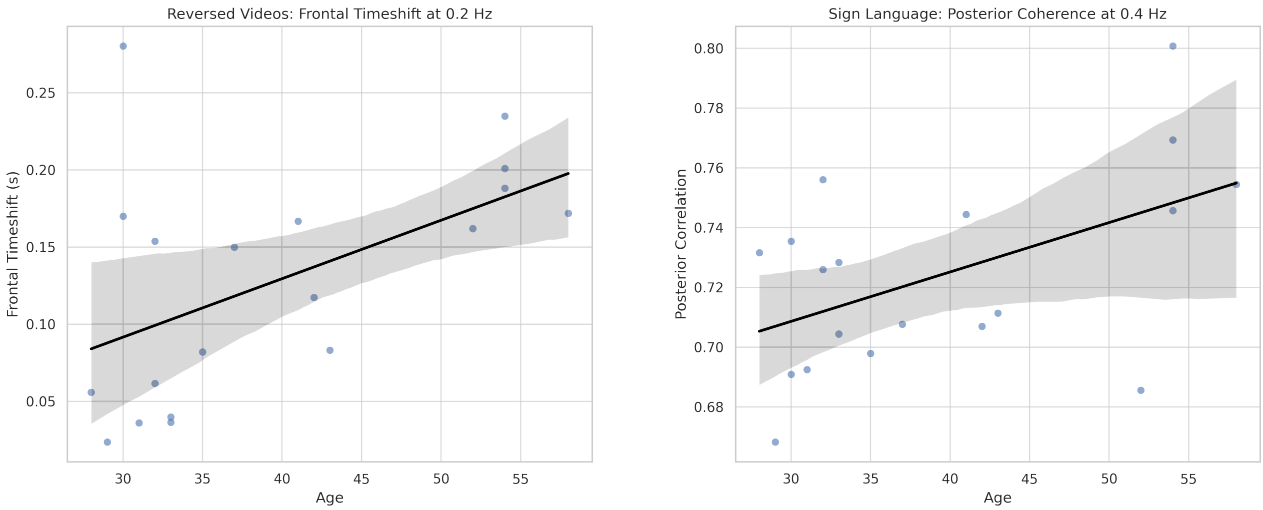


Figure 1: EEG analysis pipeline: raw EEG recordings, time-aligned with visual stimuli, subjected to two analyses: 1) spectral analysis of the EEG signal; 2) computed neural coherence with the optical flow of the stimuli subjected to ML to identify features most predictive of linguistic stimulus structure, and age correlations.



A. Relationship between age and frontal timeshift at 0.2 Hz in the reversed video condition. Older participants exhibit delayed neural response timing.

B. Relationship between age and posterior coherence at 0.4 Hz in the Sign Language condition. Older participants exhibit increased synchronization with linguistic motion.

Figure 2: Neural markers of predictive processing in visual language.

References

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