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Reply to "Reconsidering evidence for the suppression model of the octave illusion," by C. D. Chambers, J. B. Mattingley, and S. A. Moss

DIANA DEUTSCH
University of California, San Diego,
La Jolla, California

Chambers, Mattingley, and Moss (2004) present a review of research and theory concerning the octave illusion, a phenomenon that was originally reported by Deutsch (1974). The authors argue against the two-channel model proposed by Deutsch (1975a) to explain the illusory percept that was most commonly obtained and propose, instead, that the illusion results from binaural fusion and diplacusis. This article replies to the arguments raised by Chambers et al. (2004) and argues that the octave illusion and the two-channel model proposed to explain it are in accordance with growing evidence for what–where *dissociations in the auditory system and for illusory conjunctions in hearing.*

Chambers, Mattingley, and Moss (2004) review research and theory concerning the octave illusion, a phenomenon that was originally reported by Deutsch (1974) and that is characterized by substantial individual differences in perception. The authors argue against a model proposed by Deutsch (1975a) to explain the illusory percept most commonly obtained. This model, hereafter referred to as the *two-channel model*, assumes that the illusion results from a dissociation between *what* and *where* pathways in the auditory system. Chambers et al. (2004) propose, instead, that the octave illusion results from a combination of binaural fusion and diplacusis.

This article replies to the main arguments raised by Chambers et al. (2004). First, their discussion of the related literature makes inappropriate comparisons with other phenomena of sound perception and fails to consider several key findings that support the two-channel model. Second, their methodological criticisms of experiments that support the two-channel model are based on misinterpretations of the experimental designs that were employed. Third, recent findings they cite from their laboratory were based on procedures that raise problems. Fourth, the fusion–diplacusis explanation for the octave illusion is inconsistent with the available evidence. Finally, the two-channel model is in accordance with the growing evidence for *what–where* dissociations in the auditory system and for illusory conjunctions in hearing.

The pattern that was originally employed to produce the octave illusion is illustrated in Figure 1. Two tones, at 400 and 800 Hz, were repeatedly presented in alternation. The tones were delivered to both ears simultaneously; however, when the right ear received 400 Hz the left ear received 800 Hz, and vice versa. The tones were 250-msec sine waves and were presented at equal amplitude, with no amplitude drops at the transitions between tones. Eighty-six naive subjects were presented with this pattern, and they reported what they heard.

Substantial individual differences were found in the way this pattern was perceived, so the percepts were divided into three categories. The first type, termed *octave*, was obtained by the majority of the subjects and consisted of a single tone that alternated between ears, whose pitch also alternated between one octave and the other (so that a high tone was heard in one ear, alternating with a low tone in the other ear). For most of the subjects, the perceived locations of the high and low tones remained fixed when the earphone positions were reversed. The second type, termed *single pitch*, consisted of a single tone that alternated between ears, whose pitch either remained constant or shifted only slightly with a change in the perceived location of the tone. The third type, termed *complex*, consisted of a mixed group of complex percepts, which often involved three different pitches and tended to change with continued listening.

The two-channel model, which was proposed to explain the *octave* category of percept, is illustrated in Figure 2. The model assumes that this percept results from a dissociation between *what* and *where* pathways in the auditory system. To produce the perceived pitches, the frequencies arriving at one ear are followed, while those arriving at the other ear are suppressed from perception. But to produce the perceived locations, each tone is lateralized toward the ear that receives the higher frequency, regardless of whether the perceived pitch corresponds to the higher frequency or the lower one. So taking a listener who perceives the pitches that are delivered to the right ear, the percept of a low tone in the left ear results from an illusory conjunction of features of pitch and location (see also Deutsch, 1981).

Pitch Differences in the Octave Illusion

In the Deutsch (1974) study, most of the subjects perceived an octave difference between the alternating tones, a finding that was also obtained by Zwicker (1984). These findings were substantiated in a recent experiment by Deutsch (2004). Twelve naive and musically trained subjects were presented with the pattern. They were furnished with the note name of the low tone in the pattern and used relative pitch to identify the remaining pitches they perceived. The subjects wrote down in musical notation the patterns of tones they perceived and also wrote down the perceived locations of the tones. They were given the opportunity to confirm their percepts by matching the tones they perceived in the pattern with tones they played on a

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Correspondence concerning this article should be addressed to D. Deutsch, Department of Psychology, University of California, San Diego, La Jolla, CA 92093 (e-mail: ddeutsch@ucsd.edu).

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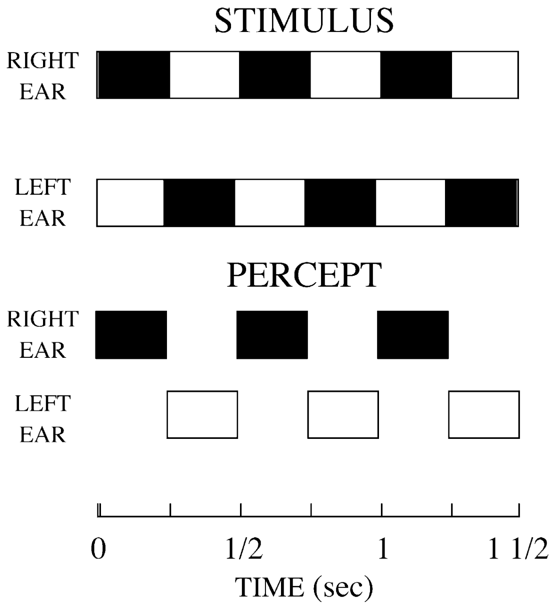

Figure 1. The pattern originally employed by Deutsch (1974) to produce the octave illusion and the percept most commonly obtained. The pattern was repeatedly presented without pause. Filled boxes represent tones at 800 Hz, and unfilled boxes tones at 400 Hz. From "An Auditory Illusion," by D. Deutsch, 1974, *Nature*, *251*, p. 307. Copyright 1974 by Macmillan Publishers Ltd. Adapted with permission.

synthesizer keyboard. Two further patterns served as controls: The first consisted of the high tone alternating between ears, and the second consisted of the low tone alternating between ears. After making judgments on the octave illusion, the subjects listened to each of these control patterns and notated what they heard, using the same matching procedure to confirm their percepts.

The notations of 3 of the subjects are shown in Figure 3. As can be seen, when presented with the octave illusion, all 3 subjects notated tones that were spaced an octave apart and alternated from ear to ear. However, when presented with the control patterns, they correctly notated the same tone alternating from ear to ear. Altogether, the notations of the octave illusion pattern by 7 subjects corresponded to the standard *octave* percept described by Deutsch (1974). The notations of 4 subjects reflected *complex* percepts, such as those described by Deutsch (1974), all of which also involved an octave difference between the tones. One subject notated a single pitch alternating from ear to ear, so that her percept fell into the *single pitch* category described by Deutsch (1974). All the subjects except 1 notated the control patterns as a single pitch alternating between ears, and the remaining subject notated a semitone difference between the pitches at the two ears.[1] The findings from this experiment, in which explicit judgments were made using musical notation, and which also involved a matching procedure, are in accordance with those of Deutsch (1974) and Zwicker (1984) and are consistent with the two-channel model.

Chambers et al. (2004) advance the alternative hypothesis that pitch differences heard on listening to the octave illusion result from diplacusis, a slight pitch difference that may be perceived when the same tone is presented to the left and the right ears. The size of the pitch difference that is characteristic of diplacusis generally corresponds to a fraction of a semitone (Van den Brink, 1975), so this hypothesis requires that pitch differences heard on listening to the octave illusion be very small. As is shown in Figure 12 of Chambers et al. (2004), the size of pitch difference predicted from their hypothesis is indeed a frac-

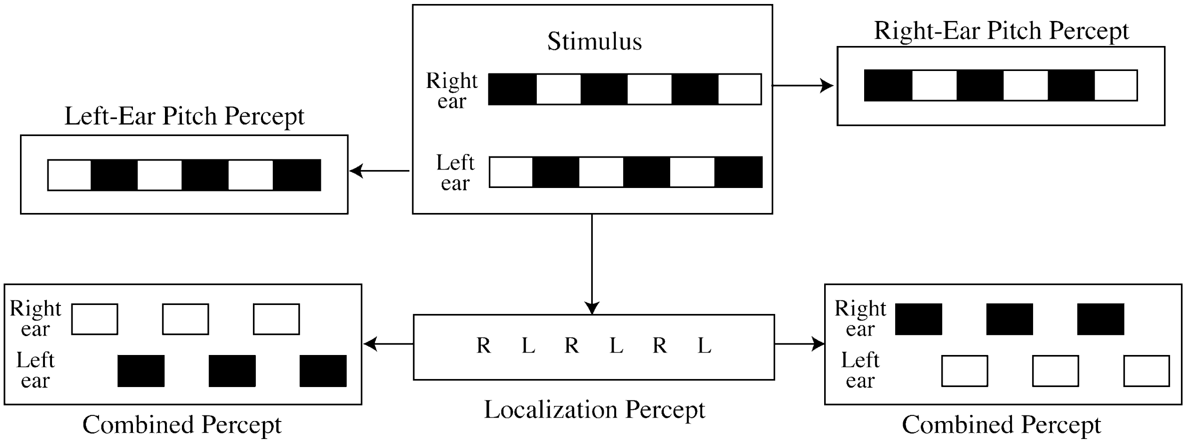

Figure 2. The two-channel model of Deutsch (1975a). The outputs of two decision mechanisms, one determining pitch and the other determining perceived location, combine to produce the octave illusion. Filled boxes represent tones at 800 Hz, and unfilled boxes tones at 400 Hz. R, right; L, left. From "Auditory Illusions, Handedness, and the Spatial Environment," by D. Deutsch, 1983, *Journal of the Audio Engineering Society*, *31*, p. 608. Copyright 1983 by the Audio Engineering Society. Adapted with permission.

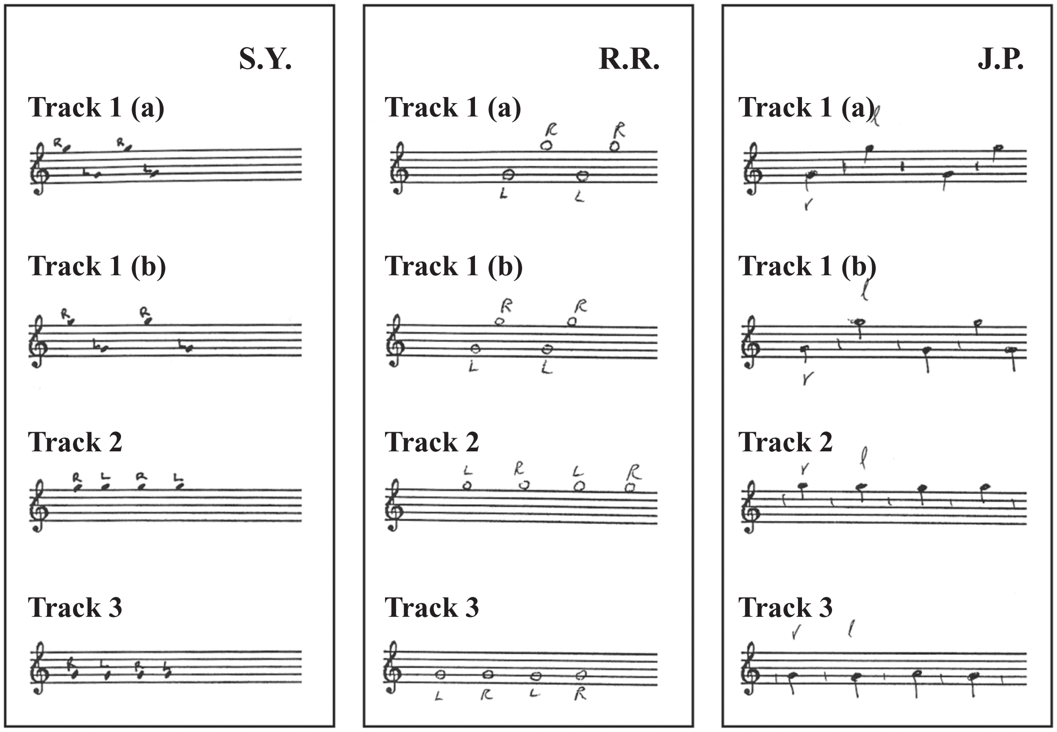

Figure 3. Notations of the octave illusion pattern and of control patterns by 3 musically trained subjects. Track 1 (a) and Track 1 (b) show notations of the octave illusion, with earphones placed both ways. Track 2 shows notations of the high tone alone alternating between ears. Track 3 shows notations of the low tone alone alternating between ears. From "The Octave Illusion Revisited Again," by D. Deutsch, 2004, *Journal of Experimental Psychology: Human Perception & Performance*, *30*, p. 361. Copyright 2004 by the American Psychological Association. Reprinted with permission.

tion of a semitone. They write, "This finding implies that, if perceived synthetically, the pitch difference between the higher and the lower pitch dichotic octave might oscillate for this listener between 0.3% (1.2 Hz/400 Hz) and 2.3% (9.2 Hz/400 Hz)" (p. 660), and it should be noted that the pitch differences given here correspond to less than half a semitone. Clearly, then, Chambers et al. (2004) cannot account for the perception of an octave difference between the tones at the two ears that were found for the majority of subjects by Deutsch (1974), Zwicker (1984), and Deutsch (2004).

As evidence for the fusion–diplacusis hypothesis, the authors cite the conclusions from a study by Chambers, Mattingley, and Moss (2002). However, as now will be explicated, this study employed procedures that raise problems, so their conclusions are unwarranted.

Experiment 1 of Chambers et al. (2002) was titled "Subjective Report" and was intended to gather informal data to be used as a basis for later, more rigorous experiments. (See, e.g., "Subjective reports were purely qualitative and were not statistically analyzed," p. 1292.) The experiment employed 15 subjects, 3 of whom were the authors, and it is not stated whether the other subjects were naive concerning the octave illusion. The subjects were first given substantial exposure to 400 and 800 Hz dichotic tone pairs at durations ranging from 200 to 800 msec. These dichotic tone pairs were then presented in alternating sequence, so that on half the trials the tones were separated by temporal gaps that were equal in duration to the tones themselves, so the intervals between successive tones varied between 200 and 1,600 msec.

The authors' observations in this experiment were based on general impressions, combining reports from sequences involving the different temporal parameters described above. The authors asserted that judgments did not vary with tone duration; yet they presented no specific data to support this assertion and, instead, stated that this finding was in accordance with those of other researchers. However, this assertion is erroneous. Deutsch (1981) found that the octave illusion was significantly degraded when the tones were of longer duration or temporal gaps were inserted between them. (See also Deutsch, 1983a, which included a sound demonstration in which the tone durations were made to vary and the octave illusion was shown to disappear at longer tone durations.) Furthermore, Zwicker (1984) presented listeners with octave illusion patterns at tone durations ranging from 0.01 to 2 sec and found substantial effects of tone duration. Zwicker wrote, "The observers' certainty in perceiving Deutsch's illusion . . . showed a clear maximum with tone durations

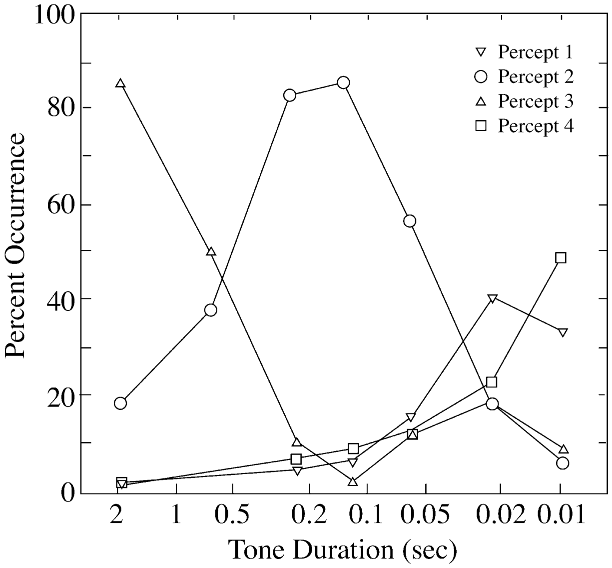

Figure 4. Percentages of occurrences of different percepts of the octave illusion, plotted as a function of tone duration. Percept 1: two tones of the same pitch that alternate between ears. Percept 2: a high tone in one ear that alternates with a low tone in the other ear (i.e., the *octave* percept.) Percept 3: a high tone that alternates from ear to ear, together with a low tone that alternates from ear to ear (i.e., no illusion). Percept 4: none of the above. From "Experimente zur dichotischen Oktav-Tauschung," by T. Zwicker, 1984, *Acustica*, *55*, p. 135. Copyright 1984 by S. Hirzel Verlag, Stuttgart. Adapted with permission.

around 200 msec; with decreasing tone durations other acoustic illusions appear, while with durations greater than about 1 s, the presentation can be perceived correctly" (p. 128). Figure 4 presents Zwicker's data, and it can be seen that often no illusion was obtained at the longer tone durations (and so, longer interonset intervals). Yet the temporal parameters employed by Chambers et al. (2002) included some that, on the basis of Zwicker's findings, should often have resulted in no illusion.

Chambers et al. (2002) had subjects evaluate the size of pitch difference perceived on listening to the octave illusion, basing their combined impressions from patterns at the different temporal parameters described above. They reported that 2 subjects perceived a pitch difference of an octave, 4 (including 1 author) perceived a pitch difference of between an octave and a semitone, 8 (including 2 authors) perceived a pitch difference of a semitone, and 2 perceived no pitch difference between the tones.

These informal results were equivocal in their interpretation. First, at least 3 of the subjects (the authors) were not naive concerning the illusion, and knowledge of the stimulus pattern could have affected their judgments. Second, before listening to the illusion, the subjects were given substantial exposure to 400- and 800-Hz dichotic sequences at different temporal parameters, and this exposure could have affected their percepts. Third, the authors' conclusions were based on overall impressions from judgments of tone patterns involving substantially differing temporal parameters, some of which, according to Zwicker (1984), would be expected sometimes to produce veridical percepts (see Figure 4). Fourth, in the large-scale experiment of Deutsch (1974) 25% of right-handers reported little or no pitch difference between the alternating tones (i.e., they reported *single pitch* percepts), so the percepts of some of the subjects studied by Chambers et al. (2002) may also have fallen into the *single pitch* category.

It should be stressed that the two-channel model was intended to explain the *octave* category of percept, and not the *single pitch* category. Furthermore, 6 of the subjects in Chambers et al.'s Experiment 1 reported pitch differences that were greater than a semitone and, so, were too large to be explained on the diplacusis hypothesis. This hypothesis might, however, apply to those subjects in the experiment of Chambers et al. (2002) who perceived little or no pitch difference between the alternating tones.

Chambers et al. (2002) revisited the question of perceived pitch differences in their Experiment 4. Seven subjects were presented with sequences of alternating 400- and 800-Hz tone pairs, with tones separated by pauses, in which tones at either 400 or 800 Hz were embedded as deviants. The deviant tones were presented simultaneously to both ears and were slightly offset in time from each other, so that they were perceptually displaced from the midline. Averaging the data across subjects, reaction times were found to be shorter for detecting 800-Hz deviants than for detecting 400-Hz deviants. The authors concluded from this result that, in listening to the standard octave illusion, subjects would, in general, perceive both of the alternating tones as closer to 400 Hz than to 800 Hz. However, given the findings, discussed below, that the way the octave illusion is perceived varies depending on sequential context (see below) and, in particular, given that the deviant tones were presented simultaneously to both ears, this conclusion cannot be drawn with confidence. In addition, the subjects had all participated in Experiment 1, and from the authors' description, a number of them may have obtained *single pitch* percepts (as defined by Deutsch, 1974). Since the data were averaged across subjects, the inclusion of even a small proportion of subjects with *single pitch* percepts would have skewed it in the direction predicted by Chambers et al. (2002).

To conclude, the available evidence with respect to the pitch component of the octave illusion for the majority of subjects (i.e., for those obtaining octave percepts) is consistent with the two-channel model, which accounts for the octave differences between the alternating tones reported by Deutsch (1974), Zwicker (1984), and Deutsch (2004). The fusion–diplacusis hypothesis cannot explain these octave differences; neither can it explain the pitch differences larger than a semitone that were reported by 6 of the 15 subjects studied by Chambers et al. (2002). Furthermore, the findings in the study of Chambers et al. (2002) were based on procedures that raise problems, so their conclusion with respect to fusion–diplacusis is unwarranted. It should also be noted that the fusion–diplacusis hypothesis cannot explain the dependence of the octave illusion on tone duration or interonset interval;

neither can it explain its dependence on sequential interactions (to be described below) nor the *complex* percepts of the octave illusion that are obtained by a significant proportion of listeners.

Lateralization in the Octave Illusion

Chambers et al. (2004) criticize the second component of the two-channel model—that is, that listeners lateralize each perceived tone toward the ear receiving the higher frequency. This hypothesis had earlier been tested by Deutsch and Roll (1976) in an experiment to which the authors refer but do not describe. Since this experiment provides strong evidence for the lateralization component of the two-channel model, it is described here.

Forty-four right-handers were presented with repeating sequences whose basic pattern is shown in Figure 5. One ear repeatedly received the pattern shown as Channel A—that is, three high tones alternating with two low tones. Simultaneously, the other ear repeatedly received the pattern shown as Channel B—that is, three low tones alternating with two high tones. The subjects counted the number of high tones they heard in sequence and the number of low tones (thus indicating which ear was being followed for pitch) and also the number of tones they heard in sequence in the right ear and the number they heard in the left ear (thus indicating to which ear each tone was lateralized).

The large majority of subjects reported hearing sequences of single tones; all of these subjects lateralized each perceived tone to the ear receiving the higher frequency. In other words, when presented with Channel A to the right and Channel B to the left, they heard three tones to the right alternating with two tones to the left. And when presented with Channel B to the right and Channel A to the left, they heard two tones to the right alternating with three tones to the left. This finding, which was based on a simple counting task, provides strong evidence for the two-channel model.

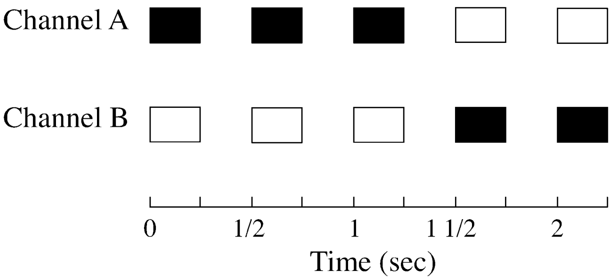

Figure 5. Basic pattern employed by Deutsch and Roll (1976) to test the two-channel model. Filled boxes represent tones at 800 Hz, and unfilled boxes tones at 400 Hz. This pattern was repeated 10 times without pause. From "Separate 'What' and 'Where' Decision Mechanisms in Processing a Dichotic Tonal Sequence," by D. Deutsch and P. L. Roll, 1976, *Journal of Experimental Psychology: Human Perception & Performance*, *2*, p. 25. Copyright 1976 by the American Psychological Association. Adapted with permission.

In further experiments, Deutsch (1978, 1981) presented 5-sec segments of the octave illusion pattern and had subjects judge, for each segment, whether it began in the left ear and ended in the right ear or vice versa. At equal amplitudes, all the subjects lateralized each perceived tone to the ear receiving the higher frequency. Furthermore, Zwicker (1984) presented subjects with octave illusion patterns and also found that, for tones at 400 and 800 Hz, there was a strong tendency to lateralize each tone to the ear receiving the higher frequency.

Chambers et al. (2004) arrive at conclusions concerning the lateralization component of the illusion that are at variance with those of Deutsch (1978), Deutsch and Roll (1976), and Zwicker (1984). Their conclusions are based entirely on observations in Experiment 1 of Chambers et al. (2002), which they stated in this article "were purely qualitative and were not statistically analyzed" (p. 1292). Here, subjects were presented with sequences of alternating dichotic 400- and 800-Hz tone pairs, at the various temporal parameters described above, and they tapped in time with the tone they heard in the right ear or the left one. The authors concluded, on the basis of overall impressions of the subjects' tappings at these different temporal parameters, that 6 subjects lateralized each tone to the ear receiving the higher frequency and 9 subjects lateralized each tone to the ear receiving the lower frequency. However, they provided no specific data to document this claim.

It is quite unclear how the authors arrived at their conclusions. Assuming that the experimenter monitored the signals, no evidence was given that he could synchronize his visualizations of the subjects' tappings reliably with the signals he was monitoring or that the subjects were able to synchronize their tappings reliably with the signals that they heard. This issue of validity was particularly serious for the rapid rates of presentation necessary to produce the octave illusion,[2] and it is important to note that at slow presentation rates, the illusion may sometimes not even have been obtained (Figure 4; Zwicker, 1984). Chambers et al.'s (2004) conclusions concerning the lateralization component of the illusion were, therefore, based on a highly problematic procedure, and it is important to note that they did not confirm these conclusions later in their 2002 article.

To this author's knowledge, no other study has produced results at variance with the hypothesis of Deutsch (1975a) concerning the lateralization component of the octave illusion. Furthermore, the argument by Chambers et al. (2004) that the finding of lateralization to the higher frequency signal is inconsistent with the existing literature is unwarranted. For example, Von Békésy (1963) presented subjects with dichotic tone pairs at frequencies of around 800 Hz. When these tones were amplitude modulated in synchrony, listeners fused them perceptually and lateralized the fused percept to the ear receiving the higher frequency signal. Furthermore, there is at present relatively little systematic evidence for the precise mechanisms that are used to localize harmonic complexes (Langendijk & Bronkhorst, 2002).

The Octave Illusion and Sequential Interactions

In parametric studies of the octave illusion, Deutsch (1978, 1980, 1981, 1988) used the two-alternative forced-choice (2AFC) method to determine how perception of the illusion varied as a function of parametric manipulation. This issue was addressed separately for the ear dominance effect and for the lateralization effect. For the ear dominance effect the percentages of pitch judgments that corresponded to the frequencies presented to the nondominant ear were measured as a function of the relative amplitudes of the tones at the two ears. For the lateralization effect, the percentages of trials on which the subjects lateralized the perceived tones to the lower frequency signal were measured as a function of the relative amplitudes of the higher and the lower tones.

Chambers et al. (2004) criticize this work on the grounds that the 2AFC method was "subjective" rather than "objective." However, in all these experiments, the sound signals varied systematically along the physical continuum of amplitude, and judgments were plotted as a function of position along this physical continuum. This standard psychophysical procedure is employed routinely to investigate, for example, perception of visual attributes, such as color and brightness, and of sound attributes, such as pitch, loudness, and timbre.

More specifically, the authors claim that the experimental findings were subject to alternative interpretations in terms of judgment variability and that, in making judgments concerning stimuli that varied along one dimension, the subjects could have mistakenly been making judgments along another dimension. However, their arguments are based on misinterpretations of the experimental designs. We first take, as an example, the study by Deutsch (1980) on ear dominance and sequential interactions, and the claim by Chambers et al. (2004) that the results of this study are amenable to an alternative explanation in terms of variability of judgment.

Ear dominance, sequential interactions, and variability of judgment. Deutsch (1980) hypothesized that one reason why ear dominance occurs in the octave illusion is that, here, the two ears receive the same frequency in succession (i.e., both the 400- and the 800-Hz tones are presented in succession to the left and right ears). Three experiments were performed to test this hypothesis. In all the experiments, subjects were presented with dichotic sequences, and they 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 (i.e., whether it was of the "high–low" type or the "low–high" type). From these judgments, it was inferred which ear was being followed for pitch. To evaluate the strength of ear dominance, 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.

In all the experiments, it was found, as was predicted, that ear dominance occurred when the two ears received the same frequencies in succession (Condition 1 in all the experiments); however, ear dominance was absent or significantly weaker where this relationship did not hold (Condition 2 in all the experiments). Chambers et al. (2004) attribute these findings to greater judgment variability in the second condition than in the first, writing "Note, for instance, that the results for Condition 1 across all the experiments were almost always more consistent than the results in Condition 2" (p. 655). However, this statement is erroneous: In all the experiments, judgments were *less* consistent in Condition 1 than in Condition 2. Because this point is a critical one, it will be explicated here in detail.

The basic patterns employed in Experiment 1 are shown in Figure 6. In Condition 1, the two ears received the same frequencies in succession, and ear dominance effects were obtained. So with signals at equal amplitude, the right-ear–dominant subject perceived a "high–low" pattern when listening to Sequence (a) and a "low–high" pattern when listening to Sequence (b), reflecting his or her following of the pitches presented to the right ear rather than those presented to the left one.

In Condition 2, the two ears did not receive the same frequencies in succession. If sequential interactions were irrelevant to ear dominance, then at equal amplitude, the same subject should also hear a high–low pattern when presented with Sequences (c) and (e), and a low–high pattern when presented with Sequences (d) and (f). However, this result was not obtained. Instead, as is shown in Fig-

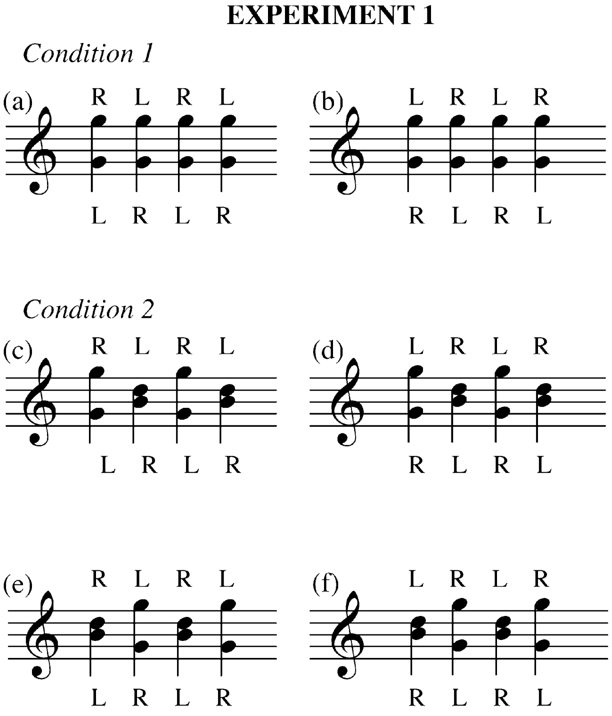

Figure 6. Patterns employed in Experiment 1 of Deutsch (1980) on ear dominance and sequential interactions. See the text for details.

ure 8A, all the subjects consistently followed all the patterns in Condition 2 on the basis of overall contour, for all levels of amplitude relationship between the tones at the two ears: One subject consistently followed the contour of the higher tones and, so, consistently reported a “high–low” pattern for Configurations (c), (d), (e), and (f). The other 3 subjects consistently followed the contour of the lower tones and, so, consistently reported a “low–high” pattern for Configurations (c), (d), (e), and (f).

Since the numbers of trials in the different subconditions of the experiment were counterbalanced, the obtaining of nearly 100% for following by contour necessarily resulted in nearly 50% for following by ear of input; this is shown in the closed circles in Figure 7 of Chambers et al. (2004). The assertion by Chambers et al. (2004) that these plots reflect a high variability in judgment in Condition 2 is, therefore, based on a misinterpretation of the experimental design.[3]

The same argument holds for Experiment 2 of the study of Deutsch (1980). The patterns used in this experiment are shown in Figure 7A. Those employed in Condition 1 are shown in Sequences (a) and (b), and it can be seen that here the two ears received the same frequencies in succession. Those employed in Condition 2 are shown in Sequences (c)–(j), and it can be seen that here, the two ears did not receive the same frequencies in succession.

Again as expected, ear dominance was found in Condition 1. However, this was not the case in Condition 2. Instead, as is shown in Figure 8B, judgments reflected a

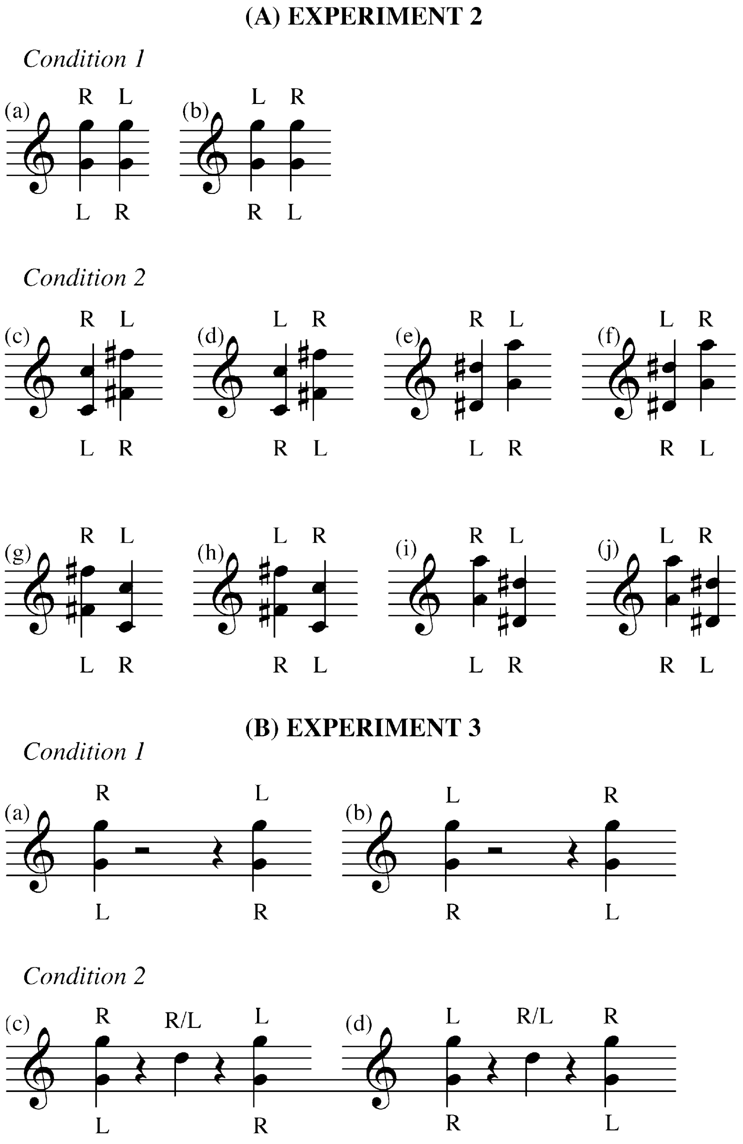

Figure 7. Patterns employed in Experiments 2 and 3 of Deutsch (1980) on ear dominance and sequential interactions. See the text for details.

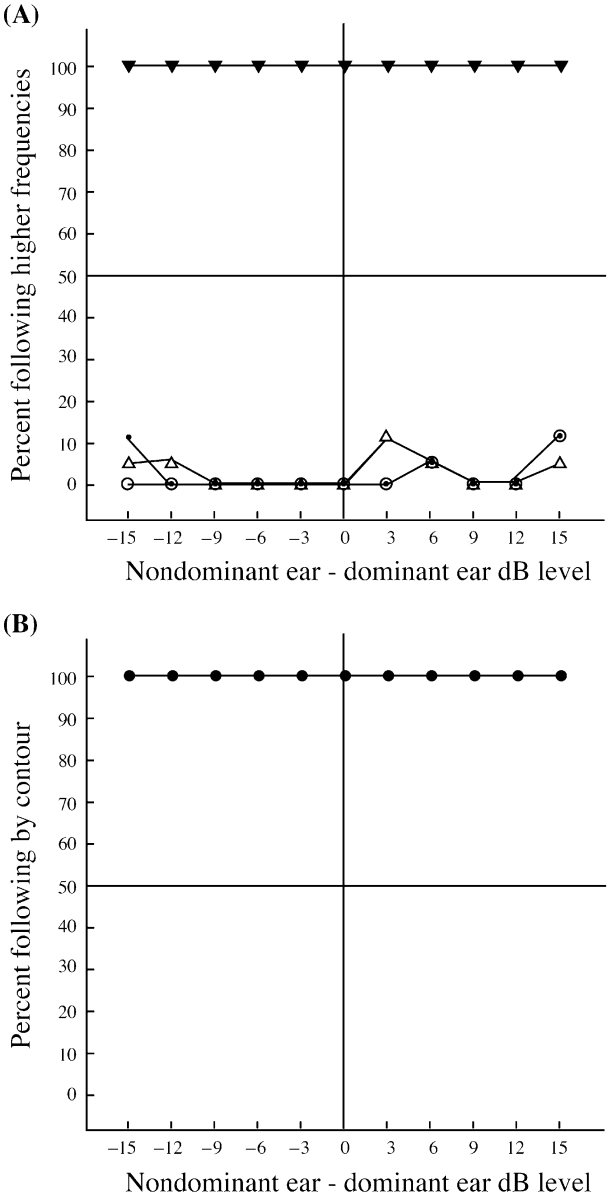

Figure 8. Plots showing consistent following by contour in Conditions 2 in Experiments 1 and 2 of Deutsch (1980). (A) Percentages for the following of the higher tones in Condition 2 in Experiment 1. The data from the 4 subjects are here presented individually. (B) Percentages for the following of the contours of the patterns in Condition 2 of Experiment 2 for all the subjects combined. From "Ear Dominance and Sequential Interactions," by D. Deutsch, 1980, *Journal of the Acoustical Society of America*, *67*, p. 223–224. Copyright 1980 by the Acoustical Society of America. Adapted with permission.

completely consistent following by contour: When presented with Sequences (c), (d), (e), and (f), the subjects always perceived a "low–high" pattern, regardless of which tones were delivered to which ear. And when presented with Sequences (g), (h), (i), and (j), the subjects always perceived a "high–low" pattern, regardless of which tones were delivered to which ear. Again, since the numbers of trials in all the subconditions were counterbalanced, this 100% for following by contour necessarily gave rise to exactly 50% for following by ear of input, for all levels of amplitude relationship between the tones at the two ears. This is shown in the closed circles in Figure 8 of Chambers et al. (2004). The authors misinterpret these plots to conclude that judgments in Condition 2 were highly variable, whereas they were, instead, completely consistent (see note 3).

Experiment 3 of Deutsch (1980) employed the patterns shown in Figure 7B. In Condition 1, Patterns (a) and (b), the two ears received the same frequencies in succession. However, in Condition 2, Patterns (c) and (d), a single diotic tone of different pitch was presented between the dichotic chord pairs, and the subjects were asked to ignore this tone. The degree of ear dominance was found to be significantly less in Condition 2, in which a tone of different pitch was interpolated, than in Condition 1, in which no tone was interpolated between those to be judged. The authors claim that judgments in Condition 2 of this experiment were more variable than those in Condition 1. However, statistical analyses showed the contrary: Judgments were significantly *less* variable in Condition 2 than in Condition 1 (Deutsch, 1983b).

In summary, the three experiments reported by Deutsch (1980) showed that the ear dominance component of the octave illusion cannot be regarded purely in terms of simultaneous interactions (as is required by the fusion–diplacusis hypothesis) but depend on sequential interactions also. The claim made by Chambers et al. (2004) that the findings from these experiments can be explained by higher judgment variability in Condition 2 than in Condition 1 is erroneous, since the opposite pattern of variability was obtained in all three experiments.

"Subjective responses" and response bias. Chambers et al. (2004) criticize experiments by Deutsch and others on the octave illusion on the grounds that they employed "subjective reports." However, the use of subjective reports has a long and distinguished history in perceptual psychology, and the validity of these methods (e.g., in magnitude estimation) is well established.

More specifically, the authors argue that the results of the experiments by Deutsch (1978, 1980, 1988) could have been due to response bias. In particular, they assert that, in making lateralization judgments, subjects may have mistakenly been making pitch judgments and that, in making pitch judgments, they may have mistakenly been making lateralization judgments. However, their arguments are based on misinterpretations of the experimental designs that were employed. In the lateralization experiments, the relative amplitudes of the higher and the lower tones were systematically varied, and lateralization judgments were plotted as a function of these amplitude relationships. However, amplitude relationships between the higher and the lower tones were always counterbalanced at the left and the right ears, so there would be no rationale for interpreting the results in terms of pitch perception rather than lateralization. Analogously, in the experiments on ear dominance for pitch, the relative amplitudes of the tones at the left and the right ears were systematically varied, and pitch judgments were plotted as a function of these amplitude relationships. However, the amplitudes of the higher and the lower tones were always identical at the two ears, so the functions obtained could not have been due to the subjects' inadvertently making lateralization rather than pitch judgments.

Chambers et al.'s (2002) Experiment 3 concerning sequential interactions. Chambers et al. (2004) assert that perceptions of the octave illusion do not depend on sequential interactions, basing this assertion on findings from Experiment 3 of Chambers et al. (2002). Here, subjects were presented with various dichotic patterns, and instead of being asked to report what they perceived, they were asked to infer what signals were being presented. All the subjects had participated in Experiment 1 and, so, had received considerable exposure to variants of the octave illusion at different temporal parameters, some of which may well have resulted in veridical percepts (Figure 4; Zwicker, 1984). This exposure would have furnished the subjects with valuable information concerning the stimulus patterns that were being presented, and on these grounds, the results were unsurprising. Indeed, the authors wrote, "The most surprising result from this experiment was the capacity listeners demonstrated to correctly segregate the octave illusion by ear, despite reporting a single image percept" (p. 1297). This shows that the subjects were distinguishing between the signal as they perceived it and the signal that was actually presented. Since this experiment did not address the issue of how the octave illusion was perceived, the authors' conclusions concerning sequential interactions are unwarranted.

The Octave Illusion and Related Literature

Finally, we address the claim made by Chambers et al. (2004) that the *octave* percept of the octave illusion and the two-channel model proposed to explain it are "inconsistent with" other work on pitch perception and sound localization. The arguments they raise are problematic on a number of grounds. For example, they argue that the findings of Dye (1990) showing that the amount of binaural interference depended on the delay between presentations of different components of complex tones would predict a large variation between individuals in the lateralization component of the octave illusion. However, the relationship of the study by Dye to the octave illusion is quite tenuous. Dye found individual differences in terms of effects resulting from different stimulus manipulations; however, variability in perception of the octave illusion is rather in terms of individual differences in perception of the same stimulus.

Furthermore, Chambers et al. (2004) argue that "the general pattern of spectral dominance observed in the precedence effect is inconsistent with the high-frequency localization dominance proposed by the suppression model of the octave illusion" (p. 647). However, one cannot appropriately compare these two phenomena here. For example, the precedence effect is most powerful in a free-field environment, whereas the octave illusion requires that the pattern be heard through headphones (except in an anechoic chamber). Second, the precedence effect involves sound signals that are quite different from those producing the octave illusion. Similar arguments apply to the Franssen effect, which occurs with free-field presentation and entirely different sound signals from those producing the octave illusion.

The discussion by Chambers et al. (2004) concerning the electrophysiological literature on the octave illusion is also unconvincing. In particular, the authors discuss a study by Ross, Tervaniemi, and Näätänen (1996) that monitored mismatch negativity over the primary auditory cortex when subjects listened to the octave illusion and were presented with deviant stimuli. Ross et al. concluded from their findings that the octave illusion arises at or above the auditory cortex. Chambers et al. (2004) take issue with these conclusions and argue, instead, that these results provide evidence against the two-channel model. However, the results of Ross et al. are entirely consistent with the two-channel model of the illusion, as Ross et al. also assumed.

The two-channel model of the octave illusion assumes that the decision mechanisms responsible for perceived pitch and for localization, are at some point, distinct and separate. At the time the model was proposed, evidence for separate *what* and *where* pathways in the auditory system was sparse; however, recent neurophysiological work has provided convincing evidence for this view (see, e.g., Rauschecker & Tian, 2000; Tian, Reser, Durham, Kustov, & Rauschecker, 2001). More specifically, the model of Deutsch (1975a) invokes the *what–where* separation in the auditory system to suggest the existence of two specific decision mechanisms that operate along these different pathways.

To take this line of reasoning one step further, it has been speculated (Deutsch, 1982) that separate pathways are involved in processing different attributes of sound, such as pitch, loudness, timbre, duration, and so on. Each sound can be considered a bundle of attribute values. If our percept is veridical, the bundle of attribute values reflects the characteristics of the sounds that are presented. However, under certain circumstances, these bundles of attribute values can fragment and recombine incorrectly, so that illusory conjunctions result. The octave illusion represents a case in point, as does the scale illusion (Deutsch, 1975b), in which the attribute values of pitch and location are again incorrectly conjoined, although in accordance with different principles. Efron and Yund (1974) have also shown that, for certain tone combinations, pitch and location can be dissociated from each other.

Other research has provided further evidence that the different attributes of sound are processed along separate pathways that involve decision mechanisms that can act at some stage independently and, so, can arrive at inconsistent conclusions (see, e.g., Carlyon, Demany, & Deeks, 2001; Darwin & Carlyon, 1995; Gardner, Gaskill, & Darwin, 1989; Moore, Glasberg, & Peters, 1986). In addition, illusory conjunctions in hearing have been reported for other configurations (see, e.g., Hall, Pastore, Acker, & Huang, 2000; Thompson, 1994). Given that the illusory conjunctions so far documented in hearing are substantial, it appears likely that future research will show the auditory system to be very prone to such effects.

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NOTES

1. The pitch difference notated by this subject on listening to tones of the same frequency alternating between ears may have reflected diplacusis. It is interesting to note that the direction of this pitch difference did not correspond with the same subject's notated locations of the higher and the lower tones in listening to the octave illusion, and this result is contrary to expectations from Chambers et al. (2002).

2. For 200-msec tones, the subjects would have had to tap reliably within 200-msec (i.e., not 400-msec) time periods, and the experimenter would also have had to judge their tapping reliably within these time periods, for this procedure to be reliable.

3. This is explicated in note 3, p. 227, of Deutsch (1980), which states: "The near-horizontal lines in Fig. 2 and 3 simply reflect a following on the basis of frequency proximity, as shown in Fig. 4, given the counterbalancing procedure of the experiment. Similarly the horizontal lines in Figs. 6 and 7 simply reflect a consistent following on the basis of contour, as shown in Fig. 8."

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