Evaluating a Tactile Aid for the Reception of Speech

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For the past 2½ years we have been working on a project in which a vibrotactile aid designed for the reception of speech, the SRA-10, has been evaluated. This paper reviews the development of the SRA-10 and our procedures and results with profoundly deaf children and adults. Our measures for both children and adults concentrated on assessing changes related to the use of the aid during connected speech, and subjects were tested in aid-on and aid-off conditions. Results from the children showed an improvement in communication skills in the aid-on condition, which decreased in the aid-off condition. The changes were found to be significant for the communication involving the vocalization plus sign language (Total Communication) measure, indicating that the vibrotactile stimulation was positively associated with the communicative act. Results from the adult subjects were less conclusive.

Tactile stimulation has been accomplished mainly in two ways: using vibratory (vibrotactile) stimulation and electrical (electrotactile) stimulation. The vast majority of studies to date have used vibrotactile stimulation, and in this paper we discuss tactile stimulation as it relates to vibrotactile presentation. As part of this paper we review the development and evaluation of a specific vibrotactile Speech Recognition Aid, the SRA-10, an instrument first described by Scott (1979).

Before describing our work, an important operating principle used in both the development and evaluation of our vibrotactile aid should be emphasized. This principle can be addressed by posing the question, "Is it

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appropriate to expect that the vibrotactile mode can act as a sensory substitute for the auditory mode in the reception of connected discourse?" Table 1 provides a comparison between the auditory and vibrotactile systems in the reception of sounds as summarized by Keidel (1974). These data point out the severe limitations that the skin has as a sensory receptor of acoustic information when vibrotactile stimulation is used. For example, the normal auditory system has a dynamic range of 130 dB, but the vibrotactile system range is only about 30 to 35 dB. Moreover, while the auditory system is responsive to frequencies ranging from 20 to 20,000 Hz and has an optimum frequency range between 300 and 3000 Hz, the upper limit of the vibrotactile system is only 400 to 500 Hz, and the vibratory receptors are best stimulated by frequencies in the 40 to 400 Hz range. The vibrotactile mode is similarly inferior to the ear in the time required for the full development of sensation and difference limen for frequency. In addition to these psychoacoustic variables, Keidel (1974) also pointed out that the vibrotactile system has a poor memory compared to the highly developed one for the auditory system. That is, there is a lack of ability to retain images that are displayed on the skin either on a short- or long-term basis.

Table 1
Comparison of Auditory and Vibrotactile Modes in the Reception of Sound
(from Keidel, 1973)

Acoustic Variable	Auditory Mode	Vibrotactile Mode
Dynamic range	0-130 dB	0 to 30-35 dB
Frequency range	20-20,000 Hz	10 to 4-500 Hz
Optimal frequency range	300-3,000 Hz	40-400 Hz
Time for full development of sensation	.18 seconds	1.2 seconds
Difference limen for frequency	0.2%	5 to 10%

With these limitations it is quite probable that the vibrotactile mode may not, in fact, be appropriate as a substitute for the ear in the reception of ongoing speech. It appears more reasonable to consider the use of vibrotactile stimulation as an aid rather than a substitute for hearing in the reception of ongoing speech, and to design experiments to determine how the addition of tactile stimulation enhances speechreading ongoing discourse. There have been few attempts to quantify the benefits that can be derived through the tactile aid in the reception of ongoing speech. Moreover, the limited work to assess the success of tactile aids with ongoing speech has used normal hearing subjects who were functionally deafened with ear plugs and/or masking noise. The underlying assumption of such a procedure is that results from a normal-hearing population can be generalized directly to the deaf, an assumption for which there is no direct validity.

It is perhaps due to the lack of conclusive studies on the benefits of tactile aids on communication in connected discourse using deaf subjects that their use is not widespread. This is despite the fact that technology now exists for fabricating a wearable tactile aid with highly sophisticated processing capabilities.

BACKGROUND ON THE SRA-10

The SRA-10 grew out of a series of experiments by Brian L. Scott and Carol DeFilippo at the Central Institute for the Deaf in St. Louis (Scott, DeFilippo, Sachs, & Miller, 1977; Scott, 1979). The guiding principle behind the development of the aid was to provide the user with qualities of sensation that corresponded to sensations perceived by the ear. In other words, the aim was to make speech feel like it sounds. For example, what are some of the qualities of fricatives that make them different from vowels? To begin with, fricatives tend to be higher than vowels in perceived pitch. Fricatives are noise-like (aperiodic) whereas vowels are tonal (periodic) in quality. Moreover, fricatives tend to sound more constricted than vowels. These were thought to be some of the desirable qualities of sensation in a tactile display of speech.

In addition, it was decided that the tactile display should convey the speech signal as emanating from a single source in space. This factor requires some elaboration. The history of tactile speech shows, with very few exceptions, that the vast majority of devices developed convey spectral information to the skin via spatial arrays of the transducers. That is, the high frequencies of speech are conveyed to one extreme position on the skin and low frequencies to another extreme. There are several problems with using spatial displays for the tactile-perception of speech, and to avoid these the SRA-10 was designed around the use of a temporal display. Rather than relying on change in location of stimulation on the skin as the criterion for perception, the temporal approach uses changes in sensation.

The rationale for the use of a temporal display comes from several sources. Empirically, there is the early evidence of Gault (1924; 1926) that sentence-length material can be learned and discriminated readily on the basis of envelope information through a single-unit vibrator. The amplitude envelope of speech is a temporal display conveying no spectral information. However, it does convey certain prosodic elements of speech such as intensity and duration. Cole and Scott (1974) also argue that the waveform envelope provides an acoustic means for the psychological integration of the spectral components of speech. In other words, the spectral structure of speech must be perceptually integrated into a single temporal stream, regardless of how it is broken up spatially by the cochlea. A tactile display of speech also should be presented as a single stream of events.

Empirical data on temporal displays also come from Scott (1974). In his study subjects performed a same-different discrimination task on syllable-length and sentence-length material. In one condition, normal-hearing, functionally deafened subjects felt the recorded stimuli through a bone conduction vibrator, and in the other condition through a five-channel spectral-type aid. Subjects did much better with the spectral aid than with the vibrator at making same-different judgments on the syllable-length material. However, performance with the two devices reversed when subjects were given sentences to discriminate. It was argued that the difficulty of using the spectral aid for sentence length units of speech was a function of the perceptual difficulty in rapidly ordering five separate channels of information.

An additional factor affecting the perception of spatial arrays may be taken from Geldard (1977). In this investigation of the "reduced rabbit," two vibrators are arrayed on the skin. Two pulses are presented using the first vibrator, at location 1. This is followed by a third pulse from the second vibrator at location 2. The second pulse, although occurring at location 1, is perceived as occurring somewhere between location 1 and location 2. The precise position at which the second pulse is felt is determined by the temporal relation between it and the third pulse. This finding suggests a problem with spatial displays of speech in that the perceived location of stimulation in a spatial array, and hence, the perceived frequency, will be confounded by the temporal relation between events.

Prior to the final product, the SRA-10 was an electro-tactile device and a combined electrotactile-vibrotactile device before being an all vibratory (vibrotactile) aid. In each configuration the aid was evaluated using a "tracking" procedure first described by DeFilippo and Scott (1978). Tracking is a term that classically describes a general psychophysical procedure in which the subject is instructed to trace a defined parameter of a specified stimulus, but in DeFilippo and Scott's procedure the term *tracking* describes an objective measure of the speechreading of continuous text. In the procedure a talker reading from a text presents material to a receiver, who attempts to repeat the text back verbatim. Performance is measured in a correct words per minute score. That is, the tracking is performed over ten-minute intervals and the measure of performace is the mean number of words per minute (wpm) correctly repeated by the subject. Data are usually displayed in one-hour units. As a guide, normal-hearing subjects average about 100 to 120 wpm when no ear plugs and noise are used.

Figure 1 is an example of results from a tracking experiment using a prototype of the SRA-10. Two conditions, lipreading alone (open circles) and lipreading with the tactile aid (closed circles), are shown for four normal-hearing subjects who were functionally deafened using ear plugs and white noise. It can be seen that two of the subjects began lipreading alone for four hours without the use of the vibrotactile aid, then switched to the aided lipreading condition for four more hours. The other two subjects

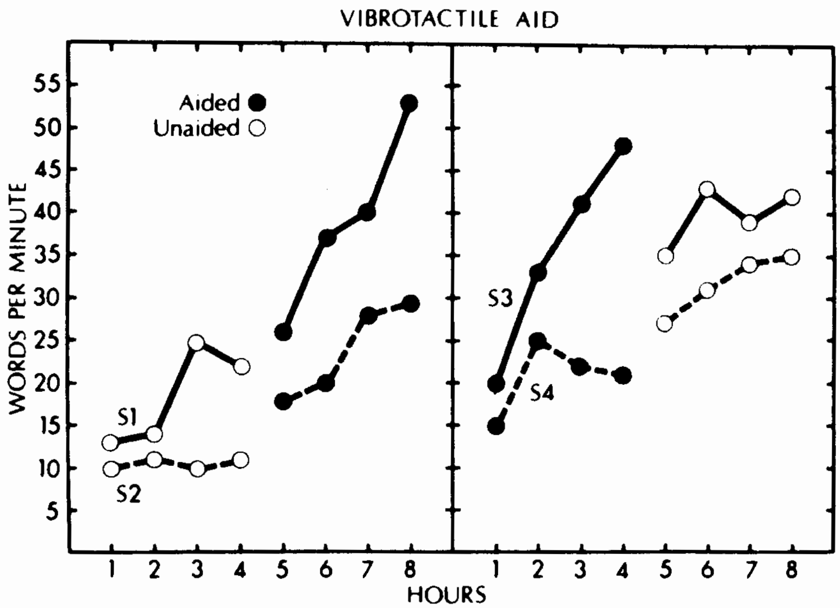

Figure 1. Tracking performance in words per minute from four subjects using Aid 3. S1 and S2 began with unaided lipreading (open circles, left panel). S3 and S4 began lipreading with Aid 3 (filled circles, right panel) and changed to unaided lipreading (open circles, right panel). (From Roeser et al., 1983).

began in the aided condition and switched to the unaided condition.

As illustrated in this figure, subjects 1, 2, and 4 showed improvement from the unaided to the aided condition. This is evident by the change in the slope of the learning curve. However, subject 3 did not appear to benefit from the aid and, in fact, complained of a feeling of nausea when using the aid. A significant point is that these subjects had no previous experience or training with the aid, yet three of the four benefitted almost immediately from its use.

These data indicated that the aid might be of considerable benefit to the profoundly hearing impaired lipreader as an aid to the reception of connected discourse. However, laboratory experiments on persons with simulated hearing-loss cannot answer the questions that field evaluation with hearing-impaired subjects may.

The final product, the SRA-10, is a portable battery-operated version of the above-described, all-vibratory aid. Figure 2 shows the instrument and how it is worn. Since the aid is battery powered, it is portable, but it is much too large to be worn on the body. It consists of an input microphone, a processing unit, and three Western Electric vibrators (Model 5A) identical to those found in the electrolarynx (Figures 2A and 2B). The vibrators are secured in a polyurethane mold and attached to an adjustable elastic belt, which holds them against the skin of the abdomen (Figure 2C). The use of the Western Electric vibrators was the only major change in the aid from the earlier version.

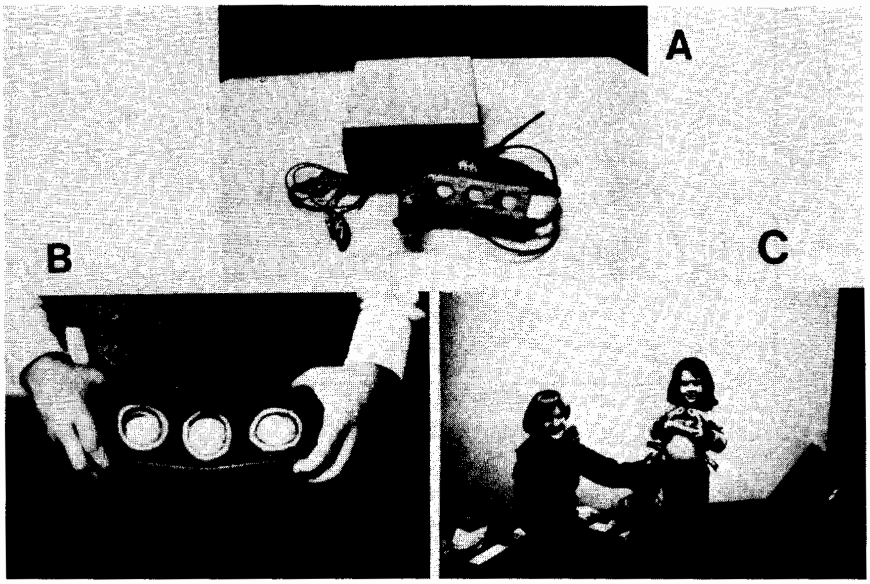

Figure 2. Photograph of the SRA-10. (A) The aid consists of a microphone, processing unit, and three vibrators. (B) The vibrators are housed in a polyurethane mold and (C) are attached to an elastic belt that holds them against the skin of the abdomen. (From Friel-Patti & Roeser, 1983).

A block diagram of the aid is shown in Figure 3. The noise generator, a low-pass filter, and peak clipper shown at the top of the schematic provide an aperiodic signal to the vibrators. The high frequency channel is conveyed by the single channel which is placed in the center, and the mid-frequency channel by the surrounding transducers. A /ʃ/ is discriminated from an /s/ by a spreading, diffuse sensation as opposed to a localized punctuate sensation. All three vibrators carry the vowel. Thus, an /s/ is punctuate and aperiodic, an /ʃ/ or /tʃ/ is diffuse and aperiodic, and vowels are more diffuse and periodic. In addition, vowels feel the loudest since all three vibrators are activated.

STUDIES ON HEARING-IMPAIRED ADULTS

We have conducted two experiments with the SRA-10 using severely

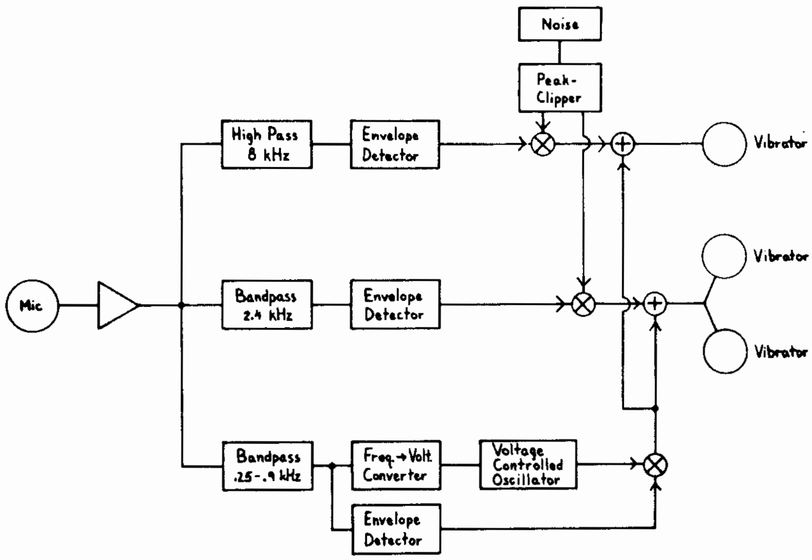

Figure 3. Block diagram of Aid 3. The two lower vibrators were worn on either side of the top vibrator and carried mid-frequency information as a low-frequency noise. The top vibrator presented a low-frequency noise for high-frequency information. All three vibrators were activated by low-frequency input with a signal whose frequency was proportional to F1.

hearing-impaired adult subjects, and one additional experiment with normal-hearing subjects (Roeser, Scott, Friel-Patti, & Henderson, 1982). In all three experiments, the tracking procedure was used. The hearing-impaired subjects had a mean age of 48.2 years. They were postlingually deafened and had an adequate command of speech and language for normal expressive communication.

One female adult subject (MA), aged 52.2 years, participated in Experiment 1. She had a history of progressive hearing loss beginning about 4 years prior to enrollment in the tracking experiment, and at enrollment into the study had no measurable responses on her audiogram at 110 dB HL for the frequencies 125 to 10,000 Hz. During the tracking experiment, the aided and unaided conditions were alternated every 10 minutes. That is, MA tracked for a 10-minute period without the benefit of the SRA-10, followed by a 10-minute period with the SRA-10. This occurred until a total of six 10-minute periods were completed for each condition; a mean wpm score was then calculated for each hour.

The initial training period was designated Series I and involved 14 hours of tracking, 7 hours with the SRA-10 and 7 hours without it. Following Series I, training was discontinued for a period of 47 days. During this period MA was instructed to use the SRA-10 at home during the activities of daily living. Series II was then conducted, and MA received an additional 12 hours of tracking, but because of the lack of benefit observed during Series I, each session in Series II was preceded by 10 minutes of training that was designed to provide the subject with training to facilitate the speech-related cues transmitted by the SRA-10. This training was called focal training. During focal training, groups of minimal pairs with the initial consonant differing only in manner of articulation and/or voicing were used.

Figure 4 compares data for MA from Series I and Series II for the aided and unaided conditions. From this figure it is readily apparent that MA improved in her overall speechreading ability, as measured by mean wpm tracking scores. Initial tracking scores at 7 to 9 wpm in Series I increased to as much as 23 to 24 wpm in Series II. However, there did not appear to be significant benefit related to the use of the SRA-10. As shown, for Series I the mean unaided wpm score was 13.0 and the aided score was 13.4 wpm, a difference of only .4 wpm. For Series II, even after giving MA practice with the aid at home and focal training, the unaided mean score was 19.5 compared to an aided score of 19.8 wpm, a difference of only .3 wpm. Based on these results, it was felt that MA may not have derived benefit from the SRA-10 because she may not have had enough continuous structured train-

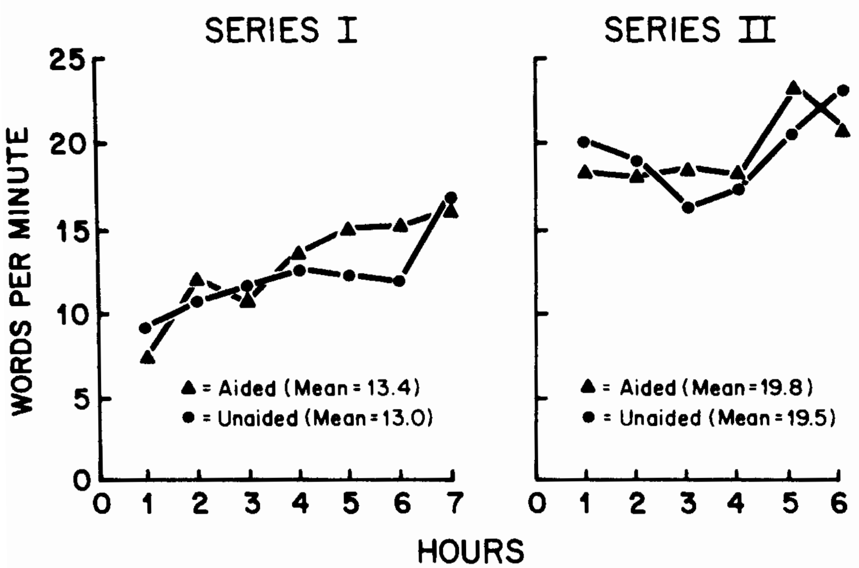

Figure 4. Comparison of SRA-10-aided and unaided tracking for Experiment I with hearing-impaired subject MA. (From Roeser et al., 1983).

ing with the device. Thus, Experiment II was designed.

Two subjects with profound hearing loss participated in Experiment II. Subject I (CB) was a 50.6-year-old female who had progressive hearing loss for 10 years prior to enrollment in the study. Subject 2 (JC) was a 41.7-year-old male who had a rapidly progressive hearing loss for 5 years prior to enrollment in the study. For both subjects the tracking procedure was used. The primary difference between Experiment I and Experiment II was that subjects were trained over an extended period of time with the SRA-10, rather than alternating in 10 minute segments. Thus, during the experiment each subject tracked in 10 minute trials while using the SRA-10 for 8 to 11 hours then for 7 to 8 hours without using the aid. The aid-on and aid-off conditions were counterbalanced. With the revised tracking procedure in Experiment II, benefit from the aid was determined primarily by comparison of the slopes of the learning curves from multiple-regression analyses for the aided and unaided conditions.

The results from Experiment II for CB and JC are shown in Figures 5 and 6, respectively. Both subjects improved considerably in their overall speechreading performance. CB began speechreading at a mean of 2 to 3 wpm (Figure 5). By the end of the experiment, after 25 hours of tracking, she was speechreading at a rate of 21 to 22 wpm. JC began at between 16 and 18 wpm and reached a maximum of 32 to 34 wpm after 19 hours of tracking (Figure 6). Although overall speechreading ability improved, there did not appear to be significant benefit from the SRA-10. Comparison of the slopes for the aid-on and aid-off conditions revealed virtually no advantage for either subject. That is, in the first two tracking conditions CB had a slope of 0.52 for the aid-on condition, compared with a slope of

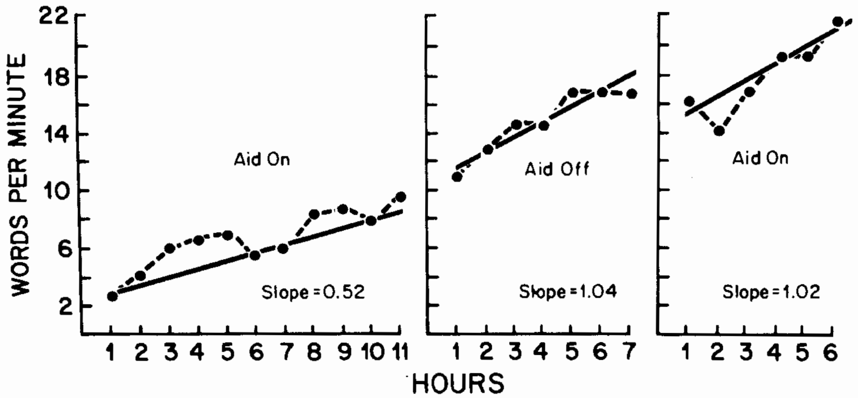

Figure 5. Comparison of SRA-10-aided and unaided tracking for Experiment II with hearing-impaired subject CB. In this Figure and Figures 6, 7, and 8, the solid line represents the slope of the learning function. (From Roeser et al., 1983).

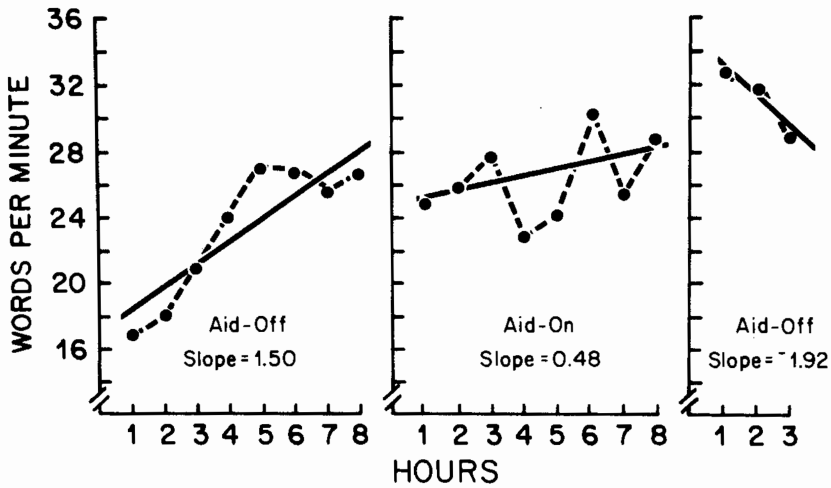

Figure 6. Comparison of SRA-10-aided and unaided tracking for Experiment II with hearing impaired subject JC.

1.04 for the aid-off condition (Figure 5). In addition, JC had a slope of 1.50 for the aid-off condition, compared to 0.48 for the aid-on condition (Figure 6).

While neither of these observations supports the hypothesis that the SRA-10 improved speechreading, there is a suggestion of possible benefit from the aid in the third condition. For subject CB, reintroducing the aid resulted in an increase in the wpm tracking score in the third (aid-on) condition after an apparent asymptote had been reached in the second (aid-off) condition. For subject JC, removing the aid in the third (aid-off) condition resulted in a clear decrease in tracking performance. Although these observations may indicate that the SRA-10 improved tracking performance, it is quite clear that the magnitude of the apparent advantage is small, especially when compared to the preliminary work of DeFilippo and Scott (1978) and Scott (1979) using normal-hearing, functionally deafened subjects.

Because of the lack of benefit shown for the three hearing-impaired adult subjects in Experiments I and II, a third experiment was conducted to replicate the previous work described by Scott (1979). In this experiment two normal-hearing subjects who were functionally deafened were studied. Both subjects tracked for two aid-on conditions and two aid-off conditions in a counterbalanced fashion. The same text was used throughout the study for subject 2, but because tracking performance for subject 1 was superior to subject 2, an additional text was required for the second set of tracking conditions for subject 1 (Figure 7 B1 and B2).

Results for the two subjects are shown in Figures 7 and 8. As with

Experiments 1 and 2, subjects improved in their overall lipreading performance during the experiment, as measured by their tracking scores. However, results regarding the benefit of the use of the SRA-10 were mixed. As shown in Figure 7, from the slopes of the learning curves there did not appear to be benefit from the SRA-10 for subject 1 on the first two conditions (A1 and A2). However, for the second two conditions (B1 and B2) the slopes of the learning curves from the aid-on condition showed a noticeable advantage compared to the aid-off condition. For subject 2 the use of the SRA-10 resulted in a noticeable, but small increase in the slope of the learning curves for the first two conditions (Figures 8A and 8B). However, this advantage was not maintained for the remaining two conditions (Figures 8C and 8D).

Overall, the results from the experiments with the hearing-impaired adult subjects failed to corroborate the preliminary data of DeFilippo and Scott (1979) for their normal hearing, functionally deafened subjects. That is, results failed to show significant change in tracking performance for the aid-on conditions. Data from our two normal-hearing subjects did reveal improvement in tracking when the SRA-10 was used at least for one subject, although the magnitude of improvement was minimal compared to that reported by DeFilippo and Scott (1978) and Scott (1979). The finding that the normal-hearing, functionally deafened subjects showed an advantage for

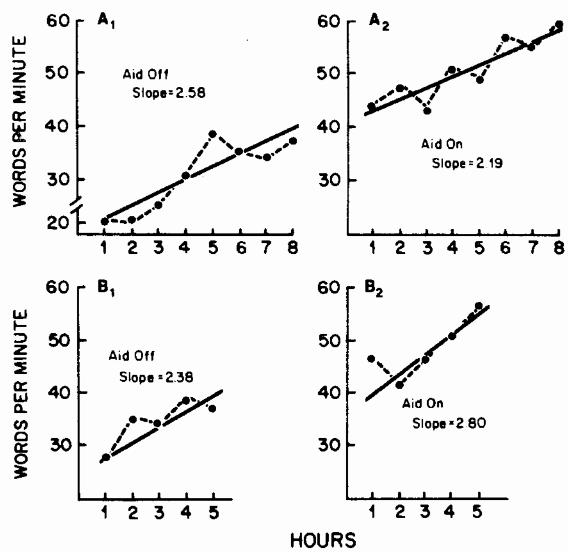

Figure 7. Comparison of SRA-10-aided and unaided tracking for subject 1 in Experiment III. Data A1 and A2 were obtained with one text and B1 and B2 with another.

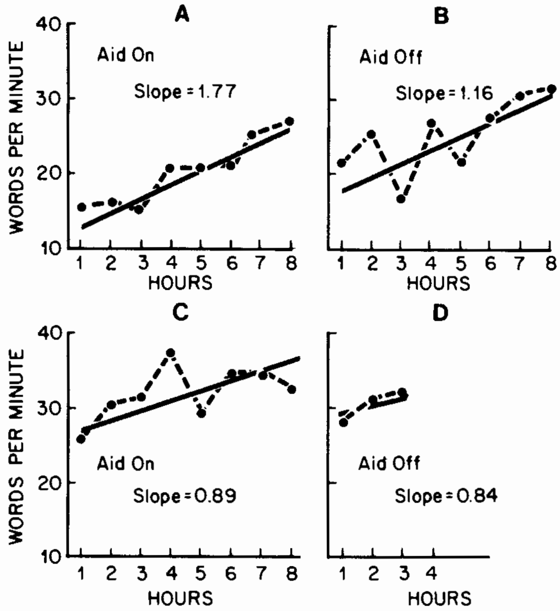

Figure 8. Comparison of SRA-10-aided and unaided tracking for subject 2 in Experiment III. In this experiment the text was the same for A-D.

the aid-on condition, which was not observed for the hearing-impaired subjects, provides preliminary evidence that results on tactile stimulation in a normal-hearing population may not be generalized directly to a hearing-impaired population. The lack of agreement in the magnitude of the advantage seen between our study and DeFilippo and Scott (1978) and Scott (1979) is not easily explained, but could be related to the small sample size for both studies, the minor change in the vibrotactile aid between the two studies (change in vibrators), the difference in the ages of the subjects, and/or the overall absolute rate of tracking of the subjects.

STUDIES WITH PROFOUNDLY DEAF CHILDREN

Parallel to our studies with adults, we have evaluated the SRA-10 with four profoundly deaf children (Friel-Patti & Roeser, 1983). The method used with the children was similar in approach to the assessment of ongoing speech in adults with the tracking procedure. Further, in our studies with children, we attempted to quantify objectively changes in socially directed, purposeful communication that could be attributed to the use of the SRA-10 vibrotactile aid. The overall project has involved evaluating the SRA-10 in the classroom and in language-interaction sessions.

The four profoundly hearing-impaired children (two males and two females) had a mean age at entry into the study of 4.0 years (ranging from 3 years, 7 months to 4 years, 3 months). These children had congenital hearing impairment in the severe-to-profound range, normal intellectual functioning, and no known or suspected abnormalities accompanying the hearing impairment.

Language Interaction Sessions

Briefly, our evaluation procedures in the language-interaction sessions consisted of the following. In addition to enrollment in a preschool program for the deaf, the children were enrolled in a program of language therapy, in which they were seen for 30 minute, tri-weekly individual therapy sessions. The overall goal of these language interaction sessions was to stimulate communicative skills and to maximize potential benefits from the vibrotactile stimulation. The language activities provided the children with multiple opportunities for active participation in the interaction, and the clinician stimulated the children to initiate and extend their communicative efforts.

Trained observers monitored the target communication behaviors during regularly occurring sessions to evaluate the effects of the SRA-10. Allowing for a warm-up period, 10 minutes of these videotaped sessions provided the record for assessing the communicative changes that occurred throughout the course of the study.

In the design of the study, each subject served as his or her own control, in that the subjects were evaluated when wearing the vibrotactile aid (aid-on) and then compared to unaided periods. Phase I was an aid-on period and occurred during the 17 weeks of the fall, 1981 academic year. During Phase I each subject wore the SRA-10 vibrotactile aid an average of 10.5 hours per week (ranging 10 to 11 hours) in both the classroom setting and in the tri-weekly individual therapy sessions. Communicative behaviors were monitored and analyzed for four sessions in Phase I during the initial, middle, and final periods of the semester. Sessions 1, 2 and 3 occurred from September to December, 1981, while session 4 was recorded after the usual Christmas break. Phase II was an aid-off condition and occurred during the 14 weeks of the Spring, 1982 academic year. Subjects were enrolled in the tri-weekly individual therapy sessions as well as in the daily classroom-education program, but did not wear the SRA-10 vibrotactile aid. Communication behaviors were evaluated weekly over an 8-week period during Phase II.

The measure used to assess the efficacy of the vibrotactile aid was termed the Communication Index. The Communication Index was defined as the total amount of time each child used some form of communication including vocalization only, sign language only, or combined vocalization and sign language. For each session, a Communication Index was obtained on both the child and the clinician (teacher). Thus, it was possible to compare the two measures and calculate speaker-dominance during the session.

The underlying theoretical assumption for using the Communication Index was based on the fact that normal-hearing children express a variety of communicative intentions through nonverbal as well as verbal means (Bruner, 1975). These nonverbal behaviors include eye gaze, facial expressions, and hand and arm gestures for pointing, showing, and offering. Nonverbal behaviors are often employed by normal-hearing children in the very early stages of language development as ways of extending and embellishing their emerging expressive repertoire (Bates, 1976). Similarly, the communicative behaviors of young deaf children are comprised of predominantly vocalizations produced in conjunction with gestures, whole body actions, facial movements, and gaze behaviors (Carr, 1971). Facility with gestures improves with chronological age, and as deaf children learn a formal manual language system they combine the formal signs with their own gesture systems (Miller, 1981).

The Communication Index, therefore, represented a composite measure of the subjects' vocalized and signed communicative attempts. The Communication Index was obtained using a custom designed, computer-based observation system. Because of the nature of the behaviors observed, a continuous, real-time measurement, or event-sampling strategy was employed. Continuous event sampling involves measurement of the onset

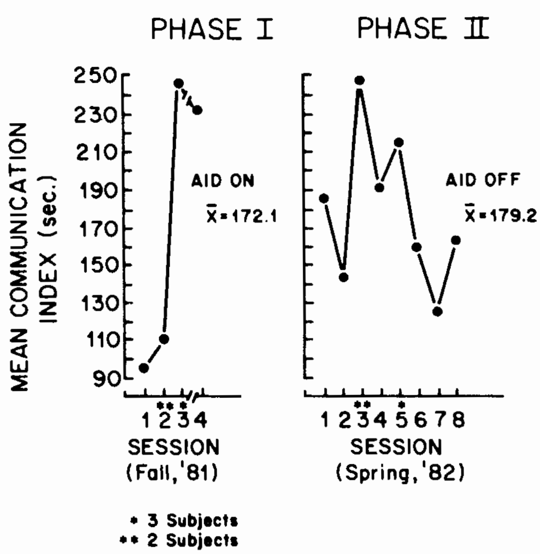

Figure 9. Mean Communication Index for four hearing-impaired children for Phases I and II. (From Friel-Patti & Roeser, 1983).

and duration (elapsed time between onset and end) of each instance of the target behaviors during an observation session.

The mean group data obtained for the Communication Index are displayed in Figure 9. Initial inspection of Figure 9 shows a sharp rise in the performance of the subjects during Phase I in which the SRA-10 was used. This was followed by a gradual decrease in performance across the 8 sessions of Phase II, after the SRA-10 was removed.

The improvement seen in Phase I could have been related to the use of the vibrotactile aid, the result of the intervention program, or perhaps a combination of these two factors. However, the decrease in performance seen in Phase II would strongly indicate that the aid provided benefit for the subjects, as all conditions remained essentially the same with the exception that the aid was removed for the whole semester.

In order to further analyze the nature of the changes that occurred between the aid-on (Phase I) and aid-off (Phase II) stages, the component responses of the Communication Index were analyzed separately. Table 2 shows these data. During Phase I (aid-on), vocalization-only and sign-only appeared to show little change over the four evaluation sessions. However, the use of vocalization-plus-sign increased noticeably during this phase, going from 48 seconds for evaluation session 1 to 183.7 seconds for session 4. During Phase II (aid-off), more variability was present. Sign-only, however, showed a gradual increase, and vocalization-plus-sign decreased sharply.

Regression analyses on each of the three responses for the two phases showed that the slope differences between Phases I and II were not significantly different at the .05 level of confidence for vocalization-only or the sign-only measures. However, the difference between Phases I and II was significant beyond the .01 level of confidence for the vocalization-plus-sign measure. Overall, these data indicate that the effect of using the aid was to improve the child's use of communication involving sign language plus vocalization (Total Communication). From the above data, we conclude that the SRA-10 is also helpful in improving the amount of communication in connected discourse in profoundly deaf children when sign-plus-vocalization is used.

Use of the SRA-10 in the Classroom

The subjects were studied in the classroom during two time periods: Summer and Fall, 1981. In the summer phase, the four deaf children attended a 2½ hour per day 5 day per week program for 6 weeks. The use of the SRA-10 was counterbalanced so that two children wore the tactile aid for the first 3 weeks and the other two children for the second 3 weeks. The children were randomly assigned to the two conditions. All four children experienced the same classroom program with the major independent varia-

Table 2

Mean number of seconds in which subjects responded by vocalizing only, signing only, and vocalizing and signing. The total of these behaviors was defined as the Communication Index (from Friel-Patti & Roeser, 1983).

	[a]Phase I (aid-on) Evaluation Session				[a]Phase II (aid-off) Evaluation Session							
	1	2[b]	3[b]	4[b]	1	2	3[c]	4	5	6	7	8
Vocalization Only	31.0	38.3	8.0	34.5	38.0	20.5	62.0	32.5	57.3	22.0	37.2	50.0
Sign Only	17.0	16.6	32.0	14.5	18.8	20.0	37.5	22.5	42.0	31.0	28.0	45.5
Vocalization Plus Sign	48.3	57.0	207.3	183.7	133.0	102.0	149.5	137.0	117.3	106.0	55.8	73.8
Total (Communication Index)	96.3	111.9	247.3	232.2	189.8	142.5	249.0	192.0	216.6	159.0	121.0	169.3

[a]Change from Phase I to Phase II was significant at .01 level of confidence ($t = 4.56$; $df = 39$).

[b]3 subjects only

[c]2 subjects only

ble being the use of the vibrotactile aid. During the 3 week aid-on condition, subjects averaged 7.9 hours of wearing time per week (range: 7.0 to 8.8 hours).

In the fall phase all four subjects wore the SRA-10 during school hours while engaged in group instructional time. The children were in the same classroom with the same teacher from the summer phase. The vibrotactile aid was worn in the classroom for an average of 10.5 hours per week for 14 weeks.

For both summer and fall programs, classroom activities were designed to promote communication with peers and the teacher. The children were encouraged to use conversational interaction to accomplish the learning activity which was related to intrinsically motivating tasks, e.g. baking cookies, making popcorn, etc. Encouragement was given for participation in the activity and the initiation of relevant communication. No specific language form was required.

The classroom activities were observed unobtrusively through a one-way glass from a specially designed enclosed deck overlooking the classroom. The team of observers, computer, and computer operator were all accommodated on the deck.

The data from the classroom sessions were ambiguous and difficult to interpret, making them inconclusive. Preliminary analyses indicated that there was a great amount of individual variation in the data which appeared to have obscured the comparison of aid-on versus aid-off conditions. The data were highly dependent upon the classroom activity expecially the level of intrinsic interest each subject had in the activity. From these observations we conclude that the aid in its present configuration is not appropriate for the classroom. It is not wearable and the children are somewhat encumbered by the electronics of the aid and long cords.

SUMMARY

We have described the development of tactile aids for the deaf with emphasis on the SRA-10, a vibrotactile device using a spatial/temporal approach. Over the past 18 months, we have evaluated the efficacy of the SRA-10 with normal-hearing, functionally deafened subjects, profoundly deaf adults, and four profoundly deaf children. The major goal of the project was to assess the efficacy of the SRA-10 in aiding in the reception of connected discourse. Overall, results hve been encouraging, and it is possible to draw the following conclusions: For adults: (a) the SRA-10 provided hearing-impaired subjects little or no benefit in speechreading, as measured by the tracking procedure; (b) at least one of the normal-hearing, functionally deafened subjects appeared to benefit from the SRA-10 in speechreading connected discourse, although not to the extent indicated by previous work; and (c) the difference in results between the normal-hearing and hearing-impaired subjects raises the question of whether data from studies on tactile aids using normal-hearing subjects can be generalized to the hearing-impaired population. With children we found a significant increase in the quantity of communication using vocalization plus sign language simultaneously (Total Communication) when vibrotactile stimulation with the SRA-10 was used in individual language-therapy sessions. This finding supports the notion that vibrotactile stimulation was positively associated with the communicative act.

One of the spin-offs from our project is that the observation system we developed can be adapted for evaluating different types of communicative devices, such as other types of tactile aids, monaural compared to binaural amplification, or perhaps cochlear implants. There are three advantages of the computer-based observation system that permit this flexibility. The first is that the measurements comprising the Communication Index were made objectively by a team of observers. The observers in this study were trained in less than five hours and interobserver agreement remained at or above 90% for all behaviors. The second is that the microcomputer and event recorder used are both portable and can be taken to a variety of observation settings; they are not limited to the videotape laboratory. The third advantage is the relatively low cost of the equipment, about $3,000 to $4,000.

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