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# Two-channel listening to musical scales*†

Diana Deutsch

*Center for Human Information Processing, University of California at San Diego, La Jolla, California 92037*
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Ss listened to a dichotic tonal sequence consisting of the repetitive presentation of the C major scale with successive tones alternating from ear to ear. The scale was presented simultaneously in both ascending and descending form, such that when a component of the ascending scale was in one ear, a component of the descending scale was in the other, and vice versa. All Ss channeled this sequence by frequency range: no S channeled by ear of input, and none reported a full ascending or descending scale. Various illusory percepts were obtained, which varied in correlation with the handedness of the listener. Right-handers tended to perceive the upper tones of the dichotic sequence as emanating from the right earphone and the lower tones from the left, and to maintain this percept when the earphones were placed in reverse position. Left-handers as a group did not display the same localization tendency.

Subject Classification: 65.22, 65.54, 65.62; 75.20.

## INTRODUCTION

Much has been learned about the way we separate dichotically presented verbal materials into channels (Cherry, 1954; Broadbent, 1958; Deutsch and Deutsch, 1963; Moray, 1969; Treisman, 1969; Mostovsky, 1970; Kornblum, 1973). In contrast, very little is know about the principles of channel formation for dichotically presented musical sequences. Instead, investigators have been concerned with comparing processing efficiency for such materials through the two ears (Kimura, 1964, 1967; Shankweiler, 1966; Curry, 1967; Gordon, 1970; Spellacy, 1970), since this issue is of importance to theories of hemispheric specialization of function (Bogen, 1969). However, the question of how we separate simultaneous streams of musical information into channels is of interest not only to theories of attention, but also to music theory (Erickson, in press), especially with increasing use of computer-generated stimuli (Matthews, 1969) and earphones in musical composition.

The present experiment investigates the principles of channel formation for sequences of tones, where a different sequence is presented to each ear. This experiment grew out of an earlier study involving the repetitive presentation of a simple two-tone sequence (Deutsch, 1974). This study produced unexpected and paradoxical results. A sequence of 250-msec tones, which alternated in pitch between 400 and 800 Hz, was presented simultaneously to both ears, such that when one ear received 400 Hz the other ear received 800 Hz, and vice versa. Virtually no listener perceived this sequence correctly, and various illusory percepts were obtained. The most common illusion was that of a single tone which oscillated from ear to ear and whose pitch also oscillated from one octave to the other in synchrony with the localization shift. Right-handers as a group exhibited a strong tendency to hear the higher of the two tones in the right ear and the lower in the left, and to maintain this percept when the earphones were placed in reverse position. No such tendency was exhibited by left-handers. Further significant differences between right- and left-handers emerged in terms of the type of illusory percept obtained, the left-handers tending more to obtain complex percepts.

In the present study, this paradigm was elaborated so that instead of two alternating tones, an eight-tone scale formed the basis of the repetitive dichotic sequence. Since significant differences between right- and left-handers had emerged in the perception of the octave illusion (Deutsch, 1974), both handedness populations were tested in this study also. The results from these two populations were treated independently, and then statistically compared.

## I. METHOD

### A. Stimuli

The dichotic tonal sequence employed in this experiment is shown in Fig. 1(a). It can be seen that this consisted of the C major scale with suc-

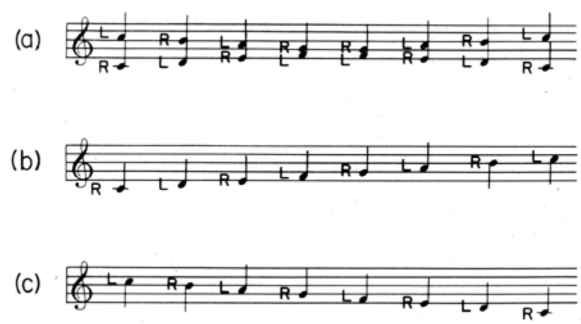


**FIG. 1.** (a) Representation of the dichotic tonal sequence employed in the experiment. This consisted of the C major scale switching from ear to ear, and presented simultaneously in both ascending and descending form. (b) Representation of the ascending component alone. (c) Representation of the descending component alone.

cessive tones alternating from ear to ear. This scale was presented simultaneously in both ascending and descending form, such that when a component of the ascending scale was in one ear, a component of the descending scale was in the other, and vice versa. Figures 1(b) and 1(c) show these ascending and descending scales separately; thus the sequence shown in Fig. 1(a) was simply the superposition of the two sequences shown in Figs. 1(b) and 1(c). The tones were sinusoids, of equal amplitude, and 250 msec in duration, with no gaps between adjacent tones. Each sequence was presented repetitively 10 times without pause. The tones were taken from an equal-tempered scale (International Pitch; A = 435) and the frequencies employed (in hertz) were C = 259, D = 290, E = 326, F = 345, G = 388, A = 435, B = 488, and C = 517.

## B. Procedure

Each S was individually tested. He was told that a repetitive tonal sequence would be presented, following which he was to report verbally what he had heard. He was instructed to attend to each ear individually so as to discover which earphone was emitting the different tones. The S was then played the dichotic sequence and asked for a verbal report. The earphones were next placed in reverse position and the procedure was repeated. (The order of earphone placement was strictly counterbalanced for both right- and left-handed Ss.) Following the verbal report, the dichotic sequence was again presented with instructions to shadow it by singing, while E monitored the tape on separate earphones.

After reporting on the dichotic sequence, the S was presented with 10 continuous repetitions of the ascending scale shown in Fig. 1(b), with instructions to report what he had heard. If he reported a scale switching from ear to ear, he was further asked to specify which ear received the highest tone and which the lowest. This procedure was repeated with earphone positions reversed. (The order of earphone placement was again strictly counterbalanced.) The same procedure was then carried out with 10 repetitions of the descending scale shown in Fig. 1(c).

## C. Subjects

The Ss were 41 right-handed and 29 left-handed students at the University of California at San Diego, and they were paid for their services.

## D. Apparatus

Tones were generated by two Wavetek oscillators controlled by a PDP 8 computer, and they were recorded at equal amplitude on tape. The tape was played to Ss on a high-quality tape recorder at a level of 75 dB SPL.

### *1. Mode of channel formation*

The Ss showed surprising uniformity of their overall mode of channel formation. No S channeled the sequence by ear of input, and none reported a full ascending or descending scale. Instead, the sequence was always channeled by frequency range. That is, all Ss reported the repetitive presentation of a sequence of four tones which first descended and then ascended. Beyond this, Ss were divisible into two categories, here referred to as "both streams" and "single stream."

(a) *Both streams*. These Ss also reported a second stream of lower tones, which repetitively ascended and then descended. The second stream moved in contrary motion to the first (Fig. 2). These Ss therefore perceived all the pitches of the dichotic sequence, but these pitches were separated into two streams on the basis of frequency range.


**FIG. 2.** Percept of the dichotic sequence depicted by an S with absolute pitch. His own written statement, "reverse headphones/ same result (high in right ear)," shows that the upper tones were localized in the right ear and the lower tones in the left, irrespective of the positioning of the earphones. (This drawing was done by the S himself.)

(b) *Single stream*. These Ss only reported one stream of four tones which repetitively descended and then ascended. Little or nothing of the second stream was perceived. All these Ss when asked to shadow the sequence by singing shadowed the upper stream and not the lower.

Table I shows the numbers of right- and left-handed Ss obtaining these two categories of percept. The two handedness populations differed significantly in the relative distributions of their percepts ($\chi^2 = 7.9$, df = 1, $p < 0.01$).

*2. Patterns of apparent localization in right-handers*

(a) *Both streams*. Of the 34 right-handed Ss who reported both streams, 30 obtained a localization illusion, whereby the higher tones all appeared to be localized in one ear and the lower tones in the other. Table II shows the numbers of these Ss obtaining the different localization patterns on the two presentations of the dichotic sequence, with

TABLE I. Numbers of right- and left-handed Ss perceiving both streams and numbers perceiving a single stream.

| Handedness | Streams | |
|---|---|---|
| | Both | Single |
| Right | 34 | 7 |
| Left | 15 | 14 |

TABLE II. Localization patterns for the two streams in Ss perceiving all upper tones in one ear and all lower tones in the other. Figures show numbers of right- or left-handed Ss obtaining a given localization pattern. RR: Upper tones localized in right ear and lower tones in left on both presentations. LL: Upper tones localized in left ear and lower tones in right on both presentations. Both: Upper tones localized in right ear and lower tones in left on one presentation; upper tones localized in left ear and lower tones in right in the other.

| Handedness | Localization | | |
|---|---|---|---|
| | RR | LL | Both |
| Right | 21 | 1 | 8 |
| Left | 2 | 5 | 4 |

earphones placed first one way and then reversed. It can be seen that there was a highly significant tendency to hear the higher tones in the right ear and the lower tones in the left ($p < 0.001$, two tailed, on a binomial test) and also to maintain a given localization pattern when the earphones were placed in reverse position ( $p < 0.02$, two-tailed, on a binomial test). The most common right-handed percept is illustrated in Fig. 2, which reproduces the written report of a S with absolute pitch. His own written statement, "reverse headphones/same result (high in right ear)," shows that the higher tones were localized in the right ear and the lower tones in the left, irrespective of the positioning of the earphones.

Of the remaining Ss, three also localized the higher tones in one ear and the lower tones in the other, with the exception of one pair of tones in each sequence. The last S correctly identified the localizations of all the tones.

(b) *Single stream*. Of the seven right-handed Ss who reported only one stream, four heard the upper components correctly switching from ear to ear; one heard the entire sequence in the right ear, and two reported idiosyncratic localization percepts.

*3. Patterns of apparent localization in left-handers*

(a) *Both streams*. Of the 15 left-handed Ss who reported both streams, 11 localized all the higher tones in one ear and all the lower tones in the other. The numbers of these Ss obtaining the different localization patterns on the two presentations of the dichotic sequence are shown in Table II. It can be seen that the left-handers did not exhibit the same localization tendency as the right-handers. In order to make statistical comparison between the two handedness populations, the localization patterns on each stimulus presentation were compared separately. In both cases a significant difference was obtained ($\chi^2 = 5.2$, df = 1, $p < 0.05$ for the first presentation and $\chi^2 = 7.2$, df = 1; $p < 0.01$ for the second).

Of the four remaining left-handers who reported both streams, two also localized the higher tones in one ear and the lower tones in the other, with the exception of one dichotic pair in each sequence, one reported the two streams as traveling from each ear to the center of the head and back again in opposite directions, and the fourth reported the upper component switching from ear to ear, with the lower component localized in the center of the head.

(b) *Single stream.* Of the 14 left-handed Ss who reported only one stream, three described the upper components correctly switching from ear to ear, three heard the entire sequence in the left ear, and the rest reported a variety of idiosyncratic localization percepts.

*4. Perception of the single ascending and descending scales*

In contrast to performance on the dichotic sequence, very few Ss misreported the single ascending or descending scales [Figs. 1(b) and 1(c)]. These sequences were correctly described by 83% of the right-handers and 86% of the left-handers. No correlations were found between performance on these sequences and performance on the dichotic sequence. Since these scales were also composed of tones switching from ear to ear at a rate of 250 msec, misperception of the dichotic sequence could not have been due to a simple inability to follow the 250-msec switching rate.

## II. DISCUSSION

In following the dichotic sequence, various channeling principles were open to the listener. He could listen to one ear and ignore the other; he could attend selectively either to the ascending or the descending scale; or he could channel the information by frequency range. In the case of linguistic materials it has been shown that channeling may take place along various lines, such as frequency range, loudness (Egan *et al.*, 1954) and semantic category (Gray and Wedderburn, 1960; Yntema and Trask, 1963; Broadbent and Gregory, 1964). However, the evidence shows that ear of input is a powerful mode of channel formation for such materials. Indeed, Moray (1969) concludes, "The most effective dimension so far discovered along which a message may be located for selection is without doubt position in auditory space."

However, this principle does not hold for the present musical sequence. Only two modes of channeling were adopted here, both of them based on frequency range. Listeners either heard all the tones–but as two simultaneous nonoverlapping pitch streams-ascending and descending in contrary motion or they heard only the upper stream and could report little or nothing of the lower.

The principle of channeling musical information by frequency range has been studied in a different context by Miller and Heise (1950), Norman (1967), Bregman and Campbell (1971), and Dowling (1973). These investigators presented sequences of single tones in rapid succession, and found that when alternating tones were drawn from different pitch ranges, the lower and upper sets of tones split perceptually into two channels. This phenomenon has been variously named "rhythmic fission" (Norman, 1967; Dowling, 1967), "stream segregation" (Bregman and Campbell, 1971), and "melodic fission" (Dowling, 1973). Such channeling appears to be responsible for an inability to perceive the temporal order of tones taken from both channels (Bregman and Campbell, 1971) and also for the ability to recognize one tonal sequence when it is interleaved with another drawn from a different frequency range (Dowling, 1973).

Extrapolating from the finding of Miller and Heise (1950) on the trill threshold, the minimum amount of frequency separation necessary to produce channeling by pitch is generally held to be 15%. However, the difference between the limits of the two streams measured here is 12.4%, and one might speculate that, with the present paradigm, channeling by frequency range could occur with even smaller differences defining the two streams.

It is also of interest that no S in this study reported a full ascending or descending scale as a component of the dichotic sequence. That is, all Ss having reached the lowest note of the upper stream returned upward; and those who also reported the lower stream, having reached the highest note of this stream returned downward. This is particularly surprising since the major scale is certainly more familiar to all listeners in our culture than the pattern actually reported. It is possible, however, that although the Ss reported the dichotic sequence as channeled by frequency range, they also noticed that it was composed of the full ascending and descending scales. So in a further experiment to test for this, I presented 15 right-handed Ss with the dichotic sequence, and then with two further sequences, with instructions to report for each whether it had been "hidden" in the dichotic sequence. An example of a hidden figure in vision was demonstrated to ensure that the S understood the task. The first test sequence consisted of the repetitive presentation of the ascending scale switching from ear to ear shown on Fig. 1(b), and so had indeed been hidden in the dichotic sequence. The second consisted of the repetitive presentation of the upper tones of the dichotic sequence, but these were presented entirely to the right ear, and so had not in fact had been hidden. The order of presentation of the two test sequences was strictly counterbalanced. However, all Ss denied having heard the full ascending scale as a component of the dichotic sequence, and all asserted that the second test sequence had indeed been included (though three of the Ss said that it had been localized differently). This further study therefore shows that the principle of channeling by frequency range is so powerful as to mask the perception of a full scale actually present in the dichotic sequence. In Gestalt terminology, the principle of proximity is here so strong as to override the principle of good continuation.

It should not, however, be concluded that channeling by frequency range occurs for all dichotic tonal sequences. In the study of the octave illusion (Deutsch, 1974), a sequence of tones alternating from one octave to the other was dichotically presented so that when one ear received the low tone the other received the high tone, and vice versa. This sequence was most commonly perceived as a single tone which alternated from one octave to the other, and which simultaneously alternated from one ear to the other. If channeling had taken place along the same lines as for the present sequence, listeners would instead have heard a single high tone sounding continuously in one ear, and also (in the majority of cases) a single low tone sounding continuously in the other ear. Yet no listener reported this percept. Thus different tonal patterns can give rise to entirely different channeling principles, even when other stimulus parameters such as timbre and duration are held constant.

The type of percept obtained for this sequence was also found to vary statistically with the handedness population. First, a significantly higher proportion of left- than right-handers perceived only the upper stream of the dichotic sequence, and little or nothing of the lower stream. An analogy may here be drawn with perception of the octave illusion (Deutsch, 1974) where left-handers reported a significantly higher proportion of complex percepts than right-handers. Second, about half of the right-handers in this study obtained a localization illusion, whereby the upper tones of the dichotic sequence were all perceived as emanating from the right earphone and the lower tones from the left. When the earphone positions were reversed, this percept was maintained, with the paradoxical consequence that the earphone which had apparently been emitting the high tones now appeared to be emitting the low tones, and vice versa. Left-handers as a group did not display this localization tendency, and the localization patterns obtained by the two handedness populations differed significantly. Again, an analogy may be drawn with the octave illusion (Deutsch, 1974) where right-handers tended significantly to hear a high tone in their right ear alternating with a low tone in their left ear irrespective of the positioning of the earphones. However, the octave illusion is based in part on the suppression of information fed to one ear; yet with the present illusion both pitch components of the dichotic sequence are simultaneously perceived. It is likely, therefore, that the two illusions are based on different underlying mechanisms.

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† Requests for reprints should be sent to Diana Deutsch, Department of Psychology, University of California at San Diego, P. O. Box 109, La Jolla, CA 92037.

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