Melody Recognition: The Experimental Application of Musical Rules

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ABSTRACT

Recognition of a transposed sequence of three tones was tested under four conditions of tone context. The melodic sequence was presented either without context or embedded in one of three types of context that varied according to the number of musical rules applied in their derivation. The recognition test (two-alternative forced choice) involved detection of a shift of one semit of one tone of the sequence, the shift being to a tone either within or without the musical key of the sequence. In addition, the test sequences were transposed either to the tritone or to the dominant of the tonic of the original sequence. Results, replicated for both piano and sine-tone stimuli, indicated significant effects of contextual conditions, key of error, and key of transposition. Ease of recognition in transposition is related to the identification and application of rules defining structures among tones and among tone sets, and to the use of rules for detecting structural violations.

Melodies transposed to different keys are recognized even though the absolute frequencies of the tones are changed. Musical transposition involves recognition of acoustic form or pattern; for the Gestaltists it represented a prototypic phenomenon (von Ehrenfels, translated by and published by Focht, 1937). Developments in experimental psychology tended, however, to ignore musical transposition. Methodological developments, concentrating upon the analysis of responses to single pure tones, provided a psychophysical function relating pitch to frequency – the mel scale (Stevens, Volkmann, & Newman, 1937) – and provided information-theoretic measures describing consistency of pitch judgment (Pollack, 1952, 1953). The problems and puzzles of melodic transposition in Western musical systems still remain. One is that the phenomenon of transposition implies perceptual constancy of frequency-ratio that is not predicted by the classical mel scale. As derived from the mel scale, musical intervals such as the octave grow increasingly larger in pitch distance up to about 4000 Hz (Stevens & Volkmann, 1940, Fig. 6). From this evidence a typical conclusion is that, 'if the mel scale were to be taken seriously, harmonic music would be theoretically impossible' (Harris, 1969, p. 265). Another problem is that our ability to recognize melodies cannot be accounted for in terms of the limited ability to recognize single tones (Miller, 1956). A third is that not all melodies are equally well recognized under transposition (Juhasz, in Peterman, 1932; Wertheimer, 1959; Cuddy & Cohen, 1976).

Our approach does not question the validity of the earlier psychophysical measures. The mel scale, for example, agrees closely with pitch projection scales obtained from non-metric scaling techniques (Parker & Schneider, 1974), and the units of the mel scale correspond with other psychoacoustic measures such as width of the critical band (Scharf, 1970). What we suspect to be the case is that the judgments of sensory pitch distance reflected by scaling procedures may be altered or restructured when tones are presented in melodic sequence. Melodic sequences in Western systems may be described by rules that specify both ratio relations among tones and tone progressions.

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In other words, the rules specify both the subset of allowable tones for a sequence and also particular orders of tones. We suggest that apprehension of the structure described by musical rules enables a listener to detect tone ratios. The ease with which the structure may be apprehended will determine the ease of melody recognition under transposition.

Students of musical composition are familiar with the use of musical rules to generate harmonic and melodic progressions. However, unlike the rules of chess or of sports, the primary historical function of musical rules was not to regulate or to generate patterns but to codify the structures of music already composed. These structures, we propose, reflect critical aspects of auditory processes – one being the ability to detect scalar relations among the tones of a melodic sequence.

The importance of tone relationships was emphasized by Helmholtz (1885/1954) in his justification of his detailed analysis of scale systems. Helmholtz repeatedly referred to 'the principle of tonality.' For example:

> Modern music has especially developed the principle of *tonality*, which connects all the tones in a piece of music by their relationship to one chief tone, called the tonic. (p. 5)

> When speaking of these systems of tones, it becomes a question of essential importance ... to inquire whether they are based upon any determinate reference of all the tones in the scale to one single principal and fundamental tone, the *tonic* or *key-note* ... This predominance of the tonic, as the link which connects all the tones of a piece, we may ... term the principle of tonality. (p. 240)

> ... we usually take the final tone of a piece to be its tonic without further inquiry ... The whole mass of tone is developed from the tonic and returns to it. Modern musicians cannot obtain complete repose at the end unless the series of tones converges into its connecting centre. (p. 242)

There are doubtless many cues to the sense of tonality; here we examine the amenability to experimental manipulation of two considered to be of primary importance by Helmholtz and by contemporary music theory.[1] These are *diatonicism* and the tone progression called a *cadence*. Diatonicism refers to what we call today the tones of the major (do-re-mi, etc.) and minor scale. More precisely, it refers to a particular set of ordered ratio relations within the seven tones of the scale. Given any tone frequency and its octave as the tonic, the rules of diatonicism fix the frequency boundaries of seven intervening steps. For the major scale the steps produce an ascending series of five whole tones (W) and two semits (S) in order from the tonic: WWSWWWS. A cadence refers to a particular order of tones at the end of a melody. The melody finishes with, or musically is said to 'resolve' to, the tonic note.

Three experiments are reported in which recognition of transposed three-tone melodies was tested in a standard two-alternative forced-choice psychophysical paradigm. Melodies were tested either alone or embedded in one of three types of context that varied in degree of conformity to the rules of diatonicism and cadential ending.

For the transposition test of each melody, two further manipulations of the rule of diatonicism were included. The first was type of error. When a melody was incorrectly transposed, one tone of the melody was altered by 1 semit. For diatonic sequences, such incorrect tones could be classified as being either within or without the diatonic scale of the sequence. If the underlying diatonic structure is a factor affecting decision accuracy the violation produced by an incorrect tone outside the scale should be easier to detect than an incorrect

[1] Sources for musical definitions and terms were: *Grove's Dictionary of Music and Musicians* (1966, 5th ed.), *The Oxford Companion to Music* (1970, 10th ed.), and *The Harvard Dictionary of Music* (1969, 2nd ed.). However, it should be pointed out that our primary orientation is not to attempt to explain musical definitions, but rather to explore the implications of musical concepts for theories of pitch processing.

tone still within the scale structure. The second was key of transposition. Melodies were transposed either to the dominant or to the tritone of the diatonic scale of the sequence. In terms of frequency distance, the dominant transposition lies 7 semits above or 5 semits below the original sequence while the tritone lies 6 semits above or below. The frequency distance above and below the original sequence is, therefore, very similar for the two transpositions. In terms of musical distance, however, the dominant is much closer to the original tonic than is the tritone. The dominant is the musical fifth of the diatonic scale while the tritone is not a member of the diatonic scale. Other comparisons, such as relative position in the harmonic series or the Pythagorean cycle of fifths, also show the dominant in closer relation to the tonic. The question is whether musical distance as distinct from frequency distance is a factor affecting ease of recognition of transposed melodies (cf. Attneave & Olson, 1971).

The main difference between the first two experiments was that the first used piano tones as stimuli while the second used sine tones under computer control. The intent was to investigate the pervasiveness of experimental effects with relatively familiar and unfamiliar sound sources. Tone frequencies throughout were determined by the equal-tempered system with A4 = 440 Hz; with this system the frequency shift of one semit is a constant frequency ratio equal to the twelfth root of 2 or approximately 1.059.

EXPERIMENT I

METHOD

Contextual Conditions

The experiments were designed to test recognition of the same three-tone melodies in all experimental conditions. In three conditions the melodies were embedded in a context of two preceding and two succeeding tones arranged so that the resulting sequence of seven tones conformed to specified musical rules. The sequences selected for the condition 'diatonic + cadence' formed the basis for all sequences in all conditions. The last seven notes of 16 one-part sight-singing exercises were selected from *The McDonough-Chevé method of sight-singing* (McDonough, 1927) where all tones belonged to the major key of the final note, and all sequences ended with a musical cadence. In addition, all tones were within the range of one octave, and there was no emphasis on practice of one particular interval, i.e., no interval was repeated more than twice. The tones of the sequences were coded as in Figure 1(a); the middle three tones were designated test-core (T) tones, and the first and last two tones were designated context (C) tones.

The 16 sequences of test-core tones formed the condition 'three-tone test core.' The remaining conditions, 'diatonic' and 'non-diatonic,' were derived as follows: all intervals formed by the context tones were placed in a pool from which intervals were randomly selected without replacement and were reassigned to the test-core sequences. There were certain constraints on assignment: for the diatonic condition, all tones of the context had to belong to the same major scale as the core, the last note of the sequence could not be the tonic, and the range of the tones could not exceed one octave; for the non-diatonic condition, the seven tones formed by the context and test core could not all belong to one major scale and the range of tones could not exceed one octave. The concepts of keyness really do not apply to non-diatonic sequences. The condition was intended to provide a control against which to check that experimental effects obtained for other conditions were not artifacts of procedure.

Test Trials and Comparison Sequences

The experimental paradigm was two-alternative forced-choice; each trial consisted of the presentation of a standard sequence (one of the 16 for each contextual condition) followed by two comparison sequences, one a correct, the other an incorrect transposition of the standard sequence.

Each standard sequence of the diatonic + cadence condition was randomly assigned to a tonic selected from the range C4 to B4 (262 to 494 Hz) so that each tonic served as key-note at least once but not more than twice. Both comparison sequences were transposed either to the dominant (ascending seven or descending five semits) or to the tritone (ascending or descending six semits). The key of transposition and the direction were both randomly assigned to sequences. The incorrect comparison was obtained by altering one tone of the test core +1 or −1 semit. On half of the trials, the error tone was a tone outside the scale of the sequence (error-out), while on the remaining half of the trials it

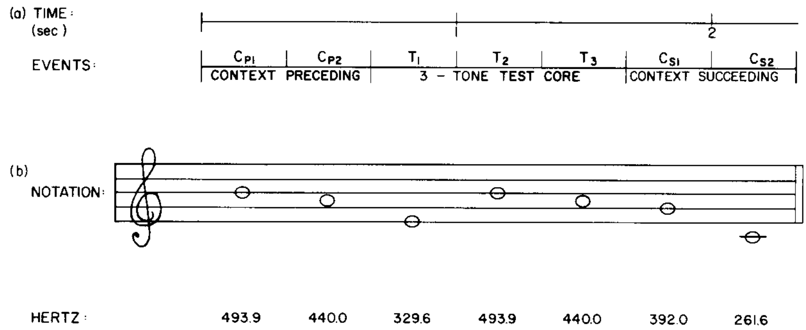

FIGURE 1 (a) The sequence of context tones and test tones. (b) The 'anomalous sequence' exemplified in the key of C. In the recognition test, the sequence was transposed to the dominant, and the incorrect comparison involved the raising of the first test tone (T_1) one semit.

was a tone that was a member of the scale (error-in). Within the constraint of these restrictions, both the direction and serial position of the error tone were selected randomly. For the remaining conditions, the frequency location of the standard and comparison sequences was determined by the corresponding test core in the diatonic + cadence condition. The three-tone test cores were thus identical in all conditions and the contexts were located about the cores so as to preserve the tone relations as defined above.

There were five consecutive presentations of each trial as defined above, with the identical standard sequence on each repetition, but with the position of the correct and incorrect transposition (first or second) randomly determined. To encourage listeners to attend to all tones of the sequence, two 'dummy' sequences were added to the main 16 standard sequences for each condition in which recognition of the second or seventh tones was tested.

Experimental Design and Listeners

Formally, the design was a mixed model, with contextual condition the between-subjects factor, and key of transposition, type of error, and repetitions the within-subjects factors. Forty-eight volunteers with a general interest in music participated as part of an introductory psychology course requirement; 12 were randomly assigned to each of the four contextual conditions. Typical listeners reported five years of musical training on one instrument, and daily exposure to music.

Procedure

The 90 trials for each condition (five repetitions of each of the 18 standard and comparison sequences) were recorded by an experienced pianist on a Heintzman grand piano tuned to standard A4, 440 Hz, in a recording studio of Queen's University Radio Station CFRC. Tones were .67 sec in duration; inter-sequence interval was 2 sec, and inter-trial interval was 4 sec. Recording was made on a Scully 380 tape recorder on Scotch 210 tape at a speed of $7\frac{1}{2}$ ips. As noted previously (Cuddy & Cohen, 1976), the tapes produced by an experienced pianist contained no perceptible variations of loudness or duration among the tones of the sequence.

Listeners were tested in sound-isolated audiometric chambers. Sequences were presented monaurally at a comfortable loudness level from a Crown tape recorder PRO-800 via MB Electronic headphones Model MBK 68. The nature of the paradigm was explained and listeners were instructed to indicate the temporal position of the correct transposition of each sequence (first or second) on response sheets provided.

EXPERIMENT II

METHOD

The general details of the method and experimental design were identical with those of Experiment 1. The stimulus tones, however, were sine tones generated by a General Radio 1161-P1 frequency synthesizer under control of a PDP 8/I computer. Tones were filtered by a Krohn-Hite low pass filter 3202 with cut-off set at 1250 Hz in order to minimize transient clicks. A new set of sequences was constructed according to the rules described. The available pool of listeners, though still restricted to first-year students, yielded a sample with slightly higher musical qualifications on the average – about two or three years further training for the typical listener.

RESULTS

The mean proportion of correct responses, P(C), for the factors of contextual condi-

TABLE I

Proportion correct responses for Experiment I (upper entry) and Experiment II (lower entry)

	Error-in		Error-out		
Contextual condition	Dominant	Tritone	Dominant	Tritone	Mean
Core					
Three-tone core	.87	.71	.77	.76	.778
	.80	.64	.80	.85	.773
Context					
Diatonic + Cadence	.88	.70	.91	.89	.845
	.75 (.88)	.76	.96	.92	.848 (.880)
Diatonic	.71	.69	.86	.74	.750
	.68	.83	.88	.82	.803
Non-diatonic	.70	.69	.72	.63	.685
	.60	.66	.59	.62	.618

tion, error type, and key of transposition for both experiments is given in Table I. The upper entry in each cell is the measure for Experiment I, the lower for Experiment II. The data are averaged across repetitions. In the first experiment there was no significant effect of repetition ($F(4, 176) = 1.69$, $p > .10$), while in the second experiment there was an improvement across repetitions of, overall, 8.0% ($F(4, 176) = 6.42$, $p < .001$). However, none of the effects of experimental interest depended upon number of repetitions. The bracketed proportions for diatonic + cadence context, Experiment II, were obtained when one particular sequence with an extremely low score (below chance) was excluded. This apparently anomalous sequence, described at a later point, was not excluded, however, from the analyses of variance.

Apart from the effect of repetition, the two experiments showed similar trends. First, the result of varying the context of the three-tone melody may be seen in the extreme right-hand column of Table I. Order of accuracy followed order of number of available musical rules: diatonic + cadence, diatonic, non-diatonic. Three-tone test performance most nearly compared with performance for diatonic conditions. When the core was embedded in a non-diatonic context, performance deteriorated; when embedded in diatonic + cadence context, performance improved. The effect of context was significant (for Experiment I, $F(3, 44) = 3.40$, $p < .05$; for Experiment II, $F(3, 44) = 13.60$, $p < .001$). Further, in the body of Table I there are, across experiments, eight ways of examining order of accuracy for the three contexts of the three-tone melody. Six of the eight followed the order reported above. For the remaining two, there was one equivalence and one reversal. The probability of obtaining this outcome by chance is less than .001.

Second, the effects within transposition were considered. The statistical analyses revealed two significant interactions: context by error type (for Experiment I, $F(3, 44) = 5.56$, $p < .01$; for Experiment II, $F(3, 44) = 6.19$, $p < .01$) and context by error type by key of transposition (for Experiment I, $F(3, 44) = 3.72$, $p < .05$; for Experiment II, $F(3, 44) = 9.11$, $p < .01$). In both experiments the most accurate recognition occurred with the following combination: diatonic + cadence context, error outside the key, transposition to the dominant. Poorest performance occurred under non-diatonic conditions.

Separate analyses of variance for each contextual condition indicated no significant effects in either experiment for non-diatonic conditions. Under the remaining contextual conditions error type and key of transposition played a significant role.[2] An error outside the defined key was more readily detected than an error within the key. Transposition to the dominant led to more accurate performance than did transposition to the tritone in most cases – in 9 out of 12 possible comparisons, with two reversals and one equivalence. Because of the two reversals there were significant, but unpredicted, interactions between error type and key of transposition in the analyses for the three-tone core and the diatonic conditions. The case of equivalence, which occurred under diatonic + cadence conditions with error in the key, would be altered if the anomalous sequence were dropped from Experiment II. For this particular sequence, P(C) was .38 while P(C) for the remaining sequences transposed to the dominant ranged from .83 to .90. For sequences transposed to the tritone under these conditions the range of P(C) was .68 to .85. The advantage, therefore, would return to the dominant transposition.

Listeners were encouraged to report comments after the experiment, and the sequences have also been played to classes of music students for comments. There was universal agreement about the following: (1) Non-diatonic sequences were judged to be completely random in order. The constraints on order described in the Method section were not detected. (2) For the two types of diatonic sequence (diatonic and diatonic + cadence) an error tone outside the key in the incorrect comparison was said to be a 'bad' note for the sequence. (3) Attempts were made to join the three sequences of each trial (standard and two comparison sequences) to form a long complete melody. Listeners in the diatonic and the diatonic + cadence conditions reported that this connecting was easier with some sequences than with others. Sequences judged easiest were those involving transposition to the dominant. In passing, it may be noted that no listener identified the anomalous sequence of the diatonic + cadence condition as being particularly difficult or peculiar.

The number of years of musical training of each listener was recorded. The frequency distribution for each contextual condition showed a range of 0 to 14 years experience; according to a chi-square analysis there were no differences among conditions in the distributions of musical experience. Within-subject error terms were compared across conditions; the F_{max} test indicated no serious violation of the assumption of homogeneity of variance. Not surprisingly, therefore, analysis of variance of arc-sine transforms of the data yielded results similar to those of the analyses of the original proportions. The data for Experiment II were re-analysed for each condition with the 12 listeners divided (according to amount of musical experience) into 4 blocks of 3 listeners each. No significant interactions among blocks and experimental conditions were found.

The stimulus sequences for the conditions diatonic + cadence, diatonic, and non-diatonic were further analysed to check any possible differences in distribution of interval size or in contour (the pattern of ups and downs in frequency direction). Of course, the method of construction of the sequences ensured that the intervals contained by the core and by the contexts were identical across conditions. For the intervals that joined the context to the core, the range of size was 1 to 8 semits. The distribution was unimodal with mode and median size in each condition equal to 2 semits (33% of all intervals in each condition). The number of reversals in frequency

[2]The separate analyses of variance permit statements to be made about significant effects within the overall interactions beyond the .05 level of confidence for Experiment I and beyond the .01 level of confidence for Experiment II.

direction was equivalent for all conditions. Sequences showed from one to five reversals in direction; the distribution of reversals was unimodal with a mode and median of three reversals.

EXPERIMENT III

Experiment III was designed to take a closer look at the anomalous sequence found in the diatonic + cadence condition of Experiment II. The sequence not only scored at chance accuracy when results for other sequences in the same condition yielded scores of P(C) = .80 to .91 in Experiment I and P(C) = .83 to .90 in Experiment II, but it was also the lowest scoring sequence within both experiments. The questions asked in Experiment III were whether the low accuracy was replicable and, if so, whether it would be obtained only under the particular combination of error within the key and transposition to the dominant.

The sequence is given in musical notation with frequency values in Hz in Figure 1(b). The incorrect comparison involved the raising of the first test tone (T_1) one semit (in musical terms, this alteration involves a shift from the mediant to the sub-dominant of the key).

The procedure for the trials was identical to that of Experiment II. Each of twenty listeners was tested under eight conditions. Four conditions resulted from combining the standard sequence of Figure 1(b) with comparison sequences transposed either to the dominant or to the tritone and with the error tone either in or outside the key. The remaining four conditions were constructed by reversing the position of the sequences, the incorrect comparison becoming the standard sequence, and the standard sequence the incorrect comparison.

The results confirmed the finding of Experiment II. Performance was at chance level with transposition to the dominant and the error tone within the key. It did not matter whether the sequence of Figure 1(b) or its incorrect comparison was used as the standard sequence; in the former case P(C) = .50, and in the latter, P(C) = .55. The remaining six conditions fared much better, with P(C) ranging from .75 to .90, at least 3.16 standard error units above chance. The highest scores were obtained for the error outside the key.

DISCUSSION

The results of the experiments indicate that the rules of musical tonality apply to psychoacoustic tasks of tone recognition and that the rules are amenable to experimental manipulation. If a short three-tone sequence is embedded in what is essentially a randomly ordered context, the difficulty of detecting an alteration of the sequence increases. This result is entirely to be expected where increasing length involves increasing the load of a memory task. However, if the context is arranged so that the entire tone pattern corresponds with higher-order structural rules, the structure itself may provide cues that aid detection of an alteration of the sequence.

The comparable results of Experiments I and II indicate that it is not necessary to employ a musically familiar timbre in order to obtain an experimental response to musical structure. Further, it does not appear to be necessary to recruit only highly trained professional musicians or music students. The samples for each contextual condition included, among the variety of musical backgrounds, two or three listeners per condition without formal training in music. If it were the case that untrained listeners could not respond to musical cues, we would expect greater variability of the data for conditions where musical cues were present. No evidence of heterogeneity of variance was found. While untrained listeners do not benefit from musical information in tasks of absolute judgment (Cuddy, 1971) or interval identification (Cuddy, Cohen, & Dewar, Note 1) they do respond to the information provided by a tone sequence (Dewar, Cuddy, & Mewhort, 1977).

The 7-tone sequences formed by the three types of context did not differ overall in terms of intervals contained by the sequences or in terms of frequency contour. They differed in the order or arrangement of the intervals that they contained – a critical aspect of tone sequences that we have noted earlier (Cuddy & Cohen, 1976). From the present data and from the verbal reports of the listeners it may be argued that listeners search for 'good form' or pattern within a sequence. Hence, a violation of 'good form' as represented by a violation of the rule of diatonicism is more readily detected than is an alteration that obeys the rule of diatonicism. Also, because transposing to different keys preserves the intervals, contours, and rhythm of the original melody, an account of the effect of varying key of transposition is forced to consider rules relating tone sets and tone sequences. Where musical cues to structure are well defined, transposition to the dominant involves fewer transformations than does transposition to the tritone. In terms of scale sets, the dominant shares all but one member with the original tonic, the tritone shares only one. In other words, transposition to the dominant is more likely to preserve the scalar alphabet of the original key (Deutsch, 1977). Recognition of the melody transposed to the dominant is easier, and may be roughly likened to the recognition of a visual pattern under a very slight rotation (Shepard & Metzler, 1971).

What remains to be explained is that transposition to the dominant does not always facilitate recognition when musical cues are present. Exceptions were found with diatonic sequences with error in the key and with the diatonic + cadence sequence of Experiment III.[3] Presumably the musical structure for certain comparisons involving these sequences was not sufficiently explicit for the tonic-dominant relationship in transposition to be successfully exploited. Our present classification of sequences successfully distinguishes between tonal and "random" sequences (see also Dewar, Cuddy, & Mewhort, 1977) but it needs further refinement in order to isolate the factors responsible for variations in ease of transposition to different keys. Formal musical analysis employs harmonic notation to provide codes for the tone progressions of individual sequences and can supply alternative codes where the musical structure suggests several possible tonal relationships. This notion of alternative coding deserves further attention. To the extent that musical analysis identifies an unambiguous code for certain highly-structured sequences and restricted sets of alternative codes for others, and to the extent that diversity of musical coding corresponds to judgments of perceived structure, musical analysis offers a potential measure of the precision of the perceptual code. When such aspects of musical analysis are experimentally established, we can then look for the essential characteristics of the code that facilitate the detection of the tonic-dominant relation in transposition, and that occasionally lead to confusion (i.e., the anomalous sequence of Experiment III).

The theoretical notions that we have proposed are in close agreement with Garner's treatment of perceptual structure (e.g., Garner, 1970, 1974). Although the auditory sequences studied by Garner and his colleagues involved different acoustical parameters, a basic interpretation holds in common: that response to the form or pattern of a sequence emerges as the con-

[3]An experimental result reported by Francès (1972, Expérience IX) is relevant. The four sequences presented were diatonic but three of the four did not end with a resolution to the tonic. Incorrect transpositions contained errors within the key. Correct and incorrect transpositions were tested both in near keys, 'ton proche,' (fa or sol major) or far keys, 'ton éloigné' (fa sharp or mi flat major keys). (Francès is referring of course to musical, not frequency, distances.) A re-analysis of the data indicates that fewer errors of recognition were obtained with transposition to the far, not the structurally nearer, key.

straints upon its construction increase (or, number of allowable alternatives decreases). We have examined, of course, only one level of rules that determine constraints (rules of tonality or musical relation) but a level rather neglected in experimental study since the time of Helmholtz. Clearly the full analysis of musical sequence perception requires the further representation of hierarchical levels of rules (Jones, Maser, & Kidd, 1978). The immediate point is that the provision of tonal context affects a listener's ability to recognize a transposed melody. As Dowling (1978) has remarked, listeners do use a logarithmic scale for pitch when 'given a meaningful task' (p. 345). Pitch contour and size of intervals in the interval array do not describe meaningfulness for the present task – the contextual conditions did not differ with respect to these two variables. Tonal rules, and the ease with which they may be applied to a sequence, are also critical determinants of acoustic pattern recognition.

RÉSUMÉ

Analyse de la récognition d'une séquence transposée de trois tons en quatre conditions de contexte tonal. La séquence mélodique est présentée soit sans contexte, soit insérée dans l'un de trois types de contexte variant selon le nombre de règles musicales ayant servi à les dériver. Le test de récognition (choix forcé à deux termes) exige la détection d'un changement d'un demi-ton de la séquence, ce changement affectant un ton se conformant ou non à la clef musicale de la séquence. De plus, les séquences utilisées comme tests sont transposées soit au triton, soit à la dominante de la tonique de la séquence originale. Les résultats – dont l'essentiel se confirme avec des stimuli pianistiques ou des tons sinusoïdaux – révèlent un effet significatif des conditions contextuelles, de la clef de l'erreur et de la clef de transposition. La facilité de récognition de la transposition est liée à l'identification et à l'application de règles définissant les structures entre tons comme entre ensembles de tons, et à l'usage de règles servant à détecter les irrégularités structurales.

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