

INTRODUCTION

- In normal hearing (NH) listeners, interaural timing differences (ITDs) are an important cue for good sound localization and speech unmasking in noisy situations^{1,2}. However, bilateral cochlear implant (CI) users typically show little reliance on ITDs when locating sounds.
- Stimulation rates that support better speech understanding do not provide good ITD sensitivity^{3,4}:

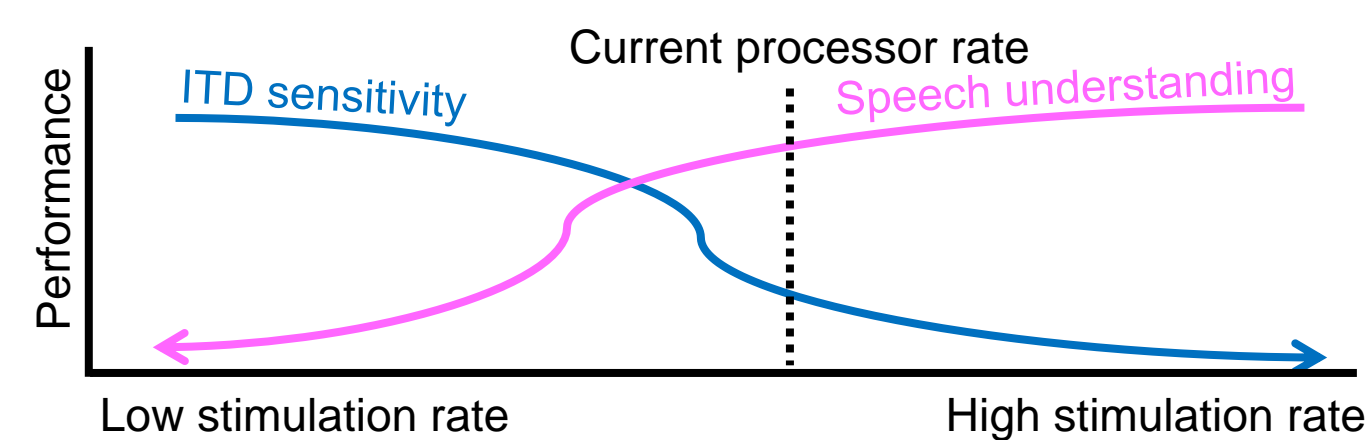


Figure 1. Simplified model of rate vs performance

- In NH listeners, frequency modulation imposed on a high frequency tone can improve ITD sensitivity⁵.

The aim of this study was to measure the extent to which frequency modulation within a high-rate electrical pulse train can promote better ITD sensitivity in bilateral CI users

METHODS

- ITD just noticeable differences (JNDs) were measured using synchronized research processors (Cochlear L34) on a pitch-matched pair of electrodes for a 4 kHz electrical pulse train.
- Four conditions:
 1. No modulation (**No Mod**)
 2. Frequency modulation (**FM**) only
 3. Amplitude modulation (**AM**) only
 4. Amplitude + Frequency modulation (**AM+FM**)
- All modulation at 100 Hz. For FM, the maximum deviation of the instantaneous frequency from 4 kHz was ~720 Hz. For AM, modulation depth was at 100% from threshold to comfortable levels.
- Four adult bilateral CI listeners who had shown ITD sensitivity in previous experiments were tested.

Table 1. Bilateral CI users' profiles and etiology

ID	Age	Years of CI experience		Etiology	Electrodes	
		Bilateral	Total		L	R
IBY	51	3.5	7	Progressive	12	12
IBZ	47	7	8	Unknown	12	12
ICB	64	9	12	Progressive	12	12
ICJ	65	7	7	Childhood illness	12	10

RESULTS

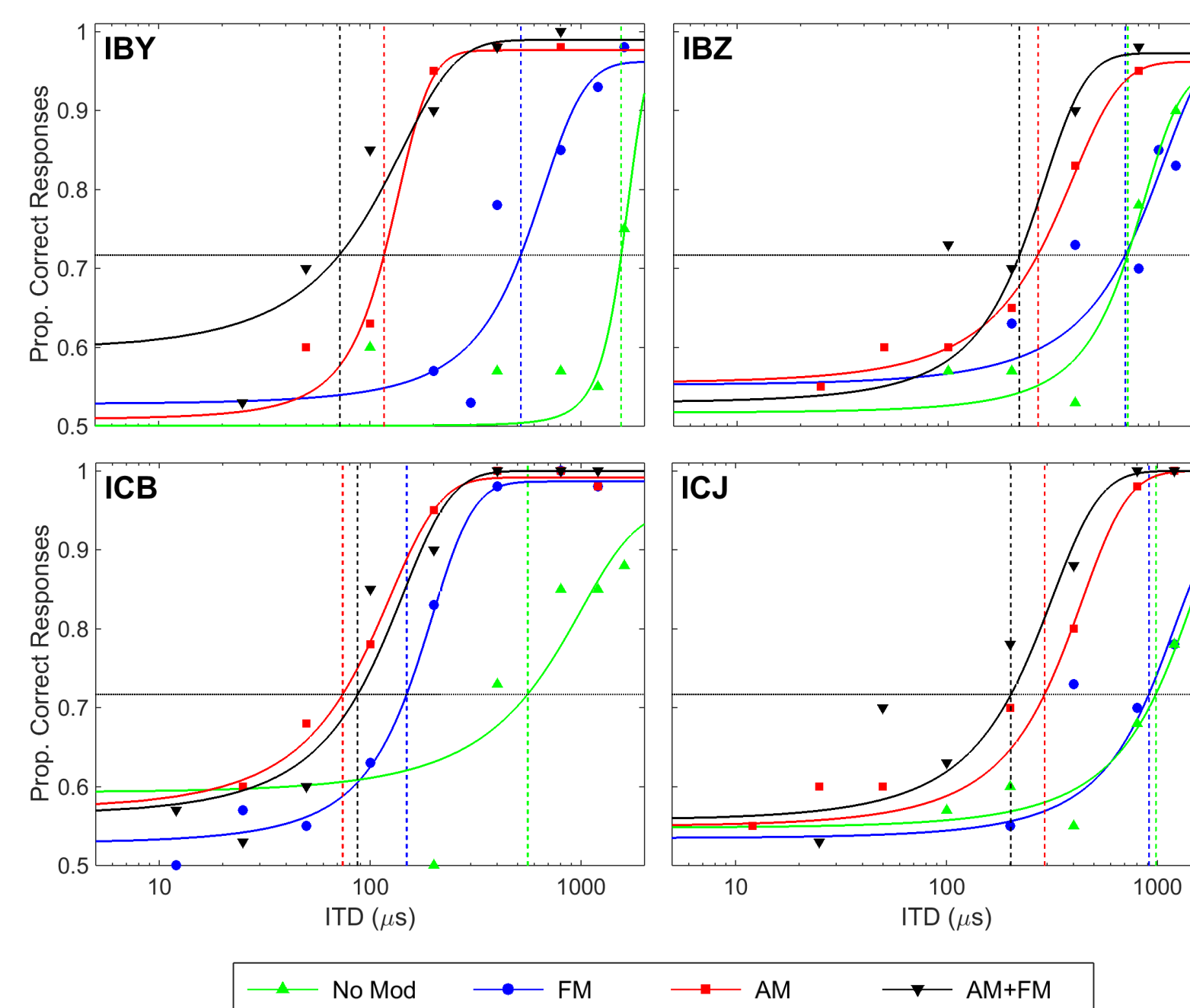


Figure 2. Individual psychometric functions for all conditions tested. The symbols show the proportion of correct responses for the corresponding ITD tested. The line shows the logistic function fitted to the data.

- Compared to the No Mod condition, FM can considerably improve ITD JNDs (— vs —), in some listeners (IBY, ICB).
- ITD JNDs with AM are always much lower than FM (— vs —).
- Small improvement with AM+FM compared to AM only (see Table 2).

Table 2. ITD JNDs in microseconds

ID	No Mod	FM	AM	AM+FM
IBY	1552	519	117	72
IBZ	559	149	74	87
ICB	711	692	267	218
ICJ	983	911	292	202
Mean	951	568	188	145

DISCUSSION

- Results support the finding that aperiodic timing of pulses at high rates can improve ITD sensitivity⁶. The advantage of using FM is that the inter-pulse interval can be controlled deterministically, which may be important for ensuring good encoding of speech envelopes.
- Compared to existing solutions for improving ITD sensitivity, the novelty of FM is that ITD information can be presented on all electrodes, while high stimulation rates can continue to be used on all electrodes to encode the speech envelope. Providing ITD information along the whole array will lead to improved ITD sensitivity in most BiCI users⁷.

CONCLUSIONS AND FUTURE WORK

- FM can improve ITD sensitivity while allowing high stimulation rates to be used.
- Future work will measure ITD sensitivity as a function of FM bandwidth and AM depth. We predict that ITD sensitivity will improve with larger FM bandwidths, and FM will provide complementary cues to maintain ITD sensitivity as AM depth decreases.

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