Poster #5aPP6

The Precedence Effect: Exploring the Build-Up of Echo Thresholds in Cochlear-Implant Listeners

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ASA 2014

Providence, RI

May 9, 2014

Binaural Hearing and Speech Laboratory

INTRODUCTION

1. The **precedence effect (PE)** refers to a perceptual phenomenon in which greater perceptual weight is given to a leading sound source (lead) than to a simulated echo of that source (lag). The PE is thought to facilitate accurate sound localization in reverberant listening environments (Wallach et al., 1949). In normal-hearing (NH) listeners, the PE is studied by varying the temporal delay between the lead and the lag. Key features of the PE are:
   - **Fusion:** At brief lead-lag delays (LLDs), a single sound source is perceived. The echo threshold (ET) is the delay at which two sources are perceived on some criterion proportion of trials (e.g. 50%). NH ETs are normally 5-10 ms for impulsive signals, such as clicks or brief noise bursts (Litovsky et al.,1999).
   - **Localization/Lateralization Dominance:** At brief LLDs (below and sometimes slightly beyond the ET), sound localization is dominated by the cues carried by the lead.

2. Prior studies have established that interaural time differences (ITDs) are particularly important for the PE (Krumbholz & Nobbe, 2002; Brown & Stecker, 2013).

3. Users of **bilateral cochlear implants (BiCIs)** are generally insensitive to ITDs when using their clinical processors (Grantham et al., 2008), and are especially poor at sound localization in reverberant environments (Kerber & Seeber, 2013) where the PE would offer the greatest benefit.

4. However, BiCI users experience a relatively normal PE when given bilaterally synchronized stimulation (restoring ITD sensitivity) via custom research interfaces (Brown et al., 2013; van Hoesel, 2007; Agrawal, 2008).

Here, while manipulating bilaterally-synchronized ITDs in BiCIs, we studied an aspect of the PE known as build-up, which would typically enhance lead-lag fusion for a recurring stimulus in NH listeners.

THE BUILDUP EFFECT

1. When a *static* lead-lag pair is presented repeatedly at a fixed LLD (i.e. at the baseline lead-lag pair ET), the lag perceptually "fades out," resulting in the perception of a single source. Stimulus repetition can increase the baseline ET two- or threefold.
   - This effect is known as "build-up" of the precedence effect (e.g., Clifton, 1987). Buildup may have substantial ecological benefit (e.g. improved speech intelligibility, Brandewie & Zahorik, 2010).

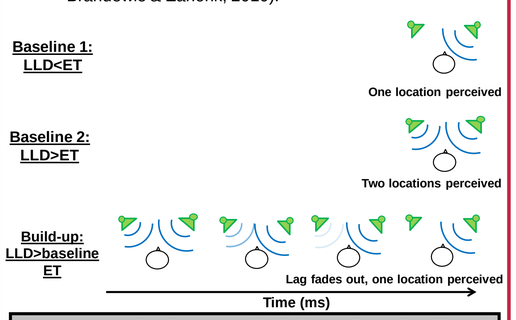
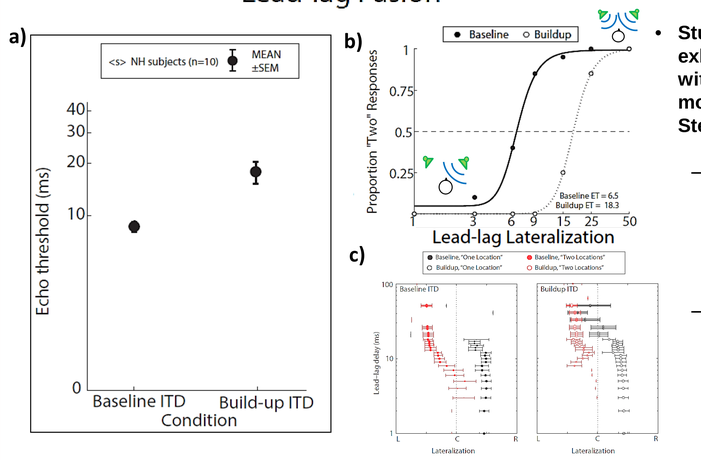


Figure 1: Perception of source and echo in Baseline and Build-up. a) When source and echo are received at short LLDs below the ET, only the source is heard. **b)** When source and echo are received at LLDs greater than the ET, both stimuli are heard **c)** When source and echo are presented repeatedly, a shift in the Baseline ET occurs, and only one source is heard.

BUILDUP IN NORMAL-HEARING LISTENERS

Lead-lag Fusion



- **Studies show that NH listeners exhibit a robust build-up effect with 123-μs broadband monophasic pulses (Brown & Stecker, 2013):**
  - **Fusion (Fig. 2a,b):** Fusion echo thresholds generally increase in Build-up conditions; *mean data indicates a reliable effect of build-up.*
  - **Lateralization/Localization Dominance (Fig. 2c):** Responses to a "right-leading" ITD in the Build-up condition fall near the midline at long LLDs, suggesting reduced localization dominance.

Figure 2: Baseline ITD and Build-up ITD for 10 NH subjects using broadband clicks (replotted from Brown & Stecker, 2013). a) Mean ETs for Baseline ITD an Build-up ITD conditions **b)** Individual psychometric function demonstrating and effect of build-up **c)** Mean normalized lateralization for trials on which the listener reported one (black) or two (red) locations for a "right-leading" ITD.

METHODS

- **Subjects:**
  - 3 bilateral cochlear implant (BiCI) listeners with demonstrated ITD sensitivity and late-onset of deafness.
- **Stimuli:**
  - "Lead-lag" pairs of biphasic pulses were delivered to a *single* electrode pair in the apical region of the electrode array.
    - Delivered to each ear, the pair was first matched for loudness and pitch, then electrically stimulated at current levels that were comfortable.
  - Stimuli were delivered via research processors that bypass the clinical processors and allow direct control over all aspects of the stimulation.
  - Baseline ITD: Single lead-lag pair with a LLD of of 1-64 ms, lead and lag carrying opposing 500 μs ITDs.
  - Build-up ITD: 12 lead-lag pairs presented at 4 Hz followed (after a 500 ms pause) by a final test pair.
- **Task:**
  - Simultaneous fusion and lateralization task using large touch-sensitive monitor.
  - Subjects indicated location of fused image in upper panel, or location of left-most of 2 images in lower panel.
  - Listeners completed 350 trials in Baseline ITD and Build-up ITD conditions (50 trials at each LLD)..

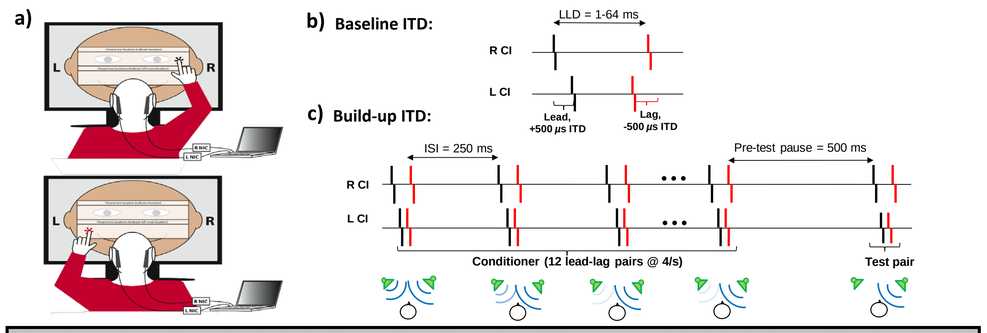


Figure 3: Precedence effect task and stimuli. a) On a touch-sensitive monitor, BiCI listeners were asked to judge the intracranial location and number of images heard on each trial. If two images were perceived, listeners were instructed to indicate the *left-most* image in the lower of 2 panels. **b)** "Baseline ITD" stimuli consisted of a single bi-phasic pulse presented with a 500 μs right-leading ITD, followed by an opposing (500 μs left-leading) pulse. The LLD, was varied randomly over the range 1-64 ms from trial to trial. **c)** "Buildup ITD" stimuli consisted of 12 lead-lag pulse pairs presented with a 250 ms inter-stimulus interval (ISI) (the "conditioner") followed by a final test pair (having an identical LLD and ITD).

BiCI RESULTS

Lead-lag Fusion

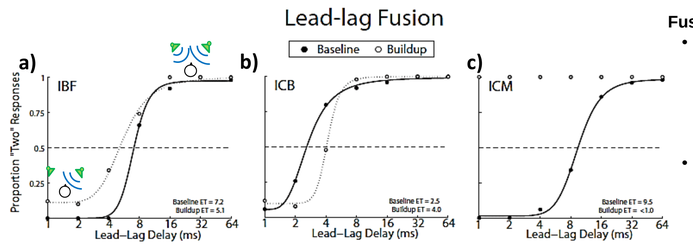


Figure 3: Individual fusion data for 3 BiCI listeners (a-c). Points give the proportion of trials on which listeners reported two images at each lead-lag delay. Logistic fits are given by solid (Baseline ITD) or dotted (Build-up ITD) lines. The echo threshold was taken as the lead-lag delay at fit(0.5). Panels a-c give data for each of three subjects.

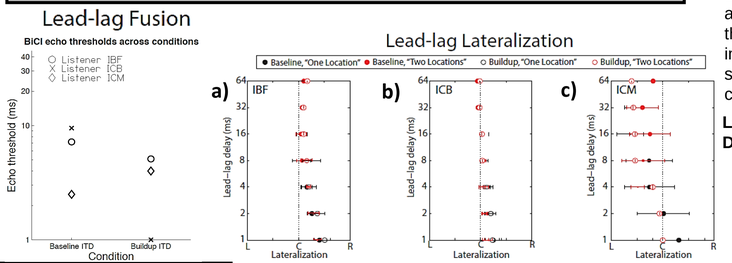


Figure 4: Echo Thresholds for BiCI listeners as a function of condition. Two of 3 listeners experienced *reduced* ETs in the Build-up condition.

Figure 5: Individual lateralization responses for 3 BiCI listeners (a-c). Points give mean lateralization (left-to-right) responses for trials on which subjects reported one (black) or two (red) images. Localization dominance (depicting only the "right-leading" ITD) was generally weak in all listeners.

Fusion:

- In the Baseline condition, BiCI listeners showed relatively normal fusion as a function of lead-lag delay, consistent with Brown et al. (2013).
- Despite apparently normal fusion in the Baseline condition and good ITD sensitivity, subjects showed little or no build-up effect. In fact, ETs *decreased* in the Build-up condition for subjects IBF and ICM (Fig. 4).
- Listener ICM (Fig. 3c) experienced a complete reversal of fusion in the Build-up condition, suggesting incongruent encoding of the stimuli in Baseline vs. Build-up conditions.

Lateralization/Localization Dominance:

- Localization dominance was generally weak in all three listeners, except at the briefest LLDs (consistent with Brown et al., 2013).
- There were no obvious differences between Baseline and Build-up conditions (Fig. 5).

CONCLUSIONS

- While all 3 of our BiCI subjects experienced ~normal PE in the Baseline condition all 3 unsuccessfully demonstrated a build-up effect (cf. NH build-up data in Brown and Stecker, 2013).
  - Listener ICM apparently experienced a total collapse of precedence, such that two images were heard at all tested lead-lag delays, including those that previously produced fusion in the Baseline condition.
  - Localization dominance was generally weak, though this was not specific to the Build-up condition.
- Due to the heterogeneity of the BiCI population, it will be essential to test additional ITD-sensitive BiCI listeners to determine whether the lack of a build-up is observed in a majority of listeners.
- One possible explanation for a lack of build-up in BiCI listeners is that the external (stimulus) ITD is centrally encoded with high variability, such that the build-up sequence is effectively dynamic rather than static.
- Future studies will look at the effect of narrowband pulses in NH listeners.

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ACKNOWLEDGEMENTS

We would like to thank all our participants and Cochlear Ltd for providing equipment and technical assistance. NIH-NIDCD (R01 DC003083 to RYL), and NIH-NICHD (P30 HD03352 to Waisman Center).