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Crossing of Auditory Streams

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The present experiment required subjects to judge the stream organization of patterns consisting of the elements of an ascending sequence of tones presented in rapid alternation with the elements of a descending sequence. The principle of grouping tones by their frequency proximity was found to dominate over the principle of grouping tones that follow a smooth trajectory. Therefore, subjects could not follow a sequence through its intersection in frequency with another sequence in a number of different tonal patterns. Differences of harmonic structure among the members of ascending and descending sequences allowed listeners to hear the sequences as crossing. The effects of rhythmic regularity and the slope and length of the tones themselves (when presented as short glides) were much less important.

Several researchers (Bregman & Campbell, 1971; Dowling, 1973; Miller & Heise, 1950; and van Noorden, 1975) have encountered an interesting phenomenon in the course of investigating organizational processes in the perception of rapid acoustic sequences. It has been found that a rapidly presented sequence of alternating high and low tones tends to split perceptually into two sequences: one restricted to the high tones and the other to the low tones. Each of these can be called an *auditory stream* (Bregman, 1978c). Both the frequency separation of the tones and the speed of the sequence contribute to splitting, so that as the presentation speed is increased, the streams become restricted to narrower ranges of frequencies. The tendency for tones to group with others that are close to it in frequency can be called the *frequency-proximity* principle.

This splitting of acoustic events into auditory streams on the basis of frequency proximity appears to affect pattern recognition. Apparently, one can perform detailed sequential analyses on only one stream at a time, and it is difficult to hear patterns that include elements of different streams. It has been shown, for example, that in repeating cycles of tones, judgments about the relative order of tones seems to be possible only within a stream, not across streams (Bregman & Campbell, 1971). Dowling (1973) also showed that when two well-known melodies are mixed together in such a way that a note of one melody alternates with a note of the other, listeners can recognize them only when the pitch ranges of the two melodies no longer overlap at all.

The continuation of a trajectory has been proposed as another factor promoting stream organization. Heise and Miller (1951) showed that if a tone deviated too far from the trajectory of a regular ongoing tonal sequence, that tone would split away from the melodic pattern of the regular tones. Bregman and Dannenbring (1973) showed that splitting could be reduced, in a rapidly presented sequence of alternating high and low tones, by adding to each tone partial glide transitions that merely pointed toward the next tone or back to the previous one. There appears, then, to exist a second principle of organization that we can call the *trajectory* principle.

The frequency-proximity and trajectory principles can be viewed as helping to define the acoustic environment. It is common to have several sources of sound active at the same time, mixing their effects in the pressure wave that reaches our ears. Any principles that can tell us which acoustic components have arisen from the same source can assist in sorting out the mixture of acoustic information in the pressure wave. Such principles of auditory organization should operate in parallel, competing with or reinforcing one another, in the process of providing us with an adequate description of the external world.

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These principles resemble those described by the Gestalt psychologists as influencing perceptual organization. The frequency-proximity principle would be an example of the principle of "similarity," and the trajectory principle would be a case of "good continuation" (see Rock, 1975, Chapter 6, for a discussion of these principles).

When the frequency-proximity and trajectory principles are placed into conflict with one another, it appears that frequency proximity dominates. This conclusion is consistent with the results of Deutsch (1975), who found that when the tones from the C major scale were presented simultaneously in a both ascending and descending form such that when a component in the ascending scale was in one ear, a component of the descending scale was in the other and vice versa, no subjects reported a full ascending or descending scale, but rather perceptually grouped the sounds of this sequence by frequency range, following, for example, the descending scale to the crossing point and then switching over to follow the second half of the ascending scale. Van Noorden (1975) also observed that when the discrete elements of an ascending tonal sequence are presented in rapid alternation with the elements of a descending tonal sequence, it is very difficult to follow either the ascending or the descending string of notes through the crossing point.

These results are, however, inconsistent with the view that the auditory system forms its perceptual groupings by predicting the positions of later sounds in a frequency-by-time space from the positions of earlier ones. Jones put forward a theory of this type (Jones, 1976; Jones, Kidd, & Wetzel, 1981). One might expect that because the prediction of the position of the next tone in a regular trajectory is more exact than a general prediction that the next tone will be near in frequency to its predecessors, the auditory system should make stronger use of trajectory-based predictions. Yet there is now some research that suggests that the perceptual grouping process in the auditory system displays little or no concern with whether or not a sound is located on the frequency-by-time trajectory that has been defined by earlier tones. Steiger and Bregman (1981) used a repeating stimulus consisting of a pure-tone glide alternating with a complex glide that contained two pure-tone glides as components. Under some circumstances the pure-tone glide would group sequentially with one of the components of the complex glide, "capturing" the latter out of the mixture in which it was embedded. This tended to occur when the "captor glide" was in the same frequency region as the "target glide" and when they both had the same slope. Another factor that they investigated was whether lining up the captor glide on a common trajectory with the target glide would promote the grouping of these two glides. In their experiment, there was no evidence that such a trajectory-based principle of grouping existed.

A second study that failed to find the extrapolation of trajectories by the auditory system was done by Dannenbring (1976). An alternately rising and falling pure-tone glide (a continuous W-shaped trajectory) was interrupted at the peaks (highest frequency points) by a burst of noise that replaced the tone energy in the vicinity of the peak. Dannenbring found that his subjects "filled in" the perception of the peak but that its apparent frequency was too low for it to have been an extrapolation of the glide to its actual (missing) peak.

The present set of experiments attempted to clarify the process whereby auditory streams are constructed by putting into competition with one another the organizing effects of the frequency-proximity and trajectory principles. This was done through the use of a number of variations of a basic X pattern consisting of an ascending sequence of tones presented in rapid alternation with the tones of a descending sequence. The following predictions could then be made. Under the influence of a trajectory principle of organization, the X pattern would be partitioned into two complementary trajectory-based streams, a descending tonal sequence, and an ascending one crossing it. These will be referred to as the two *crossing* percepts. In Figure 1, in the first half of Pattern 1A the tones shown as crosses would represent one of the two crossing percepts. The other would be composed of the tones shown as dashes. On the other hand, partitioning the X pattern according to a frequency-proximity principle of organization would involve the perception of the following two complementary proximity-based streams: the set of tones composing the upper half of the X pattern (i.e., a sequence that first descends in frequency and then bounces back upward) and the set of tones composing its lower half. These will be called the *bouncing* percepts. Again, as can be seen by looking at the first half of Pattern 1A, the set of tones joined together by lines would represent one of the two bouncing percepts, and the complementary bouncing percept would be composed of the remaining tones.

Experiment 1

Method

Subjects. The subjects were 15 (male and female) graduate and undergraduate students at McGill University who volunteered their services. All subjects reported having normal hearing.

Stimuli. The stimulus patterns used in this experiment were modifications of the first five patterns shown in Figure 1. They represent variations on a basic *X* pattern consisting of an ascending sequence of discrete tones presented in rapid alternation with the elements of a descending sequence. All stimulus patterns were composed of the same seven steady-state tones, spaced by equal log frequency intervals and ranging over the same two-octave frequency range. Each full pattern shown in Figure 1 (2.6-s duration) was repeated five times with no interrepetition silence, creating a long continuous pattern. Pattern 1 consisted of two cycles of the basic *X* pattern, known from previous research (Tougas & Bregman, 1984) to result in the bouncing percept. Pattern 2 lacked half of the tones in the lower octave of the frequency range. This was expected to strengthen the trajectory-based organization because there existed fewer tones to define the lower frequency range and to thereby strengthen the lower frequency-proximity organization. The basis for this expectation was the finding by Bregman (1978b) that the auditory system accumulates evidence for the existence of energy that is concentrated in particular frequency regions. Pattern 3 was simply the frequency inversion of Pattern 2. Pattern 4, like Pattern 2, lacked half of the tones in the lower octave, but it created a different type of pattern than did Pattern 2 when it was repeated. It was really the first half of Pattern 2 repeating exactly rather than containing the two symmetrical halves found in Pattern 2. In Pattern 4 there was never a rising trajectory, but rather a sequence of descending trajectories. If pattern continuity (i.e., the frequency proximity of every successive pair of tones) is important in helping to define a trajectory, then Pattern 2 should show a greater trajectory effect, whereas if the more frequent, exact repetition of a trajectory helps to make it more predictable, then Pattern 4 should show a stronger trajectory effect. Pattern 5 was merely the frequency inversion of pattern 4.

The frequencies of the seven tones were 400, 504, 635, 800, 1008, 1270, and 1600 Hz. All tones were of 100-ms duration, including 8-ms attack and decay times in order to prevent onset and offset clicks. There was no silence between adjacent tones. The amplitude of the tones was adjusted by four persons to appear at the same subjective loudness.

In designing the stimuli, it became evident that at the crossover point of ascending and descending trajectories, where they share a common tone (see Figure 1, Pattern 1A, for example), if the descending sequence is isochronous the ascending one cannot be (unless it skips the common tone). For the bouncing sequences, neither the upper nor the lower one is isochronous. In other patterns, both of the trajectory sequences will be isochronous, but neither of the bouncing sequences will be. (In Figure 1, the points where the within-stream intertone interval deviates from 100 ms—becoming 0 ms—are shown by arrows for one

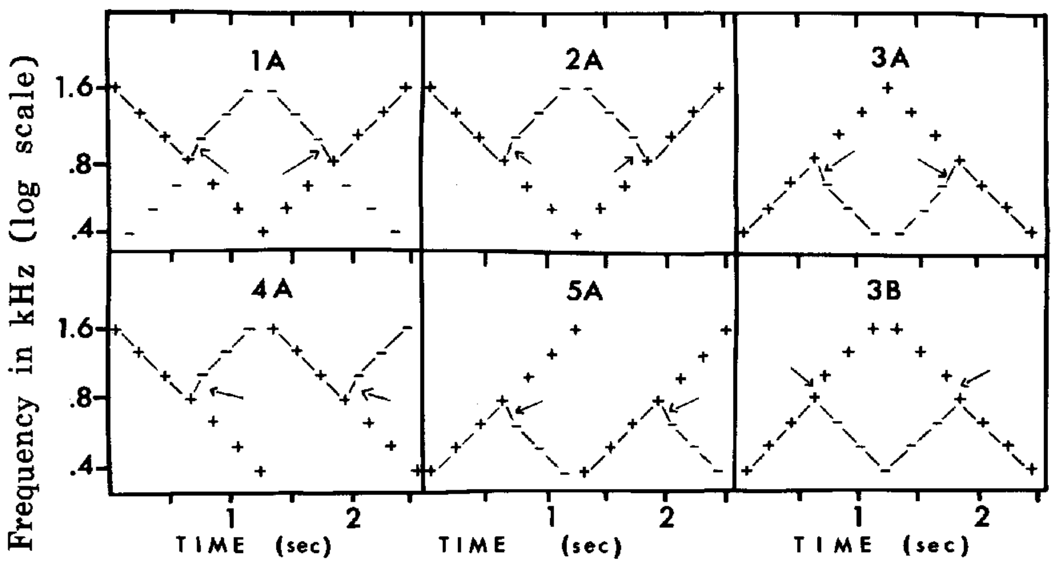

Figure 1. A sample of the patterns used in Experiment 1. (Each dash represents a 100-ms tone.)

of the bouncing sequences in each pattern). Overall, then, there would be more isochrony for the trajectory sequence. This might be expected to favor the trajectory sequence due to a "rhythmic attention" process (Jones, Kidd, & Wetzel, 1981). There would also have been other asymmetries of frequency–time proximity in the frequency–time relations of the tones that could be construed as favoring either bouncing or crossing organizations.

To balance out this asymmetry, we made two versions of each pattern (A and B), where A's rhythm produced more isochrony for the trajectory sequences, and B's rhythm produced more isochrony for the bouncing sequences. For illustrative purposes Pattern 3 is shown in Figure 1 under both its trajectory-favoring rhythm (3A) and its proximity-favoring rhythm (3B), whereas the remaining patterns are shown with their trajectory-favoring rhythms only (the A versions). It can be seen that both patterns 3A and 3B are identical up to the first cross-over point. In 3A, the next tone in the ascending sequence is spaced at a time interval identical to the ones that separated the previous tones, whereas in 3B it is the next tone in the lower pattern based on frequency proximity that occurs at this point in time.

Procedure. The subjects were informed that the experiment was to investigate the way people hear tones when they are surrounded by other tones. Subjects were told that on each trial they would be presented with two sequences of tones: a "standard" sequence followed by a "comparison" sequence that was actually composed of the standard sequence mixed together with other surrounding tones. The comparison sequence consisted of any one of the stimulus patterns described earlier. There were four types of standard sequence, consisting of the tones that formed one of the two bouncing percepts or one of the two crossing percepts that were appropriate to the comparison sequence that followed it. The standard was always an exact subset of the tones in the comparison and had the same temporal pattern.

Each trial began with a distinctive warning sound, followed 1 s later by five repetitions of the standard, a 1.6-s silence, and then five repetitions of the comparison sequence. The repetitions of the standard or of the comparison sequences occurred with no silence between repetitions so that what was heard was a continuous long pattern. There was a 4.9-s silence between trials during which the subject made his or her response.

The ability of a coherent auditory stream to be heard as an entity that is perceptually isolated from the surrounding sounds was used as an index of stream formation. The subjects were given 5 s to rate on a 7-point scale the "clarity of isolation" of the standard sequence when heard as part of the comparison sequence. The endpoint 1 was labeled *very clearly not isolated* (meaning that the standard sequence could not be heard at all within the comparison sequence); the endpoint 7 was labeled as *very clearly isolated.* The subjects understood that the standard was always present in the comparison sequence but that it would not always be heard as a part that was easy to isolate.

Design. The three independent variables in this experiment were (a) the five types of stimulus patterns, (b) the two types of rhythm, and (c) the four types of standards (two reflecting each of the two competing principles of organization).

Each experimental condition was presented twice to the subjects, yielding an overall total of 80 trials. The experiment was divided into two blocks of 40 trials each. The order of presentation of the two blocks was randomized across subjects, and there were three random orders of the trials within each block. Prior to the experiment, the subjects were given four practice trials in order to familiarize them with the nature of the task.

Apparatus. The stimuli were synthesized digitally at a 10,000-Hz sampling rate on a Digital Equipment Corporation PDP-11/34 computer, using the MITSYN software package (Henke, 1980). The signal outputs from the computer's digital-to-analog converter were filtered with a Rockland 851 filter (low-pass at 5 KHz, Butterworth filter with 48 dB/octave roll-off), single-channel recorded on Scotch 208 audiotapes and played back binaurally using an AKAI (GX-400D.SS) tape recorder. A General Radio type 1551-C sound level meter equipped with a flat-plate coupler was used to set the presentation level of the 800-Hz calibration tone at 70 dB (SPL). The subjects, tested individually, were seated in a soundproof room (IAC 1202) wearing TDH-49P earphones.

Results

The two clarity-of-isolation scores for each subject in each condition were averaged to obtain the numbers for the analysis. The mean scores for bouncing (high standard and low standard combined) and those for crossing (rising standard and falling standard combined) are shown in Table 1 for the different types of stimulus patterns and rhythms. The bouncing standards consistently came out as being more clearly isolated than the crossing standards for all types of stimulus patterns and rhythms.

We can here ask the question as to whether all of the stimulus patterns showed the same difference between bouncing and crossing standards. To assess this, a difference score called the *bouncing-superiority* score was calculated for each subject by subtracting the sum of the two crossing standards from the sum of the two bouncing standards for each stimulus type and rhythm. The data were then analyzed in a two-way ANOVA with repeated measures, testing for type of stimulus pattern and type of rhythm. The scores could range from -12 to $+12$, with a score of $+12$ representing maximum preference for bouncing and a score of -12 maximum preference for crossing. A significant main effect was found only for the type of stimulus pattern, $F(4, 56) = 3.48$, $p < .01$. However, paired comparisons using the Tukey test showed no significant differences (at the .05 level) between individual pairs of patterns. The interaction between pattern type and rhythm was also significant, $F(4, 56) = 3.57$,

Table 1
Mean Clarity Scores for the Standards in Experiment 1

Standard	Pattern 1	2	3	4	5
Bouncing					
Trajectory[a]	6.3	6.3	6.7	6.4	6.8
Proximity[b]	6.5	6.2	6.7	6.2	6.6
Crossing					
Trajectory	1.9	2.7	3.2	1.7	2.2
Proximity	1.6	2.0	2.0	1.9	1.8
Bouncing Superiority					
Trajectory	8.8	7.2	7.0	9.4	9.2
Proximity	9.8	8.4	9.4	8.6	9.6

[a] Trajectory-favoring (A) rhythm. [b] Proximity-favoring (B) rhythm.

$p < .01$. The interaction effect appears to be due to the presence of a slightly greater clarity of the trajectory sequence (i.e., lower bouncing-superiority scores) in Patterns 2 and 3, which are frequency inversions of one another, when they were presented under the A rhythm.

Discussion

The effect of frequency proximity on stream organization may be seen through an examination of the individual stimulus conditions. In stimulus Pattern 1, the set of tones included in the upper half of the *X* pattern had the tendency to group together and be perceptually segregated from the set of tones comprising the lower half. As a consequence, the crossing standards were very difficult to isolate as distinct perceptual units because they actually occurred as parts of different streams, for example, part of the two bouncing percepts. The same reasoning can be applied to the other four stimulus patterns. The slightly reduced bouncing superiority observed for Patterns 2 and 3 under the trajectory-favoring (A) rhythm may be accounted for by a lower number of tones from the upper half of the *X* pattern in Pattern 3 (lower half in Pattern 2), leading to a reduction of the effectiveness of the frequency-based organization (as we had anticipated). Because of this, the regularity of the rhythm that favored the trajectory organizations may have facilitated the isolation of the crossing standards. Although Patterns 4 and 5 also had fewer tones than the *X* pattern, the remaining trajectory tones in these patterns did not form a continuous rising and falling sequence as they did in Patterns 2 and 3. Therefore, the continuity of a sequence (i.e., the frequency proximity of pairs of successive tones) seems to favor integration.

The strongly positive values obtained for the bouncing-superiority score indicated that the tendency for bouncing was markedly superior to that for crossing in all the present stimulus patterns regardless of rhythm. The second and third experiments were designed to investigate the effects of two other variables on tonal grouping: those of harmonic structure and slope of glide, respectively. It could be expected that a set of tones sharing a similar harmonic composition or having the same slope (in the case of gliding tones) would tend to sequentially group together and, by doing so, possibly offset the bouncing superiority found in the first experiment. The same procedure and apparatus was used in all three experiments reported here.

Experiment 2

The resistance of auditory streams to crossing one another may well be the basis for the rule of voice-leading in counterpoint theory that says that the crossing of different parts should be avoided, especially when the two parts closely resemble one another, because of the difficulty of following a tonal sequence through a cross-over (Piston, 1947). Even if this generalization is essentially correct, it would be of interest to know the exact circumstances under which tones that cross one another in frequency can be followed perceptually. One circumstance in which this crossing could be followed might occur when there was some acoustic property that was shared by the ascending tones and that distinguished them from the descending ones. A factor that is known to promote perceptual grouping is the richness of the harmonic structure (Bregman, McAdams, & Halpern, 1980; McAdams & Bregman, 1979). The present experiment studied its effects on the crossing of streams. Smith, Hausfield, Power, and Gorta (1982) promoted the crossing of streams by having a synthesized piano play one stream and a synthesized saxophone the other. However, theirs was a more complex situation in which tones were also being alternated between ears in the manner of the Deutsch (1975) scale illusion.

Method

Subjects. Twenty-four volunteers (male and female) were recruited mainly from the McGill student population. Again, all subjects reported having normal hearing.

Stimuli. The four stimulus conditions used in this experiment were created by varying the harmonic composition of the tones relative to one another using only the *X* pattern, more specifically the 13 tones in the second half of Pattern 1A of Experiment 1. All tones were discrete 100-ms steady-state tones, including 8-ms attack and decay times. As in the first experiment, the *X* pattern had a two-octave range from 400 to 1600 Hz formed of seven equally spaced positions on a log frequency scale. The first condition was called *all-pure,* because its members were all sinusoidal. The second condition was called *all-rich,* its tones all being composed of the first four harmonics with equal intensity. In the third condition, called *rich-bouncing,* the tones composing the lower half of the *X* condition were rich, whereas those present in the upper half were pure. Finally, there was a fourth condition, called *rich-crossing,* in which the ascending sequence of tones was rich, whereas the descending sequence was pure. The pattern for this condition, together with one of its "bouncing" standards, is shown in Figure 2. The intensity of the rich tones was adjusted by four persons to equate their loudness to that of the pure tones; this was done in order to have all tones be of equal loudness when the stimulus conditions were composed of both pure and rich tones. The trial structure was the same as in Experiment 1 except that the stimulus pattern within each cycle was shorter (as described above).

Procedure and design. As in the first experiment, the subjects were required to rate on a 7-point scale the clarity of isolation of the standard sequence when heard as part of the comparison sequence. The two independent variables in this experiment were (a) the four types of richness conditions and (b) the four types of standard. The second of these variables represents the fact that each comparison condition was tested with four possible standards as in the previous experiment: two complementary bouncing sequences and two complementary crossing sequences. Each experimental condition was presented twice, for an overall total of 32 trials. Four random orders of this set of 32 trials was recorded, and each set of 6 subjects received one of these orders. The subjects were given four practice trials before the start of the experiment.

If harmonic richness is a factor promoting perceptual grouping, then we may expect it to challenge the perceptual segregation in the *X* pattern, which would otherwise be based on frequency proximity. As a consequence, the crossing standards should be clearly isolated in the rich-crossing condition, whereas the bouncing organizations would continue to be dominant in the other three conditions.

Results

The raw data were tabulated as in the first experiment. The mean scores for the bouncing and crossing standards are shown in Table 2 for each one of the four richness conditions. As expected, the bouncing standards stood out as being more clearly isolated than the crossing standards for all richness conditions except for the rich-crossing condition for which the reverse was true.

The question was then asked as to whether the richness condition affected the magnitude

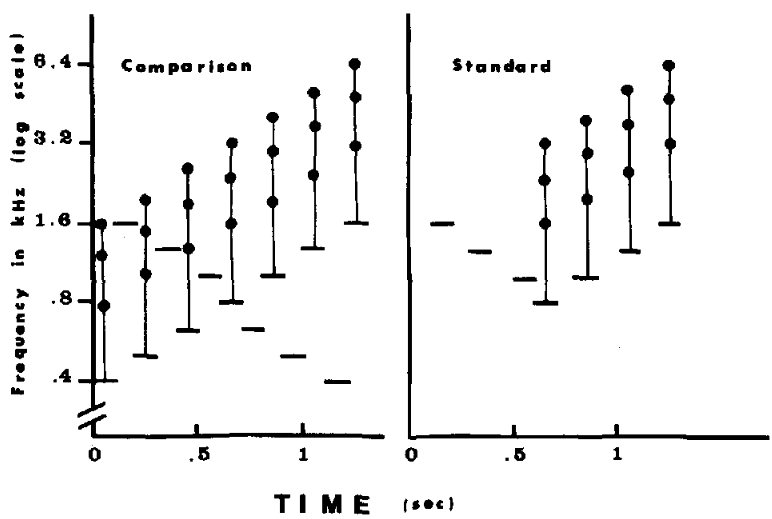

Figure 2. Left panel: the rich-crossing condition of Experiment 2. Right panel: the high-bouncing standard for that condition. (The dashes represent the fundamental frequencies of the tones. The dots connected to each fundamental by a vertical line represent its second, third, and fourth harmonics.)

Table 2
Mean Clarity Scores for the Standards in Experiment 2

	Condition			
Standard	All pure	All rich	Rich bouncing	Rich crossing
Bouncing	5.5	5.6	6.9	2.3
Crossing	2.0	2.2	2.9	6.5
Bouncing Superiority	7.1	6.8	8.0	−8.5

of the difference between bouncing and crossing. A one-way ANOVA was performed on the bouncing-superiority score, the difference between the bouncing and the crossing scores for each richness condition. The difference between conditions was found to be highly significant, $F(3, 69) = 25.15$, $p < .0001$. Comparisons of individual pairs of conditions were also made using Tukey's method. A significant difference at the .01 level was found for the rich-crossing condition when compared to any of the three other conditions. No other differences were significant.

Discussion

In agreement with the results obtained in the first experiment, bouncing dominated over crossing in all-pure and all-rich stimulus conditions. However, the reverse effect was observed when the richness was manipulated to favor crossing rather than bouncing. This suggests that unless there are differences of harmonic structure among members of the *X* pattern acting to promote differential streaming, then, other factors being equal, stream membership will be based upon a frequency-proximity principle of organization rather than on trajectories. In the present experiment, the perception of full ascending and descending sequences of tones in the rich-crossing condition does not necessarily imply that the tones were grouped because of the fact that they were on a common trajectory but simply demonstrates the fact that harmonic structure influences grouping, because the tones composing the crossing sequences also had the same harmonic structure. This interpretation is consistent with earlier studies (Bregman, McAdams, & Halpern, 1980; McAdams & Bregman, 1979), which showed that differences of harmonic structure among members of rapid sequences of tones promote their segregation into separate streams. All that the present experiment shows is that it is possible to force auditory streams to cross if the two streams are differentiated by the harmonic structure of their elements.

Finally, the tendency to see more bouncing in the rich-bouncing condition as compared to the all-rich condition, although not statistically significant, can be attributed to the positive combination of the frequency-proximity effect and the harmonic structure effect. The results from the rich-crossing and rich-bouncing conditions, respectively, exemplify the way that perceptual organization principles combine to affect auditory streaming, the factors being either competitive or cooperative.

Experiment 3

In this experiment we investigated two other factors that might be expected to affect the ability of perceptual streams to cross one another. The first was the slope of the individual elements. One might expect that if the individual tones in the sequences were actually short glides whose slope was identical to the slope of the sequence itself (on pitch-by-time coordinates), the information that might allow the auditory system to predict the position of the later tones from earlier ones would reside both in the sequence and in its individual components. This redundancy might be expected to increase the salience of the trajectory as a principle of organization.

The second factor was the temporal overlap of the tones in the ascending and descending sequences. The lengthening of the tones should act to further reinforce the trajectory effects because within each trajectory a greater proportion of the trajectory would be continuous.

Method

Subjects. The 24 subjects who volunteered their services for Experiment 3 were the same as those involved in the second experiment.

Stimuli. The four stimulus conditions used in this experiment were again based on the *X* pattern, more specifically, on the 13 tones in the second half of Pattern 1A of

Experiment 1. The variations were created by varying the slope of the tones and their length. In the *steady-nonlengthened* condition, all the tones were discrete 100-ms steady-state sinusoids with no silence between adjacent tones, a condition exactly corresponding to the all-pure condition used in the second experiment. In the *sloped-nonlengthened* condition, all tones were also discrete 100-ms long sinusoids except that each one was a short glide. The slopes of those in the ascending sequence of the X pattern were aligned along the same ascending trajectory as the sequence as a whole: Similarly, the slopes of the tones in the descending sequence were aligned along the common descending trajectory. The *steady-lengthened* condition basically corresponded to the steady-nonlengthened condition except that an extra 50 ms was added to the end of all tones. Each tone thus kept the same starting time but had 50-ms overlap with its alternating follower. Finally, the tones in the sloped-lengthened condition basically corresponded to those in the steady-lengthened condition, except that the tones were glides aligned on the trajectory of the sequence that they were in. The sloped-lengthened condition is shown in Figure 3.

Procedure and design. Again, the subjects were required to rate on a 7-point scale the clarity of isolation of the standard sequence when heard as part of the comparison sequence. The three independent variables in this experiment were (a) the two slopes, (b) the two lengths of tones, and (c) the four types of standards (two bouncing and two crossing). The trial structure was the same as in Experiment 1 except that the stimulus pattern within each cycle was shorter. Each experimental condition was presented twice, for an overall total of 32 trials. Four random orders of this set of 32 trials was recorded and each set of 6 subjects received one of these orders.

Results

The raw data were tabulated as in the first two experiments and the mean scores for the bouncing and crossing standards are shown in Table 3 for each of the four stimulus conditions. It can be seen that the bouncing standards were more clearly isolated than the crossing standards for all conditions regardless of glide orientation or length.

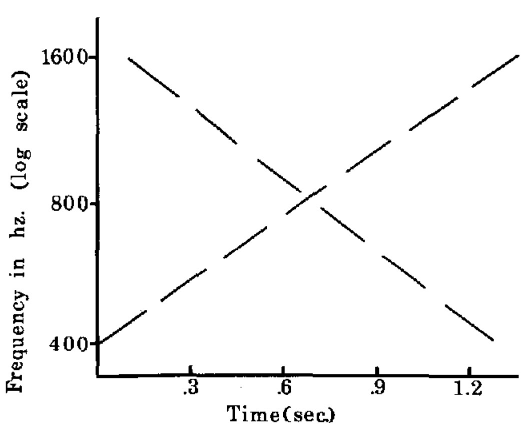

Figure 3. The sloped-lengthened condition of Experiment 3.

Table 3
Mean Clarity Scores for the Standards in Experiment 3

	Condition			
Standard	Steady	Sloped	Steady lengthened	Sloped lengthened
Bouncing	5.7	5.1	6.1	5.1
Crossing	2.3	2.5	3.0	3.0
Bouncing Superiority	6.8	5.1	6.3	4.2

In order to assess whether the type of condition affected the magnitude of the difference between bouncing and crossing, a two-way ANOVA was performed using the bouncing-superiority score. The main effect for slope was found to be significant, $F(1, 23) = 9.97$, $p < .004$. The data show a slightly reduced bouncing superiority with the sloped conditions as compared to the steady-state conditions. No other effects were found to be statistically significant. Notice, however, the tendency for the slope-lengthened condition to show a slightly (but not significantly) reduced bouncing superiority than the other three conditions.

Discussion

The magnitude of the bouncing-superiority score was slightly, but consistently, reduced by the alignment of the slope of the brief glides that served as tones in the X pattern along common ascending and descending trajectories. This effect was slightly more evident with the lengthening of the tones in the sloped condition. However, although such results would appear to support the existence of trajectory effects, an explanation based on "continuity" would be more parsimonious. By continuity, we mean the frequency proximity between the end of one tone and the beginning of the next for every consecutive pair of tones in the sequence. Continuity is simply an extreme case of frequency proximity. The slope of the tones, with or without lengthening them, would bring the end of one tone in the trajectory sequence closer in frequency to the next one. Lengthening would further decrease the distance. Regardless of the explanation for the observed effect of slope of tones, the organizations based on frequency proximity were still definitely more clearly isolated than those based on trajectories in all stimulus conditions, even when glide orientation and length was manipulated to favor the trajectory organizations.

General Discussion

The results of these experiments are consistent with those of Steiger and Bregman (1981) and of Dannenbring (1976) discussed earlier. Their results, like ours, showed no trajectory effect. The results of these experiments have led us to look for another reason for the findings of Bregman and Dannenbring (1973). They reported that the segregation of alternating high and low tones in a rapid sequence was reduced when the end of each tone consisted of a brief frequency glide "pointing" toward the frequency of the next tone. They interpreted their finding as due to a principle of grouping that makes use of the predictability of the position of the next sound (in a frequency-by-time space) from the orientation of the previous one. However, their results may not have been due to this at all. The presence of frequency transitions might simply have reduced the frequency separation between the end of one tone and the beginning of the next, and therefore the observed effect might have been entirely attributable to the principle of grouping by frequency proximity. In such a case, if the time separation between the tones were to be reduced by speeding up the presentation rate of the sequence, splitting would be expected to eventually occur because increasing the presentation rate increases the segregation of sequences of tones that differ in frequency. Similarly, Heise and Miller's (1951) finding, that the segregation of a tone from a regular ongoing tonal sequence will occur if that tone deviates too far from the trajectory of the continuous pattern, may be accounted for without resorting to a trajectory principle. The task of the subjects in their experiment was to adjust the frequency of a tone (either upward or downward) until it "popped out" perceptually from a trajectory in which it was a member. A careful examination can be made of their results in the case where the adjustable tone lay at the vertex where a rising trajectory turned around to become a falling one. The algebraic mean of the upward and downward adjustments made by the subject can be taken as an indication of the "neutral point," the place where the tone fits in best. This value was not at the actual vertex (in frequency-by-time coordinates). Instead it was at a point that was closer in frequency to the tones that came before and after it. This means that the auditory system did not project the trajectory to the apex of the pattern but rather preferred a tone that lay within the frequency range of the pattern. All their results can be explained by the tendency to prefer a tone that lies as close as possible in frequency to the nearest neighbors on both sides of it, with perhaps a weak effect of next-to-nearest neighbors. This is a continuity effect rather than a trajectory effect, and, as we pointed out earlier, a continuity effect is an extreme case of a frequency-proximity effect.

Other evidence that suggests the existence of a trajectory effect comes from experiments on the identification of order. One study, by Divenyi and Hirsh (1974), showed that the order of elements was easier to detect in sequences with unidirectional frequency changes than in sequences with bidirectional frequency changes. Similar results were obtained by Warren and Byrnes (1975), Nickerson and Freeman (1974), and McNally and Handel (1977).

A typical example of these is the study by Warren and Byrnes (1975) in which a very large superiority was found for the identification of repeated glissandi when compared with the identification of repeated irregular sequences. However, the effect may not have been due to preattentive stream segregation but to more cognitive factors. Warren and Byrnes' study required subjects to identify the *order* of tones in a sequence. Also the superiority of glissandi was greatly diminished (from 110% to 21%) when memory demands were reduced by allowing the subjects to respond by ordering a group of cards; this suggests a strong contribution from short-term memory to the observed effects. In addition, the effect of frequency separation was in the opposite direction to its known effects on primary auditory stream segregation: A greater frequency separation made order identification *easier*. Another hint that higher level cognitive processes were responsible was that the effects occurred at a rate of presentation of 5 tones/second, a slow rate that according to van Noorden (1975) requires at least a 15-semitone separation betweeen adjacent tones before compulsory stream segregation occurs. None of the conditions of Warren and Byrnes employed such large frequency separations. These observations suggest that the effect could be related to the problem of building a mental description of the event sequence, rather than simply grouping the events at a preattentive level.

More important, even if the results of all the studies that we described as finding greater coherence in unidirectional sequences (glissandi) than in irregular sequences really did result from a preattentive stream segregation process, they can be explained without resorting to a trajectory principle. The frequency-proximity principle would be sufficient to explain their results. The argument goes as follows.

When a glissando is employed, there is no competition from tones other than those in the glissando. This lack of competition may be responsible for the coherence of glissandi. One should remember that frequency proximities in sequence of tones always compete with one another (Bregman, 1978a). The grouping of temporally *nonadjacent* tones, as in the "streaming" illusion, (Bregman & Campbell, 1971) occurs because these tones are closer to each other in frequency than *adjacent* tones are, and are not far apart in time. In a repeating glissando, however, there is never any tone that is closer to a given tone (A) in frequency than its sequential neighbors are, except for the next occurrence of tone A itself on the following cycle. Because a glissando is likely to include at least four tones, the spacing of repeated occurrences of tone A is likely to be far enough apart in time to prevent their grouping. This argument deduces the coherence of glissandi as a special case of the principle of frequency proximity under the assumption that proximities compete with one another.

Despite these arguments, it is clear that there exists a sufficient variety of findings and methods to tell us that a great deal more research must be done to discover whether or not a real trajectory effect exists and, if it does, what its limiting conditions are.

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Also beginning in 1986, *JEP: Human Perception and Performance* will be published as a quarterly rather than a bimonthly. This change is a result of the change in trim size and consequent reduction in the absolute number of printed pages per issue and is not an indication that fewer articles are being published. It will also bring *Perception* in line with the other three *JEP*s, which are all quarterlies.

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