Expectancy-based model of melodic complexity

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2 authors:

Tuomas Eerola
Durham University

A. C. North
Curtin University

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Tuomas Eerola & Adrian C. North

University of Leicester
Music Research Group
Department of Psychology
University of Leicester
University Road
Leicester LE1 7RH
United Kingdom

{ tpe1, acn5}@leicester.ac.uk

1 Background

According to Berlyne (1971), preference for stimuli is related to their complexity or unpredictability. Although this claim has been supported by a large number of studies in the field of music (reviews by Finnäs, 1989; and Fung, 1995; North & Hargreaves, 1995), adequate objective ways of measuring the originality or complexity of music are in short supply. The existing objective measurements, such as the information-theoretic and tone transition probability (Simonton, 1984) models possess well-known limitations: First, research within this tradition has tended to employ limited stimuli, which have typically been specially-composed pieces or excerpts of classical music. Secondly, these models do not address the role of the listener's perceptual system in organising the structural characteristics of music.

Therefore the aim of the present research was to (i) devise an objective computer model of those perceptual processes which underlie human listeners' musical expectations and complexity judgements; (ii) determine the extent to which this model could predict experimental participants' complexity judgements in response to a range of musical stimuli; (iii) determine the effectiveness of the model relative to that of the previous models; and (iv) provide an example of the model's application to real music.

2 The expectancy-based model of melodic complexity

Existing research on music cognition and particularly melodic expectancies has already offered considerable insight into the processes by which human listeners perceive musical stimuli and translate these perceptions into judgements of melodic complexity. The expectancy-based model (EBM) of melodic complexity comprises a series of contributory factors, which are divided into tonal, intervallic, and rhythmic factors. Tonal factors include *tonal stability* (Krumhansl & Kessler, 1982), which is modified by *metrical position* (as established by Lerdahl & Jackendoff, 1983; empirically supported by Palmer & Krumhansl, 1990; Thompson, 1994) and *duration* of tones (e.g. Castellano, Bharucha & Krumhansl, 1984; Monahan & Carterette, 1985). These modifications are made since they emphasise tones that occur in more prominent locations or possess longer durations: These factors both lead to the increased perceptual saliency of tones.

Intervallic factors consist of principles derived from Narmour's (1990) implication-realization model. The principles are *proximity, registral return, registral direction, closure, intervallic difference,* and *consonance*. These principles are hypothesised to be innate and are based on a variety of Gestalt laws applied to tone-to-tone continuations. Here the principles are used to measure the extent to which these implied patterns are violated. The coding of the model is derived from Krumhansl (1995).

Rhythmic factors include *rhythmic variability*, which accounts for changes in the duration of notes, *syncopation*, which measures the amount of deviation from the regular beat pattern, and *rhythmic activity*, which is simply the number of tones per second. All three rhythmic principles have been found to increase the difficulty of perceiving or producing melodies (e.g. Clarke, 1985; Povel & Essens, 1985; Conley, 1981, respectively.).

In short, melodies which create expectancies that are clearly structured in terms of their tonal, intervallic, and rhythmic properties tend to be easier to reproduce and recognise, and are also judged by listeners as being less complex. The EBM processes MIDI melodies and produces a final melodic complexity score by calculating the weighted sum of each principle. Full details of the EBM can be found in Eerola and North (2000).

3 The predictive ability of the EBM and other models

An experiment featuring melodies of a wide range of complexity was designed in order to evaluate the ability of the EBM, the information-theoretic, and the transition probability models to predict human listeners' complexity ratings. The transition probability model was reproduced using the tone transition data provided by Simonton (1984).

3.1 Musical stimuli

There were five blocks of stimuli. These comprised both short artificial melodies and more realistic melodies. Block 1 contained nine test melodies taken from Simonton (1984), Block 2 contained five melodies taken from Smith & Cuddy (1986) that the original authors rank ordered for complexity, Block 3 contained seven melodies created by the authors for the present study, Blocks 4 and 5 each featured 10 excerpts derived from stimuli employed by North & Hargreaves (1995). These were representative excerpts taken from commercially released pieces. Block 4 comprised the melodic lines of these 10 excerpts encoded as MIDI files. Block 5 comprised the original recordings of these same 10 excerpts, which allowed a comparison of the MIDI and 'real' versions of the melodies.

The melodies in Blocks 1-4 were transposed into C-major or C-minor where necessary, and were transformed into MIDI files. Tempo was set to a constant and the timbre (pan flute) and velocity of the tones in Blocks 1-4 were kept constant throughout the experiment.

3.2 Participants

The participants were 56 psychology undergraduates (M = 18.80, SD = 0.93) who rated the complexity of 41 melodies on an 11-point scale. There was a high product-moment correlation between mean ratings assigned to each melody by participants ($r(39) = .96$, $p < .001$), and therefore the data from all participants were collapsed into a single group for subsequent analyses.

3.3 Design and procedure

A repeated measures design was employed in which each participant responded to all the excerpts. Participants rated each excerpt on an 11-point scale for complexity, on which 0 was defined as "extremely simple", 10 as "extremely complex", and 5 as "midway between the two". Simple music and complex music was defined for the listeners.

3.4 Results of experimental study

Multiple regression analyses were carried out to determine the relationship between participants' complexity ratings and each of the EBM' s predictors. The ability of the principles to predict participants' ratings was high ($R = .968$, $R^2 = .937$, $F = 29.55$, $df = 10,20$, $p < .001$). Five of the EBM predictors were associated significantly with participants' ratings. These were tonality (modified by metrical position and tone duration), two intervallic principles (namely registral direction and intervallic difference), and two rhythmic principles (namely syncopation and rhythmic variability). The redundant principles (namely rhythmic activity, registral return, consonance, closure and registral direction) were deleted and a subsequent multiple regression analysis concerning the ability of the revised EBM to predict participants' ratings confirmed that these deletions had little impact on the predictive ability of the revision ($R = .949$, $R^2 = .900$, $F = 45,13$, $df = 5,25$, $p < .001$). Therefore these remaining principles constitute the core elements of the EBM and each principle can significantly predict listeners' complexity ratings. The explanatory power of these principles is also consistent with studies of music perception and production (Carlsen 1981; Krumhansl et al, 1999; Krumhansl, 1995; Krumhansl & Kessler 1982; Schmuckler, 1989; Unyk & Carlsen 1987).

A correlation was calculated between the mean complexity rating assigned by participants to each of the 31 melodies and measures of the complexity of the melodies produced by each of the three computerised models. This revealed how the information-theoretic model ($r=.58$, $N=31$, $p<.001$) and the transition-probability model ($r=.74$, $p<.001$) were both able to predict participant' s ratings, although the EBM ($r=.95$, $p<.001$) accounted for the greatest proportion of the variance in participants' complexity ratings. This indicates that of the three models, the EBM was most capable o predicting participants' complexity ratings of the test melodies (despite the differences between the characteristics of the latter). The primary application of the EBM lies in using its ability to produce automated measures of melodic complexity which might therefore predict listeners' preferences. This application is considered in the following section.

5 Application of the EBM: Predictability and preference for the Beatles' hits

In addition to those experimental studies that have explicitly tested the relationship between complexity and preference for musical pieces (cited above), some researchers have adopted an archival approach. This approach considers large samples of data and correlates findings with a range of popularity indices. Notable in this area is work by Simonton (1984; 1994; 1995) who analysed the melodic complexity of 15618 classical music themes and found clear relationships between the melodic complexity of the themes and their popularity. A similar approach has been successfully applied to the analysis of arousal potential in lyrics and poetry (Whissell, 1996; Martindale, 1990). In this paper, the archival approach is used to investigate whether the predictions of the EBM are related to preference.

The songs of the Beatles were selected for the analysis because they are accessible, there is a large musicological literature concerning them, and because the popularity of the songs can be easily determined. Furthermore, an earlier study by West & Martindale (1996) showed that the arousal potential of the lyrics of the Beatles increased across time and was not related to the popularity of the songs, as measured by the record positions in the charts. The aim of the present research was to employ the EBM in determining (a) whether the Beatles' melodies show an increase in arousal potential over time and (b) whether the popularity of the melodies is linked with their complexity.

5.1 Analysis material

The material used in the study comprises of all of the songs that were written by the Beatles for the Beatles, published by the English record companies EMI and Apple officially in 1962-70. This sampling deliberately excludes cover versions recorded by the Beatles or recordings of Beatles' songs by other artists. This resulted in a set of 182 qualifying songs. The songs were arranged chronologically by their original recording date (which was derived from Lewisohn, 1988). The melodies of the songs were obtained from most reliable notation of the Beatles' music available (Fujita, Hagino, Kubo, and Sato 1993), encoded as MIDI files, and transposed to a common key (C major or minor) for the analyses. Grace notes and notated non-pitch information (e.g. shouting, speaking etc) were removed when encoding the melodies for the computerised analysis.

5.2 Results of the archival study

The melodic complexity of the songs was first regressed onto recording dates, to see whether linear time-trends across the Beatles' career existed. A highly significant increasing trend emerged (R^2= 12.4, F= 25.42, df= 1,180, p< .001). More simply, the melodies of the Beatles' songs became more complex over time. This is consistent with a previous study that has investigated the statistical properties of the Beatles' lyrics (West & Martindale, 1996) by means of computerised content analysis. Both results support Martindale's theory of aesthetic evolution (1990) (which proposes that art works should become increasingly arousing over time), but could also be attributed to increasingly sophisticated performance and compositional skills.

Next various popularity indices were correlated with melodic complexity. These included the number of weeks the songs spent on the chart, the chart positions, and an aggregate function of both these for singles and albums in the UK and US top 40 (Gambaccini et al, 1996; Whitburn, 1996). The popularity of singles as measured by weeks on chart in UK correlated negatively with the melodic complexity of the songs (r(23)= -.567, p< .01). This implies that the simpler the song is melodically, so the longer it spent on the charts. Also, the chart success of albums (measured either by chart position, chart duration or both) correlated negatively with the mean melodic complexity of the albums (r(11)= -.729, p< .05), suggesting that melodically simpler albums have fared better in the popular music markets. Finally, different poll results (Reed, 1982), compilations (Bronson, 1995) and expert ratings (Larkin, 1994,) were compared with the melodic complexity of the songs but no clear trends emerged from these analyses. Interestingly, the other models were not able to predict any trends in the popularity of the Beatles songs. The transition probability model, however, demonstrated the same, although weaker, increase in melodic complexity over time as the EBM (R^2= .037, F= 6.91, df= 1,180, p< .01).

It should be noted that although relationships between chart performance and melodic complexity were observed in this study, several extraneous social, cultural and commercial influences certainly affect the popularity of songs. However, the present findings may serve as a starting point for further inquiries into questions of this nature.

6 Discussion

In this paper, an expectancy-based model of melodic complexity was tested. The EBM provided the most accurate prediction of human responses to the present stimuli. However, it is important to establish the extent to which the EBM can predict humans' responses to a wider range of melodies. There is a risk that the model may be excessively tailored to the specific set of melodies employed in the present research: some principles might be more important in predicting responses to kinds of music different to those considered here. Also, the EBM ignores several aspects of music by considering only single melodic lines. For example, the richness of arrangement, harmony and tempo are factors outside the scope of the EBM but which might influence listeners' sense of the complexity of the music in question.

In conclusion, the EBM may have potential for the analysis of very large samples of 'real' musical stimuli in terms of their melodic complexity. This was demonstrated by analysing all the songs by the Beatles, which revealed modest trends between melodic complexity and chart success of the singles and albums; and also an increase in melodic complexity over time. Studies using considerably larger samples of music are currently underway. Research along these lines could have a considerable impact on our understanding of the perception and appreciation of music, as this computerised approach opens up new possibilities for studying the relationship between the properties of music and listeners' preferences.

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