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Tactile Localization of Acoustic Stimuli with an Earmold Vibratory Aid

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The ability to localize a sound is one of the most important means by which selective attention is achieved. That is, successful attention to one sound in the presence of competing sounds is dependent upon the ability to detect the different directions from which the sound originates.

In normal audition, localization of sound is accomplished through the use of binaural cues of differences in intensity or phase between the inputs to the two ears. Localization of high frequency sounds depends upon intensity differences, whereas localization of low frequency sounds depends upon phase differences.

Hearing impairment reduces or eliminates the ability of the ear to detect intensity or phase differences. Difference limens for intensity of phase are much higher for severely and profoundly hearing impaired people (Zurek and Formby, 1981; Risberg et al, 1975). Thus, the ability to localize is also reduced.

Richardson (1979) examined the ability of the tactile system to localize sound sources. In a set of experiments he placed microphones on each of the subjects' ears, and presented the resulting signals to the left and right index fingertips as a vibratory signal. Subjects were asked to localize a sound originating at one of several loudspeakers in a room. The sound was a narrow-band noise. Results showed that tactile and auditory localization abilities using his device were similar, when head movement was permitted. Richardson went on to study localization of moving sounds, judgments of directions and distance and also localization in the presence of competing sounds. He concluded that the tactile sense can be used, with some limitations, to localize acoustic signals of various kinds.

However, Richardson's apparatus was neither practical nor portable. The requirement that both index fingers be in contact with the device was a major limitation for use of the device in everyday settings. Richardson, however, did not envision this device to be adapted for use by deaf people on an everyday basis.

Promising findings by other researchers about the basic abilities of the tactile system, together with findings like those of Richardson, have led to continuing interest in the problem of using the tactile system for presentation of speech cues to aid deaf persons.

Reports about studies of tactile responses to speech sounds date back to the 1920's and 1930's (Gault, 1924). Various investigators attempted to apply the auditory place principle to the tactile system by distributing speech frequencies at different sites over the skin. More sophisticated versions of these early devices converted the acoustic energy between 300-3000 Hz to vibratory energy between 40-400 Hz which is the range to which skin is sensitive (Verrillo, 1975).

Such spectral displays are "rough analogues of the spatial frequency analysis performed by the peripheral auditory system" ( ), also known as "tactile vocoders." The acoustic signal is analyzed into frequency bands and these are transformed into place of stimulation. Various studies attempted to use this principle with different devices, but all had the basic idea of transforming different speech signals (such as vowels, consonants, single syllables, multi-syllabic utterances, etc.) into tactile code. Other investigators used a more simple transformation of speech sounds into a vibratory signal applied at a single site on the skin. These "single-channel" vibrators, unlike their "multichannel" vocoder counterparts, typically displayed only a limited set of parameters, rather than the entire speech signal.

Reed, Durlach and Braida (1982) described several specfic devices, and discussed the "state of the art" in an ASHA monograph. Their conclusion was that studies of tactile aids have to take into consideration several factors; 1. the limitations of the tactile sense, 2. the degree of training with the particular device. "Ideally, a practical aid would be applicable to a wide range of individuals, function at a distance and require no or little training, and would also be useful for all acoustic inputs, not only speech." (Reed et al, 1982 p.). The success of a tactile aid depends on satisfying at least some of these requirements.

The constraint that no special training is required could presumably be satisfied only if the aid were applied continuously and at a very early age, so that speech production, speech perception and language competence might develop in a fashion similar to that which occur when normal hearing is available. Tactile aids, unlike conventional acoustic aids or eyeglasses, involve a fundamental recoding of a signal that was specifically designed for the ear and not the skin, so one would normally expect extensive training to be necessary.

The device in the present experiments delivers vibrotactile stimulation to the ear canal through a conventional hard earmold. Acoustic input is picked up by a microphone mounted on each side of the head, and is separated into two frequency bands, a low band and a high band. The earmold resonates at two carrier frequencies, one controlled by the low frequency band and one controlled by the high frequency band. Thus, the instrument shows more frequency specificity than commercially available single-channel devices such as the "Tactaid 1" but less than multichannel devices such as those described in experimental situations.

This site and manner of stimulation were chosen for two reason; first, to put the stimulus in a place that did not eliminate normal use of the hands or arms; and second, to provide a more cosmetically acceptable prosthesis to persons who might well have been previously accustomed to wearing a hearing aid. An additional possible benefit of this type of stimulation is that the user might perceive the stimulation as "more like hearing" than would be the case had some other site been chosen. In this experiment, two identical earmold vibrators were used, one on each ear. The ability to place stimulators in both ears allows for the possibility of tactile localization of sound sources. Thus, as a first step in evaluating the usefulness of this device, deaf and hearing subjects were asked to localize a variety of sound sources with and without the device.

METHOD

Subjects: The subjects were two female and one male severely-to-profoundly hearing impaired persons with 70 dB or worse hearing loss at any frequency, and 2 normal-hearing people. Audiograms for each of the hearing-impaired subjects are shown in the Appendix. All subjects were paid for their participation in the experiment.

Apparatus: The device worn by subjects was designed at CID by Arnold Heidbreder and James D. Miller. This is a system to extract the envelope of speech using conventional RC integration and use the envelope to control the amplitude of a sine wave carrier. This amplitude modulated signal is amplified and used to drive a special bi-modal vibrator. The vibrator consists of two spring mounted bar magnets constructed to resonate at two carrier frequencies, one mode for low-frequency sounds and one for high-frequency sounds. The point of division into high and low modes is placed at approximately 2000 Hz. This vibrator is mounted on the exposed surface of a conventional hard lucite earmold. Action of the vibrator introduces sinusoidal activity of the earmold in the ear canal at frequencies of approximately 80 and 240 Hz. The sound channel is not obscured, and may be used for presentation and amplification of sounds. The microphones for the system is a hearing aid microphone, mounted on the outside surface of each ear of a pair of circumaural earphones. Each subject was fitted with individual hard lucite earmolds, one for each ear. The earmold is modified to allow service and easy insertion and removal of the vibrator by embedding a hex nut in the exposed face of the mold.

The experimental version of this device is not battery-powered, but runs on conventional current.

Test Enclosure: Testing was conducted in a 16.5' x 15.5' room, fitted with sound absorbent panels and carpeted. Subjects were seated in approximately the center of the room at a distance of 1.82 meters from each of 5 loudspeakers. The speakers were FM-42 series Soundelier, Inc. loudspeakers, showing a relatively flat frequency response between 100 Hz and 12 kHz. The loudspeakers were arranged at angles of 0°, $\pm 45^{\circ}$, and $\pm 90^{\circ}$ relative to the subject. Loudspeakers were mounted such that the center of each loudspeaker was at the level of the subject's head.

Stimuli: Stimuli consisted of pure tones at 500 Hz, 1000 Hz, and 2000 Hz; generated by a General Radio oscillator, and a broad-band pink noise produced by a specially-designed noise generator. All stimuli were presented at a level of approximately 72-75 dB as measured at the subject's head. The duty cycle for all stimuli was 750 ms, with 250 ms "on" time.

Procedure: The experimental procedure was as follows: each subject sat in the room facing the 5 loudspeakers and inserted his earmolds. A pair of circumaural earphones on which the microphones for the system had been mounted were placed on his head. At the beginning of each block of testing, a signal was presented on loudspeaker #3 (at 0 degree angle) and the experimenter adjusted the level of stimulation in each ear until the subject perceived the vibratory stimulation to be equally intense in both ears.

Testing was conducted in blocks of 30 trials, such that all trials within a block used the same stimulus. Stimuli were randomized across trials among the loudspeakers. On each trial, the stimulus remained on until the subject made a response. A brief rest period was given after each block. A broad-band masking noise was fed into the auditory port of each earmold to eliminate auditory perception of the stimuli.

The subjects reported after each stimulus presentation which loudspeaker the tone came from. Feed-back was given by lighting a light bulb mounted under the appropriate loudpseaker. All stimulus presentations, recording of responses, and delivery of feedback was controlled by the experimenter from an adjoining room.

Subjects were tested for 18 blocks under each stimulus condition. Each subject received several sessions per week; in each session 3-6 blocks were run, in which several of the experimental conditions were tested. At the conclusion of testing each subject was tested for one block under each experimental conditon without wearing the tactile aid. For these blocks subjects wore their hearing aids if they normally did so, and otherwise were unaided.

RESULTS

Table I shows percent correct performance for each subject in each experimental condition. An examination of Table 1 shows that all normal hearing subjects performed better than all hearing impaired subjects for all experimental conditions. One outstanding fact is that all normal hearing subjects perceived the high-frequency tones much better than the low and middle frequency tones. This was true only for two of the hearing impaired (SD,DW) subjects. The other subject (SM) perceived the low requency tone better than the high and the middle frequency tones. Examination of session-to-session performance did not reveal any learning trends across sessions, so this was not analyzed.

Figure 1 shows average performance for normal hearing and hearing-impaired groups across experimental conditions. This graph again shows that normal-hearing subjects have better performance across all experimental conditions. It also shows that performance was better for 2000 Hz and 500 Hz than for 1000 Hz and the noise band for the hearing-impaired subjects.

Table #1

Analysis of Variance Summary Table for Stimulus Condition by Subject Group

Source	df	SS	MS	F	p	w2
A(stimulus	3	204.45	68.15	16.95	<.01	.25
B(hearing gr.)	1	352.28	352.28	87.63	<.01	.46
A x B	3	121.08	40.36	10.04	<.01	.14
Error	20	80.33	4.02			.15
Total	23	758.14				

Analysis of variance shows all parameters of the experiment to be highly significant (P<0.01). There was significant effect of stimulus type, significant effect of subject group (normal vs. hearing impaired) and significant interaction. We were able to account for 85% of the variance; 46% were due to type of subject and 25% were due to stimulus type.

Table 2 compares localization performance with the earmold vibrator to localization without the earmold vibrator for all subjects. This shows that for both normal hearing subjects, auditory performance was clearly better than with the vibrotactile aid. Results for the hearing-impaired group show that performance with the vibrotactile device is better for some of the experimental condition. One outstanding fact is that all hearing impaired did not perceive any ssund at 2000 Hz with and wihout their hearing aid, but did fairly well using the tactile aid. Two subjects refused after a few trials to participate in the auditory condition unaided, so ti was not possible to obtain data from them. It can be inferred that their auditory performance would have been at chance levels (20%).

Figure 2 shows performance of individual subjects by loudspeakers averaged across experimental condition. Examination of Figure 2 shows that 2 of the hearing-impaired subjects showed better performance for stimuli presented at the 0° degree angle than for sitmuli presented at any other angle. This did not seem to be the case for the normal hearing subjects. Relatively equal performance is shown for all angle presentations for both normal hearing subjects.

DISCUSSION

The results from the present experiment suggest that in general normal-hearing and hearing impaired people can localize sounds in a rudimentary fashion using this device, at least for the experimental conditions tested, although performance does not approach auditory localization by normal hearing people.

The fact that normal hearing subjects preformed better with the tactile aid than hearing-impaired subjects may be explained partly by the fact that auditory cues were not completely eliminated by the masking noise presented, that is, masking was effective in eliminating acoustic perception of the loudspeakers but not for the auditory perception of the vibratory carrier frequencies. The fact that auditory sensitivity is better than tactile at many frequencies, including one or both of the carrier used implies that the normal hearing subject would "hear" the vibrations at this range, in addition "feeling" them. Another factor which might account for the improved performance of normal-hearing subjects for that is the assumption that normal hearing people have more experience with localization of sound in everyday life than hearing impaired persons, and this experience could have a carry over effect in the experimental conditions. In later studies these effects could be addressed by using lower carriers, at frequencies where tactile sensitivity is equal to or better than auditory sensitivity, to diminish auditory effects. Of course, in hearing-impaired subjects, particularly those with significant hearing loss across frequencies, audibility of the tactile carrier is less likely to be problem.

The potential of this device to aid other aspects of sound perception further by deaf persons requires testing this device with other auditory tasks, such as discrimination of environmental sounds, rhythm tasks like the MTS, and actual speech perception tasks. In addition, modification of several electroacoustic parameters of the device, such as testing different carrier frequencies, different stimulators, different filtering, etc. might result in a more optimal set of parameters for an ideal tactile aid.

One major limitation of the present tactile aid described here is that it is not portable or wearable, and therefore testing in natural conditions is not possible. Should the device continue to show promise in further testing, then miniaturizing the signal-processing equipment may be called for, to allow testing under natural conditions.

Localization of sound in the classroom is critical if selective attention to the teacher is desired. Erber (1972) cites the advantages of hand-held bone vibrators in developing and improving the child's abilities in speech perception and production. Tactile cues are assumed to improve the ability to lipread, especially for voicing and nasality which are difficult cues to lipread. Erber states that vibrotactile aids can help the profoundly deaf child develop a more natural concept of spoken langauge, which lipreading alone does not provide him with, and further notes that tactile aids used in the class allow the deaf child to monitor his speech, providing an indication of its overall loudness and rate.

For these reasons, further testing of the device used in the present study in classroom situations should yield promising results.

This device may show some potential to address some issues brought up by previous studies on auditory training and aural rehabilitation. Expanding the use of tactile aids from the laboratory to the classroom and to everyday use could provide considerable benefits for those hearing-impaired persons whose hearing loss is so extreme that a conventional hearing aid cannot provide sufficient acoustic power to reliably elicit even detection responses without discomfort or feedback squeal.

The ultimate contribution that tactile presentation of acoustic stimulation can make, is yet unknown, but the existing evidence is encouraging. More research is needed to understand the tactile system and apply this knowledge to the benefit of the hearing impaired.