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The Octave Illusion and the What–Where Connection

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ABSTRACT

The effects of delivering two sequences of sine wave tones simultaneously, one to each ear, are explored. Where pitch perception is concerned, given certain sequential configurations, the frequencies followed are those presented to one ear rather than to the other; yet given other configurations, following on the basis of frequency proximity or contour occurs instead. The decision as to which following principle is adopted depends on the frequency relationships between the tones as they occur in sequence at the two ears, and this is true even when time intervals of several seconds intervene between successive tones. Where localization is concerned, there is a strong tendency under certain conditions to localize each tone toward the ear receiving the higher-frequency signal, regardless of whether the higher or the lower frequency is perceived.

The experiments show that selection between acoustic stimuli may take place during a stage where these stimuli are fragmented into their separate attributes and that these selection processes can occur according to independent and even contradictory criteria. As a result, given certain configurations, we end up perceiving a stimulus that does not exist. A model is advanced which explains these illusory phenomena and which also explains how we generally manage to arrive at veridical rather than illusory percepts.

INTRODUCTION

This chapter explores the perceptual consequences of delivering two simultaneous streams of sine wave tones, one to each ear. Striking illusions are readily produced by this method. These demonstrate that acoustic stimuli are

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at some stage fragmented into their separate attributes, that selection processes take place during this stage, and that they can occur in parallel according to independent and in some cases even contradictory criteria. Given this stage of perceptual fragmentation, we must assume that an additional mechanism later operates to recombine these attribute values in such a way as to maximize the probability of veridical perception.

THE OCTAVE ILLUSION

When a pure tone of 400 Hz is presented continuously to one ear and simultaneously a pure tone of 800 Hz is presented at equal amplitude to the other ear, most listeners will perceive both tones and localize them correctly. However, when these same 400- and 800-Hz tones are repetitively presented in alternation, such that when one ear receives 400 Hz, the other ear receives 800 Hz, a very strange phenomenon emerges. Almost no one can guess what this simple stimulus is (at least without prolonged listening), and instead a variety of illusory percepts are obtained (Deutsch, 1974). The most common illusion is that of a single tone that switches from ear to ear, and as it switches, its pitch simultaneously shifts back and forth from high to low; that is, the listener hears a single high tone in one ear alternating with a single low tone in the other ear. The stimulus configuration and this percept are illustrated in Fig. 29.1

It was hypothesized that this illusion results from the operation of two different selection mechanisms underlying the pitch and the localization percepts. To provide the perceived sequence of pitches, the frequencies arriving at one ear are attended to, and those arriving at the other ear are suppressed. But to provide the perceived localizations, each tone is localized in the ear that receives the higher-frequency signal, regardless of whether the higher or the lower frequency is perceived. Thus given a listener who follows the frequencies presented to the right ear, when a high tone is delivered to the right ear and a low tone to the left, this listener hears a high tone because this is the tone delivered to his right ear. Further, he localizes the tone in his right ear, because this ear is receiving the higher-frequency signal. But when a high tone is delivered to the left ear and a low tone to the right, the listener now hears a low tone because this is the tone delivered to his right ear; but he localizes the tone in his left ear, because this ear is receiving the higher-frequency signal. So the entire sequence is heard as a high tone to the right alternating with a low tone to the left. However, given a listener who follows the sequence of frequencies delivered to his left ear instead, keeping the localization rule constant, the same sequence is perceived as a high tone to the

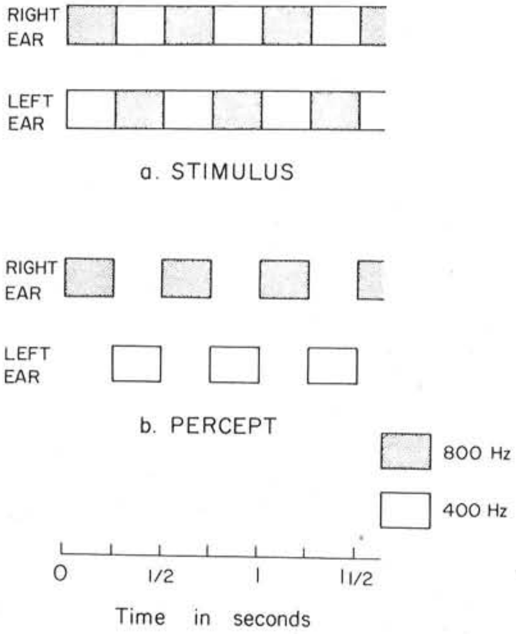

FIG. 29.1. a. Representation of the stimulus pattern used in Deutsch (1974). Filled boxes represent tones of 800 Hz, and unfilled boxes represent tones of 400 Hz. This pattern was repetitively presented for 20 sec without pause. b. Representation of the illusory percept most commonly obtained (adapted from Deutsch, 1974).

left alternating with a low tone to the right (Deutsch, 1975a). This hypothesis was confirmed in a further study (Deutsch & Roll, 1976).

The question then arises as to whether the interactions underlying these localization and frequency suppression effects take place between pathways relaying information from the two ears or whether instead pathways conveying information from different regions of auditory space are involved. To investigate this issue, the configuration was presented to listeners through spatially separated loudspeakers rather than earphones (Deutsch, 1975a). It was found that the illusion was obtained under these conditions also, even though both sequences were now presented to both ears, with only localization cues to distinguish them. This shows that the octave illusion must have a very complex basis. In order for it to occur with speakers, the listener must first identify, for each simultaneous tone pair, which speaker is emitting the high tone and which, the low. These correct assignments having been made, the information must then travel along pathways that are specific to region in auditory space, and the interactions described above must occur between such second-order pathways so as to produce the illusory percepts. The mechanism responsible for pitch perception chooses to follow the frequencies that are presented to one side of auditory space rather than to the other; that is, the decision as to *what* is heard is determined by *where* the signals are coming from. Yet the localization mechanism chooses instead to follow the higher-frequency signal; that is, the decision as to *where* the stimulus is located is determined by *what* the signal frequencies are.

(For the sake of simplicity we shall refer to the following of the signal presented to one ear rather than to the other as 'ear dominance'. However, the reader should bear in mind that the pathways responsible for this effect are specific to position in auditory space, and not simply to ear of input, and we shall return to this point later).

THE SCALE ILLUSION

In the sequence giving rise to the octave illusion, each ear always received a frequency that was identical to the frequency just received by the opposite ear. Under these conditions the frequencies perceived were those presented to one ear rather than to the other. However, using a different dichotic tonal sequence, Deutsch (1975b) found no ear dominance. Listeners were presented with a major scale, with successive tones alternating from ear to ear. This scale was played simultaneously in both ascending and descending form, such that when a component of the ascending scale was in the right ear, a component of the descending scale was in the left ear and vice versa. The majority of listeners perceived the correct sequence of frequencies, but as two separate melodies; one corresponding to the higher sequence of tones, and the other to the lower sequence. Other listeners perceived instead only a single melody, which corresponded to the higher sequence of tones, and they heard little or nothing of the lower sequence. This illusion is described in detail elsewhere (Deutsch, 1975a, 1975b). However, it should here be noted that, in sharp contrast to the results with the octave sequence, no ear dominance was produced here; instead, following always occurred on the basis of frequency proximity (Bregman, 1978; Dowling, 1973). When only one melody was heard, this corresponded to the higher frequencies and not the lower, regardless of ear of input. Moreover for most listeners, both members of each simultaneous tone pair were perceived and neither was suppressed. This experiment therefore demonstrates that ear dominance cannot be regarded simply in terms of simultaneous interactions but depends on sequential relationships also. A series of experiments was performed to obtain a better understanding of the sequential conditions for producing this effect.

PARAMETRIC STUDIES OF EAR DOMINANCE

Apparatus

Tones were generated as sine waves by two Wavetek function generators (Model No. 155) controlled by a PDP-8 computer. The output was passed through a Crown amplifier and presented to subjects in sound-insulated booths through matched headphones (Grason-Stadler Model No. TDH-49).

Experiment 1

This experiment was designed to test the hypothesis that ear dominance occurs in sequences where the two ears receive the same frequencies in succession, but not otherwise. The experiment employed two conditions. In each condition subjects were presented with sequences consisting of 20 dichotic chords, each 250 msec in duration, with no gaps between them.

The experiment employed the two basic patterns shown in Fig. 29.2. The basic pattern in Condition 1 consisted of the repetitive presentation of a single chord, whose components stood in octave relation and alternated from ear to ear such that when the high tone was in the right ear, the low tone was in the left ear and vice versa. It can be seen that here the two ears did indeed receive the same frequencies in succession. On half the trials the sequence presented

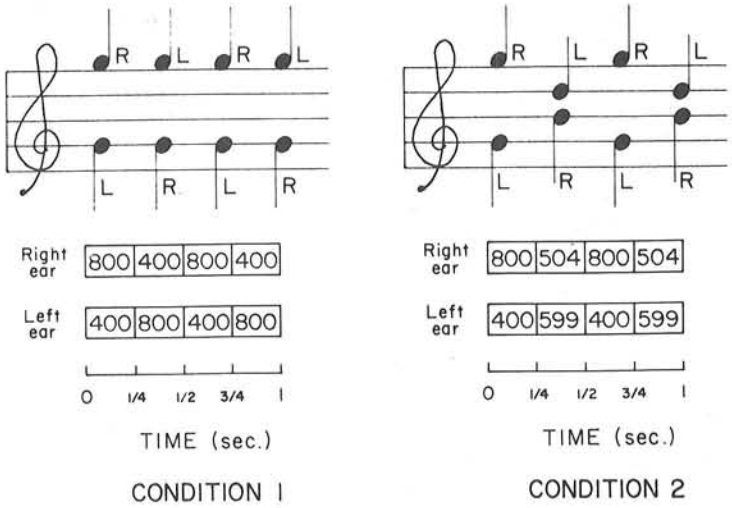

FIG. 29.2. Examples of stimulus configurations used in the two conditions of Experiment 1. Numbers in boxes indicate tonal frequencies. Musical notation is approximate.

to the right ear began with the low tone and ended with the high tone; on the other half this order was reversed. Subjects judged for each sequence whether it began with the high tone and ended with the low tone or whether it began with the low tone and ended with the high tone, and from these judgments it was inferred which ear was being followed for pitch.

The basic pattern in Condition 2 consisted of the repetitive presentation of two dichotic chords in alternation, the first forming an octave and the second a minor third, so that the entire four-tone combination constituted a major triad. It can be seen that here the two ears did not receive the same frequencies in succession. On half the trials the right ear received the upper component of the first chord and the lower component of the last chord; and on the other half this order was reversed.

To evaluate the strength of ear dominance under these two conditions, the amplitude relationships between the tones at the two ears were systematically varied, and the extent to which each ear was followed was plotted as a function of these amplitude relationships. The results, averaged over four subjects, are shown in Fig. 29.3. It can be seen that in Condition 1 the frequencies presented to the dominant ear were followed until a critical level of amplitude relationship was reached, and the nondominant ear was followed beyond this level. So a clear following on the basis of ear of input occurred, and clear ear dominance was obtained. But no such following occurred in Condition 2. Not only was there no ear dominance, but a simple

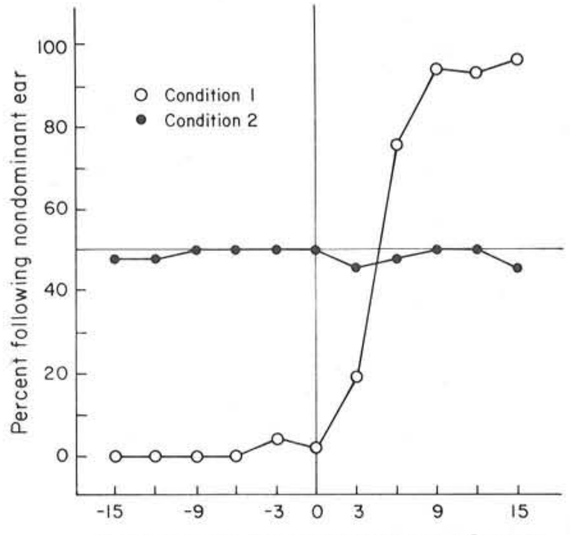

FIG. 29.3. Percent following of nondominant ear in Experiment 1 as a function of amplitude differences at the two ears. ○ Condition 1, and ● Condition 2.

following on the basis of amplitude did not occur either. However, hypothesizing that the subjects were following this sequence on the basis of frequency proximity (Bregman, 1978; Dowling, 1973), a very consistent pattern emerged. All subjects showed consistent following of either the higher frequencies or the lower frequencies, regardless of ear of input or of relative amplitude. Three subjects consistently followed the lower frequencies, and one consistently followed the higher frequencies.

This experiment therefore provides strong evidence that ear dominance occurs in sequences where the two ears receive the same frequencies in succession, but not otherwise.

Experiment 2

This experiment was performed as a further test of the hypothesis. Two conditions were again employed. Here all sequences consisted of two dichotic chords. As shown in Fig. 29.4, the basic pattern in Condition 1 consisted of two presentations of the identical chord, whose components formed an octave, such that one ear received first the high tone and then the low tone, while simultaneously the other ear received first the low tone and then the high tone. The basic pattern in Condition 2 consisted of two chords, each of which formed an octave but which were composed of different frequencies. The combinations shown in Fig. 29.4 were presented in strict alternation.

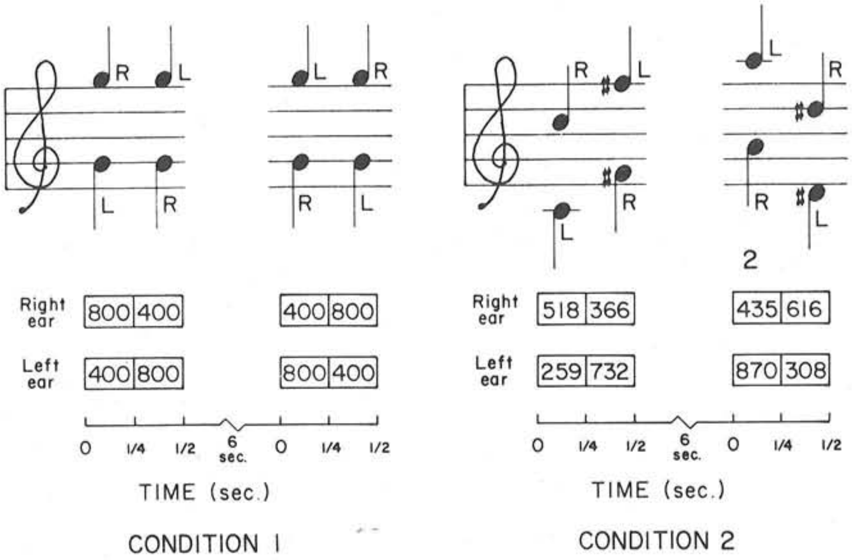

FIG. 29.4. Examples of stimulus configurations used in the two conditions of Experiment 2. Numbers in boxes indicate tonal frequencies. Musical notation is approximate.

Thus any given frequency combination was repeated only after a substantial time period during which several other frequency combinations were interpolated.

The results of this experiment, averaged over four subjects, are shown in Fig. 29.5. It can be seen that, as expected, clear ear dominance occurred in Condition 1. But there was again a total absence of ear dominance in Condition 2. And, just as in Experiment 1, following by amplitude did not occur either. Assuming, however, that the subjects were responding in this condition on the basis of overall contour, a very consistent result was obtained. Patterns of response always indicated an ascending sequence when the second chord was higher than the first and a descending sequence when the second chord was lower than the first. This always occurred even in the face of substantial amplitude differences between the tones at the two ears.

These two experiments show, therefore, that ear dominance effects occur when the two ears receive the same frequency in succession (or, rather, when the same frequency emanates successively from two different regions of auditory space). When this condition was not fulfilled, following occurred on other lines. We can therefore suggest that ear dominance effects are based on forward inhibitory interactions between elements underlying the same frequency but different spatial locations.

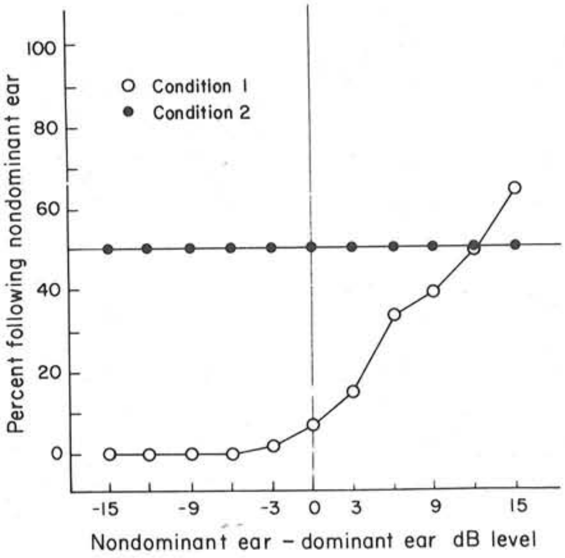

FIG. 29.5. Percent following of nondominant ear in Experiment 2 as a function of amplitude differences at the two ears: ° Condition 1 and • Condition 2.

Experiment 3

We now turn to the question of whether the absence of ear dominance found in the second conditions of Experiments 1 and 2 was due simply to the delay between successive presentations of the same frequencies at the two ears or whether this was due to the interpolation of tones of different frequencies or whether both these factors were involved. Experiment 3 explored the effect on ear dominance of interpolating a single tone of different frequency between two dichotic chords of identical frequencies, holding the delay between these chords constant.

The experiment employed the two conditions shown in Fig. 29.6. It can be seen that these conditions were identical except that in Condition 2 a single tone was interpolated during the interval between the dichotic chords. This tone was presented simultaneously to both ears.

The results of the experiment, averaged over four subjects, are shown in Fig. 29.7. It can be seen that a single interpolated tone did indeed reduce the size of the ear dominance effect. This reduction was highly consistent in three of the subjects, and the fourth showed only a small effect in this direction.

Experiment 4

This experiment was performed to evaluate the behavior of ear dominance as a function of time delay between onsets and offsets of successive chords of identical frequencies. Informal studies had indicated that the effect was

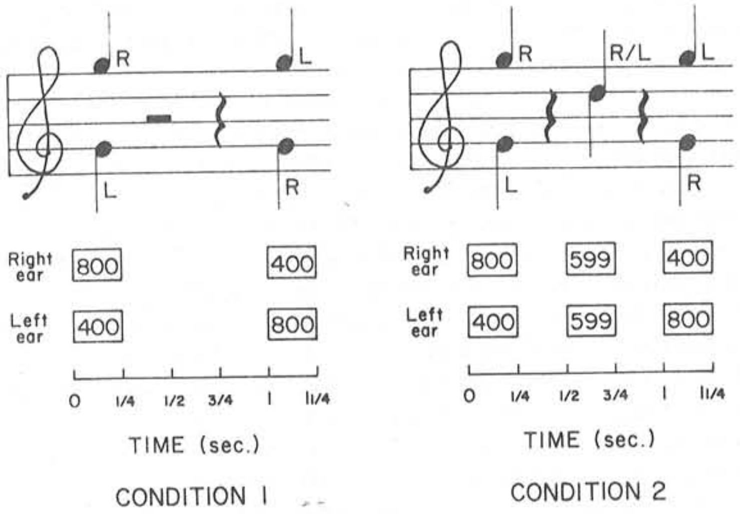

FIG. 29.6. Examples of stimulus configurations used in the two conditions of Experiment 3. Numbers in boxes indicate tonal frequencies. Musical notation is approximate.

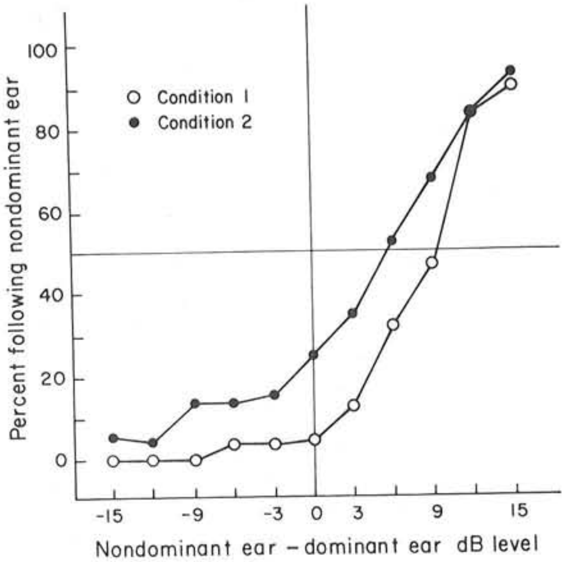

FIG. 29.7. Percent following of nondominant ear in Experiment 3 as a function of amplitude differences at the two ears: ° Condition 1 and ● Condition 2.

strongest when such chords were presented in rapid repetitive sequence and that it was attenuated when a delay was incorporated between successive chords. A further question explored was whether the critical factor here was the delay between the offset of one chord and the onset on the next or whether it was the delay between successive onsets.

In all conditions of the experiment, tones of 400 and 800 Hz were presented in alternation, such that when the right ear received 400 Hz the left ear received 800 Hz and vice versa. Four conditions were compared; in each of these, sequences were separated by a 10-sec intertrial interval. The basic sequence in Condition 1 consisted of 20 dichotic chords, each 250 msec in duration, with no gaps between them. Condition 2 was identical to Condition 1, except that only two chords were presented on each trial. Condition 3 was identical to Condition 2, except that a gap of 2¾ sec was interpolated between these two chords. Condition 4 was identical to Condition 3, except that both chords were 3 sec in duration, and there were no gaps between these chords. So in Conditions 3 and 4 the delays between onsets of successive chords were identical, although these chords differed considerably in duration.

The strengths of ear dominance under these different conditions are shown in Fig. 29.8. A highly significant effect of conditions was found $[F(3, 9) = 11.59, p < .01]$. It can be seen that the strongest effect did indeed occur in Condition 1, where 20 chords were presented in rapid repetitive sequence

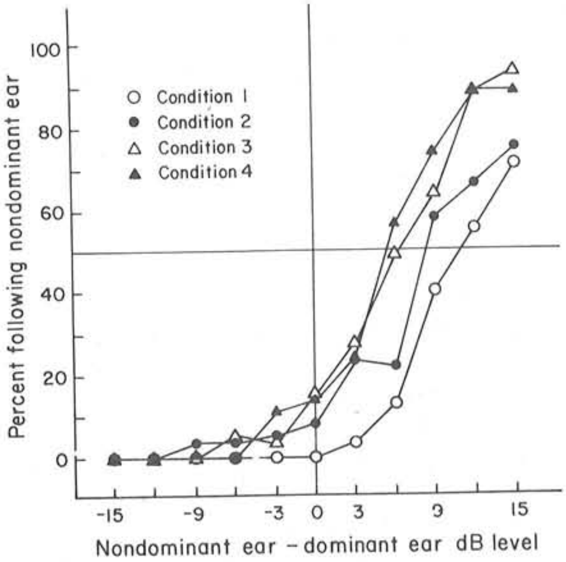

FIG. 29.8. Percent following of nondominant ear in Experiment 4 as a function of amplitude differences at the two ears.

before the 10-sec intertrial interval. The next strongest effect occurred in Condition 2, where two dichotic chords were presented in rapid sequence, but successive pairs of chords were separated by intervals of 10-sec duration (i.e., the intertrial interval). The weakest effects occurred in Conditions 3 and 4 where, in addition to the intertrial interval, 3-sec delays intervened between onsets of the two dichotic chords within each trial.

It is of particular interest to note that the strengths of effect in Conditions 3 and 4 were closely matched, even though chords of very different durations were employed. It will be recalled that the delays between onsets of the two chords in these conditions were identical. So it seems that the strength of inhibitory interaction underlying ear dominance is determined by the time interval between onsets of the successive tones. The durations of the tones themselves do not appear of importance and neither does the time interval between the offset of one tone and the onset of its successor.

Discussion

Given this set of experiments, we can propose that the mechanism underlying ear dominance has the following characteristics. First, elements underlying the same frequency but which convey information from different regions of auditory space are linked in mutual inhibitory interaction. From Experiment 4 we conclude that the inhibition exerted by one element on another acts over relatively long time periods, that is, over periods characteristic of short-term memory. We can also conclude that the inhibition exerted by one element on another cumulates with repetitive stimulation and cumulates more rapidly as repetition rate increases. The duration of the stimulus itself appears of little importance in determining the amount of such inhibition. And from Experiments 1, 2, and 3 we also conclude that disinhibition occurs when elements responding to different frequencies are activated.

We may next ask why such a system should have developed, that is, what the usefulness of such a system might be. One possibility is that this mechanism enables us to follow new, ongoing information with a minimum of interference from echoes or reverberation. In normal listening situations, when the same frequency emanates successively from two different regions of auditory space, the second occurrence may well be due to an echo. This is made more probable as the delay between these two occurrences is shortened. But if other frequencies are interpolated between two such occurrences of the same frequency, an explanation in terms of echoing is rendered less likely. If this interpretation is correct, then the present phenomenon falls into the class of mechanisms (such as those underlying the precedence effect) that operate to counteract misleading effects of echoes and reverberation (Haas, 1951; Wallach, Newman, & Rosenzweig, 1949).

LOCALIZATION BY FREQUENCY

The last section was concerned with only one component of the octave illusion, that is, the mechanism that determines what pattern of frequencies is followed. But it will be recalled that patterns of localization obey a different rule: Each tone is localized in the ear that receives the higher-frequency signal, regardless of whether the higher or the lower frequency is perceived.

This effect has also been studied as a function of amplitude relationships between simultaneous tones (Deutsch, 1978). In this case, the amplitude of the high tone was varied relative to the low tone in each sequence. It was found that with long repetitive sequences a localization toward the higher-frequency signal occurred even when the lower frequency was substantially higher in amplitude. But with short sequences consisting of only two dichotic chords, localization patterns followed patterns of relative loudness closely. This localization by frequency effect was also found to be very robust in terms of onset and offset disparities between the high and low tones, when long repetitive sequences were used. Varying the onset of the low tone relative to the high tone by 5 msec in either direction did not affect the localization toward the higher-frequency signal (Deutsch, in press).

A PROPOSED WHAT-WHERE CONNECTION

We have discussed in some detail the mechanism determining *what* frequencies we hear under these conditions and also rather briefly the mechanism determining *where* the sounds appear to be coming from. We have seen that these *what* and *where* mechanisms operate at some stage so independently that we can end up perceiving a stimulus that does not exist, that is, with its pitch taken from one source and its location from another. This brings us to the very thorny question of how the *what* and *where* information gets put back together once it has been pulled apart so as to produce an integrated percept. We do not perceive a disembodied location, together with a pitch floating in a void; rather we perceive a pitch *at* a location. If we were concerned only with explaining the illusion at this point, we could simply assume that the outputs of the *what* and *where* decision mechanisms become linked together. But unfortunately this simple solution will not work. In normal listening we are presented with sounds from several sources, and we do generally manage to recombine the different attribute values so as to arrive at a correct set of simultaneous auditory descriptions. This would not be possible if the *what* and *where* mechanisms each simply produced a set of outputs, because we would not know which output from the *what* mechanism to link with which output from the *where* mechanism.

The following solution is here proposed. As shown in Fig. 29.9, we may hypothesize two equivalent arrays. In each of these arrays individual elements are sensitive both to a specific value of frequency and also to a specific value of spatial location; that is, they are sensitive to a specific conjunction of attribute values. [Evidence for such elements has been obtained at various levels in the auditory system: for instance, by Goldberg and Brown (1967) and Moushegian, Rupert, and Langford (1967) at the superior olivary complex; by Rose, Gross, Geisler, and Hind (1966) and Geisler, Rhode, and Hazelton (1969) at the inferior colliculus; and by Brugge, Dubrovsky, Aitkin, and Anderson (1969) at the auditory cortex.] We assume that these two arrays are identical in organization as far as input is concerned; however the output of one array signals pitch and the output of the other array signals localization. We may further assume that, depending on the precise stimulus parameters (including very importantly the sequential setting), specific patterns of interaction take place within these arrays. These patterns were presumably evolved to take care of specific stimulus conditions, and in normal listening they probably function to counteract misleading effects in the environment.

What we have depicted on these arrays are the projections resulting from a high tone to the left and a low tone to the right. In this case let us assume that there are no inhibitory interactions within these arrays, and the two stimuli

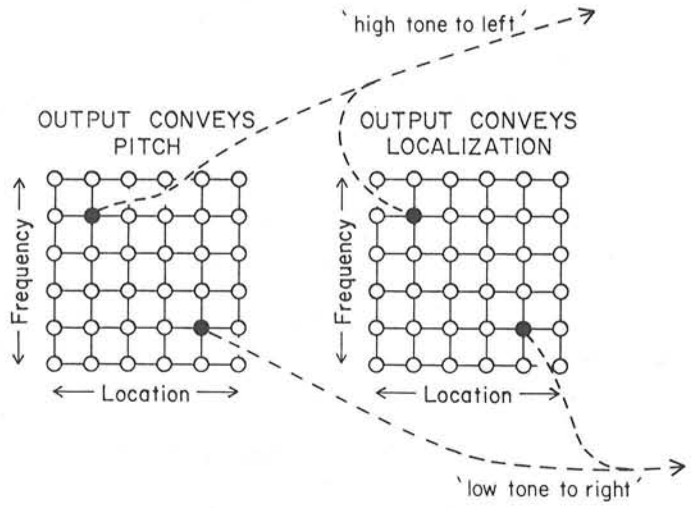

FIG. 29.9. Hypothesized arrays mediating selection of pitch and localization values. This figure displays outputs and their linkages where two simultaneous tones are veridically perceived. See text for details.

are veridically perceived. This would be the case, for instance, when steady tones of long duration are present. We can explain this outcome by assuming that there is a linkage together between the outputs of those activated elements that are in analogous positions on these two arrays. If there are no outputs from elements in strictly analogous positions, we can assume that outputs from elements in the most proximal positions are linked together.

In Fig. 29.10 we have the situation in the alternating octave sequence, where interactions within the array that conveys pitch results in the signaling only of a low tone, and interactions within the array that conveys localization results in the signaling only of a localization to source of the higher frequency. There is therefore only one output from the pitch array and only one output from the localization array. Because there are no outputs from elements situated in more proximal positions along these two arrays, these two outputs are linked together. As a result we hear a low tone to the left, which was not in fact presented. And so the octave illusion results.

DISCUSSION

Another powerful demonstration of the influence of spatial information in determining what frequencies are followed has been provided by Kubovy, Cutting, and McGuire (1974). They presented a set of simultaneous and continuous sine wave tones to both ears and phase-shifted one of these relative to its counterpart in the opposite ear. The phase-shifted tone thus

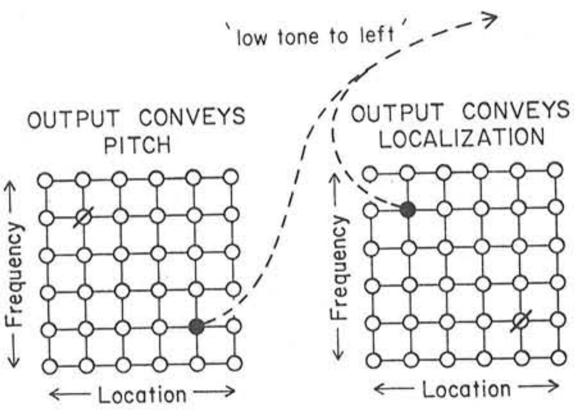

FIG. 29.10. Hypothesized arrays mediating selection of pitch and localization values. It is assumed that the same two tones are presented as in Fig. 29.9 but under sequential conditions giving rise to the octave illusion. This figure displays outputs and their linkages under these conditions. ϕ indicates inhibited elements. See text for details.

appeared to occupy a different position in space. When these tones were shifted in sequence, a melody was clearly heard whose components corresponded to the shifted tones. However this melody was undetectable when heard with either ear alone (Kubovy, in press; Kubovy & Howard, 1976).

Other studies have provided evidence for dissociations between the mechanisms processing *what* and *where* information in both the auditory and the visual systems. Poljak (1926) hypothesized on neuroanatomical grounds that the early stages of the auditory pathway involve a ventral route, subserving localization and orientation functions, and a dorsal route, subserving discriminatory functions. Recently Evans and his colleagues have provided neurophysiological support for this hypothesis (Evans, 1974). For the visual system, Schneider (1967) found that ablation of the visual cortex in hamsters produced an inability to discriminate visual patterns, while producing little decrement in the ability to localize objects in space. Yet when the superior colliculus was ablated instead, there resulted a complete inability to orient to a visual stimulus, while pattern discrimination remained excellent.

At the behavioral level, several studies have shown dissociations between *what* and *where* mechanisms in audition. Odenthal (1963) presented subjects with a dichotic chord that was followed after a silent period by a comparison tone. When the frequency difference between the components of the dichotic chord was very small, subjects heard a single pitch, which Odenthal termed an *intertone*. It was found that the pitch of this intertone did not change with changes in the relative amplitudes of the components of chord; however these changes produced a lateralization of the intertone toward the ear receiving the higher-amplitude signal.

Efron and Yund (1974) also obtained a dissociation using the following paradigm. Subjects were presented with a pair of dichotic chords, which were separated by an interval of 1-sec duration. For each dichotic chord pair, one ear received first the high tone and then the low, while simultaneously the other ear received first the low tone and then the high. It was found that a large proportion of the subjects tended to follow predominantly the pattern of frequencies presented to one ear rather than to the other. Yet when the simultaneous tones were at equal amplitude, the fused sound was heard as in the center of the head. As in Odenthal's experiment, changing the relative amplitude of the components of the dichotic chord resulted in a localization to the ear receiving the higher-amplitude signal though the pitch of the sound often remained constant within a wide range of amplitude variation.

Similar dissociations have been found using more complex stimuli. Carlson, Fant, and Grandstrom (1975) presented different formants from a synthetic vowel sound to different ears. They found that varying the relative formant amplitudes produced little effect on the perception of vowel quality, while producing a strong effect on lateralization.

For the visual system, what–where dissociations may be obtained by simultaneous manipulation of depth and pattern perception. An elegant demonstration of this nature is provided in Kaufman (1974).

Various theorists have been concerned with the general question of how attribute values, once pulled apart, are recombined so as to produce a correct set of simultaneous percepts. For instance, assuming that the processing mechanisms for color and form are at some stage separate, how is it that when presented with a red circle and a green square we see the circle as red and the square as green? Attneave (1974) has suggested that such correct conjunctions are achieved by the tagging of attribute values to placemarkers (i.e., "that *where* is the glue that holds quite different *what*-properties together. [p. 109]). Triesman, Sykes, and Gelade (1977) independently reached a similar conclusion. They further suggested that we process serially stimuli in different spatial locations, so that integration of a single perceptual object is achieved by linking together those attribute values that are identified during any one temporal interval. The mechanism proposed here for the integration of pitch and localization values to form simultaneous unitary percepts bears some similarity to these proposals for the case of vision, because it assumes that both the pitch and the localization mechanisms are composed of elements that are tagged to specific spatial locations.

CONCLUSION

In our natural environment, we are constantly presented with simultaneous streams of sound that emanate from different positions in space. These sounds are superimposed on each other before they reach our ears, and in analyzing them we are confronted with two basic tasks. First, we must decide *what* sequences of sounds are being emitted, and, second, we must decide *where* each sound is coming from.

This chapter has been concerned with the mechanisms whereby such multiple auditory descriptions are arrived at. We have been concerned only with the case where two streams of sine wave tones are presented, one to each ear, and have not even considered how we manage to reconstruct simultaneously presented complex waveforms. Yet although very simple stimulus parameters have been used, we have seen that, in most of the stimulus situations explored, the percepts that emerge are typically wildly wrong. However, the ways in which they go wrong have provided some insights into the mechanisms that our auditory system employs as it generally arrives at the right conclusions. It is clear that these mechanisms are very complex; but this is hardly surprising, for we are dealing with a very complex auditory environment.

ACKNOWLEDGMENTS

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