ILLUSIONS RELATED TO THE TEMPORAL CONTINUITY AND DISCONTINUITY OF SOUNDS

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Abstract

I take up three auditory illusions related to the temporal continuity and discontinuity of sounds. In 1) the continuity illusion, a long tone of 1-2 s interrupted by a short noise of 100-300 ms, for example, is often perceived as continuous. In 2) the gap transfer illusion, typically a glide of 1.5 s or above with a temporal gap of about 100-300 ms in the middle and a shorter continuous glide of about 400-600 ms cross each other at their central positions; the gap in the longer glide is perceived as if it were in the shorter glide. In 3) the illusory auditory completion, typically a glide of 1.5 s or above and a shorter glide of about 400-600 ms cross each other, sharing a gap shorter than 50 ms; this gap is often perceived as if it were only in the shorter glide. These illusions can be explained by assuming a perceptual mechanism to detect and combine onsets and offsets (terminations) of sounds as independent components.

One of the key functions of our auditory system is to determine the number of sounds included in an auditory stream, which is typically a concatenation of perceived sounds and silences. To investigate how discontinuous temporal points appear in an auditory stream is thus very important for understanding the mechanism of human auditory communication.

Auditory Illusions

The Continuity Illusion

This is probably one of the most well-known auditory illusions with plenty of variations (Miller & Licklider, 1950; Bregman, 1990; Warren, 1999; Riecke, van Opstal, & Formisano, 2008). In a typical situation, a long pure tone of 1 kHz and 1-2 s is interrupted in the middle for 100-300 ms. This temporal gap is clearly audible if it is unfilled. If the gap is filled with a band noise of 0.5-2 kHz which is sufficiently, e.g., 20-30 dB, more intense than the pure tone, the pure tone is often perceived as if it were continuous. There are two requisites for the illusion to take place according to a general agreement. Firstly, the offset and the onset of the pure tone just before and after the interruption should be located within or very near the temporal range of the interrupting noise so that they are masked. (Sometimes very short overlaps between the interrupting and the interrupted signals are introduced.) Secondly, the noise should be capable of masking the pure tone if the latter were uninterrupted. The second requisite leads to a general prediction that this illusion, in a typical situation, cannot take place if the interrupting signal is less intense than the interrupted signal.

The Gap Transfer Illusion

A physically continuous tone is perceived as discontinuous in this illusion (Nakajima et al., 2000; Nakajima, 2006; Kanafuka et al., 2007; Kuroda, Nakajima, & Eguchi, 2008; Remijn et al., 2008). When a frequency glide of 1.5 s or above has a temporal gap of about 100-300 ms in its central position, where it crosses a continuous glide of about 400-600 ms, the gap is typically perceived as if it were in the latter glide, which is physically shorter and continuous. The perception of the longer glide, which is illusorily continuous, may seem similar to the perception of the long tone in the above example of the continuity illusion. There is a big difference, however; the gap transfer illusion takes place to a certain degree even when the shorter glide is 6 dB less intense than the longer glide (Kuroda et al., 2008). In this level condition, the longer glide, if it were uninterrupted, could not be masked by the shorter glide at the crossing point. Thus, the illusory continuity of the longer glide in the present case should not be caused by the same mechanism as that of the continuity illusion in its typical form. One may argue that it is not necessary to call this phenomenon a new illusion because there are no available cues for the auditory system, at a peripheral level, to determine to which of the crossing glides the gap should belong. This argument, however, misses a key point of the phenomenon: why the gap is almost always perceived as if it were in the shorter glide.

The Illusory Auditory Completion

This is an illusion in which a tone with an unfilled temporal gap long enough to be detected is perceived as continuous (Remijn, Nakajima, & Tanaka, 2007; Remijn et al., 2008). When a glide of 1.5 s or above and a shorter glide of about 400-600 ms cross each other, sharing a gap typically shorter than 50 ms, the gap is perceived often only in the shorter glide. The longer glide is perceived typically as continuous, and, even when some discontinuity is perceived, it is not as clear as in the shorter glide. If degrees of discontinuity are to be compared between crossing glides, a similar phenomenon takes place when there is no real gap but two glides cross each other in opposite phases so that there is a common dip of intensity at the crossing point (Nakajima et al., 2000). The same kind of illusion also occurs clearly in a stimulus pattern where synthesized recorder tones of different durations, which have steady pitches, share a gap in their central positions (Nakajima, 2008). Ciocca (2007) and I independently noticed that it is possible to obtain an illusory continuity of a tone, which is not unlike the continuity in the continuity illusion, by interrupting it with a noise including a temporal gap or gaps, which should be very short. Although we are still in a stage to speculate about possible relationships between unexplored auditory phenomena, there seems to be a diversity of variations of this illusion. A remarkable point about the phenomenon is that there is no sound energy for a short period which is yet long enough to be detected, and that the longer glide is still perceived as continuous. This means that the illusory continuity takes place without sound energy to be interpreted perceptually to fill the gap.

Discussion

A simple model, *the event construction model* (Nakajima et al., 2000), gives possible interpretations to all the above illusory phenomena. Let us take up the gap transfer illusion first. Steiger's unpublished observations (as described in Bregman, 1990) leads to the idea that onsets and offsets (terminations) of glide tones can behave as if they were perceptually independent. I tried to generate patterns to check this issue, and presented a single-component glide of 1 s from 1000 to 2000 Hz or from 2000 to 1000 Hz repeatedly (the rise and the fall time were 20 ms). Very short tones corresponding to the onsets of the glides were heard clearly, but it was difficult to hear sounds related to the offsets of the glides. We can safely assume that glide onsets can be detected independently. Although we still have to study carefully whether and how offsets of such glides are detected independently, it should be allowed to construct a hypothesis that onsets and offsets of sounds are perceptually separable components. We can further assume that an onset and an offset that appear in this order, i.e., in grammatical order (Nakajima & Sasaki, 1996), and are close to each other in time and

frequency tend to be connected with each other perceptually even when they belong to physically different sounds. In the above stimulus pattern where the gap transfer illusion takes place, the onset of the shorter glide and the offset at the beginning of the gap of the longer glide are close to each other in time and frequency. If they are connected with each other perceptually, then they should begin and end a sound, i.e., they should form a sound. The onset at the end of the gap and the offset of the shorter glide should be connected with each other as well forming another sound. Thus, we have two successive short tones, or a short tone with a temporal gap. Because the offset and the onset bounding the gap have been interpreted once, they need not be interpreted again, leaving the longer glide perceptually continuous. That is, the listener perceives one long continuous glide and two successive short tones. The gap transfer illusion has been explained, although the explanation so far lacks a quantitative viewpoint.

This explanation is applicable to the illusory auditory completion as well. The crossing glides in the above-mentioned stimulus pattern share a very short temporal gap. The offsets of these glides that mark the beginning of the shared gap are simultaneous and very close to each other in frequency -- typically within a critical band. It should not be very unreasonable to assume that these physical offsets of sounds just give a single cue of an offset, and that this cue need not be interpreted more than once perceptually. The same kind of argument holds for the onsets of these glides that mark the end of the gap, and we can assume that they serve as a single cue of an onset. Because the onset cue at the beginning of the shorter glide and the integrated offset cue at the beginning of the gap are close to each other in time and frequency, they are likely to be connected with each other forming a percept of a short tone. In the same way, the integrated onset cue at the end of the gap and the offset cue at the end of the shorter glide are likely to form another percept of a short tone. Thus, two successive short tones are obtained, and the integrated onset and offset cues need not be interpreted again. If the temporal gap is long enough to provide cues of an offset and an onset, i.e., temporal edges, but not long enough to provide a cue of a silence, then there should be no perceptual cue left indicating that the longer glide has discontinuity, and the percept of the longer glide should be continuous. Efron (1970a; 1970b) showed that two successive and spectrally different sounds separated by a gap of about 20-40 ms can be perceived with a clear offset and onset to separate them, and yet without a percept of a gap, which should correspond to a silence in our terminology. It should not be very unnatural to assume that cues of onsets, offsets, and silences are detected independently, and that cues of an offset and an onset can be detected successively without a cue of a silence in between.

I would like to indicate one possible view of the continuity illusion (Nakajima & Sasaki, 1996; Remijn & Nakajima, 2005). A conventional view is that the masking power of the interrupting sound plays an important role for the occurrence of the illusion, but the gap transfer illusion and the illusory auditory completion have indicated that an illusory continuity of a sound can take place even when there is no interrupting sound with sufficient masking power. There must be another mechanism, and the hypothetical mechanism as I described here in a primitive manner can be a candidate. If so, one of the things we have to do is to examine whether we can explain the continuity illusion in a typical situation in terms of our hypothesis. When a pure tone is interrupted by a short and intense noise encompassing its frequency, the offset and the onset of the pure tone near or at the temporal edges of the noise are masked. Thus, there are only one onset cue at the beginning of this noise and one offset cue at the end. Because these cues are close to each other in time and, as a whole, in frequency, they are connected with each other perceptually forming a percept of the noise. Because these cues of temporal edges have been interpreted, they need not be interpreted again, and, because there is no cue of a silence between the beginning and the end of the pure tone, the percept of the tone is left continuous. The continuity illusion has been explained in the same way as the gap transfer illusion and the illusory auditory completion. The present argument is not at all meant to disprove the conventional explanation of the continuity illusion, but to view the same phenomenon from an alternative angle. It is possible that more than one mechanism is involved in the above illusions. I thus showed the outline of our attempt to understand some auditory phenomena from a unified viewpoint.

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SHORT STORIES ABOUT AUDITORY TIME AND RHYTHM

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Abstract

The length of time intervals is fundamental for organizing auditory perception. The present text offers an overview of different experiments conducted in my lab on the sensitivity of humans for discriminating such intervals. Various ways for testing sensitivity to time and for keeping track of time are proposed. It will be shown to what extent the number of intervals presented determines the level of discrimination; whether Weber's law for time applies under both of the following conditions –single vs. multiple (rhythm) interval discrimination; how segmenting time improves performance; and how sensitive humans are to temporal variations in music and language.

Number of Intervals in a Sequence

There have been many proposals about the functional nature of the mechanism(s) involved in perception of time. One general proposal is that relative judgments about the duration of events are based on an interval-by-interval comparison strategy (Keele, Nicoletti, Ivry & Pokorny, 1989; Killeen & Weiss, 1987). This proposal is central to a conventional view of timing where timekeeping is reported to be based on an internal, single clock mechanism consisting of a pacemaker-counter device (Grondin, 2001). An alternative perspective on timing, known as the beat-based approach, is that people pick up the implied beat generated by a series of successive events when it is available (Large & Jones, 1999; McAuley & Jones, 2003). For tasks where intervals have to be compared to one or multiple presentations of a standard interval, both of these perspectives on timing suggest that duration discrimination should improve when multiple standards, instead of a single standard, are presented. From an interval-based perspective, explaining better discrimination with multiple (standard) interval presentations in the first sequences places the locus of threshold improvement in memory (multiple-look model: Drake & Botte, 1993).

In an experiment designed to test the effect of the number of intervals on duration discrimination, participants were presented with two sequences, each consisting of 1 or 4 intervals (marked by 2 or 5 signals), and asked to indicate whether the interval(s) of the second sequence was (were) shorter or longer than the interval(s) of the first (Grondin & McAuley, 2007). Figure 1 shows the effect of the sequence length in conditions where the standard (= 500 ms) is presented first (left panel) or second (right panel). The results generally reveal that more intervals in Sequence 1 increase sensitivity but not when the standard is presented second and Sequence 2 has only one interval. However, having four intervals instead of one in Sequence 2 leads to better performances (see also Miller & McAuley, 2005). Indeed, additional investigations by Grondin and McAuley with different sensory modality conditions have shown that increasing the number of comparison (variable) intervals is a determinant factor. In other words, sensitivity level is not simply linked to increasing the number of intervals in the first sequence in order to reduce memory variance. Finally, it should be noted that the order of the intervals (standard in Sequence 1 vs. 2) is also a critical factor.