A RESEARCH REPORT:

Vibrotactile Discrimination of Speech Sounds by Normal, Hearing-Impaired, and Visually-Impaired Individuals

PATRICIA BENDER KRICOS
The University of Akron
Akron, Ohio

The study of vibrotactile reception of speech sounds has received considerable attention, especially from researchers such as Gault, who began his work in the early 1920's. However, since the studies by Gault, relatively little has been published regarding the usefulness of tactile stimulation as an aid to deaf individuals in understanding speech. There are three main views regarding the usefulness of the sense of touch in communication. The first, held by early investigators, was that the cutaneous receptors could serve as a substitute for the more complex, analytical hearing mechanism. Gault (1924), for example, reported a case who learned to recognize 200 spoken words by feeling vibrations of the experimenter's vocal apparatus. These were conducted through a 14-inch hollow tube to the subject's palm.

A second viewpoint regarding the possible role of taction in communication was proposed by Geldard (1957, 1961). He suggested that speech signals be recoded into tactile patterns, called "vibratese language." His code was based on the use of signals of varying intensities and durations, and on the use of vibrators at different loci.

A third view, that stimulation of the tactile sense with speech sounds may yield supplementary cues to the hearing impaired, has received only limited study. Pickett (1963), for example, used his "tactual vocoder" with deaf individuals and found that using it resulted in improved lipreading performance.

The use of supplementary tactile information is a basic aspect of the verbotonal method of aural rehabilitation, developed by Guberina (1955). Rather than restricting auditory training to aural stimulation by air conduction, the verbotonal method includes auditory training with bone conduction or body conduction. Little research, however, has been reported on the "information" transmitted and received by tactile stimulation.

Haas (1970) attempted to determine a set of distinctive features for tactile reception of 33 phonemes. Using tactile distinctive features based on three dimensions (intensity, duration, and pattern) he found agreement among subjects in judging these features for 29 phonemes. From additional findings, he concluded that the resolving power of the three-dimensional tactile distinctive feature sets is not conclusive.

In an attempt to determine perceptual features for tactile reception of speech, Danhauer and Appel (1976) used 24 normal-hearing subjects, who made "same-different" comparisons for 24 English consonants paired with the vowel /a/. The stimuli were received through the visual, tactile, and combined visual-tactile sensory modalities. The subjects' judgments were submitted to INDSCAL analysis and the features voicing and continuancy were retrieved for the tactile input.

The purpose of the study under discussion was to determine what kinds of "information" are being transmitted to an individual when speech sounds are presented to him through vibrotactile stimulation. Specifically, the study was designed to determine whether individuals can make gross discriminations of "same" or "different" to pairs of speech sounds, and whether subjects can differentiate between speech sounds on the basis of certain distinctive features, namely "stronger" versus "weaker", "shorter" versus "longer", and "changing pattern" versus "non-changing pattern", such that the speech sounds can be scaled along these dimensions. It was further the purpose of the study to determine:

1. whether performances in these areas differ for normal, hearing-impaired, and visually-impaired individuals;
2. whether performance is affected by presenting the tactile signals in either a filtered or a non-filtered fashion; and
3. whether performances during subjects' first sessions are different from their performances during a second session.

Procedures for the Study

Subjects. The subjects, all adults, included eight individuals with normal hearing and vision, eight hearing-impaired individuals (pure tone averages exceeding 70 dB in both ears), and eight visually-impaired individuals (central visual acuity of 20/200 or less in the better eye, with correcting glasses).

Experimental tasks. The study encompassed a pilot experiment, plus four experimental procedures. In the pilot experiment, the thresholds for vibrotactile detection of the consonant-vowel-consonant (CVC) syllables were obtained using the method of limits. Thresholds for each CVC syllable were obtained both when the syllable was presented full-frequency bandwidth and when it was presented in a filtered condition. Each of the syllables in the four remaining experimental procedures was presented at an intensity level of 30 dB, re: .20 volts rms for the filtered mode and re: .23 volts rms for the non-filtered mode. (1) The 30-dB level was chosen on the basis of subjects' indications of "most comfortable loudness" levels for vibrotactile perception and discrimination of speech.

The four remaining experimental procedures involved the following tasks for the subjects:

Procedure 1. In a series of paired CVC-syllable presentations, judge whether or not the two syllables presented are the same or different.

Procedure 2. In a series of paired CVC-syllable presentations, judge whether the second syllable is longer or shorter than the first.

Procedure 3. In a series of paired CVC-syllable presentations, judge whether the second syllable is stronger or weaker than the first.

Procedure 4. In a series of paired CVC-syllable presentations, judge whether the second syllable has a more changing or more non-changing pattern than the first.

Prior to the first experimental task, subjects were given the opportunity to experience the tactile sensations of 20 pairs of CVC syllables.

Stimuli. Eight consonants were selected for study, /p, b, f, v, k, g, S, 3/. The /p/ and /b/ sounds represented plosives with point of articulation at the front of the mouth; /f/ and /v/ represented fricatives with the point of articulation at the front of the mouth; /k/ and /g/ sounds represented plosives with the point of articulation toward the back of the mouth; /S/ and /3/ represented fricatives with the point of articulation toward the back of the mouth. The /p/, /f/, /k/, and /S/ sounds represented voiceless consonants, while /b/, /v/, /g/, and /3/ represented voiced consonants. The vowel /u/ was combined with the consonants to form eight CVC syllables, /pup/, /bub/, /kuk/, /gug/, /fuf/, /SuS/, /3u3/ .

The verbal material was recorded by a female speaker with a General American dialect. The verbal material was recorded on the tape (Scotch 282) via a Magnecord 1022 tape recorder with the speaker in a sound-treated booth. The syllables were spoken as naturally as possible to attain

(1) Specified as 0 dB, from threshold data (pilot experiment) representing the lowest threshold obtained for any of the syllables in each filtering condition.

proper stress, duration, and relative speech power.

Presentation of the stimuli. For each experimental task, 128 pairs of syllables were presented, 64 in a non-filtered condition and 64 in a filtered condition. In each experiment, the stimuli were presented under two conditions: with and without discontinuous bandpass filtering of frequencies. In the first condition, CVC syllables were presented in a filtered condition, such that a low and a higher octave bands, not adjacent, were presented simultaneously. The discontinuous octaves were 600-1200 Hz and 2400-4800 Hz for all of the syllables. (2)

In the second condition, CVC syllables were presented in full-frequency bandwidth, i.e., 30-16000 Hz $\pm$ 2 dB. All experimental procedures were completed with 76 dbA of broadband white noise projected from a loudspeaker in the test room to mask any auditory signals from the tactile vibrator.

Equipment. The stimuli were played back on a tape recorder (Magnecord 1022), attenuated (Daven Type T-690-A), and fed through a pair of variable bandpass filters (Allison, Model 2-AR). The filters were manually controlled by the experimenter so that stimuli could be presented in a condition of full-frequency bandwidth or in a condition of discontinuous bandpass filtering of frequencies. The stimuli were amplified (McIntosh Model 50-W-2) and fed to the tactile vibrator (Vibar Suvag, Type 73, R-16). The intensity of the stimulus was monitored visually on a voltmeter (Hewlett Packard, Model 400-D) at the output of the amplifier.

The maintenance of a constant force of the vibrator on its point of contact from subject to subject was accomplished by the use of a spring loaded device. The force used was 381 $\pm$ 30 grams. For each subject, the tactile vibrator and spring loaded device were placed on the palm and secured with adhesive tape.

Results

Procedure 1: "Same-Different" Discriminations for 64 Pairs of Speech Sounds. In Procedure 1, the three groups of subjects made "same-different" responses to 64 pairs of CVC syllables. The pairs were presented in both a filtered and a non-filtered fashion; the subjects experienced the presentations at one-week intervals. For each subject in each of the four conditions (two sessions, two filtering modes), a score was obtained, a percentage of correct responses. The scores were analyzed by an Analysis of Variance, Mixed Design, Type VI (Lindquist). This design permitted the testing of differences among:

(2) These bands were selected because they had been determined by Plummer (1972) to be the "optimal discontinuous octaves" for auditory perception of consonants.

1. three groups of subjects,
2. two filtering conditions, and
3. two sessions.

Mean scores for the groups are shown in Table 1. Significant differences at the .05 level of confidence occurred between the mean score values of the blind group and both the deaf and normal groups, with the mean score value of the blind group being higher than the others. There were no significant differences between the scores for filtering conditions or for sessions (first, second).

Subjects were able to make gross discriminations of "same" or "different" to pairs to speech sounds presented in a vibro-tactile manner. The ease with which subjects made these discriminations differed for the pairs of speech sounds. Certain pairs, such as /pup-gug/ and /fuf-3u3/ were usually called "different" while /vuv - 3u3/ and bub-vuv/ were usually called "same".

Table 1. Mean discrimination scores for three groups of subjects.

Normal group	= .63
Deaf group	= .64
Blind group	= .77

The eight consonants used in Procedure 1 might be classified with regard to three physiological categories, 1) voicing, 2) manner of articulation, and 3) place of articulation. Thus, the 64 pairs of CVC syllables in Procedure 1 could be divided into "mixed" pairs (e.g., voiced vs. voiced consonant) for each of the three categories mentioned above.

The mean proportions of pairs called "different" by subjects in each voicing category were compared. Significant differences at the .05 level occurred between the mean proportions of the mixed pairs and unmixed pairs. The results indicated that subjects gave a greater proportion of "different" responses to "mixed" pairs as opposed to "unmixed" pairs, suggesting the voicing category to be a distinctive feature in the tactile perception of these consonants.

Mean proportions of pairs called "different" by subjects in each category of "position of articulation" and of "manner of articulation" were also compared. While significant differences among the proportions of pairs called "different" in each category of "position of articulation" were evident beyond the .001 level of confidence, these differences were not of a nature to establish "position of articulation" as a tactile distinctive feature, since a greater proportion of "unmixed" pairs were called "different" than "mixed" pairs. In similar manner, data regarding "manner of articulation" were too equivocal to establish this category as a distinctive feature in the tactile reception of speech. One type of mixed pair (fricative-plosive) yielded the highest mean proportion of stimuli called "different", while the other type of mixed pair (plosive-fricative) yielded the lowest mean proportion of stimuli called "different".

Procedures 2, 3, and 4: "Stronger-Weaker", "Shorter-Longer", and "Changing Pattern" Versus "Non-Changing Pattern" Discriminations.

In procedures 2, 3, and 4, the three groups of subjects made comparative judgments of paired CVC syllables along the dimensions of "shorter-longer", "stronger-weaker", and "changing pattern" versus "nonchanging pattern" respectively. For each paired stimulus the subject always judged the second member of a pair relative to the first on one of the three dimensions. Matrices of proportions were obtained from paired

Table 2. Interval-scale values for each group of subjects along the dimensions of "weaker-stronger", "shorter-longer", and "more changing pattern" versus "more non-changing pattern".

WEAKER - STRONGER

Normal	Deaf	Blind
P = 0.00	P = 0.00	P = 0.00
G = 0.15	G = 0.62	G = 0.13
B = 1.02	K = 0.65	ʃ = 1.02
ʃ = 1.06	ʃ = 0.66	K = 1.14
ʒ = 1.09	B = 0.91	ʒ = 1.23
K = 1.10	ʒ = 1.21	B = 1.38
V = 1.98	F = 1.65	V = 2.32
F = 2.16	V = 1.74	F = 2.50

SHORTER-LONGER

Normal	Deaf	Blind
P = 0.00	P = 0.00	P = 0.00
K = 0.58	K = 0.12	K = 0.17
ʃ = 0.81	ʃ = 0.45	ʃ = 0.44
F = 1.18	F = 0.49	F = 0.72
B = 1.56	B = 1.10	B = 1.19
G = 1.57	G = 1.38	G = 1.38
ʒ = 2.38	V = 1.82	V = 2.10
V = 2.40	ʒ = 2.00	ʒ = 2.46

NON-CHANGING versus CHANGING

Normal	Deaf	Blind
P = 0.00	P = 0.00	P = 0.00
ʃ = 0.16	ʃ = 0.06	ʃ = 0.08
F = 0.28	B = 0.09	F = 0.09
K = 0.31	G = 0.11	P = 0.47
B = 0.35	K = 0.13	K = 0.75
G = 0.36	F = 0.19	V = 0.80
V = 0.57	V = 0.32	G = 1.05
ʒ = 0.93	ʒ = 0.68	ʒ = 1.44

comparisons of the eight CVC syllables for each group of subjects and each dimension. The proportions were then transformed into *z*-scores and divided into nine interval-scales. The interval-scale values are presented in Table 2. Pearson Product Moment correlations were obtained to test for correlations between interval-scale values obtained for the speech sounds for the three groups of subjects on a particular dimension, such as "stronger-weaker". All of the scales were highly correlated, at least beyond the .01 confidence level, with the exception of the blind group versus both the normal and deaf groups on the dimension of "changing pattern" versus "non-changing pattern".

Discussion

Subjects with little training were able to make gross discriminations of "same" or "different" to pairs of speech sounds presented in a vibrotactile manner. It seems likely that supplementary tactile cues would be beneficial to hearing impaired persons in programs of auditory training and speechreading. Data presented in this study should be useful to rehabilitative audiologists. The relative ease with which subjects make these discriminations differs for the pairs of speech sounds and this should be taken into consideration. Pairs such as /pup-gug/ and /fuf- ʒuʒ/ , for example were more often called "different", whereas pairs such as /vuv- ʒuʒ/ and /bub-vuv/ were usually called "same". Also, it appears from the "same-different" discrimination data that voicing is an important feature in tactile discrimination of speech. This information along with examples might be provided to aid hearing-impaired persons in perceiving and discriminating the voicing characteristics of consonants.

Finally, and extending the foregoing instance, the information on the "tactile characteristics" of consonants that were reported here could be presented to hearing-impaired individuals to aid in their discrimination of these sounds, both tactually, visually, and auditorially. Using the interval-scale values obtained for the phonemes along the dimensions "weaker-stronger", "shorter-longer", and "more changing pattern" versus "more non-changing pattern", it could be explained, for example, that the /p/ phoneme is relatively weak, short, and has a non-changing pattern. The results of this study indicate that further study in the area of vibrotactile discrimination of speech sounds is warranted. In particular, the vibrotactile discrimination of other speech sounds should be studied, and there is a need to determine how performance in this area is affected by longterm training.

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