The perceptual integration of auditory onsets and offsets in stimulus patterns of two partly overlapping frequency glides

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CHAPTER 6: Typical auditory continuity and the perceptual mechanism behind the pitch trajectory in double-glide stimulus patterns.

6.1 General purpose

In Experiments 9 and 10, the perceptual mechanism behind the perception of the long pitch trajectory in stimulus patterns consisting of partly overlapping glides is further investigated and discussed. In Experiment 9, participants are asked to judge the perceptual continuity as perceived in the double-glide stimulus patterns and in stimulus patterns that render typical auditory continuity. In Experiment 10, stimulus patterns are used that consist of a long and a short glide that cross each other, and share a short temporal gap at the crossing point. This new experimental paradigm is used to test the hypothesis of Nakajima et al. (2000) with regard to the perceptual continuity of the pitch trajectory in the 'gap transfer' illusion and the double-glide stimulus patterns.

6.2 Experiment 9: Judging the perceptual continuity of the pitch trajectory as perceived in double-glide stimulus patterns and in stimulus patterns that render typical auditory continuity.

6.2.1 Purpose

When two pure frequency components of equal intensity are presented simultaneously, the intensity of the two-tone complex increases with 3.01 dB (Moore, 1997). Physically, the overlapping part of the double-glide stimulus patterns is thus more intense than the glide components outside the overlap. In this respect, the double-glide stimulus patterns resemble those that render typical auditory continuity as discussed in the Introduction (for a review: Warren, 1999). For example, a stimulus pattern consisting of a noise band that is flanked by two glides can be perceived as consisting of a long, gliding pitch trajectory that continues through the noise band, even though physically no other sound is present behind the noise (Ciocca & Bregman, 1987). The level difference of 3 dB between the more intense overlap and the weaker glide components outside the overlap, however, is rather small compared with the level difference between the weaker and more intense sounds in stimulus patterns that render typical auditory continuity. In these stimulus patterns, an intensity difference of 3 dB between the more intense sounds and the weaker sounds is generally 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 most studies of typical auditory continuity, therefore, the interrupting sound is made much more intense (10 dB or more) than that of the weaker sounds.

A widely accepted idea behind this, it that for typical auditory continuity to occur, the more intense sound should have the potential to mask the softer sound, had the softer sound actually been present behind the more intense sound (Warren, 1999). As described in Chapter 3, for one sound to mask another, a sufficient level difference is necessary. The masking potential of a sound also improves when its frequency is close to that of the sound it is masking. When the frequency difference is large, the masking potential deteriorates and can only be restored by increasing the intensity difference even more. In the double-glide stimulus patterns, however, the intensity of the overlap is relatively weak, and, in theory, its masking potential is insufficient. Therefore, in the next experiment, it is investigated how convincing the continuity of the pitch trajectory as heard in double-glide stimulus patterns actually is, compared with typical auditory continuity. Next, the role of the masking potential of the overlap in accommodating perceptual continuity in the double-glide stimulus patterns is discussed. A rating scale is used to obtain data about the continuity in double-glide stimulus patterns and stimulus patterns that give rise to typical auditory continuity.

6.2.2 Method

Stimulus patterns

A total of 23 stimulus patterns was generated. All stimulus patterns were calculated from an 800 Hz reference frequency at the temporal midpoint of the stimulus patterns in the same way as in the former experiments. Eight of the stimulus patterns (Figure 22A) consisted of two ascending 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 reference frequency of 800 Hz, the critical bandwidth is 148 Hz, as interpolated from the values described by Zwicker and Fastl (1999). The ERB at 800 Hz is 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 one 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 was 20 dB higher than that of the glide tones (13 dB higher within a critical bandwidth, as interpolated from Zwicker and Fastl, 1999).

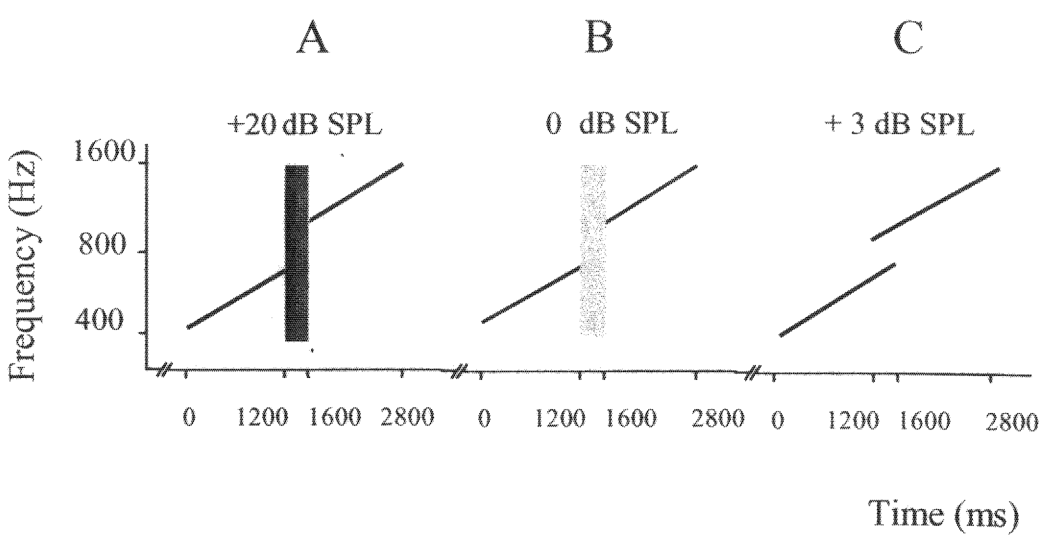

Figure 22. *Stimulus patterns used in Experiment 9. A noise band flanked by two weaker glides is indicated in (A). The overall intensity of the noise was 20 dB higher than that of the glide components (13 dB higher within a critical bandwidth). In the stimulus patterns as depicted in (B), the noise had an equal overall intensity compared with the glides (7 dB lower within a critical bandwidth). In (C), two partly overlapping glides are depicted. The overall intensity of the overlap was 3.01 dB higher than that of the surrounding glide context.*

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 22B) was that the two ascending 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 22C) consisted of ascending glides that partly overlapped each other in the temporal middle. The glides had a slope of one 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 the 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 one octave per second. This stimulus pattern was used as a control condition.

Apparatus

The same apparatus was used as in Experiment 6. The sound pressure level of the stimulus patterns maximally reached 72 dBA (fast-peak).

Participants

Four participants 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 had normal hearing. They were paid for their participation.

Procedure

The procedure was similar to that of Experiment 6. The participant was asked to judge the continuity of the ongoing glide trajectory with a 9-point rating scale. The participant was asked to judge each stimulus pattern three times, in three differently randomized sessions, each consisting of the 23 stimulus patterns. One session was used as training and was not included in the statistical analysis. Before each session, the participant received three warm-up trials. The task lasted about 40 minutes in total.

6.2.3 Results and discussion

Figure 23 shows the mean continuity judgments. The data were subjected to a sign test (two-tailed) 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 6 and 7, in which overlap duration was found to have no significant influence on the perceptual continuity of the glide trajectory either, regarding stimulus patterns with overlaps of 100, 200, 400, and 600 ms. Experiments 6 showed, however, some significant effects of overlap duration when longer overlap durations of 800 ms were used. As for noise duration in the present experiment, 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.

The single, physically continuous glide, that served as a control condition, was significantly more continuous than the pitch trajectory in stimulus patterns with two physically separate glides, either overlapping each other or interrupted by a noise band. Concerning the effect of instantaneous 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 3). 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 the former experiments, though, when the overlapping glide tones were separated by 1.5 times the critical bandwidth, the perceptual continuity of the glide trajectory did not disappear.

Regarding the relative intensity of the noise that interrupted the glide tones, a number of significant differences was found (Table 3, Figure 23). 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 idea that, for typical auditory continuity to occur, the interrupting sound should be sufficiently more intense than the flanking sounds (Warren, 1999).

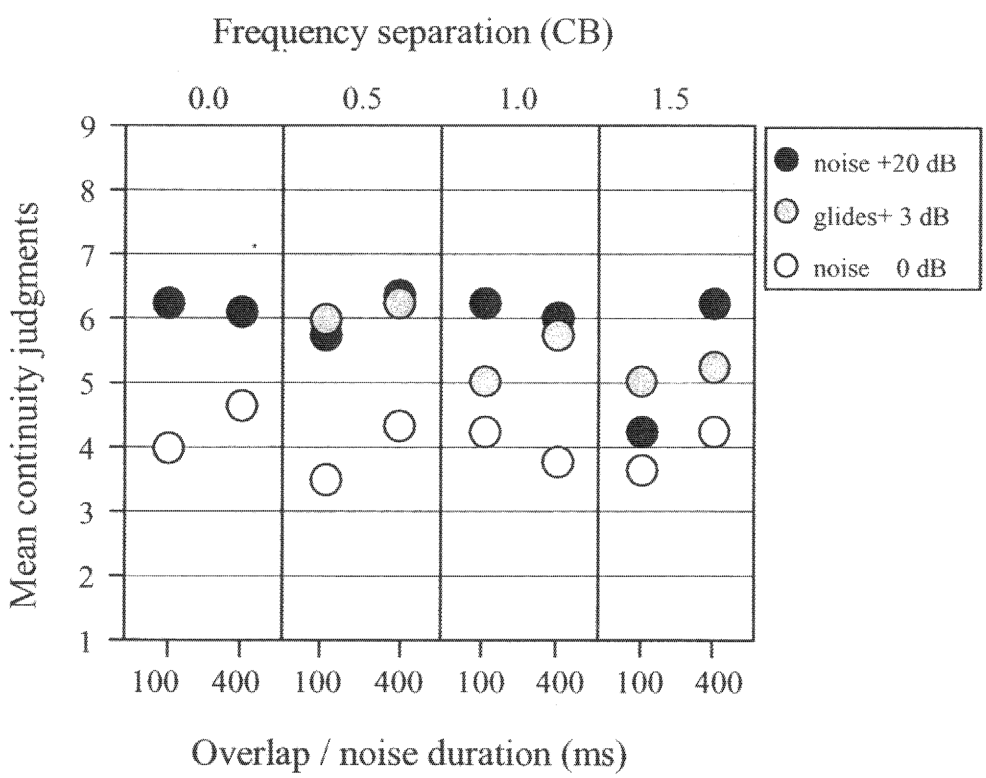

Figure 23. *Mean continuity judgments obtained in Experiment 9. The graph depicts the mean continuity judgments regarding the long pitch trajectory perceived in stimulus patterns consisting of two partly overlapping glides (gray dots, cf. Figure 22C), and stimulus patterns in which the overlap was replaced by an intense noise (black dots, cf. Figure 22A) or a weak noise (white dots, cf. Figure 22B).*

Table 3. *Significant differences ($p<0.05$) in the perceptual continuity of stimulus patterns used in Experiment 9. The upper two comparisons are between stimulus patterns in which the relative intensity level and the duration of the interrupting sound are equal. The remaining four comparisons are between stimulus patterns in which the instantaneous frequency separation and the duration of the interrupting sound are equal.*

Overlap / Noise Duration (ms):	Stimulus Pattern: (Intensity relative to glide context within a critical bandwidth)	ΔFreq. (Hz):	more continuous than:	Stimulus Pattern: (Intensity relative to glide context within a critical bandwidth)	ΔFreq. (Hz):
100	Noise (+13 dB)	0.0	>	Noise (+13 dB)	1.5
100	Glides (+ 3 dB)	0.5	>	Glides (+ 3 dB)	1.0
100	Noise (+13 dB)	0.5	>	Noise (-7 dB)	0.5
100	Noise (+13 dB)	1.0	>	Noise (-7 dB)	1.0
100	Glides (+ 3 dB)	0.5	>	Noise (-7 dB)	0.5
400	Noise (+13 dB)	1.5	>	Noise (-7 dB)	1.5

The differences in the perceptual continuity between the stimulus patterns with 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. Even though the relative intensity of the overlap is similar to the value that represents the pulsation threshold in typical auditory continuity, the perceived continuity of the pitch trajectory in the double-glide stimulus patterns did not deteriorate. Informal observations have shown that perceptual continuity can be heard when the overlap of the double-glide stimulus patterns is even less intense. When five listeners were presented with a stimulus pattern in which the intensity of the overlap of two glides was lowered by 3 dB, they all perceived a continuous pitch trajectory, accompanied by a relatively soft middle tone. The masking potential of the overlap in the double-glide stimulus patterns thus does not seem to determine the perceptual continuity of the pitch trajectory. This may indicate that the mechanism behind the perceived continuity in the double-glide stimulus patterns differs from the mechanism behind typical auditory continuity. In the following experiment, the perceptual mechanism behind the perceptual continuity in stimulus pattern consisting of partly overlapping glides is further investigated.

6.3 Experiment 10: Perceptual continuity of two crossing glides that share a short temporal gap at the crossing point

6.3.1 Purpose

An explanation for the appearance of the long pitch trajectory in the double-glide stimulus patterns may be that it appears as a consequence of the perceptual connection of the onset and the offset that delimit the overlap, as suggested by Nakajima et al. (2000). As a consequence of the attribution of the onset of the second and the offset of the first frequency component to the middle tone, the two glides are left without an offset and an onset, respectively. The simplest solution of the stimulus pattern for the auditory system is then to interpret the remaining glide components as a single pitch trajectory. In the following experiment, stimulus patterns that consist of a short and a longer glide crossing each other are used. These glides share a very short temporal gap at the crossing point. Figure 24 depicts a typical stimulus pattern. The gap in the temporal middle was 20, 50, or 100 ms in the experiment.

An important aspect of the stimulus pattern is that the offsets and onsets of the short and long glides before and after the gap occur at the same points in time. According to Bregman (1990), it is plausible that the perceptual integration of acoustically different sounds is facilitated when the sounds start and stop at the same time. Therefore, the synchrony of the stimulus edges that delimit the gap in the stimulus patterns, may promote the perceptual integration of the offsets of the short and the long glide just before the gap, and the integration of the onsets of the short and the long glide just after the gap. Since the two offsets, as well as the two onsets, are also close together in frequency, listeners may perceive only a single offset and a single onset surrounding the gap (Figure 25).

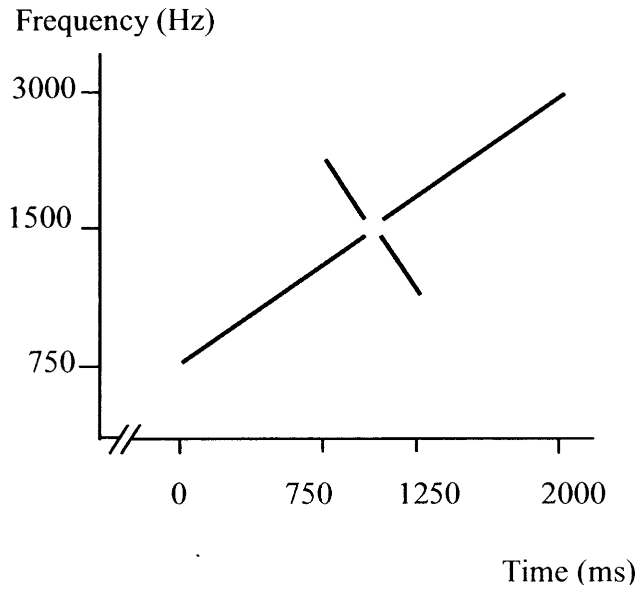

Figure 24. *Example of a stimulus pattern used in Experiment 10. The stimulus pattern consists of two crossing frequency glides that share a very short temporal gap at the crossing point.*

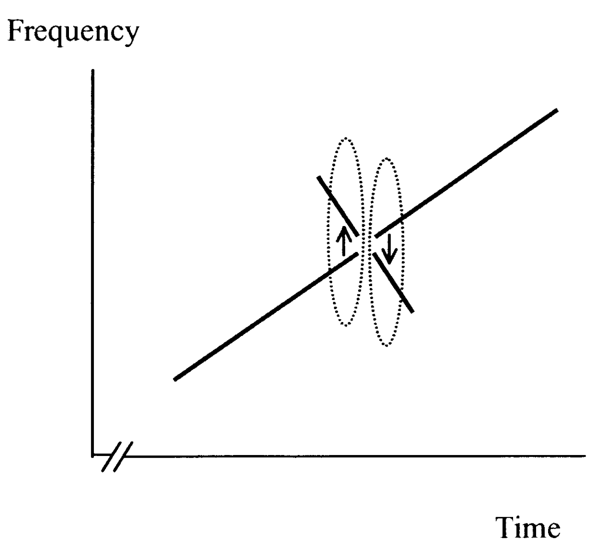

Figure 25. *Theoretical speculation with regard to the perception of the stimulus patterns used in Experiment 10. The synchrony between the two offsets before the gap and the synchrony between the two onsets after the gap may result in the perception of a single offset and a single onset that delimit the gap, as indicated by the dotted ellipses.*

According to the hypothesis of Nakajima et al. (2000), it is possible to assume that the 'single' offset before the gap will be perceptually connected to the preceding onset of the short glide, to which it is close in frequency and time. Similarly, the 'single' onset after the gap will be perceptually connected to the offset of the short glide after the gap. In other words, it can be predicted that the offset of the first long glide and the onset of the second long glide in the present paradigm are 'captured' by the first and the second short glide, respectively. If the long glide components are perceptually without an offset and an onset, then they may become integrated into a single, long pitch trajectory. The same perceptual mechanism assumed to underlie the continuity in the double-glide stimulus patterns may thus underlie the perception of continuity in the present paradigm. However, this implicates that a single, long pitch trajectory is heard, that is composed of two glides that are physically separated by a temporal gap. In the present experiment, the perception of the stimulus pattern was investigated with a method based on phenomenological observations.

6.3.2 Method

Stimulus patterns

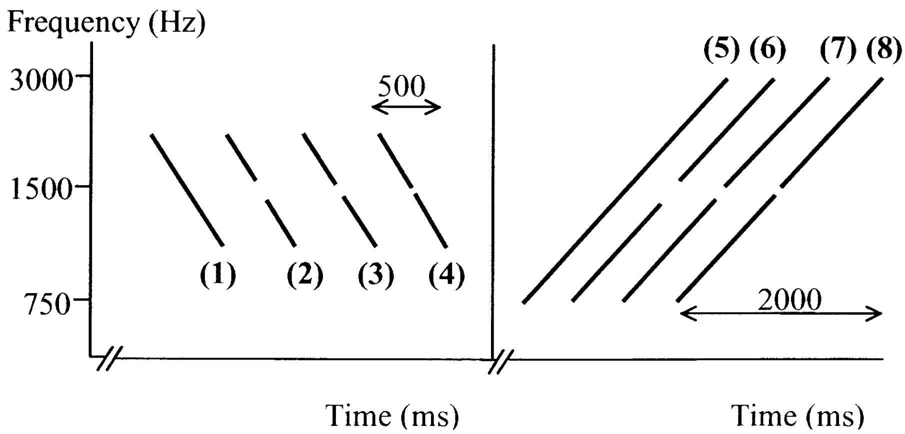

Figure 26. *Stimulus patterns 1-8 of Experiment 10. Stimulus patterns 1-4 consisted of descending short glides (left plane), and Stimulus patterns 5-8 consisted of ascending long glides (right plane). Stimulus patterns 1 and 5 were physically continuous, whereas Stimulus patterns 2-4 and 6-8 had a silent interval of 100, 50, or 20 ms in the temporal middle.*

A total of 38 stimulus patterns was generated. All the stimulus patterns consisted of glides with rise and fall times of 20 ms, with cosine shaped ramps. The rise and fall times of the glide components around a short temporal gap were also 20 ms. In all stimulus patterns, the glides had a slope of one octave per second. Stimulus patterns 1-4 consisted of a short descending glide (Figure 26, left plane). The reference frequency of glide was 1500 Hz, and it started at 1738.8 Hz and ended at 1261.3 Hz. The total duration of the glide was 500 ms. In Stimulus pattern 1 the glide was continuous, whereas in Stimulus patterns 2 - 4 the glide had a gap of 20, 50, and 100 ms, respectively, in its temporal middle. Stimulus patterns 5 - 8 consisted of an ascending glide, with a duration of 2000 ms (Figure 26, right plane). The glide moved from 750 Hz through 3000 Hz. In Stimulus pattern 5, the glide was continuous, whereas in Stimulus patterns 6-8 the glide had a gap of 20, 50, and 100 ms, respectively, in its temporal middle. The following 11 stimulus patterns consisted of combinations of the ascending and descending glides described above.

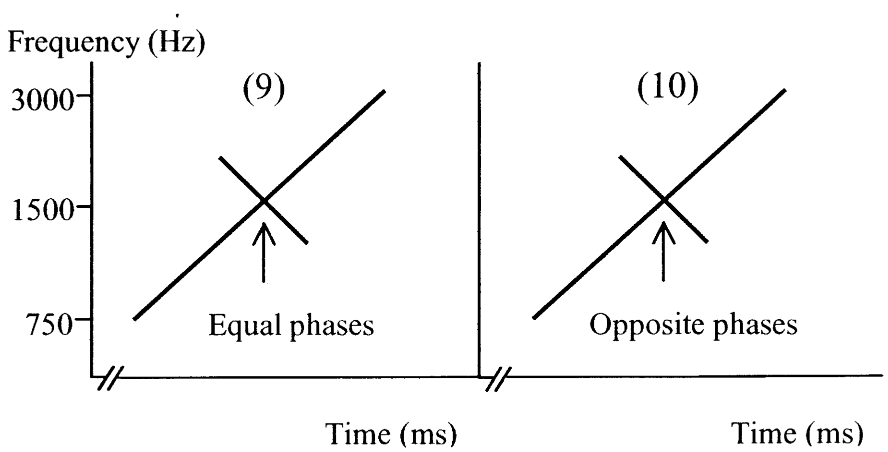

Figure 27. *Stimulus patterns 9 and 10 of Experiment 10. Both stimulus patterns consisted of a physically continuous long glide that crossed with a continuous short glide in the temporal middle of the stimulus pattern. In Stimulus pattern 9, the glides crossed with the same phase at the crossing point, whereas in Stimulus 10, the glides crossed with opposite phases.*

Stimulus patterns 9 and 10 consisted of a physically continuous, short, descending glide and a continuous, long, ascending glide that crossed each other in the temporal middle of the glides at the reference frequency (Figure 27). In Stimulus pattern 9, the glides crossed each other with the same phase, whereas in Stimulus pattern 10 the glides crossed with opposite phases. Stimulus patterns 11-13 consisted of a long, ascending glide that crossed with two successive short glides at the temporal middle of the long glide. The short glides were separated by temporal gaps of 20, 50, and 100 ms, respectively (Figure 28, left plane). Stimulus patterns 14-16 consisted of a short, descending glide that crossed with two successive long, ascending glides at the temporal middle of the short glide. The long glides were separated by temporal gaps of 20, 50, and 100 ms, respectively (Figure 28, right plane). These stimulus patterns were similar to those used by Nakajima et al. (2000) that gave rise to the 'gap transfer' illusion, discussed in the Introduction.

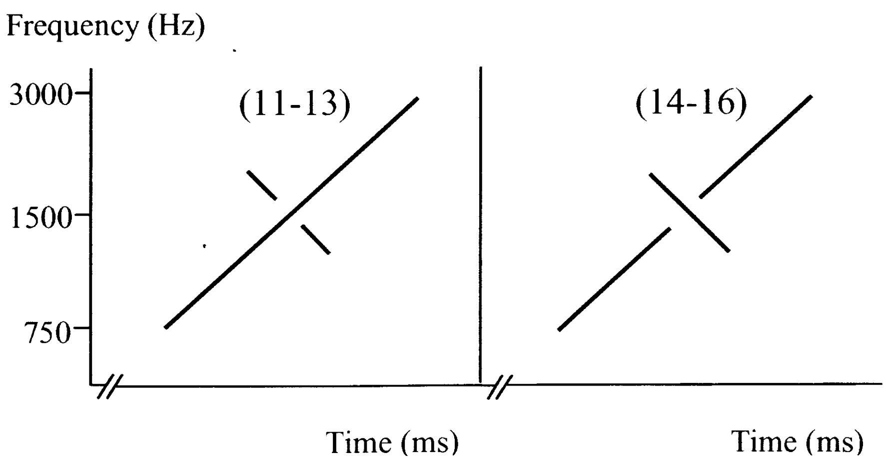

Figure 28. *Stimulus patterns 11-13 and 14-16 of Experiment 10. In Stimulus patterns 11-13, a long, ascending glide crossed with two successive, short glides (left plane). The temporal gap between the short glides was 20, 50, or 100 ms, respectively. In Stimulus patterns 14-16, a short, descending glide crossed with two successive, long glides (right plane), separated by a temporal gap of 20, 50, or 100 ms, respectively.*

In Stimulus patterns 17-19, a long, ascending glide with a temporal gap of 20, 50, or 100 ms crossed with a short, descending glide with a temporal gap of 20, 50, or 100 ms. The glides crossed each other at the reference frequency of 1500 Hz, and thus shared the temporal gap at their crossing point (cf. Figure 24). The remaining 19 stimulus patterns consisted of the same stimulus patterns as described above, reversed in time (Stimulus pattern 1R-19R).

Apparatus

All 38 stimuli were generated by a computer (16 bit, sampling frequency 44100 Hz). By using a D/A converter (TEAC D-T1), a low pass filter at 3.5 kHz (NF Electronic Instruments DV-04), an amplifier, and headphones (STAX Lambda Nova), the stimulus patterns were presented to the participant's left ear in a sound proof booth. The sound level averaged 68.7 dBA for the stimulus patterns with a single glide (Stimulus patterns 1-8, and 1R-8R), whereas the level of the stimulus patterns with the crossing glides averaged 71.7 dBA (Stimulus patterns 9-19, and 9R-19R). Levels were measured (fast-peak) with a sound level meter (Bruel & Kjaer 2209) and an artificial ear (Bruel & Kjaer 4153), mounted with a microphone (Aco 7013).

Participants

Seven participants, two females and five males, participated in the experiment. They were 21-24 years of age and had normal hearing. They were studying in the field of auditory perception, had received basic training in music, and technical listening training for acoustic engineers.

Procedure

Based on a preliminary experiment in which five listeners verbally described their percepts of all 38 stimulus patterns, six categories were made. The participant was asked to choose the category corresponding to his/her percept of each stimulus pattern. The categories were the following:

(A) Two pitch trajectories were heard. One is a long, ascending pitch trajectory and the other a short pitch trajectory, near the middle of the long pitch trajectory;

(B) Two pitch trajectories were heard. One is a long, descending pitch trajectory and the other a short pitch trajectory, near the middle of the long pitch trajectory;

(C) Two 'bouncing' pitch trajectories were heard. One pitch trajectory was moving up for a while and then shortly moving down, whereas the other was moving down shortly and then moving up for a while. (The latter pitch trajectory was generally higher in pitch than the other pitch trajectory);

(D) Two 'bouncing' pitch trajectories were heard. One pitch trajectory was moving up shortly and then moving down for a while, whereas the other pitch trajectory was moving down for a while and then shortly moving up. (The latter pitch trajectory was generally higher in pitch than the other pitch trajectory);

(E) A single pitch trajectory was heard. This category was divided in (a) a clearly ascending pitch trajectory, (b) a clearly descending pitch trajectory, (c) a steady pitch trajectory, or (d) else;

(F) If none of the categories described above fitted the perception of the participant, he/she was requested to describe the percept both verbally and graphically, on a paper sheet with the horizontal axis indicating time and the vertical axis indicating pitch.

For every stimulus pattern, a response sheet was prepared on which the categories A-F were described and depicted in random order for each trial. When a category was chosen, the participant was asked to judge the (dis-) continuity of the pitch trajectories. The long pitch trajectories and the short pitch trajectories in categories A and B, the two bouncing pitch trajectories in categories C and D, and each of the single pitch trajectories in category E were provided with 4-point scales of (dis-) continuity. A '0' on the scale equaled a completely discontinuous pitch trajectory, in which the participant could clearly hear a pitch trajectory consisting of two components separated by a silent interval. A '3' on the scale indicated a completely continuous pitch trajectory that smoothly moved without any dips or cracks in the sound.

In a sound proof booth, each of the 38 stimulus patterns was presented in random order five times to the participant's left ear. Each stimulus pattern was presented after a warning signal and each repetition was separated by 4 seconds of silence. The participant was asked to listen to the same stimulus pattern for at least two times before choosing the category corresponding to his/her perception of the pattern and indicating the (dis-) continuity of the pitch trajectory or trajectories. Three sessions were given to each participant and the last two sessions were analyzed as data. After the first session, none of the participants reported having difficulties with the task. Each session started with three warm-up trials and two warm-up trials were given after each break. The task took about 2 hours.

6.3.3 Results and discussion

Six of the seven participants all chose the same categories for each of the stimulus patterns consisting of the two crossing glides (Stimulus patterns 9-19 and 9R-19R). These observers chose category A or B, indicating that they did not hear the stimulus patterns as 'bouncing'. However, one participant heard a bouncing percept in three of the 44 stimulus patterns (over two sessions) consisting of two crossing glides. The stimulus patterns with the single glide (Stimulus patterns 1-8 and 1R-8R) were heard as consisting of a single pitch trajectory that was either ascending or descending (Category E [a,b]). Only one participant heard the trajectory as a steady-state pitch trajectory (Category E [c]) in two of the 32 stimulus patterns (over two sessions) consisting of a single glide. The small portion (5 out of 76 judgments) was left out of the analysis, so 14 judgments of 33 stimulus patterns, and 13 judgments of 5 stimulus patterns were included in the statistical analysis. The data were subjected to sign tests (two-tailed, $p<0.05$). The (dis-)continuity scores of each pitch trajectory in the single-glide as well as in the crossing-glide stimulus patterns were compared with each other.

No significant differences were found between Stimulus patterns 1-19 and the Stimulus patterns 1R-19R. The continuity of the stimulus patterns with the physically continuous glides, (1, 1R, 5, and 5R), was perfect according to all observers. The stimulus patterns consisting of a single glide with a physical gap in the temporal middle, (Stimulus patterns 2-4, 6-8, 2R-4R, and 6R-8R), were never judged as completely continuous. The participants judged these stimulus patterns mostly as '1' or '0', but never as a '3' on the scale. Generally, the larger the gap duration, the more the stimulus patterns were judged as discontinuous.

In the stimulus patterns with the crossing glides (Stimulus patterns 9-19 and 9R-19R), the longer pitch trajectory was significantly more continuous than the short pitch trajectory in all but two stimulus patterns. The relatively strong continuity of the long pitch trajectory confirms the results of a study of Tanaka, Nakajima, and Sasaki (1994). They found that when two physically continuous glides of unequal durations cross with each other with opposite phases, as in Stimulus patterns 10 and 10R (Figure 27), the longer pitch trajectory tends to be perceptually more continuous than the shorter pitch trajectory. This was also the case in this experiment. In the present experiment, the continuity of the longer pitch trajectory was also significantly better than that of the shorter pitch trajectory when they crossed with the same phase at the crossing point (Stimulus patterns 9 and 9R). The results of this experiment also confirm the appearance of the gap transfer illusion, as investigated by Nakajima et al. (2000). Although a short gap exists between the two successive, long glides in Stimulus patterns 14-16 and Stimuli 14R-16R, the long pitch trajectory was significantly more continuous than the short pitch trajectory, to which the gap had transferred.

Even when two crossing glides shared the same temporal gap of 20 or 50 ms (Stimulus patterns 17, 17R, 18, and 18R), the longer pitch trajectory was perceived as significantly more continuous than the short one (Figure 29, right plane; Table 4). Although the gap was shared by the long and the short glide in these stimulus patterns, it was generally perceived in the short pitch trajectory. Only when a 100 ms gap was inserted at the crossing point of the long and short glides (Stimulus patterns 19 and 19R), the longer pitch trajectory was not significantly more continuous than the short pitch trajectory. In these stimulus patterns, a gap was detected in both pitch trajectories. The continuity of the long pitch trajectory in the stimulus patterns containing a 20 ms and 50 ms gap, (Stimulus patterns 17, 17R, 18, and 18R), was significantly less than that of the long pitch trajectory in other stimulus patterns with crossing glides (9, 10, 14, 15, 16, and the reversed stimulus patterns). Nevertheless, about half of the judgments with regard to the long pitch trajectory of the stimulus patterns were 'completely continuous' (number '3' on the rating scale). Moreover, the long pitch trajectories in Stimulus patterns 17, 17R, 18, and 18R were significantly more continuous than those heard in stimulus patterns consisting of single glides with the same physical gap of 20 or 50 ms (Stimulus patterns 6, 6R, 7, and 7R).

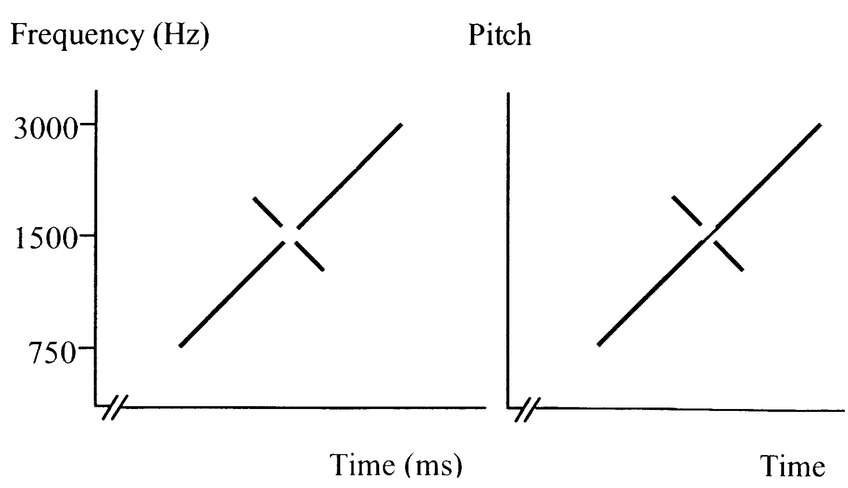

Figure 29. *Results of Experiment 10 (sample). Even though both the ascending and descending glides shared a short temporal gap of 20 ms or 50 ms in Stimulus patterns 17 and 18 (left plane), often the gap was heard only in the short, descending pitch trajectory, whereas the long, ascending pitch trajectory was perceived as continuous (right plane). The long pitch trajectory was also more continuous than the short pitch trajectory in the temporally reversed stimulus patterns, that is, Stimulus patterns 17R and 18R*

Table 4. *(Dis-) continuity judgments of the two perceptual pitch trajectories perceived in Stimulus patterns 17-19 (upper plane) and 17R-19R (lower plane) obtained in Experiment 10. The frequency of the response category is indicated for each pitch trajectory. In the scale, '0' indicates 'complete discontinuity', and '3' indicates 'complete continuity'. Each of the 7 observers responded twice for these particular stimulus patterns, resulting in 14 judgments in total. '<<' indicates that the long pitch trajectory is significantly more continuous (p<0.01, two-tailed) than the short pitch trajectory.*

Gap (ms)	Long ascending pitch trajectory				Short descending pitch trajectory				Sign test
	0	1	2	3	0	1	2	3	
20	0	1	6	7	8	4	2	0	.000 <<
50	4	3	5	2	9	5	0	0	.004 <<
100	6	7	0	1	10	4	0	0	.061

Gap (ms)	Long descending pitch trajectory				Short ascending pitch trajectory				Sign test
	0	1	2	3	0	1	2	3	
20	0	2	7	5	7	5	2	0	.000 <<
50	3	4	5	2	8	6	0	0	.002 <<
100	6	7	0	1	9	5	0	0	.124

The results thus showed that in stimulus patterns that consist of a short and a long glide that share a temporal gap, the gap was generally perceived only in the short pitch trajectory and not in the long pitch trajectory. A possible explanation for the continuity of the long pitch trajectory may be that the short glide masked the offset and the onset of the long glide components, just before and after the gap. If these stimulus edges of the long glides would be masked, and thus more difficult to perceive, the perceptual continuity of the long pitch trajectory may have been facilitated. However, one can question the influence of masking on the perceptual continuity of the long pitch trajectory beforehand, since the levels of both the short and the long glides were equal. If masking occurred, then the long glides could also have masked the stimulus edges of the short glides before and after the gap. Nevertheless, an informal experiment was done, in which the frequency separation between the short frequency components was varied, by shifting the short frequency component just before the gap upwards in frequency, and the short frequency component just after the gap downwards in frequency, whilst the long frequency components were kept fixed. As mentioned before (Chapter 3.3.3), an increase in the frequency difference between two sounds decreases the potential of either sound to mask the other (Warren, 1999). If an increase in the frequency separation between the short and the long sounds causes the continuity of the long pitch trajectory to worsen, then masking of the offset and the onset of the long glide components around the gap may have occurred. Four listeners, however, indicated that the continuity of the long pitch trajectory did not change when the frequency separation between two long and two short sounds increased, even when the sounds were separated by more than an octave. Masking of the short sounds, therefore, does not seem to be the main cause of the perceptual continuity of the long pitch trajectory.

This means that the perceptual mechanism behind the continuity of the long pitch trajectory seems to be the one that was predicted and described in the beginning of this chapter. Rather than masking of the offset and the onset of the long glide just before and after the gap, the offset and the onset were simply not attributed to the long pitch trajectory, but were 'captured' by the short glides. When two successive long glides were presented without the short glides, and 'capturing' of the offset and the onset around the gap could not occur, the gap was easily detected in the long pitch trajectory. The finding that the temporal gap and the perceived offset and onset around the temporal gap were attributed to the short pitch trajectory is in line with the hypothesis of Nakajima et al. (2000), which says that onsets and offsets are perceptually combined according to their proximity.

6.4 Summary

Stimulus patterns that render typical auditory continuity consist of weaker sounds that alternate with more intense sounds. Although physically not present behind the more intense sound, a weaker pitch trajectory can be heard as continuing behind the more intense sounds. Typical auditory continuity is facilitated when the intensity difference between the more intense and the weaker sounds is high, and when the more intense sounds and the weaker sounds are close in frequency. It has been argued that the more intense sounds must have the potential to mask the weaker sounds, had these weaker sounds actually been present behind the more intense sounds (Warren, 1999). Stimulus patterns consisting of two partly overlapping glides resemble those that render typical auditory continuity. The overlap can be considered as the more intense sound, and the glide components outside the overlap as the weaker sounds. The perceptual mechanism behind typical auditory continuity could therefore also underlie the continuity as perceived in the double-glide stimulus patterns. Moreover, in Experiment 9, it was found that the continuity of the pitch trajectory perceived in double-glide stimulus patterns was equal in degree to the continuity of the pitch trajectory heard in stimulus patterns in which the overlap was replaced by a sufficiently intense noise band. These stimulus patterns can render typical auditory continuity. A difference from the stimulus patterns that render typical continuity, however, is that the overlap in the double-glide stimulus patterns is only 3 dB more intense than the glide components outside the overlap. This value is the minimal intensity difference between the more intense and the weaker sounds necessary for typical auditory continuity to occur. The masking potential of the overlap, therefore, seems too low to suggest that the continuity of the long pitch trajectory appears in a similar way as typical auditory continuity.

An alternative explanation for the continuity in the double-glide stimulus patterns would be that the perceptual attribution of the offset of the first and the onset of the second glide to the middle tone facilitated the perceptual continuity. Regardless of the masking potential of the overlap, the integration of two glide components is facilitated when they lack an offset and an onset, perceptually. This hypothesis was tested in Experiment 10, in which stimulus patterns consisting of a shorter and a longer glide that shared a short temporal gap at their crossing point were used. It was found that even though two successive long glides were separated by a gap of 20 or 50 ms, the two long glides could be perceptually integrated into a single, long pitch trajectory. Continuity of two successive glides can thus be heard even when no excitation patterns are present between them. It was argued that the perceptual attribution of the offset of the first long glide and the onset of the second long glide to the two short glides, respectively, caused the continuity. The hypothesis of Nakajima et al. (2000) thus seems an adequate alternative explanation for the continuity of the pitch trajectory in the double-glide stimulus patterns.