Lateralization by frequency for repeating sequences of dichotic 400- and 800-Hz tones

Diana Deutsch

Center for Human Information Processing, University of California, San Diego, La Jolla, California
(Received 5 January 1977; revised 12 September 1977)

Subjects made lateralization judgments involving dichotic sequences of 250-ms tones, which alternated in frequency between 400 and 800 Hz, such that when one ear received 400 Hz the other ear received 800 Hz, and vice versa. With sequences consisting of 20 dichotic tone pairs there was a strong tendency to lateralize each fused tonal percept toward the ear receiving the 800-Hz signal. In certain subjects the effect also occurred even when the 800-Hz tone was substantially lower in amplitude than the 400-Hz tone, and when it was clearly lesser in loudness. However, with sequences consisting of only two dichotic tone pairs, this lateralization-by-frequency effect was substantially weaker.

PACS numbers: 43.66.Rq

INTRODUCTION

When a pure tone of 400 Hz is presented continuously to one ear, and at the same time a pure tone of 800 Hz is presented continuously to the other ear, and these tones are at equal amplitude, most listeners will perceive both tones and lateralize them correctly. Further, when a short tone of 400 Hz is presented to one ear, and simultaneously a short tone of 800 Hz is presented to the other, and these tones form part of a dichotic sequence consisting, for instance, of simultaneously ascending and descending scales, both tones will again generally be perceived (Deutsch, 1975). However, when these same 400- and 800-Hz tones are repetitively presented in sequence such that when one ear receives 400 Hz the other receives 800 Hz, and vice versa, an unexpected phenomenon emerges. Many listeners perceive a single high tone in one ear alternating with a single low tone in the other ear (Deutsch, 1974a, 1974b). A further study has shown that this phenomenon is based on two factors: The perception of the sequence of frequencies presented to one ear rather than to the other; and the lateralization of each fused tonal percept towards the ear receiving the 800-Hz signal, regardless of which frequency is in fact perceived (Deutsch and Roll, 1976).

This lateralization-by-frequency effect is examined in the present set of experiments. Most studies on the lateralization of dichotically presented pure tones have concerned the case where the same frequency is presented to both ears. Under such conditions, differences in amplitude will produce a lateralization toward the ear receiving the higher-amplitude signal. Now, when the two signals are unlike in frequency, there could be loudness differences between them at equal amplitude, and we could hypothesize that lateralization occurs towards the louder signal. The present study therefore investigated this lateralization-by-frequency effect as a function of amplitude differences between the 400- and 800-Hz tones. A second experiment studied the relationship between amplitude and loudness differences for such tones. Further, informal studies had indicated that this lateralization effect depends upon the repetitive presentation of the alternating tones, and that it is weaker or absent when single pairs of dichotic chords are presented instead. So the studies were performed both with long repetitive sequences and also with single dichotic chord pairs.

I. EXPERIMENT I

Subjects listened to dichotic sequences consisting of 250-ms tones, which alternated in frequency between 400 and 800 Hz such that when one ear received 400 Hz the other ear received 800 Hz, and vice versa. Each sequence consisted of 20 dichotic tone pairs, with no gaps between tones. The amplitude relationships between the 400-Hz tone and the 800-Hz tone varied systematically across sequences, so that a 400-Hz tone at 70 dB SPL was paired equally often with an 800-Hz tone of 70, 73, 76, 79, 82, and 85 dB. Similarly, an 800-Hz tone of 70 dB was paired equally often with a 400-Hz tone at each of these amplitude values. For each level of amplitude relationship, on half of the sequences, the signal in the right ear began with 400 Hz and ended with 800 Hz; and on the other half the signal in the right ear began with 800 Hz and ended with 400 Hz. Subjects were asked to judge for each sequence whether it was of the "right–left–right–left" type, or the "left–right–left–right" type; and from these judgments it was inferred to which frequency the tones were being lateralized. These sequences were presented in random order.

Each subject made 72 judgments per day on four successive days; and so made 288 judgments in all. Sequences were presented in groups of 12, with 10-s pauses between sequences within groups, and 2-min pauses between groups. A warning signal (a 500-ms tone of 2000 Hz at 70 dB) preceded each group of 12 sequences by 15 s. Subjects indicated their judgments by writing "left–right" or "right–left" on paper during each intertrial interval.

Four subjects were selected for the experiment, on the basis of perceiving a single high tone in the right ear alternating with a single low tone in the left ear at least 95% of the time, when 60 such sequences were presented with the 400- and 800-Hz tones at equal amplitude. All subjects were strongly right handed, and they all had normal audiograms. Prior to the experiment, they were given one training session, using se-

 0001-4966/78/6301-0184$00.80

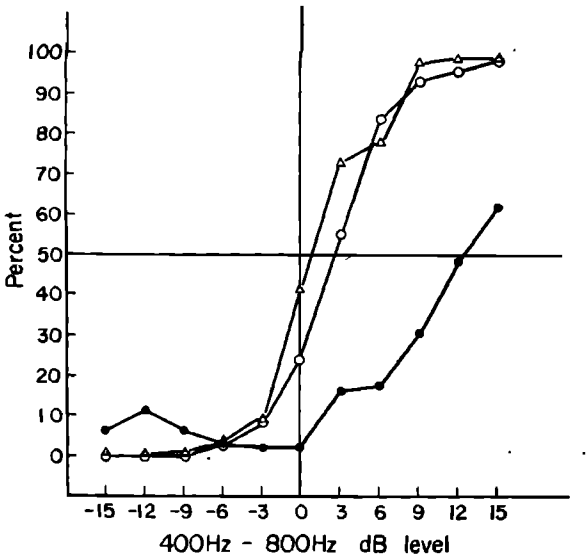

FIG. 1. Results of experiments I, II, and III, averaged over the four subjects. ●, percent lateralization to the 400-Hz tone in sequences of 20 dichotic tone pairs (experiment I). △, percent judgment of the 400-Hz tone as louder than the 800-Hz tone in sequences of 20 dichotic tone pairs (experiment II). ○, percent lateralization to the 400-Hz tone in sequences of two dichotic tone pairs (experiment III).

quences as in the experiment itself. The subjects were paid for their services.

Tones were generated by two Wavetek oscillators (No. 155) controlled by a PDP-8 computer. The output was passed through a Crown amplifier (No. 120) and was presented to subjects in sound-insulated booths through matched headphones (TDH-49). Each oscillator produced the sequence of tones that was presented to one ear (i.e., a tone of 800 Hz at one amplitude level alternating with a tone of 400 Hz at another). The level of the signal did not drop between tones within a sequence (i.e., the frequency changes were not accompanied by transient changes in amplitude).

The results of the experiment, averaged over four subjects, are plotted by the filled circles on Fig. 1. It can be seen that lateralization toward the 800-Hz tone occurred even when it was substantially lower in amplitude than the 400-Hz tone. There were, however, substantial individual differences. Two subjects showed the effect throughout the 15-dB range, one showed the effect up to a 9-dB difference, and the fourth subject showed it only at equal amplitude.

II. EXPERIMENT II

This experiment was undertaken to determine whether the lateralization effect obtained in experiment I could have been due to differences in loudness between the 400- and 800-Hz tones. Thus the same subjects were required to compare the loudness of these tones in sequences identical to those in experiment I, except that now only one channel was presented, and this was simultaneously to both ears. That is, the subjects heard a 400-Hz tone simultaneously in both ears, alternating with an 800-Hz tone simultaneously in both ears. They were required to judge for each sequence which of the two alternating tones was the louder. As before, subjects were given 72 trials per session over four successive days, making 288 judgments in all. The experiment was preceded by a single training session.

The results of this experiment, averaged over the four subjects, are plotted by the triangles on Fig. 1. It can be seen that in all cases loudness judgments mirrored amplitude relationships quite closely. This is in accordance with other studies of equal-loudness judgments in this range (such as those in Stevens and Davis, 1938). It is therefore concluded that the lateralization patterns obtained in experiment I were not due to differences in loudness between the 400- and 800-Hz tones.

III. EXPERIMENT III

The method and stimuli used in this experiment was identical to that in experiment I, except that each trial consisted of two dichotic tone pairs instead of 20. Thus, half of the trials consisted of an 800-Hz tone in the right ear accompanied by a 400-Hz tone in the left, followed by a 400-Hz tone in the right ear accompanied by a 800-Hz tone in the left. On the other half of the trials the order of the two dichotic tone pairs was reversed. Again, all tones were 250 ms in duration. Subjects were required to judge for each pair of dichotic tones whether it was of the "left–right" type or the "right–left" type; and from these judgments it was inferred to which frequency the tones were being lateralized.

The results of the experiment, averaged over all four subjects, are plotted by the open circles on Fig. 1. It can be seen that the tendency to lateralize toward the 800-Hz signal was substantially reduced in comparison with the long sequences; lateralization judgments now mirrored loudness judgments quite closely.

IV. DISCUSSION

The present experiments demonstrate that with long dichotic sequences of alternating tones, using frequencies of 400 and 800 Hz, and with subjects selected on the stated criteria, there is a strong tendency to lateralize a fused tonal percept toward the ear receiving the higher-frequency signal. In certain subjects, this effect is very robust in terms of amplitude differences between these tones.

It was also found that this lateralization effect cannot be explained in terms of differences in loudness between the 400- and 800-Hz tones. As pointed out by Scharf (1974a) various other findings have demonstrated that lateralization can be independent of loudness. Thus loudness summation between two tones is unaffected by whether or not these tones are phenomenally separated in space (Scharf, 1969, 1974a). Further, continuous stimulation of one ear causes a shift away from the stimulated ear in the lateralization of a sound which is later presented simultaneously to both ears (Ward, 1973). However, presenting a tone continuously to one

ear does not produce a shift in its loudness (Wiley, Small, and Lilly, 1973).

Lateralization by frequency effects have also been found by other investigators under different experimental conditions. Békésy (1963) reports that when a long tone of 750 Hz is presented to one ear, and simultaneously a long tone of 800 Hz is presented to the other ear, both tones are perceived and localized correctly. However, if these tones are amplitude modulated (whilst remaining in phase) with a frequency between 5 and 50 Hz, the two images fuse to form a single percept. With such amplitude-modulated stimuli, when the frequency of one tone is held constant at 800 Hz and the frequency of the other tone is set between 750 and 880 Hz, the fused tonal percept is lateralized towards the higher frequency signal. Scharf (1974b) has examined the localization of two simultaneous tones of different frequency which emanate from two spatially separated loudspeakers. The frequency separation between the tones from the two speakers was varied from 0 to 4200 Hz around a geometric mean of 2000 Hz. Tonal durations of 500 ms were employed. Under these conditions, subjects tended strongly to localize fused sounds toward the speaker emitting the lower frequency signal. In another experiment, Efron and Yund (1974) presented subjects with two 50-ms tone bursts separated by 1-s pauses. One ear received a burst of 1500 Hz followed by 1900 Hz, while the other ear simultaneously received 1900 Hz followed by 1500 Hz. Under these conditions they found no tendency to lateralize toward either the higher or the lower frequency unless amplitude differences were introduced. The relationship between these findings and that of the present study remains to be explored. Since there were large differences both in signal characteristics and mode of presentation, direct comparison between the studies is difficult at present. However, it is clear that the phenomenon of lateralization by frequency is a complex one.

ACKNOWLEDGMENT

This research was supported by U.S. Public Health Service Grant MH-21001.

Békésy, G. von (1963). "Three experiments concerned with pitch perception," J. Acoust. Soc. Am. 35, 602–606.

Deutsch, D. (1974a). "An auditory illusion," J. Acoust. Soc. Am. 55, 518–519.

Deutsch, D. (1974b). "An auditory illusion," Nature 251, 307–309.

Deutsch, D. (1975). "Two-channel listening to musical scales," J. Acoust. Soc. Am. 57, 1156–1160.

Deutsch, D., and Roll, P. L. (1976). "Separate 'what' and 'where' decision mechanisms in processing a dichotic tonal sequence," J. Exper. Psychol. Human Percept. Perform. 2, 23–29.

Efron, R., and Yund, E. W. (1974). "Dichotic competition of simultaneous tone bursts of different frequency—I. Dissociation of pitch from lateralization and loudness," Neuropsychologia 12, 249–256.

Scharf, B. (1969). "Dichotic summation of loudness," J. Acoust. Soc. Am. 45, 1193–1205.

Scharf, B. (1974a). "Loudness summation between tones from two loudspeakers," J. Acoust. Soc. Am. 56, 589–593.

Scharf B. (1974b). "Localization of unlike tones from two loudspeakers," in *Sensation and Measurement—Papers in Honor of S. S. Stevens*, edited by H. R. Moskowitz, B. Scharf, and J. C. Stevens (Reidel, Dordrecht), pp. 309–314.

Stevens, S. S., and Davis, H. (1938). *Hearing—Its psychology and physiology* (Wiley, New York).

Ward, W. D. (1973). "Adaptation and fatigue," in *Modern Developments in Audiology*, edited by J. Jerger (Academic, New York), pp. 301–344.

Wiley, T. L., Small, A. M., Jr., and Lilly, D. J. (1973). "Monaural loudness adaptation," J. Acoust. Soc. Am. 53, 1051–1055.