Tactile Communication of Speech

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Goals and Significance
The long-term goal of this research is to develop tactual aids for persons who are profoundly deaf or deaf-blind to serve as a substitute for hearing in the reception of speech and environmental sounds. This research can contribute to improved speech reception and production, language competence, and environmental-sound recognition in such individuals. This research is also relevant to the development of improved tactual and haptic displays for a broad class of applications (including virtual-environment and teleoperator systems in addition to sensory aids).

Research is being conducted in two major areas. Work in *Area 1* (Basic Studies of Human Touch) is designed to increase our knowledge concerning the transmission of information through the sense of touch. This research includes theoretical and experimental studies concerned with dynamic information transfer as well as experimental work designed to increase our understanding of the psychophysical properties of the sense of touch. Work in *Area 2* (Tactual Displays of Speech and Environmental Sounds) is concerned with the application of tactual displays to sensory aids for persons who are profoundly deaf or deaf-blind. This research includes studies related to the processing and display of speech and environmental sounds through the tactual sense as well as studies concerned with evaluations of performance achieved through these displays.

Current Studies

Basic Studies of Human Touch

Measurement of Information-Transfer Rates for Multidimensional Tactual Signals.
Experiments are being conducted to measure information-transfer rate for the identification of sequential streams of multidimensional tactual stimuli. These stimuli are made up of spectral components in the kinesthetic (2 or 4 Hz), mid-frequency (30 Hz), and cutaneous (300 Hz) frequency ranges of the tactual sensory system. Seven waveforms, including three single-frequency stimuli, three two-frequency stimuli, and one three-frequency stimulus, are presented at four different finger locations through a tactual stimulating device (Tan and Rabinowitz, 1996), yielding N = 28 signals. Subjects are trained to identify signals (at each of two durations—250 or 125 msec) presented in sequences of two or three items (using interstimulus intervals in the range 0-640 msec). Information-transfer rate (IT rate) is estimated on the basis of three parameters: the amount of information in the stimulus set (IS= log2 (N)), the identification error rate (e), and stimulus-onset asynchrony (SOA, the sum of signal duration and inter-stimulus interval). Specifically, IT rate=[(IS)x(1-2e)]/SOA. Preliminary results indicate that IT rate improves with training, is subject-dependent, decreases with the number of items in the sequence, and attains peak values in the range of roughly 6-12 bits/sec.

For purposes of comparison with previous experimental results (Tan et al., 1999; Tan et al., *submitted*), subjects were also tested in an AXB paradigm where the task is to identify only the middle signal X in a series of three stimuli. Data from the current study and the previous two studies cited above studies indicate that, under the AXB paradigm, IT rate attains a peak value of roughly 12 bits/sec independent of signal duration or IS. For a fixed value of IS, this result is associated with a decrease in optimal SOA (or conversely, an increase in the optimal delivery rate in items/sec) as signal duration decreases. This result contradicts the generally accepted notion of an optimal delivery rate of roughly 2-3 items/sec independent of IS or duration (see Garner, 1962, p. 91).

Hardware and Software Development for New Control System of Tactual Stimulating Device*.*
During the past year, a new system has been fully implemented for controlling our three-finger tactual stimulating device. A feature of the new system is the separation of stimulus generation (using a new DSP board) and movement control (using an electronic circuit), thus permitting the system to be driven by any arbitrary source. Measurements of the system specifications indicate that they are quite similar to those of the original system in terms of properties such as closed-loop frequency response, noise floor, linearity, harmonic distortion, crosstalk, and human thresholds. The capabilities of the system have also been expanded through the addition of a video capture and display card to allow precise control of timing between visual and tactual displays in proposed studies of multi-modal interactions.

Psychophysical Study of Temporal-Order Discrimination.
An experiment was conducted to measure the temporal-order threshold for stimulation of two digits (left index finger and left thumb) with a 250-Hz and a 50-Hz sinewave, respectively. A one-interval, two-alternative forced-choice procedure with trial-by-trial correct-answer feedback was employed in which the subject's task was to determine in which of the two possible orders the stimuli were presented. The experiment was conducted using trial-by-tral roving of the duration and amplitude of each of the two sinewaves. The value of duration was selected randomly for each stimulus from a uniform distribution of seven values in the range of 50 to 800 msec. The value of amplitude was selected randomly for each stimulus from a distribution of five values of sensation level in the range of 25 to 45 dB SL. Performance was examined as a function of stimulus-onset asynchrony, defined as the onset time of the signal presented at the index finger relative to that at the thumb. Psychometric functions (measured in four subjects) were created in which performance in d' was plotted as a function of |SOA|.Threshold, defined as |SOA| required for d'=1, ranged from roughly 18 to 43 msec across the four subjects. These threshold values are similar in magnitude to those reported previously for temporal-order discrimination of tactile spatial patterns presented at two different fingers (Craig & Baihua, 1990).

Tactual Displays of Speech and Environmental Sounds

Improved Tactual Displays of Consonant Voicing.
Perceptual studies of consonant discrimination have been conducted using a tactual display of consonant voicing derived from objective acoustic measurements of speech productions and based on envelope-onset asynchrony across two different frequency bands of speech. The amplitude envelope of a 3500-Hz highpass band of speech is encoded through a 250-Hz sinewave presented to the index finger and that of a 350-Hz lowpass band is encoded through a 50-Hz sinewave presented to the thumb. Perceptual tests were conducted with four normal-hearing subjects (who wore earplugs and headphones through which masking noise was presented to eliminate the possibility of auditory cues).

The speech-perception testing included tests of the ability to discriminate eight pairs of voiced-voiceless contrasts: /p-b/, /t-d/, /k-g/, /f-v/, /th-tx/, /s-z/, /sh-zh/, and /ch-j/. Speech stimuli were CVC syllables produced by two female speakers in three vowel tokens and included a total of 60 tokens of each initial consonant. Discrimination testing was conducted using a two-interval, two-alternative, forced-choice procedure. Training was provided through the use of trial-by-trial correct-answer feedback. Post-training tests were conducted in the absence of correct-answer feedback. Performance was measured under three conditions: tactual display alone, lipreading alone, and tactual display combined with lipreading. Results indicated that performance through lipreading alone was near chance (i.e., d' of roughly 0) and was equivalent through the tactual display alone and the tactual display combined with lipreading (where d' averaged roughly 2.5). These results indicate excellent ability to discriminate voiced from voiceless consonants through the tactual display employed here.

Testing was also conducted to examined the subjects' ability to identify the consonants in a one-interval, 16-alternative, forced-choice experiment. Training was provided in the form of trial-by-trial correct-answer feedback which was eliminated in post-training tests. Overall performance on the post-training tests averaged roughly 10%-correct for the tactual display alone, 30%-correct for lipreading alone, and 50%-correct for the tactual display combined with lipreading. Transmission of the feature voicing was superior for the conditions employing the tactual cue (roughly 80% reception of the voicing feature compared to 50% for lipreading alone). Thus, the display appears to provide a reliable and robust perceptual cue to voicing at the segmental level.

Survey on Reception of Environmental Sounds: Opinions of Deaf and Hard-of-Hearing Persons.

A pilot survey concerned with determining the interest of deaf and hearing-impaired persons in the reception of various types of environmental sounds has been administered to 20 individuals, five of whom returned for follow-up interviews. The survey consisted of 65 multiple-choice questions in four different areas: communication preferences, history of assistive-device use, interest in various types of environmental stimuli, and preferences regarding the design of devices for displaying acoustic environmental stimuli. The survey results are currently being analyzed and will be used in creating an improved version of the survey for administration to a larger group of subjects.

Publications

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