Hierarchical Processing of Degraded Speech: A Functional Near-Infrared Spectroscopy Study

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INTRODUCTION

Everyday conversation frequently occurs under a wide range of suboptimal and adverse listening conditions.[1] Behavioral and neuroimaging research suggest that processing degraded acoustic information creates a cascading effect on the mechanisms underlying speech comprehension, indicating that our cognitive resources are limited and causing a trade-off between effort and comprehension.[2,3]

QUESTION AND HYPOTHESES

Does listening under increasingly difficult conditions modulate language processing in response to increased demands on executive cognitive functions (e.g., short-term verbal working memory, attention)?

H1. The processing of increasingly degraded speech will result in greater contributions of executive cognitive resources.
P1. Hemodynamic activity for language processing will recruit the prefrontal cortex as a function of the amount of available speech features in the signal.

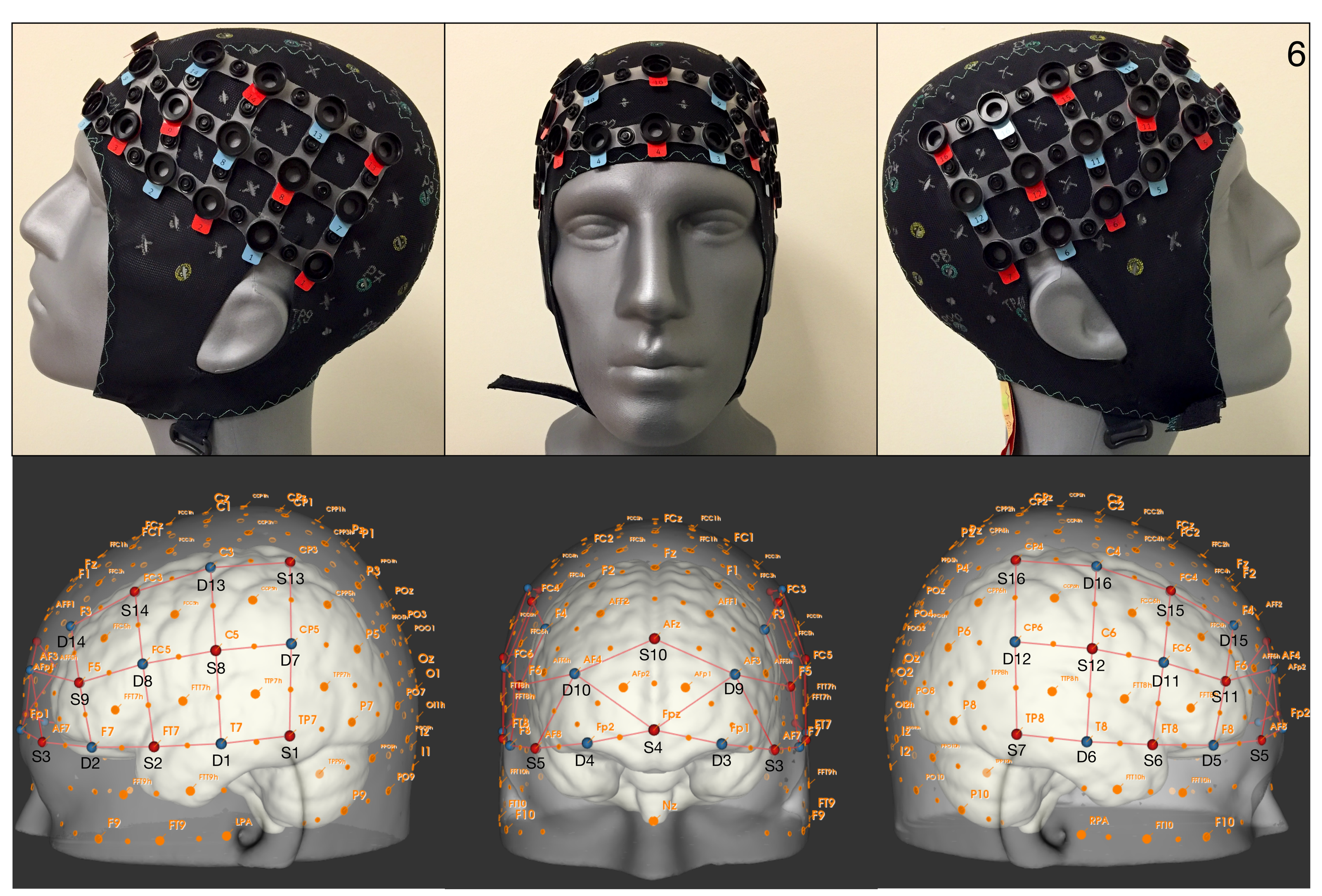
METHODOLOGY

Participants. Monolingual, English-speaking adults with typical hearing (N=11, F=7, Range=19;1 to 37;9 years old, Mean=28;5 years old).

Task. English sentence plausibility judgment task.[4,5]

Stimuli. 288 sentences presented at various speech rates and with or without distortions. *Innovation:* direct comparisons between hearing aid and cochlear implant simulations. Equal number of plausible and implausible sentences.

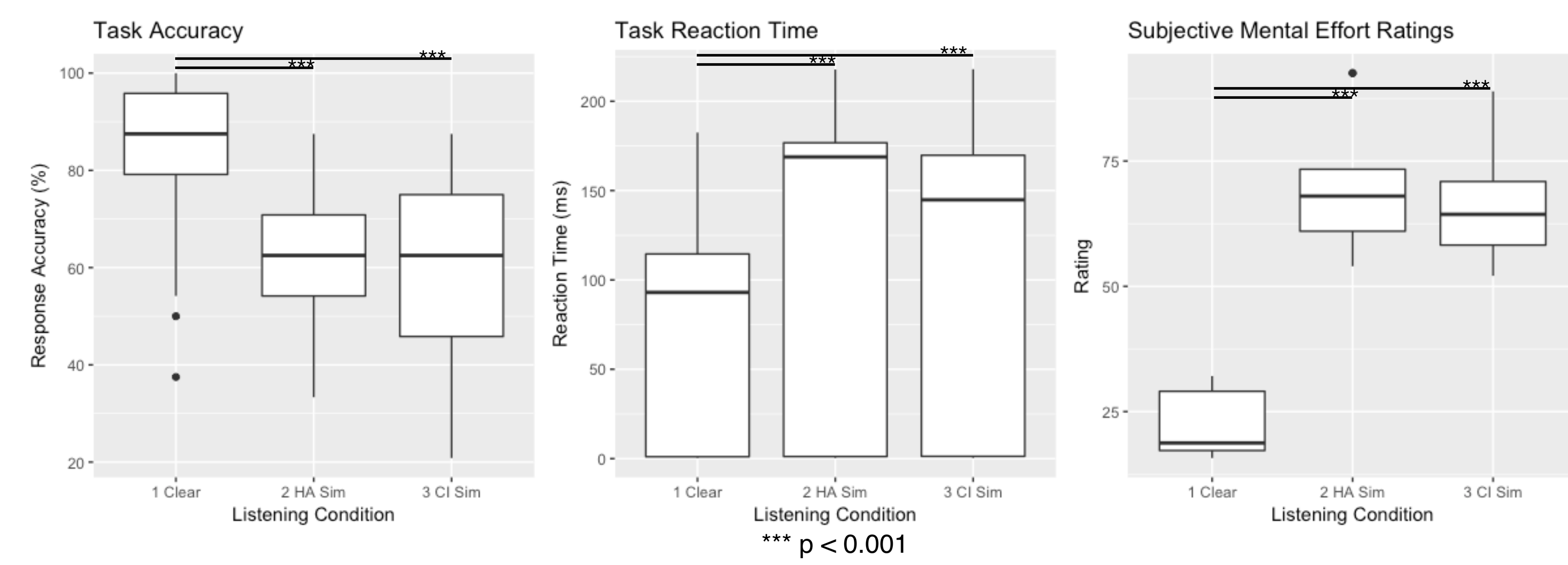
Simple (subject-relative clause): e.g., *Boys that help girls are nice.*
Complex (object-relative clause): e.g., *Boys that girls help are nice.*

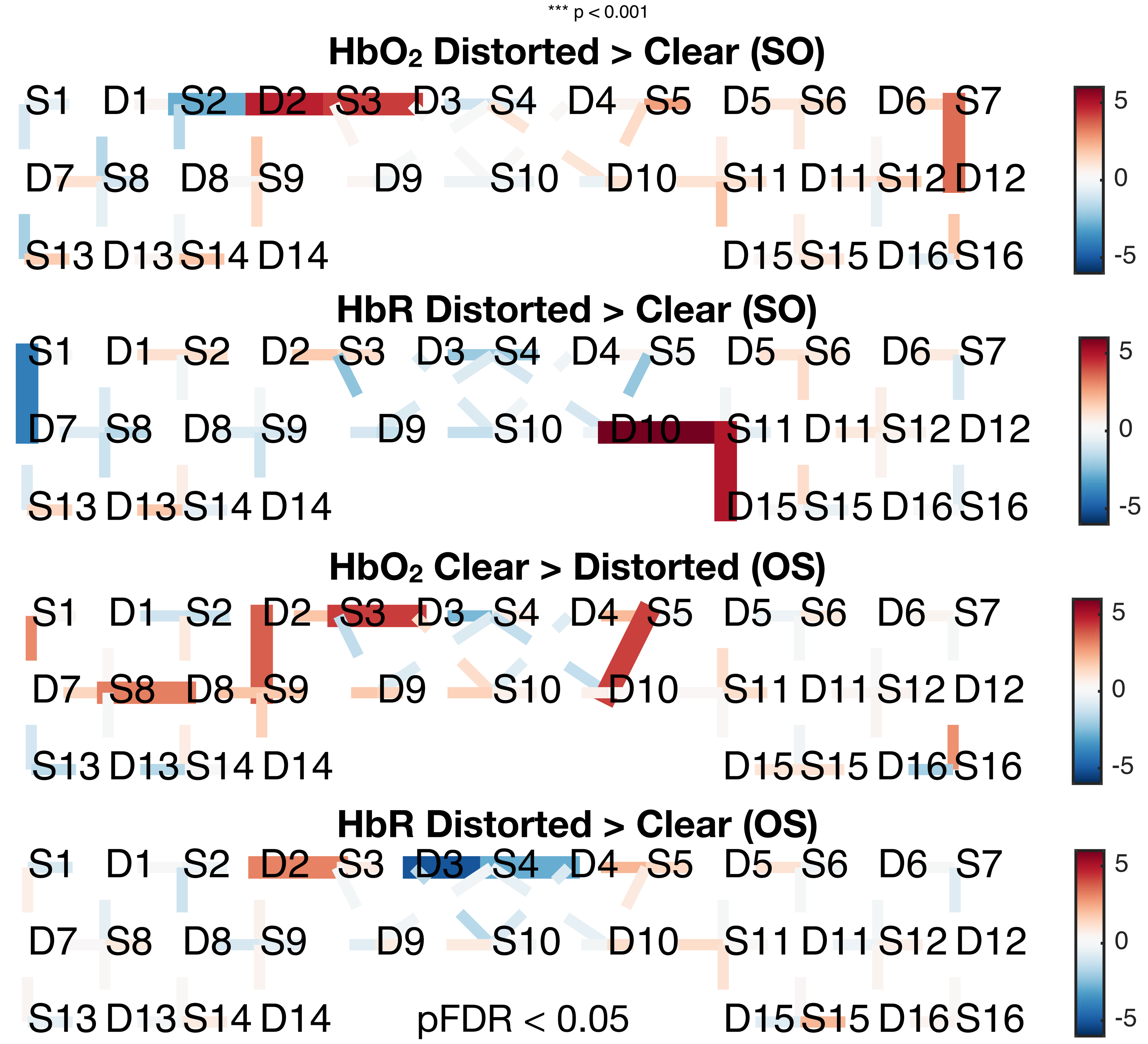


ANALYSES

Behavioral analyses were conducted using R. Functional NIRS data were preprocessed and analyzed using the NIRS Brain AnalyzIR Toolbox.[7] **Individual Analysis:** We used linear regression modeling with an autoregressive iterative re-weighted least squares (AR-IRLS)[8] pre-whitening method. **Group Analysis:** Group-level comparisons were made using fixed-effects statistical models.

BEHAVIORAL AND fNIRS RESULTS





We observed increased HbO_2 activity in the left inferior frontal gyrus (channels between S2, D2, and S3) for distorted compared to clear subject- and object-relative sentences. We also observed greater HbO_2 and HbR activity in the prefrontal cortex for object-relative sentences for the same contrast.

DISCUSSION

This study advances our understanding of how auditory degradations modulate hierarchically organized language and associated processes (e.g., short-term verbal working memory, attention) and crucially, the relationship of this modulation to the amount of speech features preserved in the signal.

H1 Language Processing: Here, we see that auditory degradations do in fact modulate the neural streams for language processing, indicating that there may be a *neural* trade-off between effort (i.e., motivated listening under suboptimal or adverse conditions) and recruitment of executive functioning brain areas.

Future Directions: This work validates the methodology outlined, and we identify relationships between different listening conditions and demands on executive functioning in listeners who are naïve to these types of degradations. We are now using this paradigm to investigate the effects of early deafness and life-long hearing aid or cochlear implant use on spoken language processing. As a whole, this work tests hypotheses surrounding the effect of auditory experience on the neurobiological systems for effortful listening.[3,5,9,10]

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