Poster 636

Using fNIRS to investigate effortful listening of normal and degraded speech with noise

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INTRODUCTION

- Every year, 60,000 people in the U.S. acquire single-sided deafness (SSD), causing deficits in spatial hearing and speech perception in noise.
- Having a cochlear implant (CI) in the deaf ear can help them restore functional (binaural) hearing [1, 2] or suppress tinnitus [3].
- Hearing via the good ear and the CI can be challenging for SSD-CI listeners; effects of CI on the listening effort has yet to be investigated.
- Brain activity for effortful listening has been studied with fMRI [4,5]. However, fMRI is not suitable for CI listeners.
- We used **f**unctional **N**ear-**I**nfra**R**ed **S**pectroscopy (fNIRS) to investigate simulated SSD listening, and tap into brain region inferior frontal gyrus (IFG), which is thought to be involved in effortful listening [5,6].

PRINCIPLES OF FNIRS

- Near-infrared light travels in brain tissue and can reveal the oxygen metabolism in blood flow (Fig.1).
- Neural activity is associated with changes in oxy- (ΔHbO) and deoxygenated hemoglobin (ΔHbR) through neurovascular coupling (Fig.2).

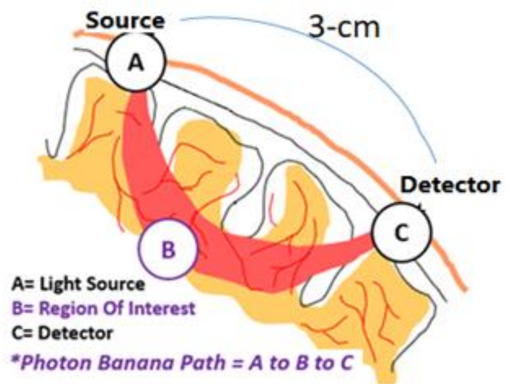


Fig. 1 NIRS light traveling through the head.

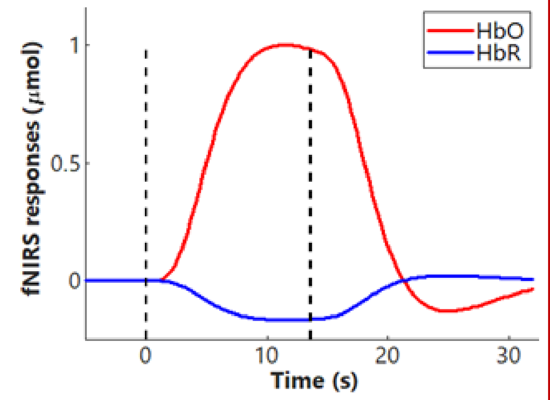


Fig.2 Neural activity related changes in HbO (red) and HbR (blue) after stimulation (black vertical dash lines).

- ✓ fNIRS is non-invasive, suitable for studies with CI listeners, quiet for auditory studies, and friendly for infants and children.
- × fNIRS signals are affected by confounds, see Fig. 3 from [7]. It is essential to remove these confounds.

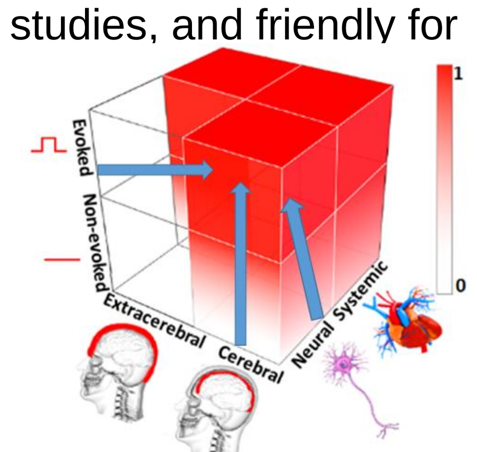


Fig.3 Components in fNIRS signals. Diagram from [7]

Objectives

- ➢ To implement a new technique (shorter-channels) for reducing confounds from extracerebral tissue and determine effects on fNIRS responses.
- ➢ To understand whether fNIRS can be used to reveal changes in brain activation under conditions that elicit changes in listening difficulty.

METHODS

Participants

- 23 native English speakers (no bilinguals) with normal hearing (13 females, 21 right-handed)
- Age: mean ± SD, 22.70 ± 3.07 years old
- None had significant experience as musicians.

Stimuli & Hearing conditions

- **Speech:** Female-talker sentences (name, verb, number, adjective, object); normal and 8-channel noise-vocoded
- **Noise:** 8-channel noise-vocoded Harvard IEEE sentenced, 4-female-talker babble, 60 dBA
- Speech to Noise Ratios (SNRs): -10 & -15 dB SPL.
- **Listening conditions (Table 1)**

Table 1. Four different listening conditions.

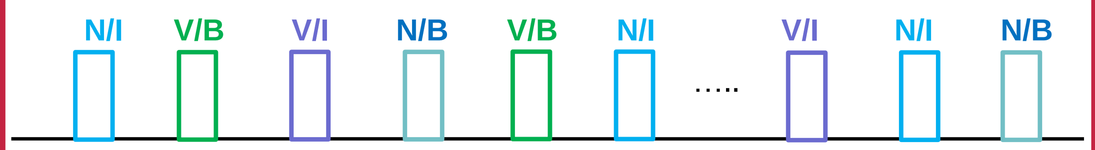
Listening conditions	Monaural (Left-ear) Normal speech	Monaural (Left-ear) Vocoded speech
Ipsilateral noise	**NIpsi**	**VIpsi**
Bilateral noise	**NBila**	**VBila**

fNIRS data collection

- **NIRScout** (NIRx Medical Technologies, LLC). Near-infrared light wavelengths at 760nm and 850nm; 16 LED sources and 16 APD detectors.
- **fNIRS data collection:** fNIRS data were collected in a sound booth (Fig. 4). Auditory stimuli were delivered through insert ER2 earphones. Text instruction was presented on a monitor in front of the participants.

Fig.4 fNIRS data collection.

- **Pseudo-random block design**



- fNIRS data were collected in six 9-min testing periods. In each testing period, 4 listening conditions at the same SNR were presented in a random order.
- Each of the two SNRs had 3 repetitions. In total, each listening condition had 9 blocks.

Shorter-channel Subtraction

Methods to reduce fNIRS confounds

1. Anti-Correlation method *without* shorter channels:

- ΔHbO and ΔHbR signals consisted of functional (neural activity) and systemic components. The functional components were assumed to be anti-correlated (Fig.2), but the systemic components were not, thus they could be separated.

2. GLM-PCA method *with* shorter channels:

- Principal component analysis (PCA) was performed on 8 shorter (0.84 cm) channels (Fig.5, 6).
- A general linear model (GLM) was used to subtract the 1st and 2nd principal components of the shorter channels from the 3-cm channels.

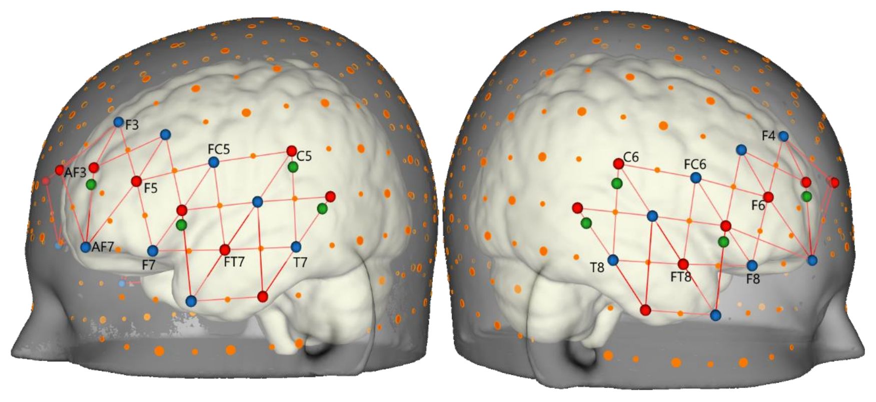


Fig.5 fNIRS montage. Red dots (16) are for light sources Blue dots (16) are for detectors. Red lines are for 3-cm fNIRS channels. Green dots (8) with their adjacent red dots provide shorter channels (0.84 cm), with 4 on each side.

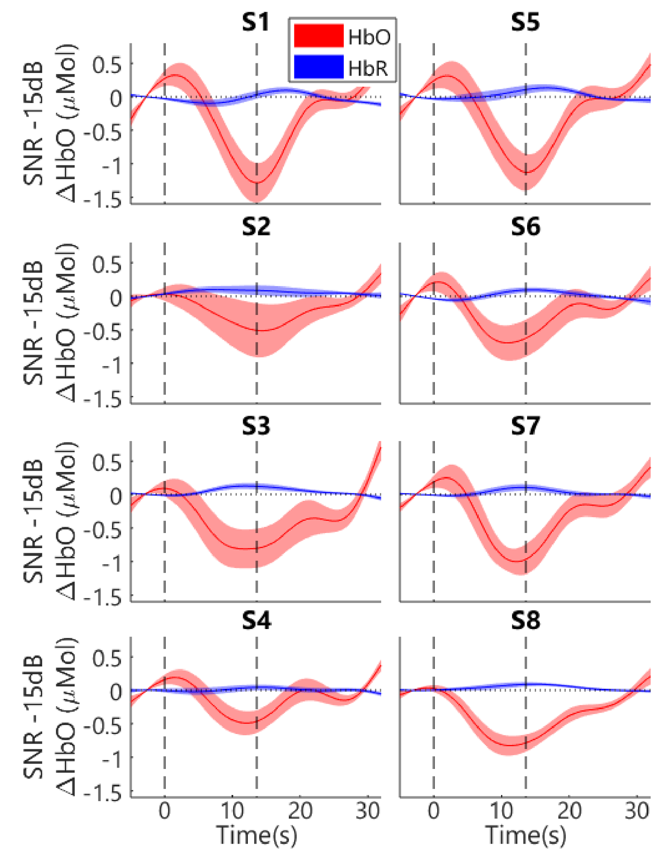


Fig.6 Group average ΔHbO (red) and ΔHbR (blue) in 8 shorter channels. Vertical dash lines plot the onset and offset of stimulation.

RESULTS: reducing fNIRS confounds with two methods

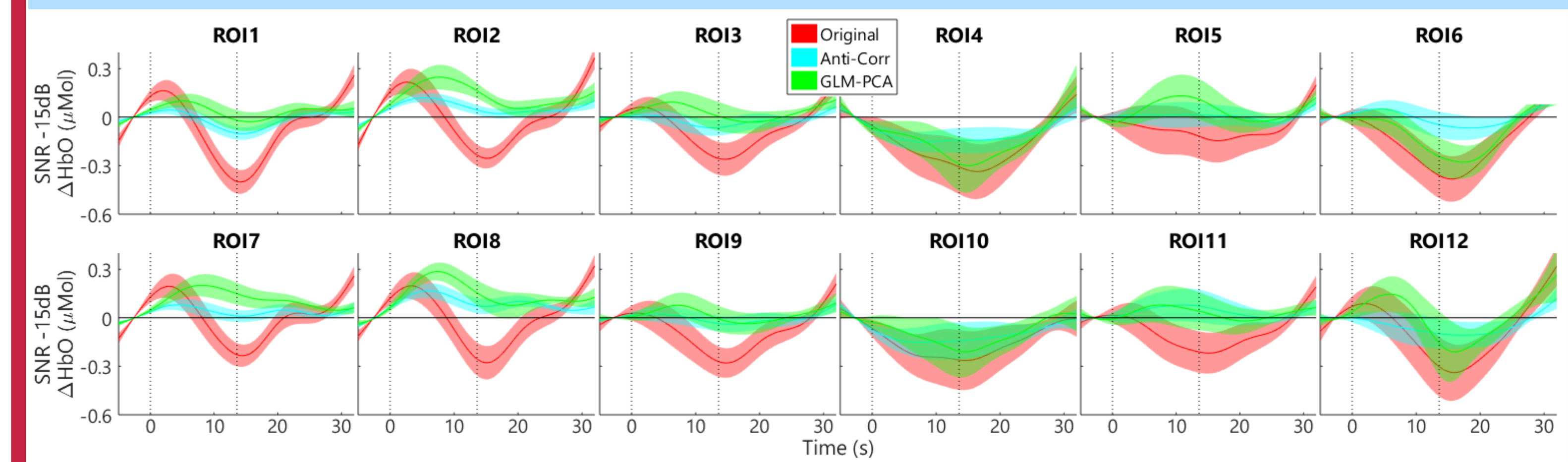


Fig.7 Group average ΔHbO response in 12 ROIs. Red plots HbO responses without confounds being reduced, cyan for Anti-correlation method (without shorter channel) and green for shorter-channel subtraction.

fNIRS & Reported Task Difficulty

We predicted that fNIRS responses would be *greater* in magnitude in the *more challenging* listening conditions. Particularly, we are interested in the IFG brain region that is thought to be involved in effortful listening.

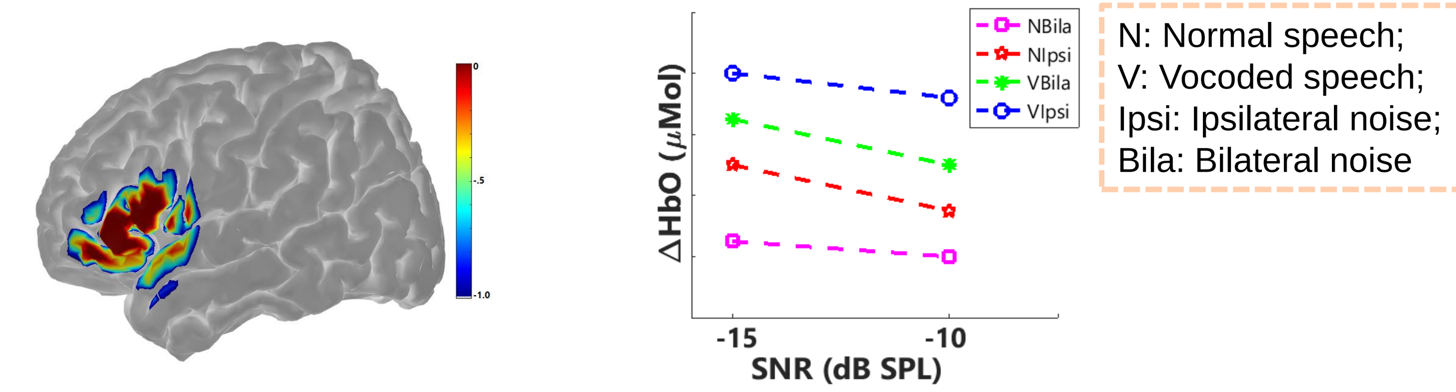
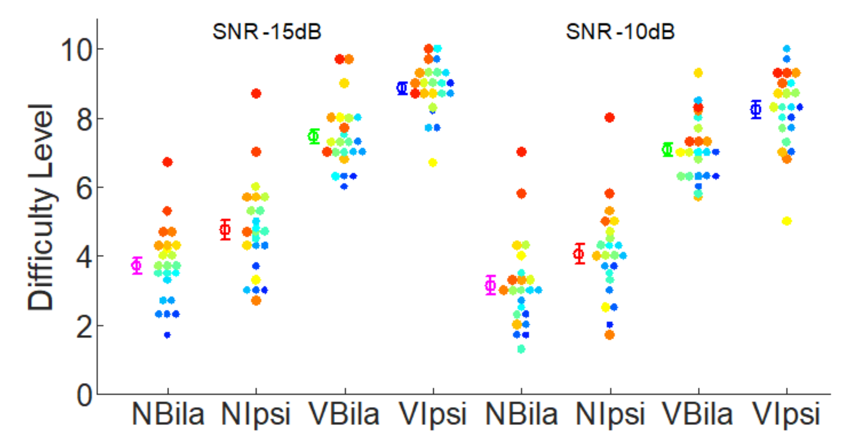


Fig.8 Region of interest - IFG (left) and predictions of ΔHbO responses of the 4 listening conditions at 2 SNRs (right).

RESULTS: subjects reported task difficulty



Friedman rank tests:

At SNR = -15 dB SPL,
$x^2 = 61.05, p = 3.5 * 10^{-13}$;

At SNR = -10 dB SPL,
$x^2 = 62.29, p = 1.9 * 10^{-13}$;

Fig.9 Subjective assessment of difficulty levels of the 4 listening conditions at 2 SNRs.

RESULTS: fNIRS & reported task difficulty

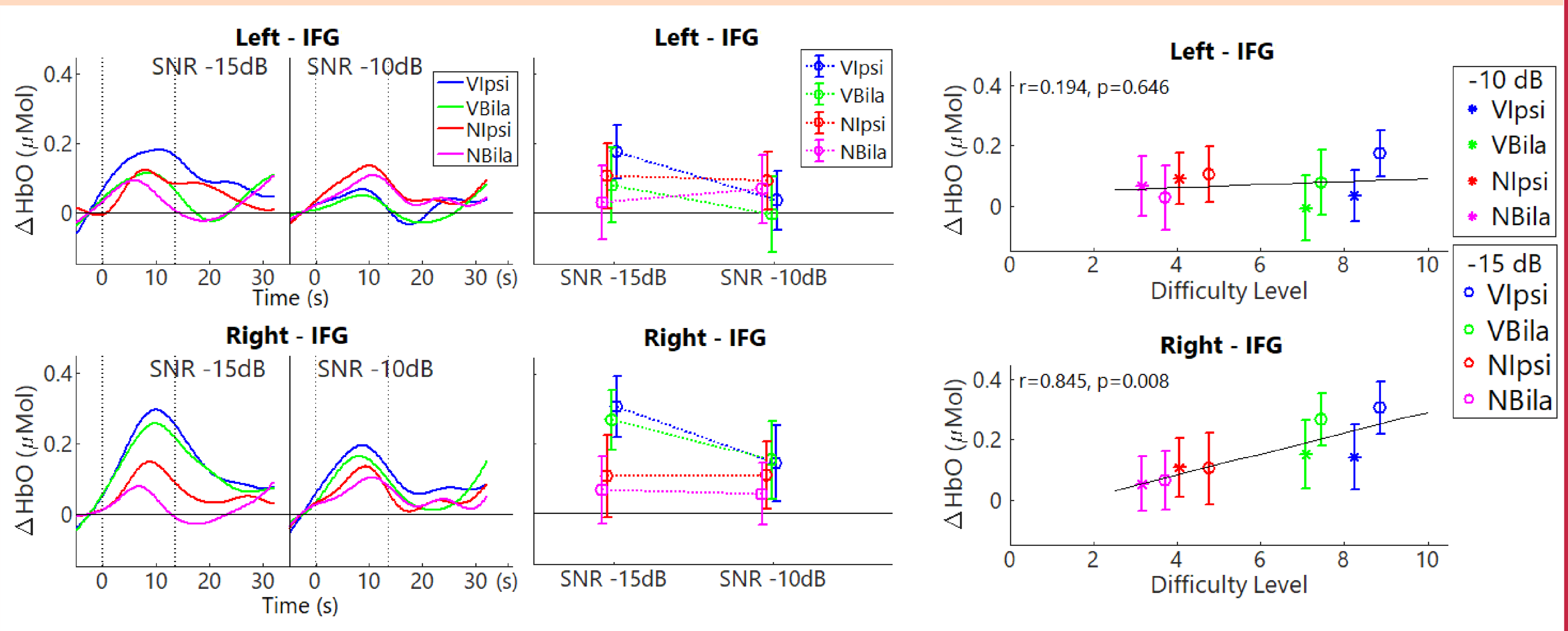


Fig.10 ΔHbO in the 4 different listening conditions. Left, ΔHbO waveforms, vertical dash lines plot the onset and offset of stimulation. Middle: amplitude of ΔHbO responses. Right: correlations between difficulty scale and ΔHbO amplitude.

CONCLUSIONS

- ❖ The fNIRS data presented here (Fig.7) showed that using Anti-Correlation and GLM-PCA methods both reduced fNIRS confounds - suppressive components from the extracerebral tissue. However, GLM-PCA with shorter channels performed better in improving the neural signal to noise ratio than the Anti-Correlation method without shorter channels.
- ❖ fNIRS data in the RIFG (Fig.10) showed a significant positive correlation with subjects' reported difficulty level, i.e., the *more difficult* participants thought the listening condition was, the greater fNIRS responses in the RIFG brain region. The left IFG is thought to be involved in effortful listening. Our results suggest that IFG on the right side is also involved effortful listening.

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