TONAL SEQUENCES, MELODY AND MUSIC.

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This paper reports an investigation of the perception of tonal sequences which are generated in various ways. A number of previous studies have relied on an 'Information Theory' description of tonal sequences whereby perception is governed by 'redundancy'. The latter is a measure of the differential probability of intervals and notes, the more evenly these probabilities are distributed the lower the redundancy. Perceptual differences between melodies which occur in music and other tonal sequences are therefore attributed to the higher redundancy of the former. (See Davies, 1978 for a review). An alternative view is presented here, which is that melodies which occur in music are constrained in <u>characteristic</u> ways. We ask whether there are perceptual differences between tonal sequences which obey these constraints and those which do not, having equated the sequences for 'redundancy'.

The change in pitch from note to note tends to be small in melodies from various cultures. This may be because large intervals are difficult to sing, but there are also perceptual reasons : Tonal sequences are organised perceptually in terms of the pitch range which they occupy. Sequences with large successive pitch intervals are heard to 'separate', that is, they are not heard as a single 'coherent' melody. (See Deutsch, 1978 for a review).

Here we use p to refer to the pitch of a note, in semitones, relative to 'middle C'. Thus the note C# is p=1, D is p = 2 and so on. Δp refers to the change in pitch from note to note thus F# to G is an interval of $\Delta p = 7-6=1$.

In 'Western' melodies certain pitch values, known as the 'scale', are more probable than others. Many authors (e.g. Helmholtz, 19[illegible]) have argued that this is because such melodies are designed to be accompanied by other simultaneous melodies, that is to be harmonised. Certain notes (pitch values) are considered compatible when played together, others less so. Compatible pairs are said to be 'consonant'. The scale is a set of notes from which a high number of consonant pairs may be drawn, thereby facilitating harmony.

Kameoka and Kuriyagqwa (1969) measured perceived 'consonance' for pairs of notes differing in pitch separation. They found consonance maxima and minima at different pitch separations. These variations were most numerous for sounds containing a number of 'harmonics' (frequency components of integer multiples of some lower 'fundamental' frequency). That is for sounds such as those generally used in music. Consonance peaks occur at particular ratios of the fundamental frequencies of the note pairs, most clearly at 2:1, 2:3, 3:5 and 3:4 for sounds with 4 or more harmonics. These values are consistent with a psychoacoustic explanation of consonance, based on the sensation of 'roughness' generated by non-overlapping harmonics which the ear fails to resolve (Terhardt, 1978).

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Pitches separated by the ratio 2:1 (the 'octave') are said to differ in pitch 'height', but are given the same name in music (e.g. 'C'), they are said to have the same 'chroma'. (See Idson and Massaro, 1978, for a review of evidence for the perceptual salience of chroma). The equal temperament tuning system divides the octave into twelve logarithmically equal steps (semitones). These chroma values are labelled (starting from C in this example) C, C#, D, D#, E, F, F#, G, G#, A, A#, B, and back to C. Of these the 'diatonic' scale of C comprises C, D, E, F, G, A and B. According to Jeans (1937) the diatonic scale values originally arose by adding successive "5ths" to the basic note. The fifth refers to the consonant ratio 3:2 and is approximately 7 equal temperament semitones (e.g. C to G or D to A). Thus, starting from C, the chroma of the next 5th is G. The chroma of the 5th above G is D; the next is A and so on. The entire 'progression of 5ths' is :

Chroma :	F,	C,	G,	D,	A,	E,	B,	F#,	C#,	G#,	D#,	A#,	F,	C,	G	etc.
q value :	-1,	0,	1,	2,	3,	4,	5,	6,	-5,	-4,	-3,	-2,	-1,	0,	1	etc.
(keynote = C)																

Thus consonant pairs of notes are close together along this 'dimension'. The ratios 3:2 (5th) and 2:1 (octave) are incommensurable so the equal temperament 5th (seven semitones) is not a perfect 3:2 ratio. However, this slight 'retuning' does not destroy the perceptual differences between consonant and dissonant note pairs thanks to the broadness of the consonance maxima reported by Kuriyagawa and Kawashima (loc.cit.). Longuet-Higgins (1976) refers to chroma values measured along the progression of 5ths as 'sharpness' values, numerically denoted by an integer, q. The value of q depends upon the keynote of the piece, those for C are shown above. Notice that here the value of q is restricted to the range -5 to +6 relative to the keynote.

The key of a melody refers to the particular diatonic scale on which it is based. According to Longuet-Higgins (loc.cit.) key has important perceptual significance being the basis for conceptualising the relationships between the musical intervals of the melody. This theory is in the form of a computer program which assigns key to a melody from information about the pitch (p) values of the notes. The program takes advantage of the fact that 'Western' melodies rarely change key, and that while they remain within a key, certain constraints are obeyed. One of these refers to the transitional probabilities governing the succession of chroma values, and is that the change in q from note to note, δq, is likely to be small, specifically less than 6, with the higher δq values being less probable. Two transitional rules are also used: The first refers to ascending semitones where the second note of the interval has a q value of 2, 3, 4 or 5. In these cases the q value of the first note of the interval is 5 units higher than the second note value. The other rule is that high δq values will not occur in adjacent intervals.

A tonal sequence which obeys the foregoing constraints is therefore expected to be more like a melody which occurs in music than tonal sequences constrained in other ways.

A computer program was written of generating constrained tonal sequences. An initial stage generates a sequence for p values in the range ± 12. Information concerning δp, δq and q probabilities is supplied to the program, q values being assigned taking p=zero as the keynote. Differently constrained sequences are obtained by using two different forms of these probability distributions.

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For example, a sequence with small pitch jumps is produced by supplying a distribution where low δp values have a high probability and vice versa. An equally and oppositely constrained sequence is produced by symmetrically inverting this distribution. In this way it is possible to produce sequences which are equal in their 'redundancy' but which differ in their presumed similarity to melodies which occur in music. Notice that because transitional probabilities are considered in two cases, the probability of the next note to be generated depends upon the value of the current note. (The initial current note is always p=zero). Thus for each constraint the program constructs probability distributions for each of the 25 possible 'current notes', each of which contains probability values for all 25 possible 'next notes'. A single set of distributions is then computed by multiplying and normalising across the three constraints. It is therefore possible to generate tonal sequences with different combinations of the two values of each constraint, i.e. 8 possibilities.

The next stage of the program generates sequences of p values using a random number generator and the appropriate probability weightings. This stage also implements the two transitional 'rules'. When low δq values are more probable the q values used in implementing the rules are 'correct', whereas when high δq values are more probable, incorrect values are used. Values for the latter were chosen which were not significantly correlated with the true values.

The final stage of the program simply adds a constant to the p values generated, bringing them into the range 1 through 88. These numbers correspond to the notes of a piano keyboard numbered successively from lowest to highest pitch. Thus, to generate a sequence having a 2 octave range around 'middle C', 40 is added to each p value.

Perceived 'melodiousness' was psychophysically scaled for differently constrained sequences using Thurstone's 'Method of Paired Comparisons' (cf. d'Amato, 1970). On each trial the observer hears two sequences successively and indicates which is the more melodious. All sequences were 21 notes in length, starting and finishing on the same note (p = zero of the initial stage). The presentation rate was an even tempo of 4 x 1/4 second long notes per second with a one second pause between sequences. The notes were pulse trains with the fundamental frequency and all harmonics up to the 2kHz cut-off of a low-pass filter. The notes were tuned to the equal temperament values with a maximum error of 0.4% at the higher pitches. Sensation level was approximately 30dB in a quiet booth. A short piece by Bach (the 'Musical Offering', see Longuet-Higgins, loc.cit.) and an unconstrained random sequence type were added to the 8 previously mentioned giving 10 sequence types in all. Each member of this set is paired with every other in both possible orders, giving 90 comparisons for each of the 20 observers. The scale score is given by the probability of a sequence being judged more 'melodious', converted to a parametric 'z score'. The same sequence was never used more than once (with the exception of the Bach piece) meaning that 9 constraints x 18 comparisons x 20 observers = 3,240 sequences were computed for the experiment. Thus, variables such as 'contour', overall note range and so on, are completely randomised and their contribution to any systematic effects may be discounted. The central note of the range was also randomised being 'middle C' $\pm$ 5 semitones, this avoids any systematic effects due to absolute pitch values. Different random orders of presentation were used for each of the observers.

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The observers had had some musical education, but not beyond secondary school level. A computing system based on a PDP-8 computed the sequences, ran the experiment and analysed the data.

The across subject mean melodiousness scores varied from Z = +1.0 for the Bach piece down to Z = -1.0 for the random notes. The remaining 8 sequences types gave varying mean values within this range. The latter were analysed by a 3-way analysis of variance with two values ('melodic' versus 'unmelodic') for each factor (δp, δq and q). The null hypothesis is that because these sequences are equally redundant there will be no systematic differences between their Z scores, which will approach zero. We found reliable main effects for all three constraints with the 'more melodic' values of each factor being judged significantly the more melodious. (For δp; $F(1,159) = 116.0$, $p<0.001$. For q; $F(1,159) = 66.2$, $p<0.001$. And for δq; $F(1,159) = 5.15$, $p< 0.05$). There was also a significant interaction between the q and δq factors ($F(1,159) = 6.26$, $p< 0.05$) and inspection of the data reveals that the effect of δq is only observed when the notes of the diatonic scale are more probable (i.e. for the 'melodic' value of the q factor).

The observed effectiveness of each constraint offers support for the a priori arguments. Indeed, the reasons given for 'scale' and 'key' are closely related, and this relationship is reflected in the interaction of these factors perceptually. That is, a clear key orientation is only effective for sequences sufficiently populated with notes of the diatonic scale. Information Theory does not provide an adequate account of the present findings; Interactions between perceptual, physical and cultural contingencies need to be considered. Similar shortcomings of the Information Theory approach to perception have been noted in other contexts. (see Corcoran, 1971 for a review).

Some caveats should be noted : The constraints discussed here are not seen as deterministic, rather as part of a framework in which creative musicians may operate. Furthermore, not all musicians will necessarily see music in these terms, (although many of them do according to Longuet-Higgins, loc.cit.). Finally many other constraints need clarification before a full formal description of melody is possible, and the possible interactions between these factors and those investigated here should be noted. However, the present results do demonstrate that it is possible to 'resynthesise' some degrees of approximation to melodies which occur in music from a formal representation of just three rather general constraints.

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