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The effect of audibility on audio-visual speech perception in infant cochlear implant recipients

Brittan A. Barker[a] & Sandie M. Bass-Ringdahl[a,b]

[a]*University of Iowa, Department of Otolaryngology—Head & Neck Surgery*
[b]*University of Iowa, Department of Speech Pathology & Audiology*
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Abstract. Very young children were followed during their pre-operative, hearing aid use and subsequent cochlear implant use. Repeated measures of audio-visual (AV) speech perception were collected from each child using the Split-Screen Preferential Looking Paradigm. Audibility was calculated using the Speech Intelligibility Index (SII) pre- and post-cochlear implantation. The relationship of AV speech perception to changes in audibility was examined retrospectively using an approximation of a single-subject design. A subset of this preliminary data was presented.

Keywords: cochlear implant, infant, audio-visual speech perception, audibility, speech intelligibility index

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1. Introduction

Previous research, using the Split-Screen Preferential Looking Paradigm (SPLP [1]), examined audio-visual (AV) speech perception in hearing-impaired infants during their pre-implant, hearing-aid trials and their post-implant experiences [2]. The results from this preliminary study suggested that, following cochlear implantation, infants begin to accurately match phonetic information in the lips and voice. It was suggested that these data provided evidence that the auditory experience afforded to these infants via their cochlear implants (CIs) may have improved their levels of audibility and subsequently contributed to their evolving AV speech perception for the vowel sounds /a/ and /i/. If such research is to contribute to the development of an empirically valid, clinical protocol, objective measures need to be paired with the behavioral findings. Pairing behavioral and objective measures will allow one to accurately assess the auditory benefit gained by infants with hearing loss who use hearing aids (HAs) or CIs. The present study began investigation of the relationship between behavioral measurements of AV speech perception and objective measurements of the auditory input provided via HAs and/or CIs by examining the relationship of performance on an AV speech perception task to changes in audibility pre- and post-cochlear implantation. Individuals' preliminary results from this on-going study are presented within.

2. Method

A total of 5 infants' (2 males, 3 females) data were examined for this study. All children were diagnosed with severe-profound, sensorineural hearing loss and fit bilaterally with HAs at the onset of data collection; during HA use better ear PTAs (500Hz, 1000Hz, & 2000Hz), based on behavioral audiological evaluation and physiologic testing, ranged from 73dBHL to no response at the limits of the audiometer. Three participants became CI users over the course of the study. Repeated measures of AV speech perception and audibility were gathered from each infant, thus the children were tested at various ages. All infants' cognitive abilities were "within the normal limits" [3] and infants had no known visual abnormalities.

2.1 Audio-visual speech perception as measured by the Split-Screen Preferential Looking Paradigm

SPLP is designed to determine if infants show a consistent preference for a video event that is related to an acoustic stimulus. The index of preference is the difference in the length of the infant's looking time to two different kinds of visual stimuli over the test-trial series. In the present investigation, SPLP was used to assess infants' AV speech perception of the vowel sounds /a/ and /i/. Please note that the methodology used in this study is the same as the one used in Barker and Tomblin [2]; the reader is referred to this previous study for details.

2.1.1 Stimuli

A female model was filmed articulating /a/ and then /i/ while a second female, native speaker of American English recorded the audio stimuli. Ultimately, the /a/ and /i/ video loops were synchronized and combined with each of the audio tracks. The final stimuli were edited onto one screen, enabling a simultaneous display of the video loops (**Fig. 1**).

Fig. 1. Still image of the final SPLP video stimuli for the present experiment.

2.1.2 Apparatus & procedure

The SPLP was housed in a double-walled sound booth. A 52" television monitor was located in the front of the booth and a video camera was mounted above the monitor. On each trial, the orientation of the infant's eyes was recorded via the camera; an off-line analysis of each infant's gaze direction/duration was conducted after each test session. Gaze duration was summed for each video image and averaged across stimulus conditions, yielding the mean total looking time for each image.

Experimental sessions consisted of a *Familiarization Phase* and a *Test Phase*. The *Familiarization Phase* consisted of silent trials in which the infant was introduced to the video images and their respective locations. The *Test Phase* consisted of the same video images presented in the *Familiarization Phase* paired with either the /a/ or /i/ speech stimuli played over the television's central loudspeakers.

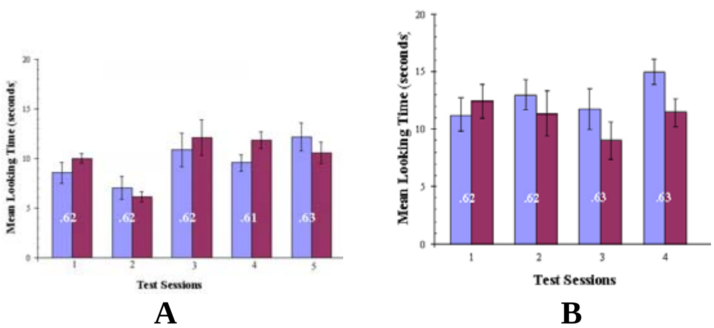
2.2 Audibility as measured by the Speech Intelligibility Index

To quantify speech audibility, a computer program was used to calculate the Speech Intelligibility Index (SII). The SII is based upon ANSI S3.5-1997 standards and is highly correlated with the intelligibility of speech under a variety of adverse listening conditions [5]. The SII is an objective measure designed to quantify the proportion of the speech signal that is audible to the listener, with enhanced weighting for the frequency regions of speech that carry the most information. The SII ranges from 0.0 to 1.0. An SII of 0.0 is consistent with none of the speech signal being audible, whereas an SII of 1.0 is consistent with the entire speech signal being audible, as in normal-hearing listeners. SII was calculated for each infant, on repeated occasions, based on the following information: (a) a speech spectrum, (b) insertion gain for speech, and (c) thresholds in dB HL. The "hip" speech spectrum [6] was investigated for its effect on audibility because it approximates the speech signal available to an infant, from the caregiver, when held on the caregiver's hip.

3. Results

Infants who successfully matched phonetic information from the lips and voice displayed longer mean looking times to the target stimuli in the AV speech perception task. For the audibility measures, a value of 1.0 indicated that the entire speech spectrum was available to the infant. Individuals' performance on the AV task and their estimated audibility, available during each test session, are displayed below. All graphs show the mean total looking times (and standard error) to the target stimuli (light gray bar) vs. the non-target stimuli (dark gray bar). The abscissa indicates the point in time at which the data were collected and the ordinate indicates the infants' total mean looking times in seconds for each of the stimuli. Available SII values are printed in white, on the bars of each respective test session.

As one can note from the data collected from the 2 infants who continue to use HAs (**Fig. 2**), these infants showed a trend of looking longer at the target stimuli in the AV task and received the greatest audibility of the speech signal during hearing-aid use (SII = 0.63).



A **B**

Fig. 2. Longitudinal data from a HA user fit with bilateral HAs at 17-months-old (**A**). Longitudinal data from a second HA user fit with bilateral HAs at 8-months-old (**B**).

In **Figs. 3-4**, data from the 3 infants who received CIs are displayed. During their pre-operative, HA testing, these infants did not look longer at the target stimuli in the AV task and received less audibility of the speech signal during HA use (SII ≤ .4).

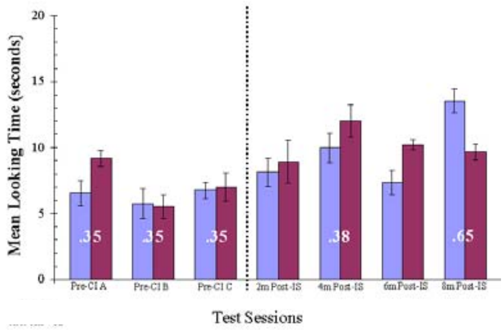
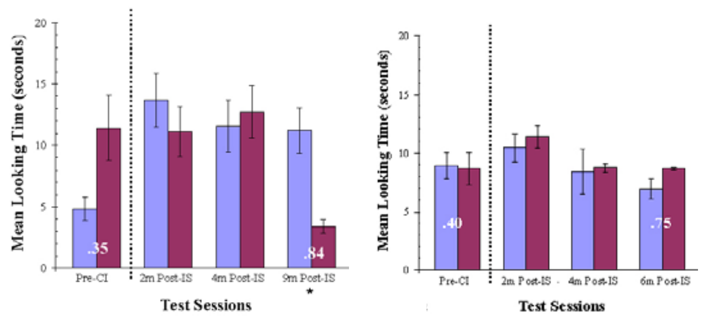


Fig. 3. Longitudinal data from a CI user whose device was initially stimulated at 17.5-months-old.



C **D**

Fig. 4. Longitudinal data from a CI user whose device was initially stimulated at 13-months-old. (**C**). Longitudinal data from a CI user whose device was initially stimulated at 14-months-old. (**D**). $*p \leq .05$

Of these 3 children, 2 showed a trend of looking longer at the target stimuli in the AV task after 8-9 months of CI use (see **Figs. 3 & 4C**). These children had SIIs equal to 0.6 - 0.8, reflecting the greatest amount of audibility achieved during any phase of this study. The third child (**Fig. 4D**) had only 6 months of listening experience via a CI with an SII of 0.75 and did not look longer at the target stimuli in the AV task.

4. Discussion

In the present study, the relationship of performance on an AV speech perception task to changes in audibility pre- and post-cochlear implantation was explored. It was demonstrated that greater levels of audibility appear to contribute to infants' abilities to perceive AV information in the speech signal; specifically, it seems that a minimum level of audibility is required before an infant begins to successfully complete the AV task in the present study. These results give promise that the combination of objective measurements of audibility and behavioral measurements of AV speech perception may contribute to the development of an empirically valid, clinical protocol that can be used to assess the auditory benefit gained by infants using HAs and/or CIs. These preliminary data have numerous implications for clinical management and future research directions:

1) *A minimum amount of audibility is necessary for AV speech perception.* These preliminary data suggest that infants with minimum SIIs (≤ 0.4) did not receive enough audibility to successfully complete the AV task, regardless of their hearing technology.

2) *A minimum amount of listening experience, via a CI, appears necessary for AV speech perception.* The data gathered from the 3 CI users in the AV task, suggests that infants require between 6 and 9 months of listening experience via a CI before they are able to match AV information in the speech signal (see **Figs. 3-4**). Additional, preliminary infant speech perception data [7] also suggests a similar amount of listening experience is necessary. However, it remains unclear what listening experience entails outside of what is known about the central and peripheral aspects of audition and speech perception. For example, the challenges associated with creating an ideal MAP for an infant are likely to contribute to the child's listening experience with the CI. The present data suggest that the widely-used concept of hearing age may be inappropriate.

3) *Complete, longitudinal data sets are needed from infants with a variety of audibility levels.* There is no documentation that indicates that infants with audibility levels between 0.4 and 0.6 are able to successfully complete AV speech perception tasks. Thus before conclusions can be drawn regarding the minimum requirements for levels of audibility/listening experience and the AV perception skills of HA and/or CI users more data needs to be collected.

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