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The Role of Tone Height, Melodic Contour, and Tone Chroma in Melody Recognition

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The present experiments assessed the contribution of tone height, melodic contour, and tone chroma to melody recognition. Rather than using highly familiar folk songs as in earlier studies, subjects were taught new melodies. Novel melodies were used to (a) more precisely control potential cues (e.g., rhythm) that are not of present interest, (b) eliminate unison intervals that cannot be transformed appropriately, (c) provide a direct analysis of the nature of confusion errors, (d) test whether recently learned melodies are recognized differently than highly overlearned melodies, and (e) evaluate the extent to which practice in the experimental task alters the process of recognition. The results replicate previous studies using familiar folk songs. Transformations of the original melodies were accurately recognized when tone height was violated, but both melodic contour and tone chroma were maintained. Violating both tone height and contour while maintaining chroma produced extremely poor recognition. Performance was intermediate when just melodic contour was preserved. There is now good evidence to support the idea that melodic contour and tone chroma, in addition to tone height, contribute to recognition of both highly familiar and recently learned melodies.

This article addresses the question of the degree to which three auditory characteristics are functional in melody recognition. The characteristics are tone height, tone chroma, and melodic contour. Tone height corresponds to a tone's frequency; for example, the note A_4 has a frequency of 440 Hz. Tone chroma corresponds to the position of a note within the musical octave. Notes of the same name could differ in terms of tone height (e.g., 440 and 880 Hz) but would be considered equivalent with regard to chroma (represented by the note name "A"). Finally, contour refers to the up-and-down pattern of the successive notes of a melody and, consequently, is defined by the direction of change of the tone heights of temporally adjacent notes.

One method to study this question is to modify well-known melodies by distorting one or more of these characteristics. Any induced changes in recognition performance should index the contribution of the corresponding auditory characteristic. In a recent study, Idson and Massaro (1978) asked subjects to identify highly familiar tunes either in their original, undistorted forms or after they had been subjected to various transformations. In Transformation PC (preserve contour), the melodic contour was preserved, but the relative size of each successive interval was not maintained. Therefore, both tone height and tone chroma were violated. Transformation OPC (octave, preserve contour) resulted in displacement of each note of the original melody by one or more octaves in a direction consistent with the original contour. In this transformation, only tone

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height was violated. Transformation OVC (octave, violate contour) caused octave displacement of the notes of the original melody without regard to contour; the direction of pitch change for approximately half of the intervals in transformation OVC was opposite to the contour of the original melody. This transformation preserved only tone chroma.

If tone height were necessary for accurate melody recognition, then performance should be significantly poorer on transformation OPC, since tone height is violated. The results showed only a slight decrement in recognition relative to the original undistorted melody. This result means that contour and chroma are usually sufficient for correct melody recognition. If both of these characteristics are necessary for recognition, then performance on transformation OVC should show a decrement because, although chroma information is present, the melodic contour is violated. Idson and Massaro's (1978) results supported this hypothesis. Recognition performance was consistently better on transformation OPC than on OVC. In addition, performance was also better on OPC than on PC, indicating that contour plus chroma rather than contour alone contributed to melody recognition. Similar results for some of these distortions have been reported by other investigators (Deutsch, 1972; Dowling, 1972; Dowling & Fujitani, 1971; Dowling & Hollombe, 1977; Kallman & Massaro, 1979). The purpose of the present study was to replicate the experimental conditions of Idson and Massaro using unfamiliar tone sequences as test stimuli to test the generality of their results.

There are many good reasons to replicate the experimental conditions using unfamiliar tone sequences. In addition to the more precise experimental control, the use of artificially designed melodies allows us to assess whether highly overlearned and familiar melodies are recognized differently than are relatively novel tone sequences. One might argue that previous results are unique to well-known melodies and, therefore, do not illuminate the processing of most tone sequences. For example, Attneave and Olson (1971) found that subjects could transpose across octaves only very well-known sequences such as the NBC chimes. Extending this finding to the present task of recognizing melodies, it might be predicted that tone chroma will not be as functional in the recognition of unfamiliar melodies as it is in the recognition of well-known melodies. By testing observers for a number of consecutive days, it becomes possible to evaluate the extent to which practice in the experimental task alters the process of melody recognition.

Most familiar melodies contain unison intervals that are impossible to transform appropriately. For example, Transformation OPC (octave displacement, preserve contour) cannot be applied to the unison interval because displacing the notes an octave apart will also change the contour from level to ascending or descending. In previous studies, unison intervals were left intact in Transformation OPC, and this could have artificially inflated performance on this transformation. The unfamiliar melodies used in the present experiments did not contain any unison intervals.

Another potential problem in the use of familiar melodies is that it is not clear whether to eliminate rhythm information entirely, as in the Idson and Massaro (1978) studies, or to include it, as in the Dowling and Hollombe (1977) and Kallman and Massaro (1979) studies. The use of unfamiliar melodies that do not differ rhythmically provides a straightforward solution to this problem.

The present study extends the body of knowledge on melody recognition by analyzing the nature of confusion errors between melodies. If a distortion of Melody A is usually called Melody B, then it is possible to determine what properties Melody B has in common with the distortion of Melody A. As an example, the distortion of Melody A may produce a contour that is similar to Melody B, and it can be expected to be identified as such to the extent that contour is functional in recognition.

To study the recognition of recently learned melodies, it is necessary to use a forced-choice procedure with a limited set of stimulus–response alternatives. This procedure is identical to that used by Idson and Massaro (1978) but differs from the procedure of Deutsch (1972) and Kallman and Massaro (1979). The latter two studies presented a given melody or transformed melody only once, and subjects were not given any specific response alternatives. Both procedures have provided converging results: Performance is very poor if chroma is preserved and contour is violated (OVC), and preserving both chroma and contour (OPC) is significantly better than simply preserving contour (PC). Given that the results of interest are the same with both procedures, it cannot be argued that the results found using the forced-choice procedure are the product of recognition strategies unique to this procedure as Deutsch (1978) has argued.

Experiment 1

Method

Subjects. The subjects were 11 University of Wisconsin students who volunteered to participate in the study to earn extra credit in an introductory psychology course. Subjects were not aware of the nature of the experiment at the time they volunteered, and musical experience was not a factor in their selection. All subjects reported having normal hearing.

Stimuli. Four six-tone sequences were chosen for use as original untransformed stimuli. Three sequences (1–3) were selected from among exercises in an introductory sight-singing text; the fourth was constructed by an experimenter. Each six-tone sequence began and ended on C_4 (262 Hz); all original melodies (we use the terms *tone sequences* and *melodies* interchangeably) were in the key of C major. The original untransformed tone sequences are referred to as Transformation O.

The notes comprising the four original tone sequences as well as the transformations on them (described later) appear in Table 1. The range spanned by each untransformed sequence, that is, the distance between the lowest and highest notes in the sequence, was less than one octave.

The transformations used were similar to those used by Idson and Massaro (1978). Like the original melodies, each transformed sequence began and ended on C_4 (262 Hz).

1. Preserving contour (PC): Transformation PC preserved the contour of the original sequence without regard to maintaining either absolute pitch information or the relative size of successive intervals from the original sequence. Each note of the original was displaced within the octave either up or down a small number of semitones. The total range in semitones of each PC transformation was comparable to the range for the original sequence.

2. Linear transformation (LT): Transformation LT was constructed by dividing the number of semitones between each directionally defined interval in the original sequence by two. For example, the first interval in Melody 1 is a two-semitone jump from C_4 (262 Hz) to D_4 (294 Hz); in transformation LT this became a one-semitone rise from C_4 (262 Hz) to $C^{\#}_4$ (277 Hz). In some cases, use of this algorithm resulted in inclusion of tones not found in the chromatic scale. For example, the original Sequence 1 contains a seven-semitone fall in pitch from D_4 (294 Hz) to G_3 (196 Hz) between Notes 4 and 5 of the sequence. In transformation LT this becomes a 3.5-semitone decrease from $C^{\#}_4$ (277 Hz) to the tone between A_3 and $A^{\#}_3$ (227 Hz). In such cases the frequencies of the tones were placed halfway between the frequencies of the two adjacent semitones.

Transformation LT had the following effects with regard to each original sequence: (a) It preserved contour; (b) it preserved the relative size of the original intervals; that is, the ratios of the distances between successive tone pairs remained the same as in the original; (c) it destroyed absolute pitch information; and (d) it reduced the total range of the original sequence by half.

3. Octave-preserving contour (OPC): Transformation OPC preserved the chroma information and the contour of each original sequence. Each note of the original melody was displaced up or down, depending on the direction of pitch change, by one or more octaves. For example, the first three notes of original Sequence 1 (C_4, 262 Hz; D_4, 294 Hz; E_4, 330 Hz) became (C_4, 262 Hz; D_5, 587 Hz; and E_6, 1319 Hz). An effort was made not to displace two successive notes into the same octave; however, because it had been decided not to include tones below 110 Hz or above 4000 Hz in any sequence, this was not always possible.

Transformation OPC preserved both the contour and chroma information of the original melodies. The sizes of successive intervals in the original melodies were changed. In addition, the absolute pitch information from the original was partially destroyed. However, each OPC sequence contained at least one tone (in addition to Tones 1 and 6) that was identical in frequency to the tone in the same position in the original sequence. In Sequences 1 and 3, the identical note in the original and transformation OPC was in the fifth position; thus these two sequences contained not only an extra identical tone but also one identical interval. Comparing performance on these two sequences to performance on the other two sequences will allow a direct assessment of this property.

Table 1
Notes and Note Frequencies of Tone Sequences Used in Experiment 1

Transformation	Frequencies	Notes[a]	Contour[b]
	Sequence 1		
O	262, 294, 330, 294, 196, 262	$C_4\ D_4\ E_4\ D_4\ G_3\ C_4$	+ + − − +
PC	262, 349, 392, 330, 220, 262	$C_4\ F_4\ G_4\ E_4\ A_3\ C_4$	+ + − − +
LT	262, 277, 294, 277, 227, 262	$C_4\ C^{\#}_4\ D_4\ C^{\#}_4\ *\ C_4$	+ + − − +
OPC	262, 587, 1319, 587, 196, 262	$C_4\ D_5\ E_6\ D_5\ G_3\ C_4$	+ + − − +
OVC	262, 147, 659, 1175, 392, 262	$C_4\ D_3\ E_5\ D_6\ G_4\ C_4$	− + + − −
	Sequence 2		
O	262, 294, 196, 294, 330, 262	$C_4\ D_4\ G_3\ D_4\ E_4\ C_4$	+ − + + −
PC	262, 330, 247, 349, 392, 262	$C_4\ E_4\ B_3\ F_4\ G_4\ C_4$	+ − + + −
LT	262, 277, 227, 277, 294, 262	$C_4\ C^{\#}_4\ *\ C^{\#}_4\ D_4\ C_4$	+ − + + −
OPC	262, 587, 196, 587, 1319, 262	$C_4\ D_5\ G_3\ D_5\ E_6\ C_4$	+ − + + −
OVC	262, 587, 784, 294, 165, 262	$C_4\ D_5\ G_5\ D_4\ E_3\ C_4$	+ + − − +
	Sequence 3		
O	262, 247, 220, 330, 294, 262	$C_4\ B_3\ A_3\ E_4\ D_4\ C_4$	− − + − −
PC	262, 220, 196, 349, 330, 262	$C_4\ A_3\ G_3\ F_4\ E_4\ C_4$	− − + − −
LT	262, 254, 240, 294, 277, 262	$C_4\ *\ *\ D_4\ C^{\#}_4\ C_4$	− − + − −
OPC	262, 123, 110, 659, 294, 262	$C_4\ B_2\ A_2\ E_5\ D_4\ C_4$	− − + − −
OVC	262, 494, 880, 2637, 587, 262	$C_4\ B_4\ A_5\ E_7\ D_5\ C_4$	+ + + − −
	Sequence 4		
O	262, 440, 392, 494, 392, 262	$C_4\ A_4\ G_4\ B_4\ G_4\ C_4$	+ − + − −
PC	262, 494, 349, 440, 330, 262	$C_4\ B_4\ F_4\ A_4\ E_4\ C_4$	+ − + − −
LT	262, 339, 320, 359, 320, 262	$C_4\ *\ *\ *\ *\ C_4$	+ − + − −
OPC	262, 880, 392, 1976, 784, 262	$C_4\ A_5\ G_4\ B_6\ G_5\ C_4$	+ − + − −
OVC	262, 220, 784, 494, 196, 262	$C_4\ A_3\ G_5\ B_4\ G_3\ C_4$	− + − − +

Note. O = octave; PC = preserving contour; LT = linear transformation; OPC = octave-preserving contour; OVC = octave-violating contour.
[a] Asterisks denote tones with frequencies that do not correspond to notes in the chromatic scale.
[b] A minus sign denotes a descending interval; a plus sign denotes an ascending interval.

The range in semitones of each sequence under transformation OPC was much larger than in the original sequence, on the average of 33 semitones.

4. Octave-violating contour (OVC): Transformation OVC was effected by displacing each note of an original sequence by one or more octaves, disregarding the direction of the interval change in the original melody. Transformation OVC preserved the chroma information but violated the contour of the original melody. The number of contour violations possible in a six-tone sequence is five; Transformation OVC of Sequences 1 and 3 each had three violations of original contour, whereas the OVC versions of Sequences 2 and 4 each had four contour violations.

Transformation OVC distorted the absolute pitch and successive interval size information of the original sequences. Sequences 2 and 4 each had one tone in Transformation OVC that was identical to the corresponding original tone. None of the melodies had any identical intervals in the original and OVC versions. The range of notes used in the OVC transformations averaged 32 semitones.

Since the range of tone frequencies used in transformations OPC and OVC was much greater than for the original, PC, and LT versions of each sequence, the latter three tone patterns were displaced as a whole into each of five octaves (one octave below and three above the octave beginning at C_4). This was done to assure that any differences found between the transformation conditions was not due to differential discrimination at different frequencies. The octave in which the original sequence, Transformation PC, and Transformation LT were presented was chosen randomly on each trial.

Apparatus. All experimental events and data collection were controlled by a PDP-8L computer. The sine-wave tones were generated by a Wavetek (Model 155) digitally-controlled oscillator. The output of the oscillator was gated by an Iconic (Model 0137) audio switch and then amplified through a McIntosh (Model MC-50) amplifier. Rise and fall times for the tones were 10 msec. The tones were diotically presented to subjects over Grason-Stadler TDH-49 headphones at an amplitude level of approximately 80 dB (A). Since the

Wavetek oscillator could be adjusted to only three decimal places, the last digit of any frequency over 1,000 was truncated. The visual displays were presented over an array of light-emitting diodes (Monsanto Model MDA-III). Four or fewer subjects could be tested simultaneously in separate sound-attenuated rooms.

Design. There were three major independent variables: melody, transformation, and octave of presentation. In addition to the original melody, there was a total of four transformations on each melody. The original melody and Transformations PC and LT were subject to presentation in any of five octaves; the first note could range from C_3 (131 Hz) to C_7 (2,093 Hz), and the frequencies of the following notes were adjusted accordingly. For Transformations OPC and OVC, octave was a dummy variable; the first note of these transformed melodies was always C_4.

Procedure. During the experiment, on each trial a six-tone sequence was presented and then followed by a response period. An asterisk presented for 250 msec over a visual display signaled the beginning of each trial. The first tone of the sequence was presented 750 msec after termination of the visual display. Including the rise and fall times, each tone had a duration of 150 msec. There was a 150-msec silent interval between tones. Immediately following the offset of the sixth tone, subjects were given 5 sec to indicate by pressing one of four buttons whether the tone sequence sounded most similar to Sequence 1, 2, 3, or 4. On those trials in which one of the four original (untransformed) sequences had been presented, visual feedback was provided indicating whether the sequence was Sequence 1, 2, 3, or 4. This feedback, which lasted 250 msec and immediately followed the response period, was designed to aid learning and retention of the four untransformed sequences. There was a 1-sec interval between trials.

The experiment was conducted on 4 consecutive days; each session lasted approximately 45 min. On the 1st day of the experiment (practice day), subjects were first introduced to the four untransformed sequences. These were presented in the order Sequence 4, 3, 2, 1. The four sequences were presented in this order six times. The temporal constraints governing presentations of the sequences were the same as on experimental trials except that 3 sec separated the presentation of each sequence. The numerical label assigned to each sequence was presented over the visual display during each tone sequence presentation. The subject's task during this phase was simply to listen and learn to recognize the different tone sequences. Following the initial presentation of the tone sequences, subjects were presented 112 practice trials. These trials were exactly like experimental trials except that only the four original sequences in their original octave (starting on C_4) were presented. The subjects' task was to indicate which sequence was presented, and visual feedback was given on each trial.

After a 5-min break, a block of 112 experimental trials was presented. The first 12 trials were practice and were not recorded (although the subject did not know this); random sampling without replacement began with Trial 13.

On experimental Days 1, 2, and 3, subjects' memories were refreshed by playing the untransformed tone sequences six times each (as on the practice day). This was followed by two blocks of 112 experimental trials separated by a short break. Given that the first 12 trials of each block were not recorded, one block involved a complete replication of the 4 melodies × 5 transformations × 5 octaves = 100 conditions of interest. Within each experimental block each experimental condition occurred randomly without replacement. Two blocks per day gave two observations per condition per day for each of the 3 experimental days.

Results and Discussion

Only data from subjects who correctly identified the original untransformed melodies on at least 50% of the trials over the 3 experimental days were included in data analysis. Of the 11 subjects, data from 8 met this criterion. An analysis of variance (ANOVA) was performed on the percentages of correct identifications. Tone sequence (four levels), transformation (five levels), octave of presentation (five levels), and day (three levels) were all within-subjects variables.[1]

The percentages of correct identifications of each transformation of each sequence on the 3 experimental days appear in Table 2 along with the data averaged over the 3 days. The main effect of transformation was significant, $F(4, 28) = 44.36$, $MS_e = 1.041$, and thus orthogonal comparisons were conducted to test differences between the means. The absence of a significant difference between the O and OPC conditions ($F < 1$) replicates the findings of Idson and Massaro (1978). One factor that might bias the results on the OPC trials toward good performance is the fact that two of these sequences (Sequences 1 and 3) included one melodic interval identical to the corresponding interval in the original sequences. However, examination of the data shows that per-

[1] Unless otherwise noted, the claim of a significant effect will denote a p value of less than .05.

Table 2
Percentages of Correct Identifications of Each Transformation of Each Melody in Experiment 1

Melody	Day 1 transformation					Day 2 transformation					Day 3 transformation					Averaged over days transformation				
	O	PC	LT	OPC	OVC	O	PC	LT	OPC	OVC	O	PC	LT	OPC	OVC	O	PC	LT	OPC	OVC
1	99	78	89	76	3	100	84	95	80	3	99	75	91	78	5	99	79	92	78	3
2	80	49	53	69	24	86	53	56	89	25	95	56	79	88	16	87	53	63	82	22
3	74	58	78	78	7	85	69	84	83	5	89	65	80	96	3	83	64	80	85	5
4	74	54	38	81	23	89	78	51	94	11	85	66	38	94	1	83	66	42	90	12
M	82	59	64	76	14	90	71	72	86	11	92	66	72	89	6	88	65	69	84	10

Note. O = octave; PC = preserving contour; LT = linear transformation; OPC = octave-preserving contour; OVC = octave-violating contour.

formance on the OPC transformation relative to the original sequence was no better for Sequences 1 and 3 than for Sequences 2 and 4. Thus the good performance on Transformation OPC cannot be explained by the fact that one interval in two of the melodies was identical under this transformation to an interval in the original melodies.

No difference was found between the two conditions that maintained the contour of the original sequence but violated tone chroma (i.e., PC and LT, $F < 1$). However, although performance was quite good under these contour-preserving conditions, the third orthogonal comparison indicates that when correct chroma information was available as well as contour information (O and OPC), performance was approximately 20% better than when only contour information was correct (PC and LT), $F(1, 28) = 15.87$. Finally, when contour information was incorrect but accurate chroma information was maintained (OVC), performance was much worse than on the contour-preserving transformations, $F(1, 28) = 161.05$. This latter finding is in agreement with the results of Idson and Massaro (1978) and suggests that accurate tone chroma is only useful for melody recognition when it is accompanied by accurate contour information.

Two of the OVC transformations (Sequences 2 and 4) contained one note (in addition to the first and last note of the sequence) that was identical to the corresponding note in the original sequence. It is noteworthy that performance on these two OVC sequences was higher than on the other two sequences (22% and 12% correct vs. 3% and 5% correct). This finding could be interpreted as suggesting that the presence of an identical note in the original and transformed sequences resulted in a performance increment. Extending this line of reasoning, good performance on OPC trials might be due to the fact that *all* OPC transformations had a note (other than the first or last) identical to the corresponding note in the original sequence. However, such a conclusion is not warranted by the data. Both the

OPC and OVC transformations of Sequences 2 and 4 contained a note identical to a corresponding note in the original tone sequence, and yet performance on the OPC transformations of these sequences was substantially better than on the OVC versions of the same sequences. The higher performance found on the OPC trials of Sequences 2 and 4 clearly cannot be explained by the presence of notes identical to corresponding notes in the original sequences, since the OVC transformations had an equal number of identical corresponding notes.

There was an overall improvement of approximately 7% in performance from experimental Day 1 to Day 2, as is reflected by a significant day effect, $F(2, 14) = 9.43$, $MS_e = .118$. Furthermore, there was a significant interaction between day and transformation, $F(8, 56) = 2.49$, $MS_e = .118$. An examination of Table 2 reveals that performance on the four contour-preserving transformations improved over days, but performance on Transformation OVC actually deteriorated. It will be argued later that to the degree that subjects used melodic contour information in making their decisions about OVC transformations, performance should have been poor on these transformations. Given this interpretation, the form of the interaction between days and transformations suggests that the subjects continued to learn the contours of the melodies and used this information to identify the melodies.

Although melody was not a significant factor, $F(3, 21) = 2.22$, $MS_e = .690$, there was a significant interaction between transformation and melody $F(12, 84) = 3.73$, $MS_e = .493$. This interaction may be explained, at least in part, by noting that for sequences that yielded relatively poor performance on the OVC transformations (Sequences 1 and 3), performance on the contour-preserving, chroma-violating transformations (Transformations PC and LT) was relatively good compared to those melodies yielding better performance on the OVC transformations. It is interesting to note that the melodic contours of the untransformed Sequences 1 and 3 appear more salient than do the contours of the untransformed Sequences 2 and 4 (see Table 1). Sequence 1 could be coded as "two ups, two downs, and one up," whereas Sequence 3 consists of "two downs, one up, and two downs." The contours of original Sequences 2 and 4 appear more difficult to code. These possible coding differences could have accounted for differences in the degree to which contour information was used to identify the different sequences. If contour information was weighted more heavily in identifying Sequences 1 and 3 than in judging the other sequences, we would have expected both the relatively low performance on the OVC transformations of Sequences 1 and 3 and the elevated performance on the PC and LT transformations of these sequences.

Octave of presentation was not a significant variable ($F < 1$, $MS_e = .051$), although octave did interact with transformation, $F(16, 112) = 1.81$, $MS_e = .045$. However, no systematic trend underlying this interaction was apparent, and the statistical significance probably reflects primarily the high power of the test given the large number of degrees of freedom.

Performance on Transformation OVC was not only much worse than for any of the other transformations, it was well below the 25% correct expected by chance. To understand this result, consider that the relatively good performance with Transformations PC and LT indicates that contour information played a substantial role in subjects' identifications. To the extent that the OVC transformation of a tone sequence results in a sequence whose contour resembles that of an untransformed sequence other than that from which the OVC sequence was derived, confusions between the OVC sequence and the O sequence with similar contour would be expected. The response confusion matrix for the OVC transformations presented in Table 3 supports this analysis (for reference refer also to the contours of the tone sequences presented in Table 1). For example, the OVC transformation of Sequence 2 was identified as Sequence 1 69% of the time. This high percentage of mis-

Table 3
Percentage of Each of the Four Transformed Sequences Identified as Each of the Four Original Sequences for the Five Transformations in Experiment 1

	Response[a]			
Melody	1	2	3	4
	Transformation OVC			
1	3 (2)	40 (2)	11 (4)	46 (3)
2	69 (5)	22 (1)	5 (1)	3 (2)
3	6 (3)	24 (3)	5 (3)	65 (4)
4	54 (4)	22 (0)	12 (2)	12 (1)
	Transformations OPC, PC, O, and LT			
1	87 (5)	7 (1)	5 (1)	1 (2)
2	9 (1)	71 (3)	4 (3)	17 (4)
3	4 (1)	11 (3)	78 (5)	8 (4)
4	6 (2)	19 (4)	4 (4)	70 (5)

Note. O = octave; OPC = octave-preserving contour; OVC = octave-violating contour; PC = preserving contour; LT = linear transformation.
[a] Scores in parentheses are the number of successive intervals shared by the transformation and the original tone sequence.

identifications occurred because the contour of the OVC transformation of Sequence 2 was identical to that of the untransformed (O) Sequence 1. Similarly, the reason why the OVC transformation of Sequence 2 was identified as Sequence 2 on only 22% of the trials was probably because its contour differs from the untransformed (O) Sequence 2 at four of the five intervals.

One way to test this interpretation more directly is to calculate, for all combinations of OVC transformations and original sequences, the number of corresponding successive intervals that have the same direction of pitch change. We would expect that the probability of confusing the OVC transformation of Tone Sequence X for the untransformed Sequence Y should increase as the number of corresponding intervals between the sequences having the same direction of pitch change increases.

For each combination of O and OVC sequences used in Experiment 1, the number of successive intervals having the same direction of pitch change appears in Table 3. Although the fit is not perfect, the data generally are in accord with our interpretation. Disregarding correct responses (i.e., a response of X to OVC Sequence X), a test of correlation was performed between the number of common (in terms of ups and downs) successive intervals between the OVC and O stimuli and the number of times the OVC stimuli were identified as the incorrect O sequences. This correlation was significant, $r(10) = .60$, supporting our analysis.

It is also possible to examine the degree to which the response confusions on trials other than those in which OVC transformations were presented depended on the degree of contour similarity between the presented melody and the response melody. To compute a correlation coefficient, the confusion data were averaged over Transformations O, OPC, LT, and PC; these averaged data are given in Table 3. The correlation coefficient was computed using the same procedure as for the OVC confusion data; correct responses were disregarded. Although there was a relatively high correlation between the number of common directions of the successive intervals and the number of response confusions for each tone sequence pair, the correlation was only marginally significant on a one-tailed test, $r(10) = .49$, $.05 < p < .10$. Nonetheless, the presence of a relatively high correlation is consistent with the view that contour information did play an important role in subjects' judgments.

Two general points can be made about Experiment 1. First, melodic contour played a substantial role in subjects' judgments. Second, the elevated performance on Transformation OPC relative to Transformations LT and PC suggests that in addition to melodic contour, tone chroma played a role in the judgments. These findings are consistent with the findings of Idson and Massaro (1978).

Experiment 2

In Experiment 1, performance on OPC trials was about as good as when the original melodies were presented. We tentatively interpreted this result as indicating that tone chroma was a functional dimension in melody recognition. This conclusion followed because when only contour information was available (PC and LT transformations), performance suffered relative to the OPC condition. Presumably, the use of chroma information in addition to contour information resulted in the increment in performance found on OPC trials.

An alternative explanation of the good performance found on OPC trials is possible. Since the intervals were on the average much larger under the OPC transformations than under the other transformations, the contour of the OPC melodies may have been more salient (cf. Idson & Massaro, 1978). Since the results of Experiment 1 indicated that contour was an important cue used by subjects in making their decisions, the added saliency of the contour on OPC trials may have been the sole cause of the good performance found on these trials. If this were the case, it would follow that chroma information played no role in the OPC decisions.

To test this idea we used a transformation, PCS (preserve contour, stretched), in Experiment 2 that preserved the contour of the original melody *and* had intervals approximately as large as those used under Transformation OPC; however, correct chroma information was not available under Transformation PCS. Using a similar transformation, Idson and Massaro (1978) found that in their experiments, the possible added saliency of the OPC contour could not account for the good performance on OPC trials. However, given the prominent role of contour found in Experiment 1 of the present study, it is important to determine whether the stretched contour hypothesis could account for the good performance on OPC trials. If the good performance on transformation OPC was due solely to the added saliency of the contour under this transformation, then equally good performance should be found on Transformation PCS. If, instead, the good performance found on OPC trials resulted from accurate chroma information rather than the enlarged intervals, then performance on Transformation PCS should be worse than on Transformation OPC and about equal to that on Transformation PC.

Method

Subjects. Ten students at the University of Wisconsin participated in Experiment 2. Musical experience was not a factor in their selection, but all reported having normal hearing. In return for their services, 6 were awarded extra credit in an introductory psychology course and 4 were paid $2.50 an hour.

Stimuli and procedure. Four six-tone sequences different from those used in Experiment 1 (but similar in nature) were chosen from exercises in a sight-singing book for use as original untransformed stimuli. Each six-tone sequence began and ended on C_4 (262 Hz); all original melodies were in the key of C major. The original tone sequences and their transformations are given in Table 4.

The same transformations used in Experiment 1 were used in Experiment 2 with the exception that a new transformation, PCS, was tested in place of Transformation LT. Transformation PCS was similar to Transformation OPC; however, rather than displacing tones by an octave (12 semitones) relative to the original melody, the tones in Transformation PCS were changed an additional ± 2 semitones. This transformation thus preserved contour without preserving chroma but yielded sequences whose ranges were approximately the same as those of the sequences in Transformation OPC, which preserved both contour and chroma.

Unlike the OPC transformations in Experiment 1, none of the OPC transformations shared tones or intervals with its corresponding original sequence. Also, only one OVC transformation (Melody 2) contained a note identical to the corresponding note in the original sequence.

With the exception of the use of different melodies and the use of the PCS transformation instead of the LT transformation, the procedure of Experiment 2 was identical to that of Experiment 1. Since the PCS transformation spanned a wide range of frequencies, the PCS sequences always began on C_4, as did the OPC and OVC sequences. The PC and O transformations, however, were subject to presentation in any of five octaves as in Experiment 1.

Results and Discussion

Only data from those subjects who correctly identified the original untransformed tone sequences on at least 50%

Table 4
Notes and Note Frequencies of Tone Sequences used in Experiment 2

Transformation	Frequencies	Notes	Contour[a]
	Sequence 1		
O	262, 392, 294, 440, 349, 262	$C_4\ G_4\ D_4\ A_4\ F_4\ C_4$	+ − + − −
PC	262, 330, 247, 392, 294, 262	$C_4\ E_4\ B_3\ G_4\ D_4\ C_4$	+ − + − −
PCS	262, 698, 165, 1568, 784, 262	$C_4\ F_5\ E_3\ G_6\ G_5\ C_4$	+ − + − −
OPC	262, 784, 147, 1760, 698, 262	$C_4\ G_5\ D_3\ A_6\ F_5\ C_4$	+ − + − −
OVC	262, 196, 587, 220, 698, 262	$C_4\ G_3\ D_5\ A_3\ F_5\ C_4$	− + − + −
	Sequence 2		
O	262, 247, 262, 349, 330, 262	$C_4\ B_3\ C_4\ F_4\ E_4\ C_4$	− + + − −
PC	262, 220, 294, 494, 349, 262	$C_4\ A_3\ D_4\ B_4\ F_4\ C_4$	− + + − −
PCS	262, 147, 466, 1175, 740, 262	$C_4\ D_3\ A^{\#}_4\ D_6\ F^{\#}_5\ C_4$	− + + − −
OPC	262, 123, 698, 1397, 659, 262	$C_4\ B_2\ F_5\ F_6\ E_5\ C_4$	− + + − −
OVC	262, 494, 131, 349, 659, 262	$C_4\ B_4\ C_3\ F_4\ E_5\ C_4$	+ − + + −
	Sequence 3		
O	262, 330, 294, 392, 349, 262	$C_4\ E_4\ D_4\ G_4\ F_4\ C_4$	+ − + − −
PC	262, 392, 330, 494, 440, 262	$C_4\ G_4\ E_4\ B_4\ A_4\ C_4$	+ − + − −
PCS	262, 587, 165, 1397, 784, 262	$C_4\ D_5\ E_3\ F_6\ G_5\ C_4$	+ − + − −
OPC	262, 659, 147, 1568, 698, 262	$C_4\ E_5\ D_3\ G_6\ F_5\ C_4$	+ − + − −
OVC	262, 165, 587, 196, 698, 262	$C_4\ E_3\ D_5\ G_3\ F_5\ C_4$	− + − + −
	Sequence 4		
O	262, 294, 330, 247, 330, 262	$C_4\ D_4\ E_4\ B_3\ E_4\ C_4$	+ + − + −
PC	262, 349, 392, 294, 440, 262	$C_4\ F_4\ G_4\ D_4\ A_4\ C_4$	+ + − + −
PCS	262, 523, 1175, 139, 587, 262	$C_4\ C_5\ D_6\ C^{\#}_3\ D_5\ C_4$	+ + − + −
OPC	262, 587, 1318, 123, 659, 262	$C_4\ D_5\ E_6\ B_2\ E_5\ C_4$	+ + − + −
OVC	262, 147, 659, 494, 165, 262	$C_4\ D_3\ E_5\ B_4\ E_3\ C_4$	− + − − +

Note. O = octave; PC = preserving contour; PCS = preserving contour, stretched; OPC = octave-preserving contour; OVC = octave-violating contour.
[a] A minus sign denotes a descending interval; a plus sign denotes an ascending interval.

of the trials over the 3 experimental days were included in data analysis. Of the subjects who participated in Experiment 2, data from seven met this criterion.

The percentages correct for each transformation of each sequence on the 3 experimental days appear in Table 5 along with the data averaged over the 3 days.

The main effect of transformation was significant, $F(4, 24) = 14.61$, $MS_e = .734$, and thus orthogonal comparisons between the means were carried out. Although performance on the original melodies was slightly better than performance on the OPC melodies, this difference was not significant, $F(1, 24) = 3.46$, $.05 < p < .10$. This finding agrees with the results of Experiment 1 and with those of Idson and Massaro (1978) in suggesting that the difference between the O and OPC conditions is relatively small and usually nonsignificant. In agreement with the results of Experiment 1 was the finding that performance on the contour-preserving transformations that preserved chroma information (O and OPC) was better than on the contour preserving transformations that did not (PC and PCS), $F(1, 24) = 17.93$. Of particular interest in Experiment 2 was the absence of a significant difference between Transformations PC and PCS, $F(1, 24) = 1.40$. This finding suggests that the good performance on Transformation OPC cannot be explained by referring to the stretched contour present under this transformation. As expected, performance on Transformation OVC was worse than the average performance on the

Table 5
Percentages of Correct Identifications of Each Transformation of Each Melody in Experiment 2

Melody	Day 1 transformation					Day 2 transformation					Day 3 transformation					Averaged over days transformation				
	O	PC	PCS	OPC	OVC	O	PC	PCS	OPC	OVC	O	PC	PCS	OPC	OVC	O	PC	PCS	OPC	OVC
1	56	30	39	59	7	56	27	39	56	14	66	26	51	66	10	59	28	43	60	10
2	80	43	66	80	37	80	47	49	70	40	84	56	57	74	51	81	49	57	75	43
3	53	40	36	39	30	61	23	26	31	31	53	43	29	41	33	56	35	30	37	31
4	94	64	66	54	30	90	67	87	73	37	93	79	86	90	37	92	70	80	72	35
M	71	44	51	58	26	72	41	50	58	31	74	51	56	68	33	72	45	52	61	30

Note. O = octave; PC = preserving contour; PCS = preserving contour, stretched; OPC = octave-preserving contour; OVC = octave-violating contour.

transformations that preserved the original sequences' melodic contour, $F(1, 24) = 35.51$.

Overall performance remained constant from Experimental Day 1 to Day 2 but improved by 6% on Day 3, $F(2, 12) = 10.44$, $MS_e = .082$. Unlike Experiment 1, day did not interact with transformation ($F < 1$, $MS_e = .124$).

Tone Sequences 2 and 4 were identified correctly more often than were Sequences 1 and 3, as indicated by a significant effect of tone sequence, $F(3, 18) = 13.08$, $MS_e = .990$. Sequence did not interact with transformation, $F(12, 72) = 1.70$, $MS_e = .556$.

Both the effect of octave of presentation and the interaction of octave and transformation were not significant ($F < 1$) in each case (MS_es were .088 and .104, respectively). The absence of an interaction between octave and transformation in Experiment 2 supports our view that the significant interaction between these factors in Experiment 1 was due primarily to the high power of the test.

Response confusion matrices for Experiment 2 are presented in Table 6 for both the OVC transformation and averaged over the other transformations. To test the degree to which performance on Transformation OVC depended on contour information, we calculated the correlation between the number of common directions of the successive intervals between the OVC and O stimuli and the number of times that the OVC stimuli were confused for incorrect O sequences. This correlation based on the data presented in Table 6 was only marginally significant on a one-tailed test, $r(10) = .42$, $.05 < p < .10$. Although this degree of correlation is somewhat less than what was found in Experiment 1, performance on the other transformations indicated that contour information did play an important role in the judgments made in Experiment 2. Table 6 presents the averaged confusion matrix averaged over Transformations O, OPC, PCS, and PC. The correlation (disregarding correct responses) between the number of common directions of the suc-

Table 6
Percentage of Each of the Four Transformed Sequences Identified as Each of the Four Original Sequences for the Five Transformations in Experiment 2

	Response[a]			
	1	2	3	4
	Transformation OVC			
1	11 (1)	47 (3)	25 (1)	17 (4)
2	16 (2)	43 (2)	30 (4)	11 (3)
3	5 (1)	42 (3)	32 (1)	21 (4)
4	7 (1)	40 (3)	20 (1)	34 (2)
	Transformations OPC, PC, O, and PCS			
1	48 (5)	11 (3)	34 (5)	8 (2)
2	10 (3)	65 (5)	15 (3)	10 (2)
3	41 (5)	53 (3)	40 (5)	6 (2)
4	6 (2)	10 (2)	6 (2)	79 (5)

Note. O = octave; OPC = octave-preserving contour; OVC = octave-violating contour; PC = preserving contour; PCS = preserving contour, stretched.
[a] Scores in parentheses are the number of successive intervals shared by the transformation and the original tone sequence.

cessive intervals and the number of confusions between tone sequences was very high for the data from the contour-preserving transformations, $r(10) = .71$, and suggests that contour played an important role in the judgments.

The major results of Experiment 2 are in accord with those of Experiment 1 and, moreover, suggest that the salience of the contours of the OPC tone sequences was not the sole contributing factor to the good performance on the OPC sequences.

General Discussion

The main purpose of the present study was to evaluate the relative contributions of tone chroma, melodic contour, and tone height to melody recognition when unfamiliar tone sequences were used as stimuli. The results of the present experiments implicate both tone chroma and melodic contour as important. The small decrement in performance on Transformation OPC relative to performance on the original melodies replicates the Idson and Massaro (1978) experiments but contrasts somewhat with the results of a recent study by Kallman and Massaro (1979). In that study, subjects heard familiar melodies (e.g., "Yankee Doodle") and were asked to try to identify the melodies; however, each melody was presented to a given subject only once. One of the three melodies ("London Bridge") gave a relatively large decrement in identification performance on the OPC relative to the untransformed version. It may be that distortions of tone height can be easily compensated for when they are expected (as would be the case when subjects hear numerous repetitions of distorted melodies), but distortions of the relative tone height of successive intervals might result in poorer recognition when the distortions are unexpected. However, because the relatively large decrements on Transformation OPC occurred for only one of the melodies in the Kallman and Massaro study, this result must be interpreted with caution.

Similar to the case with tone height, it is necessary to evaluate how the importance of tone chroma and melodic contour varies depending on the experimental task. For example, both the results of Idson and Massaro (1978) and those of the present study showed relatively good performance when melodies with correct contour but incorrect tone chroma were presented. But Kallman and Massaro (1979) found that when subjects heard each of three melodies only once and were not told the names of the possible melodies in advance, PCS transformations of the familiar melodies were almost never recognized. This is not to say that contour information was not used as effectively by subjects in the Kallman and Massaro study. Rather, good recognition of the melodies depended on the presence of both contour and chroma information.

To effectively use contour information in the absence of tone chroma information, it may be necessary that the subject know the possible melodies in advance. In this case, the subject could find the best match between the contour of the presented melody and the contours of the possible melodies. To the extent that this strategy seems effective, the subject might use contour as the primary cue. In fact, in a postexperimental interview, one of the subjects in the present study indicated that he remembered the untransformed tone sequences by drawing lines in his head corresponding to the direction of pitch changes. This representation of melodic contour was then used as a basis for categorizing the test stimuli.

Despite some differences in results due possibly to experimental procedure, there are important consistencies among the results of Idson and Massaro (1978), Kallman and Massaro (1979), and the present experiments. Specifically, performance on the OPC transformations was consistently much better than on the OVC and the PCS transformations. This result strongly suggests that tone chroma is functional in recognition of both highly familiar and recently learned melodies. Furthermore, all of the studies demonstrate that tone chroma information alone is not sufficient for accurate melody recognition. For chroma to be effective it must be accompanied by accurate contour information.

We have argued that tone height, melodic contour, and tone chroma may all contribute to the perception of a melody. How these characteristics are processed remains an important concern. For example, to say that tone height is important is not to say that the heights of the individual tones in a melody provide the cues necessary for melody recognition. Whether a given melody is sung by a bass or by a soprano voice does not usually influence a listener's ability to recognize the melody. The important feature for melody recognition is that the *relative heights* of successive tones are maintained when a melody is transposed from bass to soprano.

Exact tone height is not necessary, however, for melody recognition as indicated by the good performance on Transformation OPC. When an ascending major ninth is substituted for an ascending major second, the relative height of the successive tones (interval) is violated. We propose that octave generalization is responsible for the good performance on Transformation OPC. Octave generalization refers to the perceived similarity of notes standing in an octave relationship (Blackwell & Schlosberg, 1943; Humphreys, 1939). In the melody recognition task, octave generalization suggests that the ascending major ninth should be perceived as similar to an ascending major second. Although octave generalization facilitates melody recognition, substituting an ascending major ninth in a melody for a major second might increase the difficulty of recognizing the melody (cf. Kallman & Massaro, 1979). This is because octave generalization does not fully compensate for the violation of the relative height of the successive interval.

The relatively good performance on transformation PC suggests that the direction of pitch change (melodic contour) provides an important cue to the listener. Given an ascending ninth, octave generalization would suggest a number of possible interpretations of the interval, among them an ascending major ninth, an ascending major second, and a descending minor seventh. However, given that the direction of pitch change was up, a descending minor seventh would represent an inappropriate interval; the interval would thus not be interpreted as a descending major seventh. It is for this reason that we found that tone chroma information was not helpful when the melodic contour was violated. An explanation for why a major ninth might be readily interpreted as a major second rather than a ninth is that melodies rarely contain very large successive intervals, and, consequently, an interpretation of the interval as a second would be appropriate.

In summary, melodic contour, tone chroma, and relative tone height all contribute to melody recognition. Any theory of melody recognition will have to describe how these characteristics are evaluated and integrated together in perception and recognition.

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