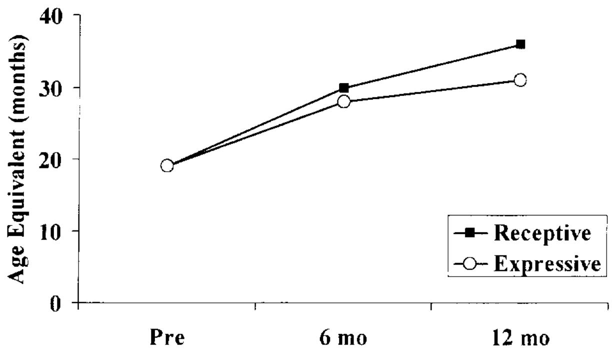

Mean age equivalent language scores on Reynell Developmental Language Scales–Revised for 18 prelingually deafened children at preoperative interval with hearing aids (Pre) and 6 and 12 months after implantation with Clarion cochlear implant.

RATE OF LANGUAGE GROWTH ON REYNELL DEVELOPMENTAL LANGUAGE SCALES FOR 18 CHILDREN IMPLANTED WITH CLARION COCHLEAR IMPLANT

	Preimplantation to 6 Months	*Preimplantation to 12 Months*	*6 to 12 Months*
Receptive language	1.62 ± 1.10	1.38 ± 0.81	1.10 ± 1.39
Expressive language	1.40 ± 1.10	0.98 ± 0.77	0.51 ± 1.06

Data are mean ± SD. Rate is expressed as proportion (change in age equivalent score divided by amount of time between intervals). Child with normal hearing is expected to demonstrate growth rate of 1.0 (6 months' increase in age equivalent score over 6 months' time).

the first 12 months of implant use. The rate of language learning was more accelerated during the first 6 months than during the second 6 months of implant use, especially for expressive skills. Because the children were so delayed in their language abilities at the time of implantation, rapid gains were more likely to occur during the first 6 months of device use, when testing occurred on linguistic tasks more appropriate for children of a much younger chronological age. As the children grow older and the gap closes between the children's language and chronological age, the test tasks become more difficult, slowing the apparent learning rate. Access to new sensory information through the use of a cochlear implant appears to bring about an acceleration in learning within the communication domain, as observed in these children during the first 6 months of device use. Developmental psychologists' notion of "equilibration," in which periods of accelerated growth in a cognitive skill are typically followed by less growth,[6] may also help to explain the leveling-off of language learning in the second 6 months of implant use. Even with the marked improvements observed in the language skills of the children in this study, the language levels of the implanted children remain delayed compared with those of their peers with normal hearing of the same chronological age, a finding also reported in other investigations.[4,7] Further study of language development over a longer period is warranted, as well as investigations that identify the variables underlying individual differences in language development.

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USE OF FAST FORWORD™ TO ENHANCE LANGUAGE DEVELOPMENT IN CHILDREN WITH COCHLEAR IMPLANTS

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INTRODUCTION

Cochlear implantation has become an established option for (re)habilitation of profound deafness in children. Given uniform auditory thresholds after implantation, children still demonstrate a wide spectrum of performance in language acquisition and speech development, a finding that suggests that neural substrate differences and training effects underlie variable outcomes. Professionals working with children who have been fitted with implants must identify effective strategies for addressing the significant auditory perceptual, speech, and language needs of this population.

We report our experience with a computer-based language-auditory skill training protocol (Fast ForWord™, Scientific Learning Corporation, Berkeley, Calif) with 11 children with cochlear implants. Fast ForWord™ strategies are based on observations, gleaned from assessment of temporal processing capabilities,[1] indicating that hearing children with language-learning impairments (LLI) require significantly longer interstimulus intervals to perceive and sequence 2 short-duration tones than do normal peer controls. Improvement in perceptual task performance appears to result from intense practice with modified signals that incrementally approximate normal processing conditions.[1] Using common standardized measures of auditory and language skills, Tallal et al found that significant post-test gains were achieved in their initial trials[2] and for more than 300 children who completed the program at 35 field trial sites around the United States.[2,3]

Fast ForWord™ was made available to licensed clinicians in January 1997 and has been used most extensively with LLI children. The program consists of 7 exercises in game format, each addressing an area of auditory or language skill. Children play five 20-minute games per day, 5 days a week, until a completion criterion is reached, usually around 8 weeks. Initially, stimuli are presented with significant reduction in formant transition speed and maximum highlighting of acoustic features of formant transitions. As the child's performance improves, processing demands are incrementally adjusted toward normal presentation. Subjects register their responses to challenging auditory tasks by using the mouse to select the correct picture in a 2-, 3-, or 4-item forced-choice model or by using the mouse to carry out directions or copy a sequence. Immediate feedback and virtual rewards for correct responses are provided, and items with incorrect responses are repeated with demonstration of correct answers. The games are designed to be entertaining and motivating while addressing the following skill areas: 1) imitation of a sequence of 2 pure tone sweeps, associated with shapes on the screen; 2) detection of a subtle consonant change in a string of consonant-vowel syllables; 3) matching a target syllable to 1 of 2 choices; 4) matching consonant-vowel and consonant-vowel-consonant syllables by remembering their placement in a grid of unrelated pictures; 5) following directions of increasing length and complexity involving size, shape, color, and position; 6) discrimination of pictured words differing by 1 phoneme; and 7) selection of pictures in response to sentences of increasing length and grammatic-syntactic complexity.

Our study was designed to address 2 questions: 1) Do children with cochlear implants have the auditory capability to perform the fine discrimination, memory, and comprehension tasks presented through computer-generated, temporally altered signals? and 2) will intense training and incremental increases in processing demand produce benefits in real-time language and auditory skills for the cochlear implant population?

SUBJECTS AND METHODS

We studied 11 children who received cochlear implants at Johns Hopkins and were either currently or previously enrolled in our rehabilitation program. These subjects represented a heterogeneous group in terms of history and functional communication skills. Their average age was 7 years 6 months (range, 4 years 10 months to 11 years 5 months), and average length of implant experience was 2 years 5 months (range, 6 months to 5 years). Two subjects used the Clarion device, and 9 used the Nucleus 22. Communication mode and school placement varied (5 total communication, 2 cued speech, 4 oral). All of the children were familiar with the clinical setting and staff and were judged to possess the attention and cognitive abilities necessary to understand the tasks of Fast ForWord™. The subjects displayed no significant handicapping conditions other than language and auditory processing deficits associated with their hearing loss. The conduct of the study was in compliance with the regulations of the Johns Hopkins University Joint Committee on Clinical Investigation.

The Fast ForWord™ program was presented without modification for the implant population, with the exception of signal delivery: since use of headphones was not possible, we used custom-designed patch cords (Audiovisual Systems, Baltimore, Md) to couple the speech processor directly to the audio output port of the computer (Macintosh 6400). The cords electrically isolate the implant and eliminate background noise. Trained adult monitors provided encouragement and supervision to enhance compliance, but no substantive assistance was given.

Pretraining. The general skills needed to engage in the Fast ForWord™ games include knowledge of the concepts *same, different, match, change, circle, square, large,* and *small*; the ability to use the mouse; and comprehension of 5 color labels. The subjects were briefly instructed in these areas as needed before beginning play.

Test Protocol. Performance was assessed with the use of repeated standardized measures commonly used by speech-language pathologists. All tests were administered according to the standard procedures designated in the manuals. Sign language or cued speech was used during testing only as needed to clarify instructions and provide encouragement. The children's signed or cued responses were accepted if appropriate to the task. The examiner's face was visible to the child during all tests except the Test of Auditory Perceptual Skills–Revised (TAPS-R) Word Discrimination subtest.

The following tests were used to measure performance in auditory memory, discrimination, receptive and expressive grammar and syntax, and phonological awareness: 1) the Clinical Evaluation of Language Fundamentals–Preschool (CELF-Pre)[4], a comprehensive battery testing varied components of receptive and expressive language for children ages 3 years to 6 years 11 months; 2) the Clinical Evaluation of Language Fundamentals–3 (CELF-3)[5], a comprehensive receptive-expressive battery for ages 6 years to 21 years 11 months; 3) the Test of Auditory Perceptual Skills–Revised (TAPS-R)[6], an assessment of auditory memory for varied stimuli and open-set auditory word discrimination; 4) the Token Test for Children[7], following directions of increasing length and complexity involving a limited lexical set; 5) the Assessment of Children's Language Comprehension (ACLC)[8], picture selection based on increasing number of critical linguistic elements; 6) and the Phonological Awareness Test (PhAT)[9], assessment of segmentation, blending, rhyming, and association skills given auditory stimuli.

The Token Test for Children closely resembles the items

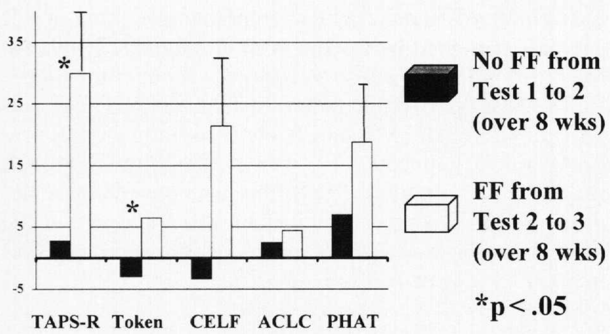

Fig 1. Comparison of mean changes in raw scores for 5 measures under no–Fast ForWord™ (no FF) condition and Fast ForWord™ (FF) condition. See text for abbreviations of test names.

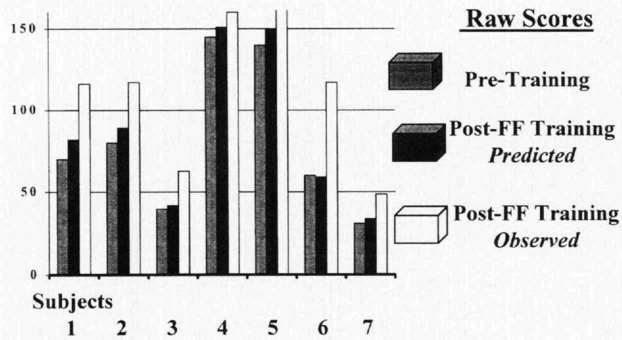

Fig 2. Pre-FF, predicted post-FF, and observed post-FF changes on CELF raw scores. All subjects exceeded gains expected from maturation alone.

presented in one of the Fast ForWord™ exercises (Block Commander). The other tests used, however, are general skill assessments that do not employ any items practiced during Fast ForWord™. The format, stimuli, and response modes are unrelated to those incorporated in the Fast ForWord™ exercises.

Crossover Design. Four subjects were tested 3 times, at 8-week intervals, and trained with Fast ForWord™ during the second 8-week period. We compared the changes in test results during these equivalent time spans. The remaining subjects were tested before and after Fast ForWord™ only. For children with 3 sets of scores, the higher of the 2 pretest levels was included in the group data.

Analysis of test results yielded raw scores, standard scores, and (for the CELF) age equivalencies. For CELF data, the Predicted Developmental Rate (PDR)[10] was used to compare observed test score gains with those expected to occur with maturation. For all tests, changes in raw score and standard score for individual subjects, and changes in group means were also compared.

RESULTS

The first set of results involved the 4 subjects who were tested 3 times under the single crossover model. The mean differences between raw score 1 and raw score 2 (no Fast ForWord™ condition) and between raw score 2 and raw score 3 (Fast ForWord™ condition) are illustrated in Fig 1. Performance under the Fast ForWord™ condition was significantly higher on the TAPS-R and Token Test ($p < .05$) and was consistently improved on the other tests as well.

Next, predicted and observed changes were calculated for 7 subjects who were given the complete CELF. Pretest language quotients were calculated by dividing language age by chronological age, and the resulting figure was used as the PDR for that child. The predicted language age at post-testing was determined by multiplying the post-test chronological age by the PDR. The maximum expected raw score was then determined from tables of test norms. Each subject's observed raw score exceeded the predicted level (Fig 2). Group mean score changes (Fig 3) were significant ($p = .006$).

Figure 4 illustrates pretest and post-test results for the entire subject cohort for the CELF, TAPS-R, ACLC, and PhAT. The subjects showed significant improvement on all tests ($p < .05$) after 8 weeks of Fast ForWord™ training. The standard score changes were also significant ($p < .05$).

In addition to objective measures, the parents were asked to complete a 45-item survey of perceived changes in communication skills after the training. The survey items dealt with receptive, expressive, and pragmatic language skills. The total number of responses in each rating category is illustrated in Fig 5. Improvement was noted on 83% of the survey items (n = 7), although "marked" changes in particular skills accounted for only 5% of the responses.

DISCUSSION

Conversational speech comprises a stream of acoustic

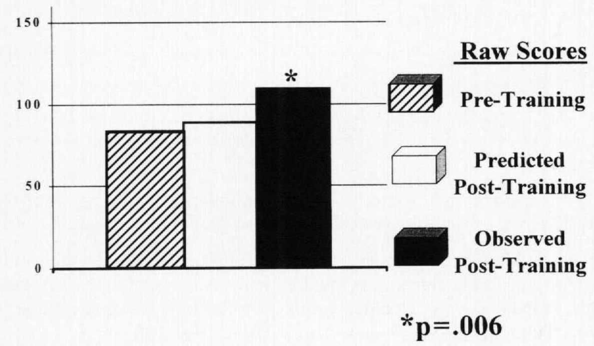

Fig 3. Comparison of mean raw score change on CELF with changes predicted from maturation alone.

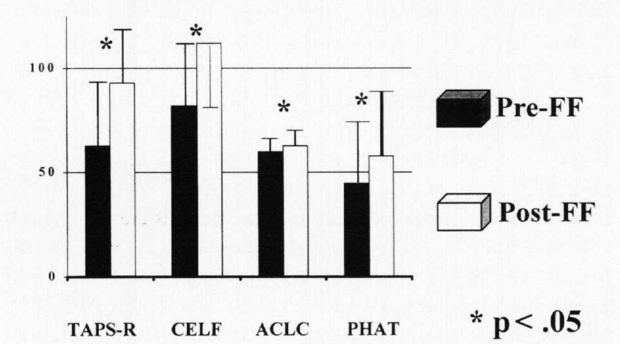

Fig 4. Pre- and post-FF test results on indicated tests. Raw scores are illustrated; standard score differences were also significant.

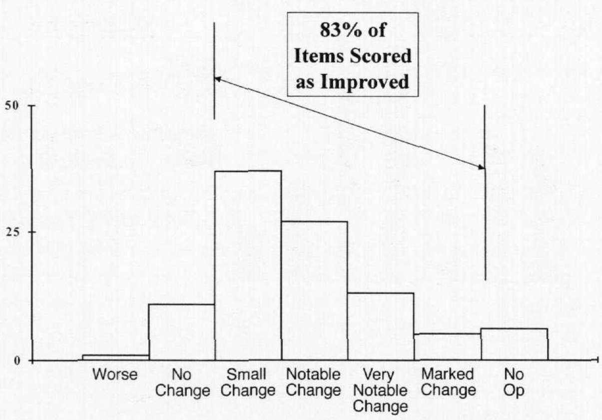

Fig 5. Parental rating scale completed following FF training. Scale consisted of 45 items covering receptive, expressive, and pragmatic language skills.

events that normal listeners segment and interpret with ease. Sequential acoustic signals are characterized by rapid transitions in formant frequency reflecting modifications in the shape of the vocal tract as phonemes are co-articulated. Formant transitions constitute important cues for identifying phonemes, particularly stop consonants and affricates.[11] Fast ForWord™ presents auditory signals that are parametrically altered by changes in the rate of formant transitions and by acoustic enhancement of transitions. One factor that may underlie the observed gains is that training with Fast ForWord™ improves subjects' ability to perceive, sequence, and interpret formant transitions.

In addition to qualitative changes in stimuli, a major component of the Fast ForWord™ training paradigm lies in its practice intensity. Fast ForWord™ provides children with more than 1,000 consistent, structured, and incrementally modified auditory stimuli during each daily session, a model that cannot be replicated in traditional intervention. Only computer-based strategies can offer this density of auditory stimuli, which may be critical to the gains observed.

The structure of Fast ForWord™ resembles normal language acquisition in that it addresses learning from a gestalt, or top-down, perspective (practice with syllables, words, and connected language) and, simultaneously, from an elemental, "bottom-up" perspective (temporal alteration and acoustic enhancement of formant transitions). It is not possible to draw conclusions concerning the relative importance of these components in the observed outcome. However, it appears that this intervention strategy as a whole can produce measurable progress over a relatively short period and may provide a beneficial adjunct to traditional therapy. The characteristics of Fast ForWord™ — intersession consistency, signal modification, and intense repetition — do not provide exposure to the interpersonal language exchanges that nurture optimal communication skills. Long-term follow-up will examine the durability of observed gains and the future language-learning curve of our subjects. Fast ForWord™ may allow children to derive increased benefit from subsequent intervention and incidental learning opportunities. It is important to note, however, that even with the benefits of Fast ForWord™ and cochlear implantation, most of our subjects remained below the normal language levels for their chronological ages (compared with hearing peers). Before Fast ForWord™, the mean delay on the CELF was 33.1 months (SD, 24.9; range, 9 to 76 months). After Fast ForWord™, the mean delay was 24.6 months (SD, 23.2; range, 0 to 58 months). The difference between these degrees of delay compared with chronological age at the time of testing was significant ($p = .003$), and delays remained for all but 1 of our subjects.

CONCLUSIONS

Our results indicate that children with cochlear implants can perform the auditory perceptual and linguistic tasks of the Fast ForWord™ program. Our subjects showed consistent post-test benefit on 5 standardized measures of language and auditory processing abilities. The degree and distribution of gain varied among subjects, and no correlations with any of the demographic characteristics of our sample were found. Children who use total communication benefited as much as those using oral or cued speech methodologies, even though auditory skills only were practiced through experience with Fast ForWord™. The preliminary evidence presented here suggests that specialized training of linguistic and perceptual tasks may provide an avenue for enhancing receptive and expressive communication skills.

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