A Longitudinal Study of Audiovisual Speech Perception by Prelingually Deaf Children with Cochlear Implants

Tonya R. Bergeson†, David B. Pisoni† and Rebecca A. O. Davis†
† Indiana University School of Medicine, Department of Otolaryngology, 699 West Street – RR044, Indianapolis, Indiana, USA 46202
E-mail: tbergeso@iupui.edu, pisoni@indiana.edu

ABSTRACT

Previous cross-sectional research has shown that prelingually deaf children who use cochlear implants (CIs) show enhancement when speech is presented in an audiovisual (AV) format compared to auditory-alone (A-alone) and visual-alone (V-alone) formats. The purpose of the present study was to investigate the development of AV integration skills in this clinical population. We examined the AV sentence comprehension skills of a large group of prelingually deaf children with CIs longitudinally, from pre-implantation to 5 years post-implantation. The children were asked to repeat everyday sentences under three presentation conditions: A-alone, V-alone, and AV. Overall, the results revealed that these children performed better in the AV condition than in the A-alone and V-alone conditions. Performance improved over time after cochlear implantation only for A-alone and AV conditions. Finally, measures of AV sentence comprehension were strongly correlated with other clinical outcome measures of speech perception, speech production, and language processing.

1. INTRODUCTION

The primary focus of research on speech perception has typically been on the auditory and acoustic aspects of the speech signal. Fortunately, in everyday experience, speech communication is not limited to input from only the auditory sensory modality. Optical information about speech articulation and spoken articulation and spoken language obtained from lipreading has been shown to improve speech understanding in adults with normal hearing [1, 2], hearing loss [3], and deaf adults with cochlear implants (CIs) [4, 5, 6]. Audiovisual enhancement has also been found in children with normal hearing [7, 8, 9], hearing loss [3, 7, 9], as well as deaf children who have received cochlear implants [10, 11, 12]. While lipreading cues have been shown to enhance speech perception in substantial ways, the sensory, perceptual, and cognitive processes underlying this gain in performance are still not well understood, especially in prelingually deaf children who receive CIs, and are a topic of current debate [13, 14]. The purpose of the present study was to investigate the development of audiovisual speech perception skills in prelingually deaf children with CIs and to assess the changes in performance over time after implantation.

2. METHOD

2.1 Participants

Participants in this study consisted of 83 children who experienced a profound hearing loss before the age of 36 months, received a cochlear implant (CI) before 9 years of age, and used either Oral Communication (OC) or Total Communication (TC) methods. Because many of the children lived or moved a great distance from the Indianapolis area, not all children were tested at each interval. Table 1 provides a summary of the characteristics of these children.

Communication Method		Age at Implantation (months)	Unaided PTA (dB HL)	Number of Electrodes
OC	M	51	112	19.54
(n = 39)	Range	17-106	98-121	8-22
TC	M	57	115	20.55
(n = 44)	Range	22-106	106-122	8-22

Table 1: Characteristics of participants.

2.2 Procedures

All test measures were administered by a licensed speech-language pathologist or audiologist at the Indiana University School of Medicine. The Common Phrases (CP) test [15] was administered live-voice under three presentation conditions in the following order: Auditory-alone (A-alone), visual-alone (V-alone), and audiovisual (AV). To eliminate visual cues in the A-alone condition, the clinician covered her face with a black mesh-cloth screen that did not mask the auditory signal.

The CP test is an open-set clinical measure that is used to assess a child's ability to understand phrases used in everyday situations. Although the child was asked to repeat the entire sentence, performance in each condition was scored by the percentage of phrases correctly repeated in their entirety, questions correctly answered, or directions

ISBN 1-876346-48-5 © 2003 UAB

correctly followed by the child. Examples of sentences included in the test and some typical responses are shown in Table 2. A percent correct score is calculated based on the total number of correct trials out of a possible 10 trials in each condition.

Phrase	**Correct Response(s)**
When is your birthday?	"When is your birthday?" "July"
Clap your hands.	"Clap your hands." Child claps his/her hands.
What time is it?	"What time is it?" "It's three o'clock."

Table 2: Examples of phrases and correct responses in the Common Phrases Test.

In addition to the CP test, we also carried out analyses of results from other behavioral tests that are routinely used to assess outcome of speech and language development: Phonetically Balanced-Kindergarten test (PBK) [16], a live-voice, open-set test used to assess A-alone word recognition; Peabody Picture Vocabulary Test (PPVT) [17], a closed-set test used to assess receptive vocabulary knowledge, Reynell Developmental Language Scales (RDLS) [18], used to assess receptive and expressive language skills, and Beginner's Intelligibility Test (BIT) [19], a measure of speech intelligibility.

3. RESULTS AND DISCUSSION

3.1 CP Accuracy Scores

Figure 1 shows the longitudinal results obtained from the three presentation formats (A-alone, V-alone, AV) over five years in the CP. We found statistically significant main effects of duration of implant use ($F(5, 559) = 52.60$, $p < .0001$), communication mode ($F(1, 115) = 16.89$, $p < .0001$), and presentation format ($F(2, 518) = 92.71$, $p < .0001$). Performance of all children, regardless of communication mode and presentation format, improved from pre-implantation to five years post-implantation. Also, OC children performed better on the CP test compared to TC children. Finally, performance was better in the combined AV presentation condition compared to the A-alone and V-alone presentation conditions.

We also found statistically significant interactions between presentation format and duration of implant use ($F(10, 515) = 3.53$, $p < .0001$), as well as between communication mode and duration of implant use ($F(10, 559) = 2.70$, $p < .05$). Children's performance on the CP test increased over time in A-alone and AV presentation conditions, but remained essentially flat over time in the V-alone

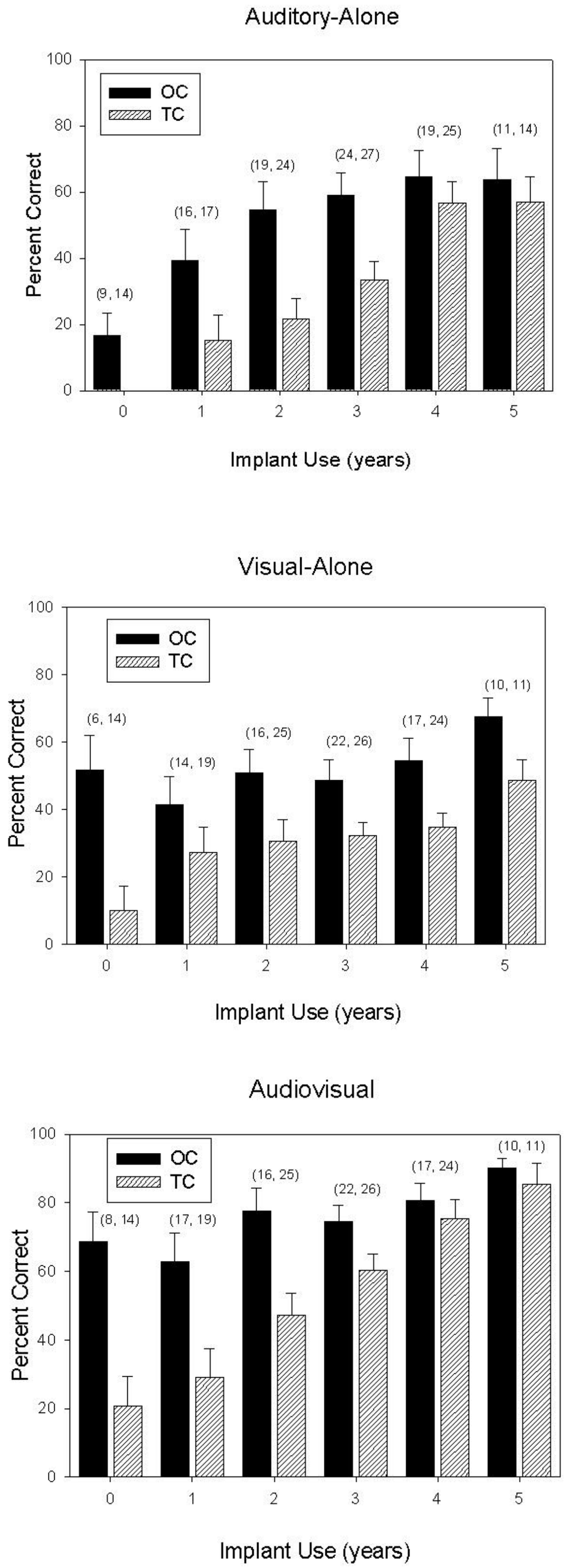

Figure 1: Mean percent correct sentence comprehension on the Common Phrases Test for Oral Communication (OC) and Total Communication (TC) children. Error bars represent standard error; numbers in parentheses represent number of children (OC, TC) tested at time period.

presentation condition. Moreover, OC children performed much better than TC children in all three presentation conditions at the pre-implantation interval, as well as the 1- and 2-year post-implantation intervals. However, TC children's performance was similar to OC children's performance in the A-alone and AV presentation conditions after five years of CI use.

3.2 Correlations between CP and Speech & Language Outcomes

To determine the relation between scores on the CP test and other outcome measures of speech and language skills, we performed correlation analyses on these scores for all children at the three-year post-implantation interval. As shown in Table 3, children's performance on the CP test was significantly correlated with outcome measures of open-set word recognition (PBK), vocabulary (PPVT), language (RDLS Expressive/Receptive), and speech intelligibility (BIT). The correlations were consistently stronger for the OC compared to TC children.

Outcome Measure		OC			TC		
		A	V	AV	A	V	AV
PBK	*r*	.64**	.31	.56**	.56**	-.23	.39
	N	24	21	22	25	25	24
PPVT	*r*	.42*	.63**	.58**	-.01	.48*	.31
	N	23	20	21	25	25	24
RDLS Expr	*r*	.70**	.57*	.79**	.21	.45*	.50*
	N	13	14	13	20	20	20
RDLS Rec	*r*	.69**	.39	.82**	.02	.33	.41
	N	14	14	12	20	21	20
BIT	*r*	.73**	.56*	.73**	.61**	.04	.53*
	N	16	15	16	17	18	17

Table 3: Correlations for Common Phrases and outcome measures, both at 3 years post-implantation. $*p < .05$, $**p < .01$

Further correlation analyses were conducted to determine whether children's pre-implantation accuracy scores on the CP test could predict their skills on speech and language outcome measures three years post-implantation. In order to obtain an adequate sample size for this analysis, the correlations were carried out by combining the scores for both OC and TC children. As shown in Table 4, all correlations were strong, positive, and significant, with the exception of the correlation between CP A-alone and PPVT. Interestingly, in all cases the V-alone CP pre-implant measure was the strongest predictor of speech and language outcomes after three years of implant use. In short, pre-implantation performance on the CP test could serve as a behavioral marker to predict subsequent speech and language performance and measure benefit after implantation.

Outcome Measure		Common Phrases		
		A	V	AV
PBK	*r*	.74**	.91**	.72**
	N	17	10	17
PPVT	*r*	.14	.70**	.68**
	N	16	9	16
BIT	*r*	.85**	.88*	.84**
	N	11	6	11

Table 4: Correlations for pre-implantation Common Phrases and 3 years post-implantation outcome measures. $*p < .05$, $**p < .01$

4. CONCLUSIONS

The results of the present investigation of audiovisual speech perception in prelingually deaf children over a period of five years following cochlear implantation revealed that performance was best in the AV condition, followed by A-alone and V-alone conditions. The longitudinal data also showed that while A-alone and AV scores improved substantially over time following implantation, the V-alone scores for this group of children remained essentially flat over the five-year period following cochlear implantation. This pattern of results suggests that the gain in performance observed under audiovisual presentation conditions after cochlear implantation is highly selective in nature and appears to be closely tied to sensory information coded by the auditory modality. The CI provides the auditory system with acoustic-phonetic information about spoken language, but such auditory input does not appear to affect the visual processing of speech measured by the CP test.

Although not the primary focus of the present study, another finding that emerged from the present study was an effect of age at implantation [20]. We found that children who were implanted at a younger age performed much better overall than children implanted later in life. However, children who were profoundly deaf for longer periods of time actually turned out to be better lipreaders than children who were profoundly deaf for shorter periods of time.

We also found strong and positive correlations of the CP test scores with several independent measures of spoken word recognition, receptive vocabulary development, expressive and receptive language, and speech

ISBN 1-876346-48-5 © 2003 UAB

intelligibility. Moreover, the pattern of these correlations was much stronger for OC than TC children. This pattern of correlations is revealing because it indicates that the basic underlying sensory, cognitive, and linguistic processes used to carry out audiovisual speech perception are also accessed and used in other language processing tasks.

Finally, we found that pre-implantation CP scores were strongly correlated with open-set word recognition, vocabulary, and speech intelligibility scores obtained after three years of implant use. These findings suggest that measures of audiovisual speech perception may provide a reliable behavioral marker that can be used to predict and identify the children who will obtain the most benefit from their CIs at an early point following implantation.

REFERENCES

[1] N. P. Erber "Interaction of audition and vision in the recognition of oral speech stimuli", *Journal of Speech and Hearing Research*, **12**, pp.423-425, 1969.

[2] W. H. Sumby, I. Pollack, "Visual contribution to speech intelligibility in noise", *Journal of the Acoustical Society of America*, **26**, pp. 212-215, 1954.

[3] N. P. Erber, "Auditory-visual perception of speech", *Journal of Speech and Hearing Disorders*, **40**, pp. 481-492, 1975.

[4] K. W. Grant, B. E. Walden, P. F. Seitz, "Auditory-visual speech recognition by hearing-impaired subjects: Consonant recognition, sentence recognition, and auditory-visual integration", *Journal of the Acoustical Society of America*, **103**, pp. 2677-2690, 1998.

[5] A. R. Kaiser, K. I. Kirk, L. Lachs, D. B. Pisoni, "Talker and lexical effects on audiovisual word recognition by adults with cochlear implants", *Journal of Speech, Language, and Hearing Research*, in press.

[6] R. F. Tyler, A. J. Parkinson, G. G. Woodworth, M. W. Lowder, B. J. Gantz, "Performance over time of adult patients using the Ineraid or nucleus cochlear implant", *Journal of the Acoustical Society of America*, **102**, pp. 508-522, 1997.

[7] P. Arnold, A. Köpsel, "Lipreading, reading and memory of hearing and hearing-impaired children", *Scandinavian Audiology*, **25**, pp. 13-20, 1996.

[8] R. N. Desjardins, J. Rogers, J. F. Werker, "An exploration of why preschoolers perform differently than do adults in audiovisual speech perception tasks", *Journal of Experimental Child Psychology*, **66**, pp. 85-110, 1997.

[9] N. P. Erber, "Auditory, visual, and auditory-visual recognition of consonants by children with normal and impaired hearing", *Journal of Speech and Hearing Research*, **15**, pp. 413-422, 1972.

[10] L. Lachs, D. B. Pisoni, K. I. Kirk, "Use of audiovisual information in speech perception by prelingually deaf children with cochlear implants: A first report", *Ear & Hearing*, **22**, pp. 236-251, 2001.

[11] R. F. Tyler, J. M. Opie, H. Fryauf-Bertschy, B. J. Gantz, "Future directions for cochlear implants", *Journal of Speech-Language Pathology and Audiology*, **16**, pp. 151-163, 1992.

[12] R. F. Tyler, H. Fryauf-Bertschy, D. M. Kelsay, B. J. Gantz, G. Woodworth, A. Parkinson, "Speech perception by prelingually deaf children using cochlear implants", *Otolaryngology Head and Neck Surgery,* **117**, pp. 180-187, 1997.

[13] D. W. Massaro, M. M. Cohen, "Speech perception in hearing-impaired perceivers: Synergy of multiple modalities", *Journal of Speech, Language, and Hearing Science*, **42**, pp. 21-41, 1999.

[14] L. E. Bernstein, E. T. Auer, Jr., J. K. Moore, "Audiovisual speech binding: Convergence or association?", In G. Calvert, C. Spence, & B. E. Stein (Eds.), *Handbook of Multisensory Integration*, Cambridge: MIT Press, in press.

[15] A. M. Robbins, J. J. Renshaw, M. J. Osberger. *Common Phrases Test*. Indianapolis: Indiana University School of Medicine, 1995.

[16] H. A. Haskins. *A phonetically balanced test of speech discrimination for children*. Unpublished master's thesis. Evanston, IL: Northwestern University, 1949.

[17] L. Dunn, L. Dunn. *Peabody Picture Vocabulary Test, Third Edition*. Circle Pines, MN: American Guidance Service.

[18] J. K. Reynell, M. Huntley. *Reynell Developmental Language Scales – Revised, Edition 2*. Windsor, England: NFER-Nelson Publishing Company, Ltd., 1985.

[19] S. Jerger, S. Lewis, J. Hawkins, J. Jerger, "Pediatric speech intelligibility test. I. Generation of test materials", *International Journal of Pediatric Otorhinolaryngology*, **2**, pp. 217-230, 1980.

[20] T. R. Bergeson, D. B. Pisoni, R. A. O. Davis, "Development of audiovisual speech perception skills in prelingually deaf children with cochlear implants", manuscript submitted for publication.

ACKNOWLEDGMENTS

This work was supported by NIH-NIDCD Training Grant T32DC00012 to Indiana University and NIH-NIDCD Research Grant R01DC00064 to the Indiana University School of Medicine.