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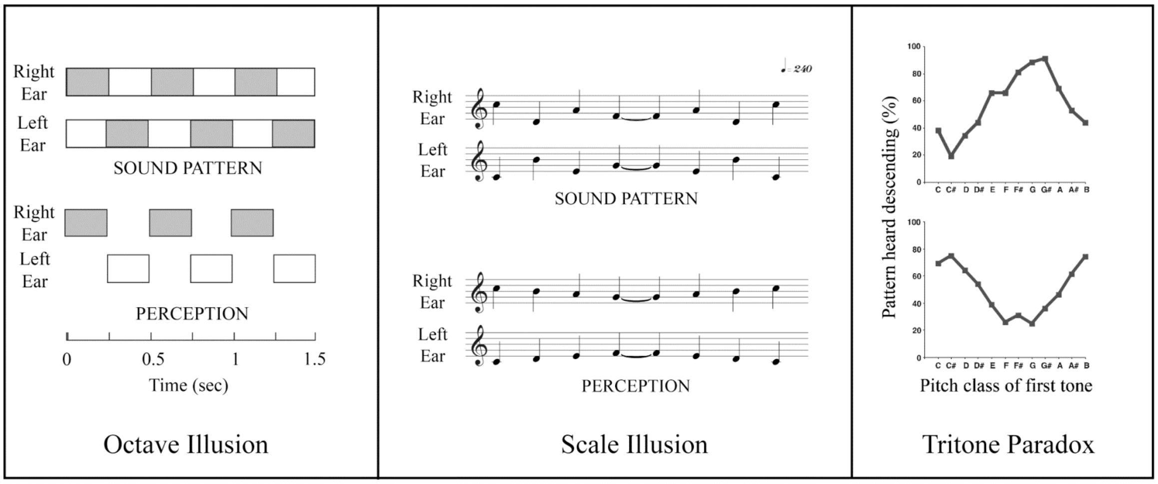
Auditory Illusions

Diana Deutsch

The sounds we perceive do not always correspond to those that are presented. When such a mismatch occurs, we are experiencing an auditory illusion. These illusions show that the auditory system does not faithfully transmit the sound information as it arrives at our ears, but alters and reorganizes this information in various ways.

THE PRECEDENCE EFFECT

Our hearing mechanism has evolved an ingenious mechanism for minimizing problems caused by echoes in the environment. Instead of correctly perceiving a set of overlapping sounds, each coming from a different location in space, we obtain the illusion of a single sound that appears to be coming from its original source. This phenomenon was first discovered by the 19th century physicist Joseph Henry. To demonstrate this effect in the laboratory, the listener is seated in front of two loudspeakers, with one to his left and the other to his right. A single stream of speech is presented through both loudspeakers; however the signal at the right loudspeaker is delayed relative to the left one. When the sounds are offset by less than around 30 ms, the listener perceives the sound as coming only from the left loudspeaker. The right loudspeaker contributes to the loudness and liveliness of the sound, but appears to be completely silent. When the offset exceeds the critical time limit, two distinct streams of sound are correctly heard as coming from separate loudspeakers.



Left panel: The pattern that produces the octave illusion, and the percept most frequently obtained. Filled boxes indicate tones of 800 Hz and unfilled boxes tones of 400 Hz. Adapted from Deutsch (1974). Center panel: The pattern that produces the scale illusion, and the percept most frequently obtained. Adapted from Deutsch (1975). Right panel: The tritone paradox as perceived by two different listeners. Adapted from Deutsch (1995).

THE OCTAVE ILLUSION

The octave illusion was discovered by Diana Deutsch in the mid-20th century, and is experienced with tones that are presented via stereo headphones. Two tones an octave apart are alternated repeatedly at a rate of four tones per second. The identical sequence is presented to both ears simultaneously; however the tones are offset in time such that when the right ear receives the high tone the left ear receives the low tone; and vice versa.

Despite its simplicity, this pattern is almost never heard correctly, and instead produces a number of illusions. Many people hear a single tone that alternates from ear to ear, while its pitch simultaneously switches back and forth between high and low. So it appears that one ear is receiving the sequence 'high tone - silence - high tone - silence' while the other ear is receiving the sequence 'silence - low tone - silence - low tone'. Even more curiously, when the earphone positions are reversed most people hear exactly the same thing: The tone that had appeared in the right ear still appears in the right ear, and the tone that had appeared in the left ear still appears in the left ear. As a further surprise, righthanders tend to hear the high tone as on the right and the low tone as on the left, regardless of how the earphones are positioned; yet lefthanders vary considerably in terms of where the high and low tones appear to be coming from. The illusion is hypothesized to result from the use of incompatible cues to determine *what* sounds are being presented, and *where* each sound is coming from. The strong association with handedness indicates that the ways in which the octave illusion is perceived reflect differing patterns of brain organization.

THE SCALE ILLUSION

The scale illusion was discovered by Diana Deutsch in the mid-20th century, and is best experienced through stereo headphones. The pattern that produces this illusion consists of a musical scale with successive tones alternating from ear to ear. The scale is played simultaneously in both ascending and descending form; however when a tone from the ascending scale is in the right ear a tone from the descending scale is in the left ear; and vice versa. This sequence of tones is played continuously without pause.

As with the octave illusion, the scale pattern gives rise to a number of illusions which tend to vary with the handedness of the listener. Most commonly, a melody corresponding to the higher tones is heard as coming from one earphone, with a melody corresponding to the lower tones from the other one. Righthanders tend to hear the higher tones as on their right, and the lower tones as on their left. And as with the octave illusion, when the earphone positions are reversed, the right ear continues to hear the higher tones, and the left ear the lower ones. However, lefthanders as a group are less likely to localize the tones in this way. As with the octave illusion, the handedness correlates with the way the scale illusion is perceived indicate that this illusion serves as a reflection of differing patterns of brain organization.

Variants on the scale illusion can be produced with other melodic patterns, and by natural instruments in concert halls. They have even been shown to operate in certain passages from the classical concert repertoire - for example, in the last movement of Tchaikowsky's Sixth Symphony. This indicates that on listening to complex orchestral music, individual members of an audience may well be hearing certain musical passages in different ways.

THE GLISSANDO ILLUSION

The glissando illusion was created by Diana Deutsch in the late 20th century. It is best heard when the listener is seated in front of two stereophonically separated loudspeakers, with one to his left and the other to his right. The pattern producing the illusion has two components: A synthesized oboe tone of constant pitch, and a sine wave whose pitch glides up and down. These two components are presented simultaneously, and switch repeatedly between the loudspeakers so that when the oboe tone is coming from the speaker on the left the glissando is coming from the speaker on the right; and vice versa.

On listening to this illusion, the oboe tone is heard correctly as switching between the loudspeakers. However, the segments of the glissando appear to be joined together quite seamlessly, so that a single, continuous tone is heard that appears to be moving around in space in accordance with its pitch motion. Handedness correlates again emerge in terms of where the higher and lower portions of the glissando appear to be located: Righthanders tend strongly to perceive the glissando as moving from left to right as its pitch moves from low to high, and from right to left as its pitch moves from high to low. Yet nonrighthanders vary considerably in terms of where the higher and lower portions of the glissando appear to be located.

The scale and glissando illusions can be explained in part by assuming that the listener adopts the most plausible interpretation in terms of the environment. In the case of the scale illusion, it is extremely unlikely that two jerky but overlapping pitch patterns should be coming from different positions in space. We therefore reorganize the tones perceptually, so that the higher tones appear to be coming from one location and the lower tones from another. In the case of the glissando illusion, it is extremely unlikely that a sound which changes smoothly in frequency should be switching abruptly between two different spatial locations. It is far more probable that such a sound is coming from a single source that is either stationary or that is moving slowly through space. So we perceptually reorganize the gliding tone accordingly.

PITCH CIRCULARITIES

Tones whose frequencies stand the ratio of 2:1 are said to be in octave relation, and they are in a sense perceptually equivalent. This is acknowledged in the system of notation of the Western musical scale. The core of this scale consists of twelve tones, which correspond to the division of the octave into equal steps, called semitones, and each tone is given a name (C, C#, D, D#, E, F, F#, G, G#, A, A#, and B). The entire scale, as it ascends in height, consists of the repeating presentation of this sequence of note names across successive octaves. Pitch can therefore be described as varying along two separable dimensions: The dimension of *pitch height* corresponds to the position of the tone from high to low, and the circular dimension of *pitch class* (corresponding to note name) corresponds to the position of the tone within the octave.

In the mid-20th century, Roger Shepard showed that the two dimensions of pitch can be separated by employing computer-produced tones whose pitch classes are clearly defined, but whose heights are ambiguous. This can be achieved, for example, by generating a bank of twelve tones whose names correspond to those of the musical scale, but each of which consists only of components that are related by octaves. For example, one such tone would consist only of components C_2, C_3, C_4, …, and so on; such a tone would clearly be heard as a C, but its octave placement would be ambiguous. Another such tone would consist of components G_2, G_3, G_4, …, and so on; this tone would clearly be heard as a G but again its octave placement would be ambiguous.

Shepard found that when two such octave-ambiguous tones were played in succession, people heard either an ascending pattern or a descending one, depending on which was the shorter distance between the tones along the pitch class circle. So, for example, when C was played followed by C#, the pattern was heard as ascending, since the shorter distance along the circle here was clockwise. And when G was played followed by F# the pattern was always heard as descending, since the shorter distance here was counterclockwise. This enabled Shepard to create an illusion of pitch circularity: When a bank of such tones is played that traverses the pitch class circle clockwise in semitone steps (C, C#, D, and so on), it is heard as eternally ascending in pitch. When it traverses the circle counterclockwise (C, B, A#, and so on) it is heard as eternally descending instead. Soon after this, Jean-Claude Risset generated analogous pitch circularities using a similar algorithm but with gliding tones.

THE TRITONE PARADOX

Demonstrations of pitch circularity raise the question of what happens when pairs of octave-ambiguous tones are presented that stand in opposite positions along the pitch class circle, so that the same distance between them can be traversed in either direction. Such tones form an interval called a tritone. Diana Deutsch discovered in the 1980s that when such tone pairs are presented, paradoxical differences in perception emerge. For example, when presented with C followed by F#, one listener will clearly hear an ascending pattern; however another listener may clearly hear a descending pattern instead. And when the pattern G# followed by D is presented, the first listener now hears a descending pattern and the second listener an ascending one. Furthermore, for any one listener, the pitch class circle is oriented with respect to height in a systematic way, so that tones in one region of the circle are heard as higher and tones in the opposite region as lower.

Such differences in perception correlate with the pitch range of the listener's speaking voice, and with the language or dialect to which listeners have been exposed. Strong differences were found, on a statistical basis, between listeners who had grown up in California and those who had grown up in the south of England. Such differences in perception of this musical pattern again indicate that individual members of an audience may hear certain musical passages in different ways.

ILLUSIONS OF AUDITORY CONTINUITY

Another class of illusions involves perceptually replacing missing portions of sounds that would otherwise be drowned out by noise. When we are conversing with someone in the street, for example, the noise of traffic masks out many portions of the speech we are listening to, and our perceptual system generates these missing portions, so that the speech sounds continuous. Richard Warren found that when listeners heard a recorded sentence in which a speech sound was deleted and replaced by noise, they were unable to tell which sound was missing, and could not locate the position of the noise in the sentence. The sound that listeners 'reconstructed' changed depending on the context. When presented with the sentence 'It was found that the *eel was on the ___', listeners tended to ‘hear’ the missing sound depending on the last word. So, for example, when the last word was 'table', listeners tended to hear the word 'meal', and when the last word was 'shoe' they tended to hear the word 'heel'. Similar effects have been found on listening to music. When a note in a repeating scale is deleted and replaced by a noise burst, listeners reconstruct it perceptually. Also, as discovered by Albert Bregman, when a gliding tone is sounded, and a portion of the glide is removed and replaced by a loud noise burst, the listeners reconstruct the missing portion of the glide.

SUMMARY

The illusions described in this entry show that what we hear is by no means a direct reflection of the sounds that are presented to our ears; instead, high-level brain mechanisms can substantially modify what is perceived. The study of these illusions plays a valuable role in shedding light on these mechanisms.

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Cross-references:

Feature integration theory; Audition: cognitive influences; Auditory imagery; Auditory scene analysis; Auditory localization; Audition: pitch perception

Further readings:

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