Tactual Frequency and Amplitude Discrimination with Fixed and Roving Background

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Abstract

The authors present frequency and amplitude discrimination thresholds for motional and vibrational stimuli presented with and without the presence of roving background signals. Participants received on their left index fingertip sinusoidal displacement waveforms over a range of 2-200 Hz in frequency and 20-35 dB sensation level in amplitude. When the target stimulus was presented in isolation, the average Weber fraction for frequency was 0.18–0.25, and the average amplitude discrimination threshold was 2.2–2.5 dB. When roving background signals were presented with the targets and the participants were instructed to ignore the interfering backgrounds, the discrimination thresholds for both frequency and amplitude increased. The amount of increase depended on the nature of the background signals. The results are discussed in terms of their implications for tactual displays of speech in communication aids for the deaf.

1. Introduction

This work was motivated by our desire to use the sense of touch as a substitute speech communication channel for individuals with profound hearing impairment. A multi-finger tactual stimulator capable of delivering displacement waveforms from low-frequency large-amplitude kinesthetic movements to high-frequency small-amplitude cutaneous vibrations has been developed [1]. The device is capable of transmitting information at a relatively high rate of 12 bits/sec [2], roughly the same rate that has been demonstrated by dead-blind individuals who use a manual method called Tadoma to "feel" speech [3]. The present study was concerned with documenting tactual resolution in the frequency-amplitude space for transmitting broad-band modified speech signals through such a device. Although previous studies have documented tactile frequency and amplitude resolution (cf. [4]), few have addressed the effects of background maskers on resolution ability (although see [5]). The present set of experiments provided a systematic measurement of frequency and amplitude discrimination thresholds for sinusoidal displacement waveforms delivered to a fingertip with or without the presence of other masking background signals.

2. Experiment Methods

The experimental apparatus was a three-channel multidimensional tactual display called the Tactuator [1] with a new controller that takes into account human detection thresholds from dc to 300 Hz [6]. The controller preserves the relative magnitudes of spectral components in a broadband input signal in terms of sensation levels (SL; dB above detection threshold).

Four participants (2 males and 2 females; 21-28 years old; average age 24) took part in the present study. Six target frequencies, 2 and 4 Hz in the low-frequency region, 15 and 30 Hz in the mid-frequency region, and 80 and 200 Hz in the high-frequency region (representing frequency bands corresponding to motional, fluttering/rough and vibrational sensations [2]), were selected at two amplitude levels of 20 (A_1) and 35 (A_2) dB SL. The duration of the stimulus was always 250 msec. A Hanning window with a 25-ms rise and fall time was applied to all signals. All stimuli were presented to the left index fingertip.

A three-interval forced-choice paradigm with a one-up three-down adaptive procedure [7,8] was used to measure frequency and amplitude discrimination thresholds for each of the 12 target signals (6 frequencies × 2 amplitudes). The target stimuli were presented either in isolation (fixed background: no-masker) or in the presence of one or two maskers that occurred simultaneously with the target (roving background: single-masker or double-masker). In the single-masker condition, the masker was selected from one of the two frequency regions of which the target was not a member. In the double-masker condition, two maskers were employed (one from each of the two frequency regions of which the target was not a member). The frequency of the masker was selected randomly from 10 equal steps between the two target frequencies for that frequency region (i.e., 2–4 Hz, 15–30 Hz, or 80–200 Hz in the low-, mid- or high-frequency regions, respectively). The masker amplitude for a target presented at 20 or 35 dB SL was randomly selected from 10 logarithmically-scaled levels within 10–20 dB SL or 20–35 dB SL, respectively. The masker frequency and amplitude were randomly selected for each of the three intervals on each trial.

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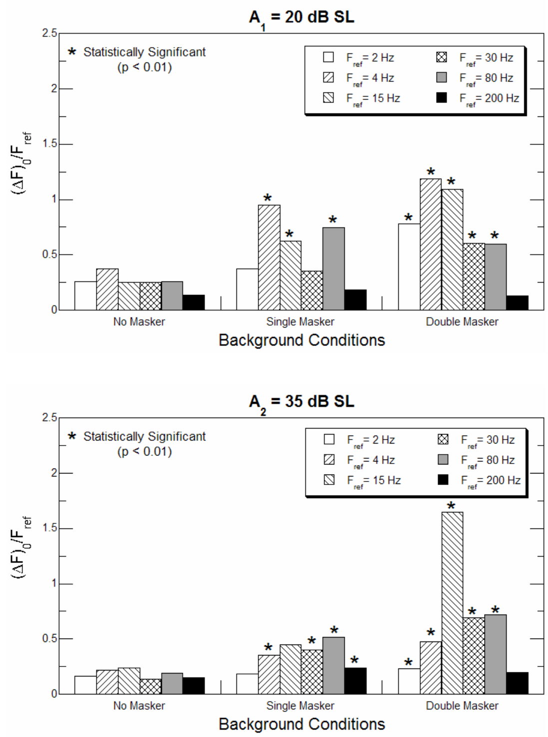

Figure 1. Frequency discrimination results in Weber fractions.

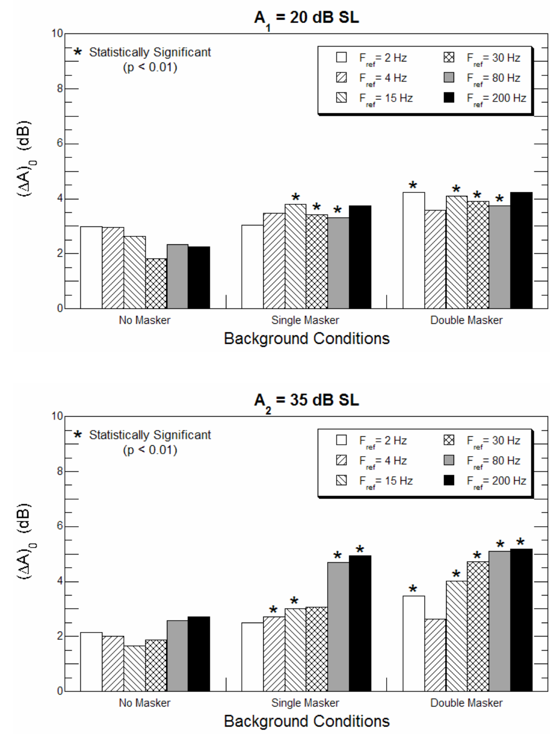

Figure 2. Amplitude discrimination results in $(\Delta A)_0$ in dB.

3. Results

Frequency discrimination. Thresholds are shown in terms of Weber fractions as $(\Delta F)_0/F_{ref}$ (Fig. 1; top panel for A_1 = 20 dB SL, bottom panel for A_2 = 35 dB SL). The asterisks indicate statistically significant differences between the results for roving background masker conditions relative to the corresponding no-masker conditions. For the no-masker condition and at A_1, Weber fractions ranged from 0.13 at 200 Hz to 0.38 at 4 Hz with an average of 0.25. At A_2, Weber fractions ranged from 0.14 at 30 Hz to 0.24 at 15 Hz with an average of 0.18. The Weber fractions increased in the roving background masker conditions, and more so for the double-masker condition. At A_1, the average values increased to 0.54 and 0.73 for the single- and double-masker conditions, respectively. At A_2, the average fractions increased to 0.36 and 0.66, respectively.

Amplitude discrimination. Thresholds are shown in Fig. 2 as $(\Delta A)_0$ in dB. For the no-masker condition and at A_1 = 20 dB SL, the thresholds ranged from 1.8 dB at 30 Hz to 3.0 dB at 2 Hz with an average of 2.5 dB. At A_2 = 35 dB SL, the thresholds ranged from 1.7 dB at 15 Hz to 2.7 dB at 200 Hz with an average of 2.2 dB. Detrimental effects of roving background masking conditions were observed in the amplitude discrimination experiments as well. At both A_1 and A_2, roving effects were again larger in the double-masker condition than in the single-masker condition. The average values of $(\Delta A)_0$ in dB for the single- and double-masker conditions were 3.46 and 3.96 dB at A_1, and 3.49 and 4.19 dB at A_2, respectively.

4. Discussion

Our results obtained in the no-masker conditions for both frequency and amplitude discrimination were similar to those reported previously [4]. In general, lower thresholds were found at the higher amplitude A_2 than at A_1. Thresholds were higher for the double-masker compared to the single-masker conditions. There were differential effects for background maskers, that is, some maskers are more effective than others with a given target signal. For example, low-frequency targets were not significantly affected by high-frequency maskers and vice versa. The results provide quantitative resolution data for designing multi-attribute signals for speech communication through the Tactuator, and suggest the sparing use of more than two frequency components on a single digit. In view of the relative independence of low- and high-frequency signals, they can be used simultaneously to encode separate or redundant speech features to improve information transmission.

Acknowledgments

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