Continuity perception in stimulus patterns consisting of two partly overlapping frequency glides

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Abstract

Two physically separated frequency glides that partly overlap each other can be perceived as one continuous pitch trajectory, accompanied by a short tone in the temporal middle. This “middle tone” can be perceived even when the glides are separated by more than one critical bandwidth [Nakajima et al., (2000). Perception & Psychophysics, 62(7), 1413-1425]. Here, the perception of the continuous pitch trajectory was investigated. It was found that the perceptual continuity also appears when the frequency separation between the glide components was larger than a critical bandwidth, or one ERB. Moreover, the continuity perception in stimulus patterns with two partly overlapping frequency glides was found to be as compelling as that in stimulus patterns where the overlap was replaced with an intense noise band of the same duration. That is, the perceptual continuity of the long trajectory in the present paradigm is comparable to a typical auditory continuity effect. The experiments show that any explanation of the perceptual continuity of the pitch trajectory cannot be easily given in terms of peripheral activity alone.

Keywords: auditory organization, frequency glides, auditory continuity, critical bandwidth

部分的に重なり合った二つの周波数変化音からなる刺激パターンにおける連続性の知覚

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概要

時間および周波数域上で分離しており、時間上で部分的に重なり合うような、二つの周波数変化音は、高さが連続的に変化する一つの音と、その時間的中央にあるもう一つの短い音として知覚されることがある。この「真中の音」は、二つの周波数変化音が臨界帯域幅より離れているときにも知覚される場合がある [Nakajima et al., (2000). Perception & Psychophysics, 62(7), 1413-1425]。本論文では、高さが連続的に変化する音の知覚について調べた。知覚上の連続性は、二つ
の周波数変化音が臨界帯域幅、あるいは ERB よりも大きく離れている場合にも生ずることが見出された。更に、部分的に重なり合った周波数変化音において知覚される連続性は、重なった部分を、持続時間の等しい強い帯域雑音に置き換えた刺激パターンにおいて知覚される連続性に匹敵する。すなわち、ここでの実験の枠組みにおいて得られる、高さが連続的に変化する音の知覚上の連続性は、典型的な連続聴効果に比べるものである。そして、この連続性に対して、未梢のみによる説明を与えることはできない。

キーワード：聴覚体制化、周波数変化音、連続聴、臨界帯域幅

**Introduction**

Two partly overlapping glide tones can be perceived as one continuous pitch trajectory, accompanied by a short tone in the temporal middle (1). This percept can appear when both glides are either ascending or descending, and even when the frequency separation between the glides is as large as 0.3 octave (Nakajima et al., 2000). The appearance of this percept can be explained by a model of the perceptual construction of auditory events, the “event construction model.” According to this model, auditory events can be results of the perceptual connection of onsets and offsets of sounds, which can be perceptually connected when they are close together in frequency and time. The basic assumption of the model is that the auditory system treats onsets and offsets as independent entities. Therefore, even when an onset and an offset belong to physically different sounds, they can constitute and belong to the same auditory event perceptually.

When two frequency glides partly overlap each other, the onset of the second glide and the offset of the first glide are close to each other in time and frequency under conditions of a short overlap duration and a small frequency separation between the glides. The proximity seems to cause the perceptual connection of the first glide’s offset to the second glide’s onset, resulting in a subjectively constructed short tone. This short tone is referred to as the “middle tone.” Because of the perceptual allocation of the onset and the offset to the middle tone, the first glide component in the percept lacks an offset, and the second glide component lacks an onset. The remainders of the first and the second glide are therefore not eligible to be perceived as independent auditory events. Since excitation patterns are, at least partially, present between the two glides to accommodate their perceptual connection, a long pitch trajectory is perceived (Figure 1).

Nakajima et al. (2000) thus showed that the physical simplicity of a stimulus pattern does not necessarily facilitate the veridical perceptual solution, namely that of two overlapping pitch trajectories separated in pitch. Instead, the auditory system often resolves the stimulus pattern into a long pitch trajectory and a short middle tone
Figure 1. The perception of two partly overlapping glide tones. The left plane of the figure shows a stimulus pattern of two physically separate glide tones that partly overlap each other. The right plane shows a typical percept consisting of a single continuous pitch trajectory, accompanied in the temporal middle by a short, often louder, tone.

(see also Sasaki and Nakajima, 1996). The perceptual continuity of two physically separate glide tones seems to be related to the typical auditory continuity effect (e.g. Warren, 1999; Ciocca & Bregman, 1987). And we decided to take up the appearance of the continuous pitch trajectory to further investigate the perception of two partly overlapping frequency glides. In Experiment 1, a rating scale was used to investigate under what physical conditions a long continuous pitch trajectory can be perceived. Related experimental results obtained by Nakajima et al. (2000) were not easy to analyze quantitatively. The phenomenological reports obtained in their experiment did not give a clear picture about the relative perceptual continuity of the long pitch trajectory under different conditions of frequency separation between the overlapping glides. In Experiment 2, comparisons were made between the continuity as perceived in the present paradigm and the continuity as perceived in stimulus patterns that cause a typical auditory continuity effect. The latter stimulus patterns consisted of two separate frequency glides, interrupted by a noise, as in Ciocca and Bregman (1987).

As for the middle tone, Nakajima et al. (2000) found that it sometimes could be perceived even when the glides were separated by 1.3 octaves. Accordingly, they concluded that the perceptual connection of the onset of the second glide and the offset of the first glide "cannot be attributed simply to the activity of the peripheral system associated with critical bands or auditory filters" (Nakajima et al., 2000). On the other hand, they found that the continuity of the long pitch trajectory could be perceived only when the frequency separation between the glides was 0.3 octave or smaller. A frequency separation of 0.3 octave is not far from a frequency separation of a critical bandwidth (Zwicker & Fastl, 1999), or one equivalent rectangular band-
width (ERB), a measure of a critical bandwidth proposed by Glasberg and Moore (1990). Two spectral components that lie within a critical bandwidth fully interact with each other (Moore, 1997), and we investigated whether the continuity perception of the long pitch trajectory depends on this interaction or not.

**Experiment 1**

Judgments of the perceptual continuity of the long pitch trajectory were gathered by utilizing a variety of frequency separations expressed in critical bandwidths, instead of octaves. The set of stimulus patterns was expanded also with variations in the slope and the overlap duration of the glide tones. Because Nakajima et al. (2000) found no substantial differences between the perception of descending and ascending stimulus patterns, only stimulus patterns with two partly overlapping ascending glides were used.

**Method**

**Stimuli and Apparatus.** All stimulus patterns consisted of two partly overlapping ascending glides of 1200 ms each. The rise time of the first glide was 200 ms and the fall time 4 ms, with linearly shaped ramps. Conversely, the rise time of the second glide was 4 ms, and the fall time 200 ms. The glides could overlap each other for 100, 200, 400, or 800 ms, making the total duration of the stimulus patterns 2300, 2200, 2000, and 1600 ms, respectively. The slope of the glides was 0.5, 1.0, or 1.5 octaves per second.

The frequency separation between the overlapping glide tones was 0.5, 0.75, 1.0, 1.5, or 3.0 times a critical bandwidth of the reference frequency, from which the stimulus patterns were calculated. The reference frequency between the two components at the temporal midpoint of each stimulus pattern was fixed at 1600 Hz. The critical bandwidth at this point is 240 Hz, as interpolated from the data reported by Zwicker and Fastl (1999). The ERB at this reference frequency is 197.4 Hz (Glasberg & Moore, 1990). In this experiment, the value of 240 Hz was used to calculate the frequency separation between the overlapping glides. For each stimulus pattern, the frequency separation value was divided by two, and this value was both added to and subtracted from the reference frequency. This resulted in two frequency points at the temporal middle of the stimulus pattern, from which the first and the second glide were calculated linearly on a log scale. Combining the variations in overlap duration, slope, and frequency separation, a total of \(4 \times 3 \times 5 = 60\) stimulus patterns was generated.

The stimulus patterns were generated by a computer (Hewlett Packard MPS-500 with a TEAC PS 9353 D/A converter), low-pass filtered at 7 kHz, and recorded on a
DAT (Digital Audio Tape) with a DAT deck (Sony 500-ES) in random order. The stimulus patterns were presented to the participant in a sound proof booth via a DAT deck (Sony 500-ES) and an amplifier (Sansui 607 KX) through headphones (Rion AD 02) monaurally to the left ear. The sound levels maximally reached 74 dBA (fast-peak), as measured with a sound level meter (Brüel & Kjaer 2209), and an artificial ear (Brüel & Kjaer 4152), mounted with a microphone (Aco 7023).

Participants. Six students, two females and four males, took part in the experiment. They had received basic training in music, and training in technical listening for acoustic engineers. They were 21-25 years of age. The participants had normal hearing. They were paid for their participation.

Procedure. The participant was asked to judge the continuity, in pitch and in time, of the ongoing pitch trajectory of each stimulus pattern. The judgments were made on a 9-point rating scale. The right extreme of the scale, the number "9", corresponded to an ongoing trajectory that was completely continuous, i.e., did not stop to exist in time and was coherent with respect to pitch trajectory and loudness. The left extreme of the scale, the number "1", indicated that the pitch trajectory was discontinuous, i.e., consisted of two successive sounds. The participant received two differently randomized sessions, each consisting of the 60 stimulus patterns in random order, and performed four warm-up trials before starting each session and after each break. In each trial, a stimulus pattern was presented three times, with silent intervals of 3 s between each presentation. The silent time between consecutive trials was 10 s. The participant was asked to give his/her judgment on the continuity of the pitch trajectory during the silent intervals between presentations or during the 10 s before the start of the next trial. The participant was allowed to take a break at any time he/she wanted during the task, and was required to take a break between the two sessions. The whole experiment lasted about one hour.

Results and Discussion

Figure 2 (a-c) depicts the means of the judgments of the perceptual continuity of the pitch trajectory. The data for the 60 stimulus patterns, which were judged twice by each of the six participants (12 times in total), were subjected to the Friedman analysis of variance. For \( n = 12 \) and \( df = 60 - 1 = 59 \), the obtained \( F = 229.7 \) (not corrected for ties) was significant \((p < 0.05)\), and multiple comparisons followed.

No significant differences existed between stimulus patterns with slopes of 0.5, 1.0, and 1.5 octaves per second, under equal values of overlap duration and frequency separation. As for the variations in frequency separation, though, a number of significant differences was found. In five cases, the stimulus patterns with frequency separations of 3 times the critical bandwidth were judged as yielding less continuous
pitch trajectories than the stimulus patterns with frequency separations of 0.75 or 0.5 time the critical bandwidth. The significant cases are indicated in Figure 2 (a-c). The comparisons between the perceptual continuity scores for stimulus patterns in which the glides were separated by 0.5, 0.75, 1, and 1.5 times the critical bandwidth, on the other hand, showed no significant differences at all. As can be seen from Figure 2 (a-c), the mean continuity scores in general showed a gradual decline in perceptual continuity with increasing frequency separation between the glides, for patterns with overlap durations of 100 ms through 400 ms. The perceptual continuity of the pitch trajectory did not disappear suddenly when the glide tones were separated by more than one critical bandwidth at the temporal midpoint of the stimulus patterns. The notions of the critical band or ERB do not seem to play a decisive role in explaining the mechanism behind the continuity perception of the long pitch trajectory.

The judgment scores in Figure 2 (a-c) seem to suggest that the continuity of the long trajectory weakened when the overlap duration was 800 ms. Closer inspection of the data revealed that this was the case for five of the six participants and that this trend appeared in stimulus patterns with frequency separations of 0.5 through 1.5 times the critical bandwidth. The stimulus patterns in which the glides were separated by 3 critical bandwidths, on the other hand, did not show this trend. As discussed before, the judgment scores of these stimulus patterns already showed a relatively low perceptual continuity compared with the other patterns. Regarding the possible influence of overlap duration on perceptual continuity, therefore, the stimulus patterns with the largest frequency separation did not seem to provide much information, and they were left out of the following analysis. Three separate Friedman tests were done, corresponding to each variation in slope (0.5, 1, and 1.5 octaves per second). The scores obtained from the stimulus patterns with frequency separations of 0.5, 0.75, 1, and 1.5 critical bandwidths were averaged for each of the four overlap durations (100, 200, 400, and 800 ms), for each of the six participants. The three tests ($n=6$, $df=4-1=3$) all showed a significant difference ($p<0.05$) in the perceptual continuity between patterns with a 100 ms overlap and an 800 ms overlap. Next to an increase in frequency separation, an increase in overlap duration thus seems to have an effect on perceptual continuity, although more systematic research needs to be done to confirm this observation.

**Experiment 2**

In Experiment 1, only relative comparisons were made between a variety of stimulus patterns that all consisted of two partly overlapping frequency glides. In Experiment 2, the continuity of the pitch trajectory perceived in such patterns was compared with the continuity as perceived in stimulus patterns consisting of two
Slope: 0.5 octave / second

Slope: 1.0 octave / second

Slope: 1.5 octave / second

Figure 2. Mean continuity judgments in Experiment 1 (n = 12). The graphs (a-c) show the mean continuity judgments regarding the long pitch trajectory perceived in stimulus patterns of two partly overlapping glides. The reference frequency of the stimulus patterns is 1600 Hz, and the corresponding critical bandwidth is 240 Hz, as interpolated from Zwicker and Fastl (1999).
separate glides that immediately precede and follow a noise band, as used by Ciocca and Bregman (1987). The latter stimulus patterns cause a typical auditory continuity effect: when the noise band is sufficiently intense, e.g., 20 dB more intense than the pre-noise and the post-noise glide as in Ciocca and Bregman (1987), the whole pattern can be perceived as comprising a single, continuous trajectory with a short, loud noise in the temporal middle of the trajectory. The physical overlap in the present paradigm, however, is only 3.01 dB more intense than the flanking glide context. Comparisons with stimulus patterns that yield typical auditory continuity would indicate whether this affects the perceptual continuity of the long pitch trajectory or not.

**Method**

**Stimuli and Apparatus.** A total of 23 stimulus patterns was generated. All patterns were calculated from an 800 Hz reference frequency at the temporal midpoint of the stimulus patterns in the same way as in Experiment 1. Since stimulus patterns with noise bands that span two octaves were generated in this experiment, the 1600 Hz reference frequency as used in Experiment 1 was not used here. Creating noise bands that span two octaves from a reference frequency of 1600 Hz might result in relatively loud noise components at frequencies higher than 3 kHz. In order to prevent any noise components from standing out too much perceptually, the 800 Hz reference frequency was used. Pilot studies, as well as the experiment of Nakajima et al. (2000) in which a 1000 Hz reference frequency was used, had shown that a continuous pitch trajectory could also be perceived at reference frequencies lower than 1600 Hz.

Eight of the stimulus patterns (Figure 3a) consisted of two ascending frequency glides that were interrupted by a more intense noise in the temporal middle. The duration of each glide was 1202 ms. The duration of the noise was either 100 or 400 ms. The glides would have been separated, if they had been extended through the noise, by 0.0, 0.5, 1.0, or 1.5 critical bandwidths. At the present reference frequency of 800 Hz, the critical bandwidth was 148 Hz, as interpolated from the values proposed by Zwicker and Fastl (1999). The ERB at 800 Hz was 111 Hz, calculated from Glasberg and Moore's (1990) data. The value of 148 Hz was used in this experiment. A frequency separation of zero implied that the two glide components before and after the noise aligned on a single trajectory in logarithmic frequency.

The glides had a slope of 1 octave per second. The glide before the noise band had a rise time of 200 ms and a fall time of 4 ms, and ended 2 ms after the start of the noise band. Conversely, the glide after the noise band had a rise time of 4 ms and a fall time of 200 ms, and started 2 ms before the end of the noise band. The ramps were linearly shaped. The slope, duration, and rise and fall times of the glides were kept the same throughout the experiment. The overall intensity of the noise band
Figure 3. Stimulus patterns used in Experiment 2. A noise band flanked by two weaker frequency glides is indicated in (a). The overall intensity of the noise was 20 dB higher than that of the glide components (13 dB within a critical bandwidth). In the stimulus patterns as depicted in (b), the noise had an equal overall intensity compared with the frequency glides (-7 dB within a critical bandwidth). In (c), two partly overlapping frequency glides are depicted. The overall intensity of the overlap was 3.01 dB higher than that of the surrounding glide context.
was 20 dB higher than that of the glide tones (13 dB higher within a critical bandwidth, as interpolated from Zwicker and Fastl, 1999).

The noise band covered a frequency range of 400-1600 Hz. The frequency range was divided and numbered into 96 equal units (from 1 to 96) on a logarithmic scale. For each n from 1 to 95, one spectral component was randomly chosen from either unit n or unit n+1. One component was chosen randomly from either unit 96 or unit 1. All the components had equal amplitudes, random initial phases, and random frequencies. Of the 96 steady-state components, 47 to 49 components had random frequencies in the 400-800 Hz frequency range, whereas the other 47 to 49 components fell in the 800-1600 Hz range. The rise and fall time of the noise was 4 ms.

The only change in the next eight patterns (Figure 3b) was that the two ascending frequency glides were interrupted in the middle by a noise with an overall intensity that was equal (0 dB) to that of the glides. (7 dB lower than the glides within a critical bandwidth, as interpolated from Zwicker and Fastl. 1999). The same variations in noise duration (100 or 400 ms) and frequency separation between the glides (0.0, 0.5, 1.0, 1.5 critical bandwidths) were used and combined to generate the stimulus patterns.

The next six stimulus patterns (Figure 3c) consisted of ascending frequency glides that partly overlapped each other in the temporal middle. The glides had a slope of 1 octave per second. The frequency separation between the glides was 0.5, 1.0, or 1.5 times a critical bandwidth of the 800 Hz reference frequency. In three stimulus patterns, glides of 1300 ms each overlapped each other for 100 ms. These stimulus patterns had the same total duration as the stimulus patterns with the noise band of 100 ms. In the other three stimulus patterns, two glides of 1600 ms overlapped each other for 400 ms. These stimulus patterns had the same total duration as the stimulus patterns with a 400 ms noise band. In these six stimulus patterns that consisted of partly overlapping glide tones, the overall intensity difference between the physical overlapping part and the flanking glide context was 3.01 dB. The last stimulus pattern consisted of a physically continuous, single ascending glide of 2500 ms that moved through the 800 Hz reference point. The slope of the glide was 1 octave per second. This condition was a control condition. The same apparatus as in Experiment 1 was used. The sound pressure levels maximally reached 72 dBA (fast-peak).

Participants. Four of the participants who took part in Experiment 1 also took part in this experiment. They were two male and two female students, who received basic training in music and training in technical listening for acoustic engineers. They were 23-25 years of age, and all had normal hearing. They were paid for their participation.

Procedure. The procedure was similar to that of Experiment 1. The participants were asked to judge the continuity of the ongoing pitch trajectory in each
stimulus pattern twice, in two differently randomized sessions, each consisting of the 23 stimulus patterns. The task lasted about 40 minutes in total.

Results and Discussion

Figure 4 shows the mean continuity judgments. The data were subjected to a sign test (two-tailed; \( p < 0.05 \)) and each data point was compared with each other data point. Regarding overlap duration, no significant differences existed between the continuity judgments for stimulus patterns with overlaps of 100 and 400 ms, under equal conditions of frequency separation between the glides. This corresponds to the results of Experiment 1, in which duration was found to have no influence on the perceptual continuity of the pitch trajectory either, regarding stimulus patterns with overlaps of 100, 200, and 400 ms. Under equal values of frequency separation and relative noise intensity, no significant differences were found between stimulus patterns with noises of 100 and 400 ms as well.

The single, physically continuous glide, that served as a control condition, was significantly more continuous than any pitch trajectory in stimulus patterns with two physically separate glides, either overlapping each other or interrupted by a noise

![Frequency separation (CB)](image)

**Figure 4.** Mean continuity judgments in Experiment 2. The graph depicts the mean continuity judgments regarding the long pitch trajectory perceived in stimulus patterns consisting of two partly overlapping glides (gray dots, cf. Figure 3c), and stimulus patterns in which the overlap was replaced by an intense noise (black dots, cf. Figure 3a) or a weak noise (white dots, cf. Figure 3b).
band. Concerning the effect of frequency separation in the latter patterns, no large differences in continuity perception appeared, with values of overlap/noise duration and relative intensity level of the interrupting noise being equal. Only two significant cases were found (Table 1). That is, when two aligning glides flanked a more intense noise band of 100 ms (+20 dB), a significantly better perceptual continuity for the pitch trajectory was found than when the two flanking glide components were separated by 1.5 times a critical bandwidth (2 ERBs). The perceptual continuity of glide tones separated by 0.5 times a critical bandwidth and an overlapping part of 100 ms was also significantly better than that of two glides separated by 1 critical bandwidth and with the same overlap duration. Similar to the results of Experiment 1, though, when the overlapping glide tones were separated by 1.5 times the critical bandwidth, the perceptual continuity of the pitch trajectory did not disappear (Figure 4).

Regarding the relative intensity of the noise that interrupted the glide tones, a number of significant differences was found (Table 1, Figure 4). The stimulus patterns in which the overall level of the noise was equal to that of the glide components (0 dB) were generally judged as having a less continuous pitch trajectory than the other stimulus patterns, with other parameter values being equal. This is in line with the widely accepted idea that, for typical auditory continuity to occur, the interrupting sound should be sufficiently more intense than the flanking sounds (Warren, 1999).

The differences in the perceptual continuity between the stimulus patterns with

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Table 1

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<th>Duration noise/overlap (ms):</th>
<th>Stimulus pattern:</th>
<th>Frequency separation glides (cbs):</th>
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<td>noise +20 dB</td>
<td>0.0</td>
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<tr>
<td>100</td>
<td>glides +3 dB</td>
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<td>400</td>
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Sign test: *p < .05
**p < .01

The significant differences regarding the perceptual continuity of the stimulus patterns used in Experiment 2. The stimulus patterns in the left plane yielded a significantly more continuous pitch trajectory than the stimulus patterns in the right plane. The upper two stimulus pairs show a significant difference in the perceptual continuity of the pitch trajectory caused by the frequency separation between the glide tones. The remaining four comparisons are between stimulus patterns in which significant differences in perceptual continuity were caused by the relative intensity difference between the more intense overlap/noise and the surrounding glide components.
the relatively intense noise (+20 dB) and those with the overlapping part (+3 dB) were surprisingly small. No significant differences were found between the stimulus patterns with the intense noise bands and those with the glide overlaps, under equal values of frequency separation and "overlap/noise" duration. It seemed that the overlapping part and the relatively intense noise band were almost interchangeable in accommodating auditory continuity.

General Discussion

When two physically separate glide tones partly overlap each other, a long pitch trajectory accompanied by a short tone in the temporal middle of the pitch trajectory can be perceived (Nakajima et al., 2000). Here, we concentrated on the appearance of the long pitch trajectory, and the results of the experiments showed that it appears quite robustly. The long pitch trajectory is significantly clearer when the slope of the glides is 0.5, 1.0, or 1.5 octaves per second, and the duration of the overlap is 100, 200, or 400 ms. Furthermore, it appears to a certain degree when the frequency separation between the glide tones ranges from 0.5 through 1.5 times the critical bandwidth of an 800 or 1600 Hz reference frequency at the temporal midpoint of the stimulus pattern. Although more research needs to be done on these parameters and parameters such as the duration of the glide tones, the common tendency in Figure 2 suggests that the continuous, long pitch trajectory disappears gradually when the overlap duration becomes longer and the frequency separation becomes larger.

Many studies on auditory integration and segregation of sound, for example, studies on auditory streaming, reflect the tendency of the auditory system to integrate components of similar frequencies (Bregman, 1990). The experiments reported here reflect this tendency. However, it is to be noted that, even when the frequency separation was larger than a critical bandwidth, two physically separate glides could be integrated into a single, continuous trajectory. The finding that the perceptual continuity of the long pitch trajectory becomes weaker when the overlap duration becomes very long corresponds to the experimental results on typical auditory continuity (Dannenbring, 1976; Bregman et al., 2000). Bregman et al. (2000) found that the inter-stimulus interval (ISI) is essential for the sequential integration of sound. and argued that, in studies of typical auditory continuity, a shortening of the sound that interrupts weaker sounds leads to a decrease in the ISI between the weaker sounds, which then become more liable to perceptual integration. This seems to hold for the perceptual continuity of the pitch trajectory in stimulus patterns with two partly overlapping glides as well.

Moreover, Experiment 2 revealed that the perceptual continuity of a long pitch trajectory, as caused by stimulus patterns with two partly overlapping glides, is
similar in its degree to the continuity of a pitch trajectory as heard in stimulus patterns that evoke a typical auditory continuity effect. However, the stimulus patterns investigated here differ from stimulus patterns that cause typical auditory continuity in some important aspects.

First, stimulus patterns that cause typical auditory continuity consist of weaker sounds that alternate with a more intense sound. In the stimulus patterns consisting of overlapping glides, however, the louder middle tone is physically not existing as such. As suggested by Nakajima et al. (2000), the middle tone may be a result of the perceptual connection of the onset of the second glide to the offset of the first glide. However, both the onset and the offset component physically do not contain the frequency points that can bridge the remainders of the two long glides outside the overlap. Nevertheless, the remainders of the two glides could be perceived as a single, long trajectory. It is possible, though, that the perceived middle tone has a pitch that exactly covers the frequency gap between the two components, and more data on this matter should be gathered.

Second, in studies of typical auditory continuity, the existence of a large level difference between the more intense sounds and the weaker sounds is one of the prerequisites for continuity perception of the softer trajectory (Warren, 1999). A value of 3 dB was named as the minimal level difference ("pulsation threshold") necessary for the perception of auditory continuity between pure tones of the same frequency (Warren et al., 1972). In the present paradigm, the relative level difference between the overlapping part and the surrounding glide context was 3.01 dB, and a long, continuous pitch trajectory could be perceived quite robustly even when the sound energy of the overlapping part was distributed to more than one critical bandwidth. Informal listening also indicated that perceptual continuity can be accommodated by an even less intense overlapping part. When five listeners were presented with a stimulus pattern in which the intensity of the overlapping part of two glides was lowered by 3 dB, they all perceived a continuous pitch trajectory, accompanied by a relatively soft middle tone.

Whether the continuity perception in the present paradigm is solely based on peripheral activity can be questioned by the results obtained from stimulus patterns in which the glide tones were separated by more than a critical bandwidth, or an ERB, of the reference frequency at the temporal midpoint of the stimulus patterns. When two pure tones are placed within a critical band, they interact fully and, in the stimulus patterns as studied here, may give rise to a continuous pitch trajectory. However, continuity perception appears even when the glide tones are placed outside a critical bandwidth. The present study shows also that the overlap can take the role of an intense noise to facilitate perceptual continuity.
References


Authors' Notes

(1) Related demonstrations are available on the second author's website (http://www.kyushu-id.ac.jp/~ynhome/index.html). The present study was supported by the Japan Society for The Promotion of Science (Grant-In-Aid for Scientific Research 10610076 in the Fiscal years 1998, 1999, 2000, and 2001).

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