#271

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

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OBJECTIVE

Previous research, using the Split-Screen Preferential Looking Paradigm (SPLP; Hollich, Hirsh-Pasek, & Golinkoff, 2004), examined audio-visual (AV) speech perception in hearing-impaired infants during their pre-implant, hearing-aid trials and their post-implant experiences (Barker & Tomblin, *in press*). 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 ability to match audio and visual phonetic information 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 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. Combining such measures may also help in determining whether an infant meets audiometric criteria for cochlear implantation.

The present study began investigation of the relationship between objective measurements of the auditory input provided via HAs and/or CIs and behavioral measurements of AV speech perception. More specifically, we were interested in 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.

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 (SNHL) and fit bilaterally with HAs at the onset of data collection; during HA use better ear PTAs (average of thresholds at 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 on each infant, thus the children were tested at various ages. All infants' cognitive abilities were "within the normal limits" in accordance with the *Bayley Scale of Infant Development-II*'s "Mental" subscale (Bayley, 1993). Infants had no known visual abnormalities.

Audio-Visual Speech Perception as Measured by the Split-screen Preferential Looking Procedure

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 the two different kinds of visual stimuli over the test-trial series. The resulting data are utilized to make inferences about various aspects of infants' speech perception and language development. In the present investigation, SPLP was used to assess infants' audio-visual speech perception of the vowel sounds /a/ and /i/.

Stimuli

Video stimuli. A female model was filmed articulating /a/ and then /i/. The final edited stimuli yielded two videos in which the model's articulations were matched in duration.

Audio stimuli. A second female, native speaker of American English recorded the audio stimuli. The final audio stimuli set consisted of 3 articulations of /a/ and 3 articulations of /i/ spoken in an infant-directed manner.

Figure 1. *SPLP video stimuli for the present experiment.*

Bimodal stimuli. *Cinestream 3.1* software was used to ultimately combine the video tracks to form two, 27-s-long loops of 9 articulations. These videos were then synchronized and combined with each of the audio tracks. Finally, the /a/ and /i/ video loops were edited onto one screen, enabling a simultaneous, side-by-side display of the video loops (Figure 1).

Apparatus & Procedure. The set-up for 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 this video camera. The booth was lined with curtains, thus only the monitor-screen and the video camera's lens were visible.

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*, however the infant was now presented with speech stimuli played over the television's central loudspeakers and the two video images were presented simultaneously. The stimuli for each trial continued to played until its completion. Sound presented, left-right positioning of the two videos, and order of familiarization were counterbalanced. (for details, see Barker & Tomblin, *in press*).

Coding

Coding was performed in accordance with Hollich's (2001) coding-method for the SPLP. Using the video footage recorded of each infant during his or her test session, *cinestream 3.1* was utilized to conduct a frame-by-frame analysis of each infant's gaze direction and duration. Gaze duration was summed for each video image (i.e., the /a/ articulation and the /i/ articulation) and averaged across stimulus conditions. This yielded the mean total looking time (in seconds) for each image during the *Test Phase.*

Audibility as Measured by the Speech Intelligibility Index

In order to quantify speech audibility for each infant, a computer program was used to calculate the Speech Intelligibility Index (SII). An SII is based upon the ANSI S3.5-1997 and is highly correlated with the intelligibility of speech under a variety of adverse listening conditions (ANSI, 1997). 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 *all* of the speech signal being audible, as in normal-hearing listeners. SII was calculated for each child, 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 (Stelmachowicz, Lewis, Kalberer, & Creutz, 1994) was investigated for its effect on audibility. This speech spectrum was chosen because it approximates the speech signal available to an infant, from the caregiver, when held on the caregiver's hip.

RESULTS

In the AV speech perception task, a proper matching of the auditory and visual stimuli was assumed if the infant spent significantly more time looking at the woman articulating the same vowel sound presented via a loudspeaker. Infants who successfully matched phonetic information from the lips and voice displayed longer mean looking times to the target stimuli. For the audibility measures, a value of 1.0 indicates 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.

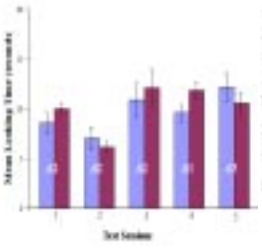

Figure 2. *Longitudinal data from a HA user fit with bilateral HAs at 17-months-old.This figure shows the mean total looking times (and standard error) to the target stimuli (light purple bar) vs. the non-target stimuli (maroon bar). The abscissa, indicates the point in time at which the data were collected 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.*

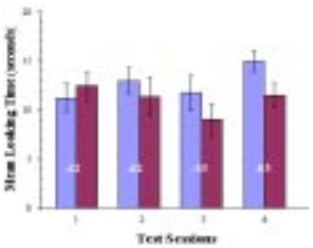

Figure 3. *Longitudinal data from a HA user fit with bilateral HAs at 8-months-old.This figures shows the mean total looking times (and standard error) to the target stimuli (light purple bar) vs. the non-target stimuli (maroon bar). The abscissa, indicates the point in time at which the data were collected 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 hearing aids (Figure 2 & 3), 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).

In Figures 4-6, data from the 3 infants who received CIs is 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). 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 Figures 4 &5). 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 (Figure 6) 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.

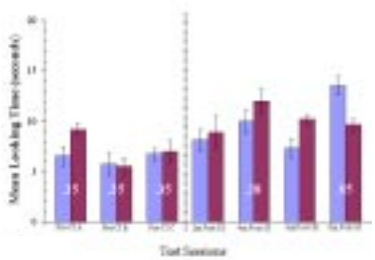

Figure 4. *Longitudinal data from a CI user whose device was initially stimulated at 17.5-months-old. This figures shows the mean total looking times (and standard error) to the target stimuli (light purple bar) vs. the non-target stimuli (maroon bar). The abscissa, indicates the point in time at which the data were collected and the ordinate indicates the infants' total mean looking times in seconds for each of the stimuli. "Post-IS" refers to the number of months following initial stimulation of the infants' cochlear implants. Available SII values are printed in white, on the bars of each respective test session.*

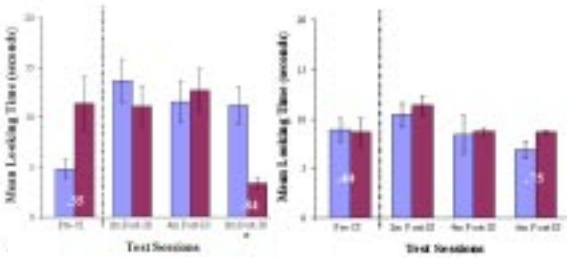

Figure 5. *Longitudinal data from a CI user whose device was initially stimulated at 13-months-old. This figures shows the mean total looking times (and standard error) to the target stimuli (light purple bar) vs. the non-target stimuli (maroon bar). The abscissa, indicates the point in time at which the data were collected and the ordinate indicates the infants' total mean looking times in seconds for each of the stimuli. "Post-IS" refers to the number of months following initial stimulation of the infants' cochlear implant [*p< .05]. Available SII values are printed in white, on the bars of each respective test session.*

Figure 6. *Longitudinal data from a CI user whose device was initially stimulated at 14-months-old. This figures shows the mean total looking times (and standard error) to the target stimuli (light purple bar) vs. the non-target stimuli (maroon 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. "Post-IS" refers to the number of months following initial stimulation of the infants' cochlear implant. Available SII values are printed in white, on the bars of each respective test session.*

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. Specifically, it was demonstrated that greater levels of audibility appear to contribute to infants' abilities to match phonetic information in the lips and voice. It was demonstrated that a minimum of audibility is required before an infant begins to successfully complete the AV speech perception 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 match phonetic information in the lips and voice, 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 the audio and visual information in the speech signal (see Figures 4-6). Additional, preliminary infant speech perception data (Houston, Pisoni, Kirk, Ying, & Miyamoto, 2003) 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 (e.g., for some infants one may be unable to obtain electrophysiological measures or behavioral measures to aid in programming the CI in a reasonable amount of time) 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. In this study, it was shown that once children received CIs it took, on average, 6 to 9 months to reach a level of audibility consistent with success in the speech perception task.

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 hearing-aid and/or cochlear-implant users more data needs to be collected.

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