Multivariate statistical analysis of songs of the male Common Blackbird (*Turdus merula*): an example from western Victoria, Australia

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Abstract

Variation in the song of the male Common Blackbird was investigated within and between two locations in western Victoria. Each of 400 phrases (100 phrases per male) was characterised by 61 measurements relating to 13 aspects of each phrase. Principle component and stepwise discriminant analyses were undertaken on these measurements. Classification of blackbird song for location and individuality was based on timing within the phrase of the loudest elements. Evidence was found for within-phrase variability, with the greatest variation in the middle of the phrase. Within- and between- site comparison found that blackbird song exhibited both individual and site-specific characteristics consistent with earlier suggestions of phrase sharing within local populations. The study demonstrated that an objective statistical approach to song analysis was able to discriminant between individual birds from different locations.

Introduction

Common Blackbirds (*Turdus merula*) were introduced to Australia in the 1860s (Long, 1981) and have colonised urban habitats in Victoria, southern South Australia and New South Wales (Blakers et al. 1984). Dabelsteen (1984) suggested that Common Blackbird song is adapted to woodlands and has social functions that convey different messages. Males establish breeding territories in spring, singing to defend territorial boundaries and attract females (Dabelsteen 1984; Snow 1988) and convey information about the singer's identify and location (Dabelsteen 1988).

Song types of the Common Blackbird are complex (Hall-Craggs 1962; Jellis 1977; Snow 1988) and consist of phrases (short, well-defined sequence of sounds) of approximately two seconds' duration (Dabelsteen 1984; Dabelsteen & Pedersen 1985) (see Fig 1). Each phrase is a series of elements (single sounds represented as continuous trace on a sonagram). A motif is any series of elements that are typically combined and repeated immediately or periodically (Jellis 1977; Dabelsteen 1984; Dabelsteen & Pedersen 1985).

Most analyses of Common Blackbird song have concentrated on sequence, variation and occurrence of motifs or phrases (Hall-Craggs 1962; Dalbelsteen 1984, 1988; Dabelsteen & Pedersen 1985; Snow 1988). Hall-Craggs (1962) analysed songs of an individual male and found it produced 26 different basic phrases at the outset of the season with some 24 variants delivered during the season. Dabelsteen (1984) estimated 6-30 different motifs per individual but 2-5 different motifs were used more frequently. These may be under-estimates because, in practice, measurements of the size of an individual's complex song repertoire is difficult (Kroodsma 1982). Complexity of Common Blackbird song is due to extensive vocal imitation of a range of sounds (Kroodsma & Baylis 1982) and song sharing (Mundinger 1982). There is no evidence of Common Blackbirds having dialects although the definition of song dialect is problematic. Mundinger (1982) suggested that a dialect is where a variant song tradition is shared amongst members of a local population and distinct dialect boundaries are evident.

Much of the description and comparative studies of blackbird song are by visual comparison of sonagrams (Hall Craggs 1962; Jellis 1977; Dabelsteen 1984, 1988; Dabelsteen & Pedersen 1985). Although useful, classification and discrimination of sonagrams by visual clues requires subjective judgement of differences. Visual discrimination by an observer between phrases in a sonagram may bear little relationship to auditory discrimination by Common Blackbirds in real time. This paper demonstrates statistical analysis of sonagrams comparing blackbird song phrases from different males at two locations. In this pilot study multivariate statistical techniques of principal components analysis and linear discriminant analysis were used to examine individual and geographical variation in blackbird song phrases. The aim was to demonstrate the feasibility of an objective statistical method for discriminating between the song phrases of different individuals and from different locations.

Methods

Breeding territories of male Common Blackbirds on the University of Melbourne campus, Creswick (37^0 25' S 143^0 53' E,) and University of Ballarat campus, Ballarat (37^0 33'S, 143^0 50' E,) were identified by mapping techniques during early spring. These locations are approximately 25 km apart. Individual bird's song posts were identified and mapped. Although birds were not individually marked, individuals were known from their discrete, non-overlapping, territories and use of particular song posts. At each location, two adjacent territory-holding males were chosen for investigation.

Recordings of song was made with a Nagra 4.2 tape recorder and Sennheiser 816T microphone. Afternoon or evening song was recorded. Recordings from individuals were mainly from sustained bouts of singing when males were defending their territory and attracting females. A sample of 100 complete phrases, from several singing bouts, from two males at each location were transferred to TDK™ SA 90 cassette tape for sonagram analysis. Sonagrams were produced by SPECTROGRAM ™ Version 2.2 software with an IBM compatible computer. SPECTROGRAM ™ represents vocalisations as *.WAV files viewed directly on the computer screen. The *x* axis of the sonagram represented time (milliseconds) and *y* axis, frequency (kHz). Loudness was measured as amplitude or intensity and quantified into six levels represented by different colours on the computer screen (from black to red with increasing amplitude).

The aim was to objectively characterise each sonagram for variation and then make comparisons amongst sonagrams from different males at the same and different locations. Each of 400 phrases (100 phrases per male) was characterised by 61 measurements, relating to 13 aspects of the phrase. For each sonagram ten equally spaced times (the 5^{th}, 15^{th},..., 95^{th} percentage points of phrase duration, which by analogy with statistical usage, we will refer to as percentiles) were used as sampling points. The choice of ten as the number of sampling points was regarded as adequate to ensure that each individual phrase was represented in the data. Selection of regularly spaced sampling points meant that, on occasion, samples coincided with a period of silence between elements.

Five variables were measured at each sampling point: minimum and maximum frequency; frequency of peak amplitude; relative loudness (peak amplitude expressed as a proportion of the average of the ten measured peak amplitudes) and number of harmonic peaks. In addition, for each of the two loudest elements, starting time, duration, maximum and minimum frequency and frequency of the peak harmonic were measured. The final variable was phrase duration.

Principal components analyses (PCA), a technique for reducing the dimensionality of multivariate data,   was undertaken on 61 variables for all 400 phrases and separately for each 100-phrase sample from individual birds. We sought to represent most of the information in a large set of correlated variables (61 in this case) by a relatively small number of derived variables (the principal components). Each of these was a linear combination of the original variables and uncorrelated with other components. Thye amount of information carried by each component indicated by its variance or eigenvalue. A standard criterion was to retain components with eigenvalues larger than 1.0 was used. Retained components were rotated to improve interpretability.

Stepwise multiple discriminant analyses were undertaken on both the 61 original variables and on 16 rotated principal components to distinguish between phrases of different birds, between different locations and to identify key discriminating variables. Multiple discriminant analysis is a technique the prime objective of which is to discriminate between a number of classes or categories of objects (in this case, phrases of two individual birds at two different locations). Analagously to the PCA, we began with a set of correlated variables (61 in this case) and sought a relatively small number of derived variables (the discriminant functions), each of which was a linear combination of the original variables, which maximally discriminate between the various classes. An associated objective was to classify the individual objects into classes. Stepwise multiple discriminant analysis incorporates a sequential variable selection aspect, so that only variables that contribute to a statistically significant degree are identified and utilised in the discriminant functions and classification functions. In principle, a discriminant analysis should always be cross-validated by testing the classification performance not only on the cases that have been used for estimating the discriminant functions, but also on other unseen cases. An alternative approach to cross-validation, as used in this study, was an algorithm that is mathematically equivalent to omitting each case in turn and thus classifying each case on the basis of the data from all the other cases. The analyses were performed using SPSS Win ™ Version 9.1.

Results

Principal Components Analysis

Principal components analysis of the 61 variables for each phrase resulted in 16 components with eigenvalues greater than, or equal to, 1.0. These components which together accounted for 77.9% of the variation in the set of measurements were retained and rotated. After varimax rotation the patterns of coefficients or loadings were such that each component was strongly identifiable with one of the 13 aspects of each phrase. Whilst this reflected the structure of the set of input variables it also meant that the eigenvalues associated with each rotated component indicated the relative variability of aspects of each phrase. Percentages of total variation were associated with each of the ten sample points and are presented in Fig. 2, both for the overall data setand for the data for each individual bird.

The principal component structure reflected high correlations between five variables measured at each sampling point. This was to some extent an artefact of the presence of zero values associated with silent pauses. Fig. 2 shows the percentage of variation at each percentile of the 400 phrases where there was silence (zero values). In a general sense zero values might be regarded as spuriously inflating the correlations and hence the eigenvalues. However, in the present context the result was not spurious since the presence of a proportion of zero values reflected variations in the timing of the elements in the phrase.

Fig. 2 shows that for 400 phrases most variation was between the 25^{th} and 85^{th} percentile, with less variation near the beginning (5^{th} and 15^{th} percentiles) and at the end (95^{th} percentile) of each phrase. The proportions of zero values exhibited a similar, though more exaggerated, profile (Fig. 2). The low percentage of variation found at the 5^{th} and 95^{th} percentiles was, in part, attributable to the fact that each phrase must start and finish with sound. The small proportion of zero values at the 5^{th} and 15^{th} percentiles reflected a characteristically longer element at the beginning of the phrase. There was broad similarity between the results for the percentile data of each individual bird (Fig. 2).

The levels of variability associated with the other three aspects of the phrase could not be directly compared with the percentile data. Firstly, there were no zero values to inflate the correlations. Secondly, duration was represented by a single variable (compared with five variables for all the other aspects) and hence might be expected to contribute proportionately less to the overall variability. Nevertheless, the two elements with the greatest amplitude were compared. The second-loudest element was slightly more variable than the loudest in all but one case (and in the case of one bird, considerably more variable).

Discriminant Analysis

Four sets of stepwise multiple discriminant analyses were carried out, with respect to the two sites, all four birds, and the two birds at each location. In each case two analyses were performed. One was based on the original 61 variables and another on the 16 rotated principal components derived from all 400 phrases. Better classification was obtained using the original variables. This approach was also more parsimonious as fewer variables were required. All subsequent analyses were based on the original variables.

Table 1 shows for each of four analyses (two sites, all four birds, two Ballarat birds and two Creswick birds) the following outcomes: (a) the number of discriminating variables selected by the stepwise procedure as contributing significantly ($P<0.05$); (b) details of the first five selected variables; and (c) the overall percentage of correct classifications achieved under cross-validation. For example to discriminate between phrases from two sites 10 variables were selected, of which the most discriminating was Amplitude at the 15th percentile of the phrase. Seven variables were selected to discriminate between phrases from the two Creswick birds. The most discriminating variable was phrase duration.

The overall classification rates achieved for phrases from the two sites was 72% and for the four individual birds, 57%. Tables 2-5 show greater detail of these analyses where phrases of the two birds at Creswick site (88% correct) differed much more than at the Ballarat site (70% correct). Classification of individuals was 57% correct. This classification represented a statistically significant improvement over chance (50% for two categories, 25% for four categories). In each analysis (Table 1) a different set of variables was important for discrimination, indicating that the differences between birds and locations were not consistent.

Although PCA found relatively little overall variation in the early sections of the phrases (5th to 45th percentiles), nevertheless amplitude at the 15th percentile was amongst the most important discriminators between phrases from two locations and between two individuals at Creswick (Table 1). Timing in the phrase sequence of the two loudest phrase elements was the next most important discriminator between sites. The most marked difference between individual birds at Creswick was phrase duration. Amplitude at the end of the phrase (95th percentile) was an important distinguishing feature for the two Ballarat birds. Various characteristics of the middle section of the phrases were important discriminators in all analyses.

To explore the possible effect of the within-group non-normality of many of the explanatory variables (particularly the percentile-based variables with zero values due to silence) a number of logistic regression analyses were performed. Logistic regression is an alternative approach to discriminant analysis, which is more computationally demanding and has a less intuitive conceptual basis and interpretation, but is not dependent on distributional assumptions about the explanatory variables. The classification rates obtained were similar although there were differences in the detail of the explanatory variables selected. These results supported the decision to use discriminant analysis.

Extraction of the percentile-based variables from the spectrogram was a time-consuming and tedious process. With regard to the practical potential of this method for more general use, it was noted that three easily measured variables featured prominently in Table 1. These were the duration of the phrase and when (at what percentile) the two elements of greatest amplitude commenced. Four discriminant analyses were carried out using these three variables. A further four analyses were carried out using two variables, which were the actual times at which the two elements of greatest amplitude of the phrase commenced. The rationale for this was that these two variables contained much of the information present in the three-variable set. The overall percentages of correct classifications achieved under cross-validation for two- and three- variable models are shown in Table 6. Table 6 shows that the final two-variable analyses produced consistent classification rates (60-65%) between sites and between individual birds within each site. These classification rates, whilst statistically significant, represent only a moderate improvement over the chance rate of 50%. Again, similar classification rates were obtained using logistic regression. This two-variable classification was not suitable for individuals (38%).

Discussion

This pilot study showed that the song of male Common Blackbird exhibited both individual and site-specific characteristics consistent with suggestions of phrase sharing within a local population (Mundinger 1982). Analysis of song phrases demonstrated a degree of specificity for both individual and location with a moderate, but statistically significant, degree of accuracy. These results support earlier suggestions (Dabelsteen 1988; Snow 1988) that song differs between individuals. Phrase characteristics may be localised because resident juvenile male blackbirds learn their song from parents and local birds (Simms 1978).

We demonstrated that measuring the timing within the phrase when the two elements of greatest amplitude were produced would classify Common Blackbirds for location and for individuals within a location. Amplitude, and the timing of increased energy output within the phrase, may be an important individual characteristic. However, some caution should be exercised because recordings of amplitude can be affected by vegetation, wind and recording equipment. Nevertheless, it is suggested that objective methods may be important for future studies of song variation in species with extensive vocal repertoires, imitation and song sharing capabilities. Objective measurement and multivariate analysis of sonagrams was considered an improvement compared to the subjective visual comparisons as used by Hall-Craggs (1962) and Dabelsteen (1984). The approach taken provided further support to the value of earlier suggestions to use multivariate analysis for bird song (Martindale 1980).

The distance between the populations was sufficient to indicate some geographical variation of Common Blackbird song. Common Blackbirds, similar to many other species, may use song to identify both location and individual (Bradley, 1977; Jellis 1977; Moller 1982; Miller et al. 1983; Trainer 1983; Ficken & Weise 1984; McGregor & Thompson 1988; Espmark, 1995; Tracy & Baker 1999). Such individual characteristics of male song are important where females select males on the basis of song quality (McGregor et al. 1981; Lampe & Espmark1994; Mountjoy & Lemon 1996) which may be suspected for Common Blackbirds.

This study showed evidence of within-phrase variability, with the greatest variation in the middle of the phrase. Conformity might be expected to be greatest at the beginning of each phrase, ensuring rapid species recognition by the listener. These early phrases were often louder and longer to gain the attention of the listener. Individual and site-specific information would be in the middle of the phrase when there would be a greater chance that the listener was attentive after hearing the earlier louder elements. Conformity at the end of the phrase would ensure a species signature at the end of the message. PCA provided some support for this explanation though discriminant analysis revealed some individual and site-specific information quite early in the phrase. It is suggested that individual- and site-specific information may be communicated within local populations.

This study has demonstrated the feasibility of an objective statistical method for discriminating between the phrases of different individual birds from different locations. One direction for further research is to explore different ways of quantifying the characteristics of phrases and phrase elements. Another is to compare the classification obtained using this method with those based on more subjective assessments.

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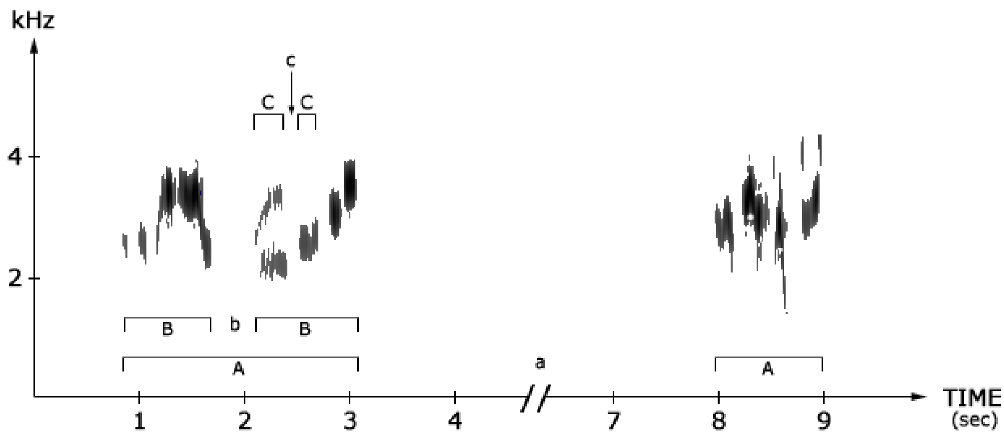

Fig. 1. A sonogram of a typical blackbird song. The *x* axis of the sonagram represents time and the *y* axis, frequency (kHz). Amplitude is measured as shades of grey. Blackbird song consists of *phrases* (A), typically 2-3 s in duration, separated by pauses (a) usually of several seconds. Each phrase consists of one or more *motifs* (B), separated by shorter pauses (b). Each motif consists of one or more *elements* (C) separated by still shorter pauses (c).

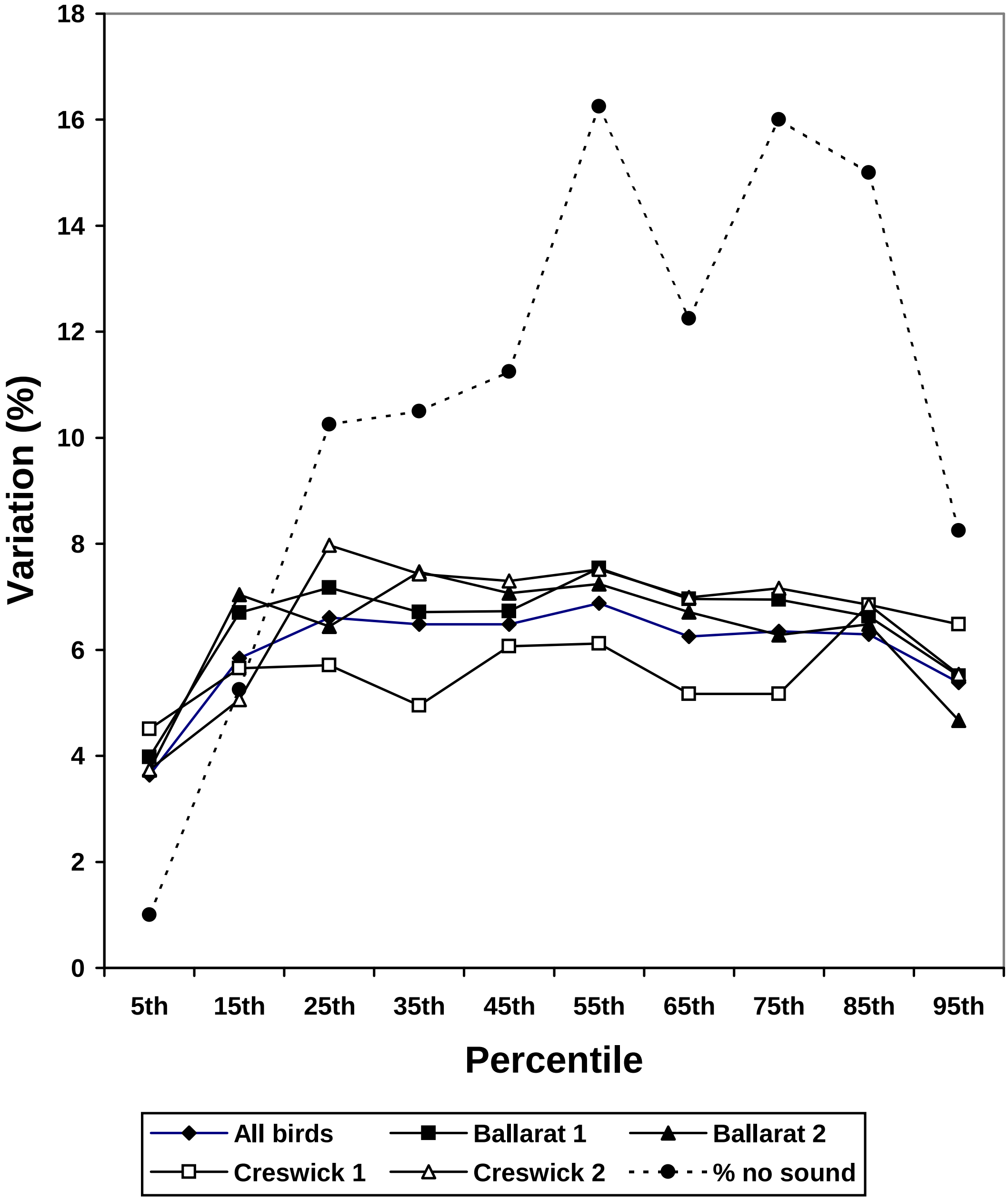

Fig. 2. Profiles of variation of 13 aspects of phrases of all and individual Common Blackbirds from Ballarat and Creswick.

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Table 1. Summary of results of discriminant analyses of Common Blackbird phrases from four individual males from two locations

Aspect of phrase to which the variable is related	The five most important variables for discriminating between: Two sites		All four birds		Ballarat birds		Creswick birds	
	Rank	Variable	Rank	Variable	Rank	Variable	Rank	Variable
5th percentile							5	Max freq.
15th percentile	1	Amplitude	2	Amplitude			2	Amplitude
25th percentile					5	Max freq.		
35th percentile								
45th percentile								
55th percentile	5	Amplitude	4	Peak freq.	3	Max freq.		
65th percentile			5	Max freq.	4	Peak freq.	3	Peak freq.
75th percentile			3	Max freq.	2	Max freq.		
85th percentile								
95th percentile	4	Min freq.			1	Amplitude	4	Max freq.
Loudest element	3	Start time						
2nd loudest element	2	Start time						
Total duration			1	Duration			1	Duration
Total number of variables	10		19		5		7	
Percentage of phrases correctly classified	72%		57%		70%		88%	

Table 2. Classification of phrases from four individual Common Blackbirds by location

Actual site	Classified as: Ballarat	Creswick	% correct
Ballarat	141	59	70.5
Creswick	54	146	73.0
		Overall	71.8

Table 3. Classification of phrases from four individual Common Blackbirds

Actual Bird	Classified as: B1	B2	C1	C2	% correct
B1	51	25	8	16	51.0
B2	27	38	24	11	38.0
C1	10	19	60	11	60.0
C2	12	6	4	78	78.0
				Overall	56.8

Table 4. Classification of phrases from two Common Blackbirds from Ballarat

Actual Bird	Classified as: B1	B2	% correct
B1	68	32	68.0
B2	29	71	71.0
		Overall	69.5

Table 5. Classification of phrases from two Common Blackbirds from Creswick

Actual Bird	Classified as: C1	C2	% correct
C1	87	13	87.0
C2	12	88	88.0
		Overall	87.5

Table 6 Classification results from three- and two-variable discriminant analyses

Discrimination between phrases from:	Overall rate of correct classifications (%)	
	Three-variable model	Two-variable model
Sites	59.0	62.5
All birds	44.5	37.5
Ballarat birds	47.0	62.0
Creswick birds	81.0	65.0