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CATEGORIZATION OF NOTES USED BY FEMALE RED-WINGED BLACKBIRDS IN COMPOSITE VOCALIZATIONS[1]

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Abstract. During the breeding season female Red-winged Blackbirds (*Agelaius phoeniceus*) give vocalizations containing a series of individual notes. Using a visual categorization system based on sonagrams of individual notes, five categories of notes were identified that commonly occurred in this population. Notes within categories were distinguishable, but there was extensive grading between some note types. The visual categorization was tested using naive judges and multivariate analyses of structural characteristics. Structural variables used to characterize notes did not differ among females, but variables differed significantly among note types, and note types varied differently among females. Multivariate cluster analyses supported the visual note categories and reflected the grading between some note types. If individual notes convey different information, combining these notes into composite vocalizations gives a female tremendous communication potential. Defining categories among individual signal units is the first step in analyzing the information content of female Red-winged Blackbird vocalizations.

Key words: Categorization; notes; female; composite vocalizations; Red-winged Blackbird; Agelaius phoeniceus.

INTRODUCTION

Researchers attempting to understand acoustic communication systems often must simplify those systems for analytic purposes. Description of the entire range of vocalizations may be adequate for species whose repertoire contains a limited number of discrete signal units, but description of complex repertoires containing large numbers of graded signal units can produce unmanageable amounts of information. Identifying general patterns or categories among signal units is one way of reducing large amounts of information into a more manageable form (Marler 1982). Simplification of complex systems usually entails a loss of information but may provide preliminary insights into the communication system.

During the breeding season, female Red-winged Blackbirds (*Agelaius phoeniceus*) give composite vocalizations containing a series of individual notes. The rate of vocalization reaches a peak early in the breeding season and then tapers off as the season progresses (Yasukawa et al. 1987). A composite call may contain one type of note or several different note types. Individual notes within composite vocalizations range from harsh, broad bandwith notes to high-frequency notes rich in frequency overtones, with some modulated intermediate notes. Individual notes clearly differ in structure and sound quality, but there is extensive grading between some note types. Some combinations of individual notes occur more frequently than others within composite calls (Dickinson 1987), but individual variation in calling patterns is high (Nero 1956, Orians and Christman 1968, pers. obs.). The arrangement, or syntax, of individual notes within female vocalizations and the duration of the vocalizations correlate with a female's physiological state and the social context (see Green 1975 for a similar phenomenon in primates, Zahavi 1982, Beletsky and Corral 1983, Beletsky 1985, pers. obs.).

Early observers described the variability within female Red-winged Blackbird vocalizations (Nero 1956, Orians and Christman 1968), but more recent researchers have classified composite vocalizations based on the predominant notes within the calls and the functional significance of the vocalizations (Beletsky 1983a, 1983b; Beletsky and Orians 1985; Yasukawa et al. 1987; Yasukawa 1990). Vocalizations containing primarily chit notes (see Fig. 1) are typically used in intersexual contexts and are classified as type 1 calls. Vocalizations containing teer notes (see Fig. 1) are typically used in intrasexual contexts

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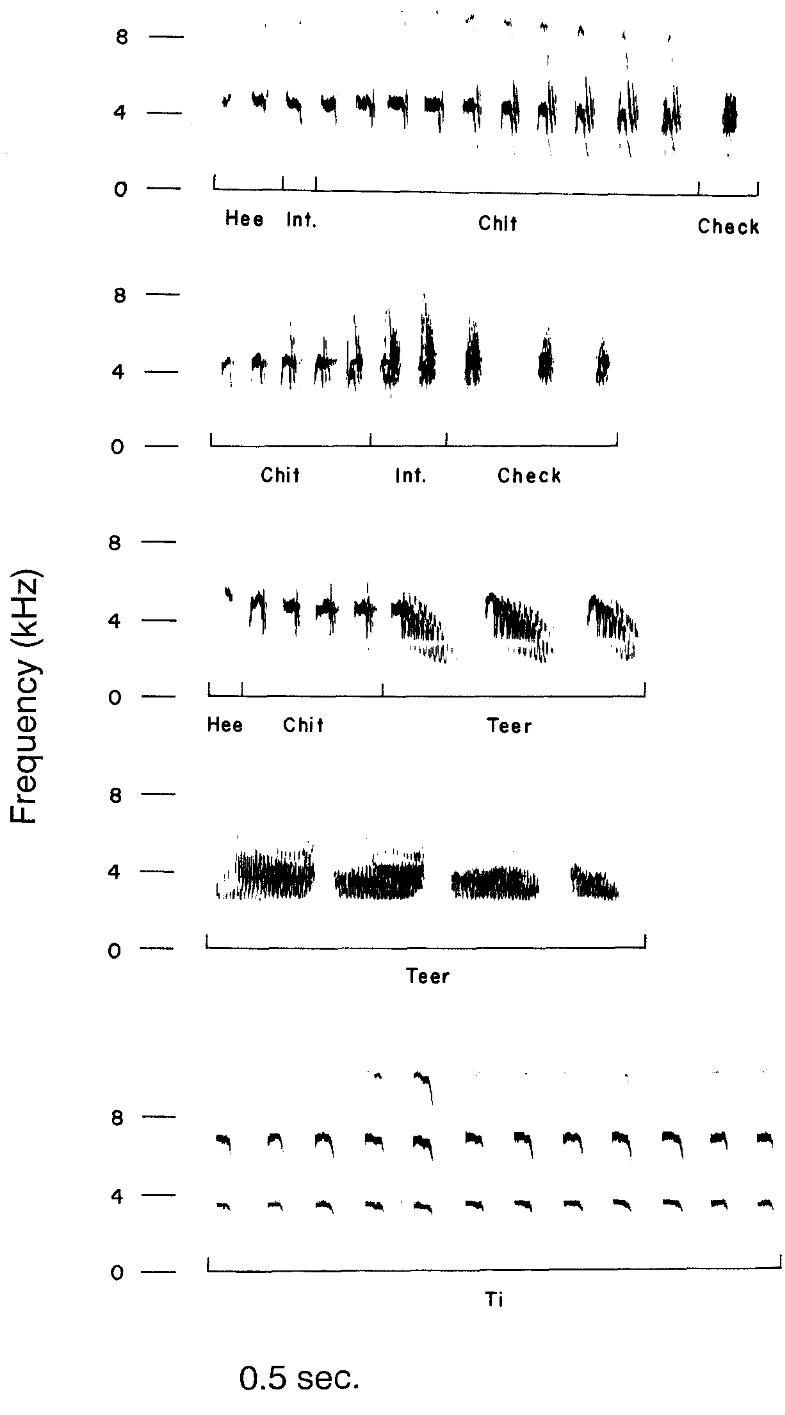

FIGURE 1. Sonagrams of typical female Red-winged Blackbird vocalizations with individual note types labeled (see Table 1). All sonagrams are complete composite calls except for the sonagram of *ti* notes, which is part of a longer call. Int. = intermediate notes. Each sonagram is from a different female. X-axis is time in seconds (Kay 5500 DSP Sona-Graph, Hi-shape, 0–16 kHz range, 256 point FFT, 234 Hz frequency resolution, Hamming analysis).

and are classified as type 2 calls (Beletsky 1983a, Beletsky and Orians 1985). The functional significance of calls containing a combination of chit and teer notes remains uncertain (Beletsky 1983a, Beletsky and Orians 1985). Closer examination of the syntax of composite vocalizations revealed that composite vocalizations contain a wider range of note types than is indicated by the current classification system (see Fig. 1).

Instead of classifying composite vocalizations, I here categorize the individual notes used to construct composite vocalizations in a population of female Red-winged Blackbirds in Massachusetts. I first identify notes using a visual classification system, and then test my *a priori* categorization using independent, naive judges and multivariate analyses. Methods used here retain information on the individual signal units within composite vocalizations, information that was lost using the previous classification system.

METHODS

FIELD METHODS

I sampled the vocalizations of 14 female Red-winged Blackbirds at two locations in western Massachusetts. My primary study site was a heterogeneous marsh of approximately 7 ha located on the eastern side of state Route 116, on the Amherst-Sunderland town line in the town of Sunderland, Franklin County, Massachusetts. Predominant vegetation included cattail (*Typha*), canary-reed grass (*Phalaris*), sedge (*Scirpus*), dogwood (*Cornus*), and red maple (*Acer*). My secondary study site was a marsh of approximately 4 ha at the southern edge of Old Deerfield, Franklin County, Massachusetts. The marsh is bordered by state Route 5 on the east and Mill Village Road on the north and west. Predominant vegetation included cattail, canary-reed grass, and red maple.

Recordings were made from dawn until approximately 10:00 EST from April–June during three consecutive breeding seasons. In 1988, I used a Uher 4400 tape recorder with a Dan Gibson model P-200 parabola fitted with a Radio Shack dynamic electret microphone. In 1989, I used a Uher 4200 tape recorder with a Sennheiser MKH-106 microphone mounted in a 60 cm aluminum parabola, and a Sennheiser MKH-816T shotgun microphone. In 1990, I recorded females on a Nagra IV-S tape recorder with a Sennheiser MKH-106 microphone mounted in a 60 cm aluminum parabola. All recording was done on 270 m reels of 3M 806 recording tape. Recordings were made at 9.5 cm/sec in 1989 and 1990, and at 9.5 and 19 cm/sec in 1988.

The order in which females were sampled each day was determined at random, with samples of each territory lasting 15 min. At my primary study site, all females included in my analysis, and all males that controlled territories on which these females nested, were banded with U.S.F.W.S. aluminum bands and unique color-band combinations, except for one male that I was unable to capture. The one female recorded at my secondary study site was unbanded, but the territorial male was banded. With the exception of the unbanded female from territory #4 (referred to as female #4) of the Deerfield marsh, females are referred to throughout this paper by the last two numbers of their U.S.F.W.S. leg bands. Banding was done under federal subpermit 21345L and MA state permit BB29.90. For territories in which more than one female nested I alternated sampling of each female for the entire 15 min sample in 1989; in 1990 I recorded all females on the territory during the 15 min sample in random order. Females 03 and 45; 12, 46 and 50; 22 and 47; 31 and 52; and 43 and 51 nested on territories controlled by the same male, with the first-to-nest (primary) female listed first for each territory.

VISUAL CATEGORIZATION

Whenever possible, I use existing terminology to refer to notes, giving priority to the first published names (see Table 1, Fig. 1). "*Check*" (Orians and Christman 1968), "*chit*" (Hurly and Robertson 1984), "*hee*" (Yasukawa, pers. comm.), "*ti*" (Hurly and Robertson 1984), and "*teer*" (Hurly and Robertson 1984) are onomatopoeic. Notes referred to by Dickinson (1987) and Hurly and Robertson (1984) as "*chet*" are here called "*check.*"

I categorized a total of 1,509 notes from the composite calls of 14 females (mean = 109 notes/female, range 59–155 notes/female; mean = 36 calls/female, range 17–61 calls/female, mean = 3 notes/call; see Appendix). Females were divided into two groups of seven for purposes of sampling and analysis. Multivariate linear models estimated using data from one group of females were tested on data from the second group. For the first group of females (03, #4, 12, 23, 43, 45, 51), I measured consecutive notes within a composite call, but not more than ten notes from a single call and no more than ten notes of the same note type from any 15 min sample ($\bar{x}$ = 3 notes/call, see Appendix). For the second group of females (22, 31, 46, 47, 50, 52, 65), I measured every other note within composite calls, with no more than five notes sampled from a single call. The order of samples from which notes were measured was randomized, and notes were sampled opportunistically within recorded samples. All notes were sampled from composite calls containing three or more notes.

Individual notes were categorized using the structural characteristics in Table 1. Although seven note categories are described in Table 1, only five of these note types (*check, chit, hee, ti,* and *teer*) occurred regularly in my study population (see Appendix). Because of the grading between some note categories (see Fig. 1), I was unable to place 127 (8.4%) of the notes I measured into a single note category. In these instances, I classified the note as intermediate between two categories (for example, a note intermediate between the *check* and *chit* categories was classified as *check-chit*). For simplicity, Table 1 contains distinct note categories only.

One of the original goals of this research was to categorize all notes used to construct composite calls. While sampling notes from the first group of females I specifically looked for unusual notes. Thirty-four of these notes (2%) did not clearly fit into any of the six note categories in Table 1 and were classified as unknown (see Appendix). Banded notes containing multiple frequency overtones (Nowicki and Capranica 1986a, 1986b) were uncommon in this population, with 29 (2%) banded notes recorded from five females (see Appendix). Although banded notes were uncommon at my study sites, they may be more common in other populations (pers. observ.). Tremendous variation among the unknown and banded notes made summarizations about these notes virtually impossible and they were therefore not included in the analysis.

To test the general utility of my visual classification system, four independent judges categorized a sample of female Red-winged Blackbird notes using a dichotomous key based on the structural characteristics in Table 1. The sample included 126 individual notes contained in sonagrams of 15 composite calls from ten females. The notes represented the entire range of note types found in the population, including banded, intermediate, and unknown notes. All judges had previous experience with sonagrams, but were unfamiliar with female Red-winged Blackbird vocalizations.

TABLE 1. Structural characteristics used to categorize sonagrams of notes. Notes are defined as sonagram traces clearly separated from other traces by 2 mm (19 msec) or more. Intermediate notes contained structural characteristics of more than one note type.

Check	Dense, with no obvious frequency overtones; height in mm/kHz approximately three or more times width in mm/sec.
Chit	Contains either an inverted "U" or "V" pattern or distinct leading and/or trailing edges.
Banded	Contains more than two equally spaced horizontal frequency bands in addition to the fundamental (lowest frequency) trace.
Hee	Height in mm/kHz approximately equal to width in mm/sec, without distinct leading or trailing edges.
Ti	Contains a horizontal trace that is separate from, but as prominent or nearly as prominent, as the lowest frequency trace.
Teer	Contains a repeated modulation component.
Unknown	Notes that do not fit into any of the above categories.

STRUCTURAL MEASUREMENTS

As a further test of my visual classification, notes were characterized based on their structural components. All structural measurements were made using a Kay DSP Sona-Graph. After classifying each note according to type, I measured the duration of the note on the waveform display in conjunction with the sonagram display (512 point [pt] fast fourier transform [FFT], 0–16 kHz, time axis 100 msec, Hi-shape, Hamming averaging, dynamic range 42 decibels [dB], analysis attenuation 20 dB, resolution 3 msec) to locate the onset and end of each note. Minimum and maximum frequencies were determined using the power spectrum display (1,024 pt FFT, dynamic range 72 dB, frequency resolution 40 Hz) in conjunction with the sonagram display. The frequency of peak amplitude of the lowest (fundamental) frequency trace (Nowicki et al. 1991), the frequency below the fundamental at which the amplitude was 30 dB below peak amplitude

(−30 dB), the frequency above the fundamental at which the amplitude was 30 dB below peak amplitude (+30 dB), and the frequency of peak amplitude of the frequency overtone were measured using the power spectrum display. Input attenuation was selected to balance between high frequency artifacts (see below) and retaining the low frequency sonagram traces. The −30 dB and +30 dB points were chosen after making preliminary measurements to reflect differences in the sharpness of the amplitude peak between *check* and *chit* notes. Because of the complete separation between the frequency overtones and the fundamental in *ti* calls (see Fig. 1), minimum and maximum frequency were measured on the fundamental only. When measuring the frequency of peak amplitude, if frequency measurements at two consecutive 40 Hz cursor steps were the same amplitude, I used the lower frequency; if divergent frequencies, or more than two consecutive cursor steps, were the same amplitude, frequencies were averaged. To avoid biases that might have occurred because each note was classified by type before measuring variables, I carefully followed the same sampling procedures for all notes.

Among the measured variables, I have the least confidence in measurements of maximum frequency for the following reasons: it was often difficult to determine where the sonagram of the actual note stopped and artifacts produced by aliasing in the analysis equipment or overloading in the recording equipment began. Measurements of maximum frequency may also have been affected by differences in the distances from which females were recorded. Higher frequencies degrade more rapidly than lower frequencies over distance and are more subject to scattering by vegetation (Wiley and Richards 1982). The vegetation was more open on some territories than others at my main study site, and females on the open territories were more difficult to approach without disturbing them. Thus, the distance from which a female was recorded was consistent for a given territory, but differed among territories. I do not believe that either of these potential problems influenced my overall results significantly, but differences in maximum frequency measurements among notes should be interpreted with care.

For each note I also calculated the frequency range (maximum frequency–minimum frequency) and the difference between the peak amplitude of the fundamental and the peak amplitude of the first frequency overtone, if overtones were present. Both of these variables, however, were eliminated from the final analysis. Correlation coefficients were calculated among all variables and frequency range was eliminated because of high correlations with frequency of peak amplitude, minimum frequency, and maximum frequency. The difference in peak amplitude between the fundamental and first frequency overtone, and the frequency of maximum amplitude of the first frequency overtone were also eliminated in the final analysis because of high numbers of cases with missing values.

MULTIVARIATE ANALYSIS

Note categorization. The visual classification of notes was further tested using multivariate analyses of structural characteristics. Two linear models were estimated using data from the first group of females. The computers' ability to distinguish among notes was then tested by applying the models to data from the second group of females. Both linear models were then used to categorize combined data from all females. Cases with missing values were eliminated from the multivariate analyses.

Discriminant analysis. Discriminant function analysis is a special type of the general linear model that is normally used to identify distinguishing factors among objects in previously defined groups (Wilkinson 1989). Following standard procedures in SYSTAT (Wilkinson 1989), discriminant functions were calculated for the five categories of notes that occurred regularly in this population using data from the first group of females. To test the model, group classification coefficients and group constants were then calculated using data from the second group of females and each case was assigned to a note category (Table 4). After testing the model, discriminant functions were calculated for combined data from all females. Because the probabilities of assigning a note to a given group by chance alone were unequal due to different sample sizes of notes in each category, prior probabilities were specified for each note category (Wilkinson 1989). Notes identified as intermediate between categories were not included in the discriminant analysis because the program required that they be treated as distinct categories, which they were not.

Cluster analysis. Cluster analysis is a linear model used to identify natural groupings in data that normally requires no prior assumptions about the number of groups or group membership. Because of the grading between some of the *a priori* note categories, I repeated the above analysis using the quick cluster program in SPSS^{X}, (SPSS^{X} 1983). I chose the quick cluster program because the data set was too large for the available mainframe hierarchical cluster programs. Although hierarchical cluster analysis does not require prior assumptions about groups, quick cluster analysis requires that the number of groups be specified. Quick cluster uses the squared Euclidean distance to assign each case to the nearest cluster center, with all clustering variables weighted equally. Because duration was measured using units different than the frequency variables, all variables were standardized to Z scores. I provided starting points for the cluster program by specifying initial cluster centers for the six variables in each of five note categories. Cluster centers for the first group of females were initialized using the median of each variable (SPSS^{X} 1983). The model was then tested by initializing cluster centers for the second group of females with the final cluster centers computed for the first group of females (Table 4). After testing the model, note clusters were calculated using combined data from all females (Table 5). For the combined data, note clusters were initialized using the mean of each variable, rather than the median, because of the large sample size. Unlike the discriminant analysis, intermediate notes did not require classification as distinct categories in the quick cluster analysis and these notes were sorted among the five common note categories.

Hypothesis testing. Hypothesis testing was limited to data from nine females (03, #4, 12, 31, 43, 46, 51, 52, 65) from which I had samples of all five note types. Individual females were treated as independent even though some females nested on territories controlled by the same male (see Field Methods). For hypothesis testing, one exemplar of each note type was selected at random from each composite vocalization. The syntax of individual notes within composite calls appears stochastic, with some arrangements of notes occurring more frequently than others (Dickinson 1987). Because virtually all possible combinations of notes have been observed, I considered individual note types statistically independent. The critical value for rejecting the null hypothesis when true (alpha) was set at 0.05. Structural variables measured from each note were tested individually (univariate) and together (multivariate) for differences among note types and females using analysis of variance. The ANOVA models were mixed, with "female" a random effect, and "note type" a fixed effect (Wilkinson 1989). Because variables −30 dB and +30 dB were included after making preliminary measurements, the experimentwise type I error rate was adjusted using the Bonferroni procedure (see Wilkinson 1989). Significance levels for all *post-hoc* comparisons were also Bonferroni-adjusted (Day and Quinn 1989).

RESULTS

The ability of someone unfamiliar with female Red-winged Blackbird vocalizations to categorize notes was tested by four independent judges. Using a dichotomous key based on structural characteristics of each note type in Table 1, these judges placed an average of 89% of notes into the same category as the author (individual percentages of agreement: 72%, 94%, 94%, and 97%). Variation in the percentages of agreement among observers may be the result of minor changes made in the wording of the dichotomous key based on suggestions by the first judge (72% agreement).

There were no significant differences in structural variables among females, but notes differed among note types, and note types varied differently among females (Table 2). All variables differed significantly among note types, and all variables except −30 dB and +30 dB varied significantly by the interaction of note type by individual female (Table 2). Multivariate ANOVA of all variables also showed significant variation among note type (Wilks' lambda $F[24, 538] = 48.0$, $P < 0.001$) , and note type by female (Wilks' lambda $F[192, 918] = 1.65$, $P < 0.001$). Variation among females was not significant (Wilks' lambda $F[48, 761] = 1.22$, $P = 0.149$).

Although there were no significant differences among females, I compared primary females with non-primary females to see if there were status-related (Yasukawa and Searcy 1982) differences among structural variables. No variables showed significant variation between primary and non-primary females (Table 3).

The graphical representation of frequency variables in Figure 2 illustrates several dimen-

TABLE 2. Sources of variation among structural variables. Upper case E indicates a positive exponent.

Source of variation	Duration		Frequency of peak amplitude		Minimum frequency		Maximum frequency		−30 dB		+30 dB	
	MS[1]	P[2]	MS	P	MS	P	MS	P	MS	P	MS	P
Note type	0.409	<0.001	2.46E6	<0.001	4.83E7	<0.001	9.84E7	<0.001	1.71E7	<0.001	2.82E7	<0.001
Female[3]	0.021	0.161	2.81E5	0.736	2.84E5	1.48	1.63E6	0.185	1.53E5	4.04	1.53E5	2.63
Female by note type	0.022	<0.001	3.32E5	0.020	5.64E5	<0.001	1.88E6	<0.001	2.19E5	2.58	7.93E5	1.43
Error	0.009		1.75E5		2.19E5		7.56E5		2.13E5		6.68E5	

[1] MS indicates the mean-square ratio.
[2] All probabilities are Bonferroni-adjusted (n = 6, see Wilkinson 1989).
[3] Females 03, #4, 12, 31, 43, 46, 51, 52, 65. Degrees of freedom: Duration and Frequency of peak amplitude, [4, 8, 32, 317]; Minimum frequency [4, 8, 32, 315]; Maximum frequency [4, 8, 32, 265]; −30 dB [3, 8, 32, 227]; +30dB [4, 8, 32, 201] for note type, female, female by note type, and error term, respectively.

TABLE 3. Single degree of freedom comparisons among females and note types. Comparisons not made are indicated by dashes. All probabilities are Bonferroni-adjusted (n = 25). See Table 2 for abbreviations.

Contrast	Duration		Frequency of peak amp.		Minimum frequency		Maximum frequency		−30 dB		+30 dB	
	MS	P	MS	P	MS	P	MS	P	MS	P	MS	P
Female[1]	0.017	4.42	2.32E4	17.9	9.53E4	12.7	1.48E6	4.05	3.39E4	17.2	6.56E6	8.07
Chit vs. *check*	0.002	16.4	4.09E5	3.18	9.97E6	<0.001	2.20E5	14.7	1.78E7	<0.001	1.59E7	<0.001
Chit vs. *teer*	1.18	<0.001	323	24.1	9.53E4	12.5	9.01E7	<0.001	1.25E7	<0.001	1.47E6	3.47
Hee vs. *ti*	0.001	18.4	9.14E6	<0.001	5.45E6	<0.001	1.43E7	0.001	6.89E6	<0.001	1.04E7	<0.001
Teer vs. all other notes	1.53	<0.001	—	—	—	—	—	—	—	—	—	—
Error[2]	0.009		1.75E5		2.19E5		7.56E5		2.13E5		6.68E5	

[1] The comparison among females contrasted first-to-nest (primary) females with non-primary females.
[2] See Table 2 for error degrees of freedom.

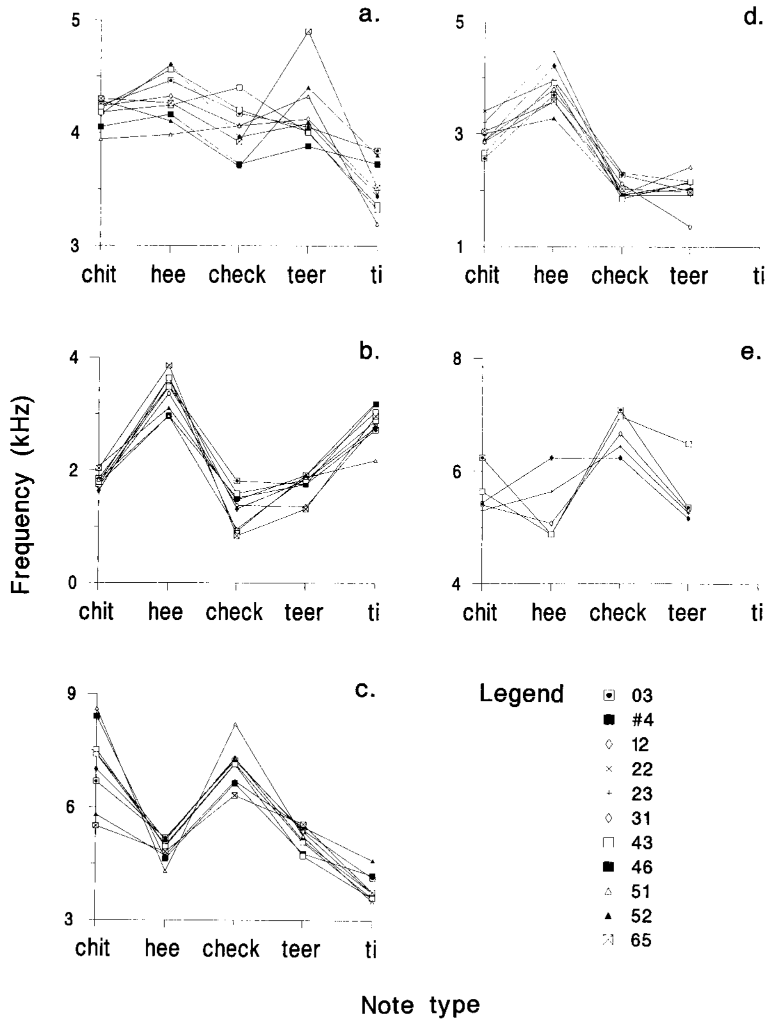

FIGURE 2. Mean values of frequency variables for note types and individual females. Key indicates symbol for each female, numbers are last two numbers from U.S.F.W.S. leg bands for all females except #4 (see text). Lines serve only to connect data points for individuals. (a) Lowest (fundamental) frequency of peak amplitude. (b) Minimum frequency. (c) Maximum frequency. (d) Frequency below the fundamental at which amplitude is 30 dB below frequency of peak amplitude (−30 dB). (e) Frequency above the fundamental at which amplitude is 30 dB below frequency of peak amplitude (+30 dB). Graphs for variables −30 dB and +30 dB do not include *ti* notes because of uneven sample sizes. Note that the range on the y-axis differs among graphs. Order of note types is arbitrary. See Appendix for sample sizes of each note type by female.

sions of variation among females and note types. Similarities and differences in mean values for each variable across note types are clearly illustrated. While Figure 2 reflects similar trends among females, at the same time it shows how mean values of some note types varied differently among females, with some females (particularly females 51 and 65) falling at the extreme end of the ranges for variables frequency of peak amplitude, minimum frequency, and maximum frequency.

Figure 3 is a 2-dimensional plot of the discriminant functions of notes from all females. Factor 1 is primarily a frequency axis, including minimum frequency (canonical loading [loading] −0.862), maximum frequency (loading 0.598), and −30 dB (loading −0.660). Factor 2 reflects note duration (loading 0.793) and, to a lesser

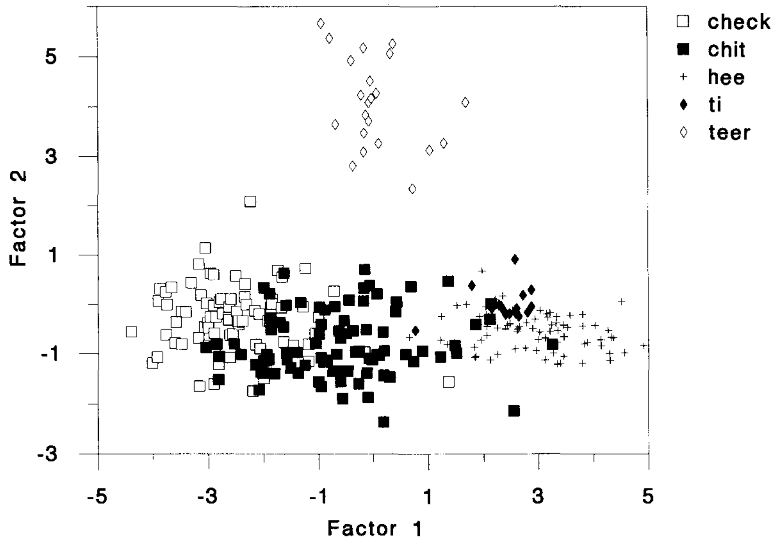

FIGURE 3. Plot of discriminant analysis of 285 notes from all females with no more than one exemplar of each note type from a composite call. With y-axis as shown, data points for three *teer* notes were eliminated from the upper edge of the plot (coordinates 0.28, 9.74; −0.18, 7.90; −0.46, 6.64) for factors 1 and 2 respectively).

extent, the frequency at −30 dB (loading −0.441). The separation between *teer* notes and the other note categories is evident, with *teer* notes distinct because of their long duration. The minimum and maximum frequencies of *teer* notes are intermediate. *Chit* notes lie on a continuum between *check, hee,* and *ti* notes, with a large degree of grading between *check* and *chit* notes, and a lesser degree of grading between *chit* notes and *hee* and *ti* notes. *Check* notes have the lowest minimum frequencies, with relatively high maximum frequencies. *Chit* notes have intermediate minimum and maximum frequencies and are the most variable of the note categories. *Ti* notes have higher minimum frequencies than *check* or *chit* notes but the minimum frequencies of *ti* and *hee* notes overlap. Maximum frequencies of *hee* and *ti* notes are generally lower than the maximum frequencies of *check* and *chit* notes. Similarities between *hee* and *ti* notes are clearly illustrated by the tight clustering of the two note types. *Ti* notes are, on average, slightly longer in duration than *hee* notes but again, there was overlap between the two note types. *Hee* notes have the highest minimum frequencies.

Differences among notes were further examined using pair-wise comparisons between selected note types. Note types were selected for comparison based on visual similarities and the relationships illustrated in Figure 3. Because of the high degree of grading between *check* and *chit* notes (Figs. 1, 3), I compared these two note categories. *Check* and *chit* notes differed significantly in minimum frequency, −30 dB, and +30 dB, but were similar in duration, fundamental frequency, and maximum frequency (Table 3). To determine if *hee* and *ti* notes should be combined into a single note category, I compared the two note types. *Hee* and *ti* notes differed significantly in all frequency variables measured, but were similar in duration (Table 3). Because of the similarity of the beginning of some *teer* notes to *chit* notes (see Fig. 1), I tested for differences between these notes. *Chit* notes differed from *teer* notes in duration, maximum frequency, and −30 dB, but were similar in fundamental frequency, minimum frequency, and +30 dB (Table 3). *Teer* notes differed from all other note categories in duration (Table 3).

The ability of the computer programs to categorize a new sample of notes is illustrated in Table 4. Results from the two computer programs are similar; differences are due to slightly different clustering algorithms. Differences between the computer programs' categorizations are most evident between *check* and *chit* notes. Categorization of these notes was particularly difficult because of the extensive grading between note categories. The quick cluster routine agreed more closely with my *a priori* classification of

TABLE 4. Agreement between visual assignment of note types by author and computer assignment of note types of a new sample of notes from females 22, 31, 46, 47, 50, 52, 65. n = the number of notes, with no more than one note of each type sampled from a composite call. All values for computer-generated note clusters are percentages for discriminant; quick cluster analyses. Intermediate notes not included in the discriminant analysis are indicated by dashes. See text for procedures.

		Computer-generated note clusters				
	n	*Check*	*Chit*	*Hee*	*Ti*	*Teer*
Note type						
Check	68	52; 94	48; 6	0; 0	0; 0	0; 0
Chit	134	4; 17	86; 71	10; 10	0; 2	0; 0
Hee	43	0; 0	0; 0	93; 87	7; 13	0; 0
Ti	5	0; 0	0; 0	0; 0	100; 100	0; 0
Teer	3	0; 0	0; 0	0; 0	0; 0	100; 100
Intermediate notes						
Check-chit	23	–; 74	–; 26	–; 0	–; 0	–; 0
Chit-hee	28	–; 3	–; 29	–; 68	–; 0	–; 0

check notes than did the discriminant analysis, but the discriminant analysis agreed more closely with my categorization of *chit* notes. Although both programs agreed with my classification of *hee* and *teer* notes, the results should be viewed in light of the small numbers of these notes included in the analysis. Quick cluster categorization of intermediate notes that I was unable to assign definitely to one category or another (i.e., *check-chit* and *chit-hee*) reflects the grading between note categories, with high percentages of notes grouped into the categories between which I classified the intermediate notes (Tables 4 and 5).

Table 5 compares the percentages of agreement between my *a priori* visual categorization of notes and categorization of notes from all females by the quick cluster and discriminant analysis programs. Although the computer programs placed some notes into different categories than did I, there is good agreement among categorizations with the discriminant analysis in closer agreement with my visual categorization of *check* and *chit* notes.

DISCUSSION

Various methods are used to define categories of natural sounds (Marler 1982). Distinctions among female Red-winged Blackbirds' notes are apparent to the ear of an experienced listener, but the grading between some note types makes categorization by sound alone difficult (Yasukawa, pers. comm., pers. observ.). Visual categorization of sonagrams by human observers is a traditional method, and, although it is considered subjective, this method has generally been the standard to which other methods are compared (Hafner et al. 1979, Martindale 1980, Clark 1982, Nowicki and Nelson 1990). Although the results from the two computer programs used here to

TABLE 5. Agreement between visual assignment of note types by author and computer assignment of notes from all females (see Appendix). See Table 4 for values and symbols. See text for procedures.

		Computer-generated note clusters				
	n	*Check*	*Chit*	*Hee*	*Ti*	*Teer*
Note type						
Check	194	87; 72	13; 27	0; 0	0; 0	0; 1
Chit	263	15; 22	81; 69	4; 7	0; 2	0; 0
Hee	115	0; 0	5; 1	90; 89	5; 10	0; 0
Ti	11	0; 0	0; 0	9; 0	91; 100	0; 0
Teer	35	8; 3	3; 6	0; 0	0; 0	89; 91
Intermediate notes						
Check-chit	36	–; 33	–; 58	–; 3	–; 6	–; 0
Chit-hee	37	–; 3	–; 24	–; 62	–; 11	–; 0

categorize notes agreed closely with my visual classification, I influenced the computer's categorization of notes by basing note clusters on groups I had identified visually. And, as pointed out by Nowicki and Nelson (1990), agreement between categorization methods does not validate any of the methods.

The close agreement among visual categorizations by independent, naive judges and my own visual categorization of notes demonstrates the practical utility of using the structural characters identified here to categorize Red-winged Blackbird notes. These structural characters can be used to categorize female Red-winged Blackbird notes from other populations and as a starting point in categorizing sonagrams of call notes from male Red-winged Blackbirds. The non-song repertoires of male Red-winged Blackbirds generally contain more distinct call notes than female repertoires, but the sexes share several note types (see Orians and Christman 1968, Beletsky and Orians 1985).

Multivariate computer programs available for analyzing avian vocalizations are summarized in Sparling and Williams (1978). Techniques used here differ somewhat from those used by Nowicki and Nelson (1990) to categorize notes from Black-capped Chickadees (*Parus atricapillus*). I retained data on individual variables in the cluster routines, rather than combining variables into their principal components as did Nowicki and Nelson (1990). Combining individual variables into their principal components separates the analysis from the biology one step further and may make meaningful biological conclusions more difficult. The quick cluster analysis used here classifies cases in a manner similar to the k-means analysis used by Nowicki and Nelson (1990), although the quick cluster analysis is designed to cluster a large number of cases efficiently. One advantage of the quick cluster program over the discriminant analysis used here is that intermediate notes could be included in the quick cluster analysis. The discriminant analysis provided a graphical display of the relationships among notes (Fig. 3), output that was not available from the quick cluster analysis.

The computer's categorization of notes using only six variables was remarkably similar to my own visual categorization. Figure 3 provides an accurate 2-dimensional representation of my perception of the relationships between notes based on visual characteristics, even though the discriminant analysis did not include notes classified as visually intermediate. *Check* and *chit* notes were visibly distinct at the far end of the spectrum of each note type, but the grading between note categories made classification of intermediate notes difficult. *Teer* notes were very distinct visually from all other notes because of their duration and modulation, and the discriminant analysis grouped *teer* notes apart from all other note types with no information on the presence of modulation. *Hee* and *ti* notes were distinct from other notes because of the high fundamental frequency and the low frequency range of the fundamental. In Figure 3, *hee* and *ti* notes are grouped together, with *ti* notes significantly lower in frequency (Table 3), and slightly longer in duration than *hee* notes. The fundamental frequency of peak amplitude in *ti* notes seemed to decrease as females concentrated more energy into the frequency overtones (see Nowicki and Capranica 1986a, 1986b; Williams et al. 1989). It is interesting to note that the computer programs distinguished between *hee* and *ti* notes without any information on the presence of frequency overtones that I used to separate the notes visually (see Table 1, Fig. 1). Although there are three main clusters of notes illustrated in Figure 3 (*teer, check* and *chit,* and *hee* and *ti*), visual differences in note structure and *post-hoc* comparisons supported further subdivision of these groups into five categories. Although there is agreement between my categorization of notes and the computer programs', the note categories described here may or may not be the same categories the birds recognize (Marler 1982, Nowicki and Nelson 1990).

Although the analysis of variance of structural characteristics produced significant differences among note types and in how notes differed among females, the biological significance of these differences is unknown. I attempted to identify variables that reflected the visual *gestalt* of the entire range of notes, but whether the variables I identified as important are the same cues Red-winged Blackbirds use to distinguish among notes, and whether Red-winged Blackbirds distinguish among notes, remains open to question. Birds, including Red-winged Blackbirds of both sexes, are sensitive to temporal, frequency, and amplitude characteristics of sound signals (Sinott et al. 1976, 1980; Dooling 1982), and both Swamp Sparrows (*Melospiza georgiana*) and Great Tits (*Parus major*) have demonstrated the ability to distinguish between note categories based on these parameters. During field playback experiments Swamp Sparrows responded more strongly to notes of varying duration from different natural categories than to notes within a category (Nelson and Marler 1989). Great Tits distinguished between notes from different frequency categories (Weary 1990), but did not respond categorically to notes of different duration during operant tests (Weary 1989). How Red-winged Blackbirds perceive differences among individual notes within composite female vocalizations is, as yet, undetermined.

Comparisons of individual notes from primary and non-primary females showed no status-related differences. Yasukawa et al. (1987) reported status-related differences in the seasonal use of composite calls between primary and non-primary females, and assisted and unassisted females, but I found no differences in the individual notes primary and non-primary females use to construct composite calls (Table 2). Zahavi (pers. comm.) suggested that vocalizations of individuals who are more confident of their status may be less variable (see also Lambrechts and Dhondt 1986, 1987), but I found no differences in the variance among notes from different status females.

Combining a series of graded signals into composite vocalizations gives a female tremendous communication potential if different notes convey different information (Hailman et al. 1985, 1987). The way in which female Red-winged Blackbirds construct composite calls using individual notes is remarkably similar to the combinatorial systems described for chickadees (Hailman et al. 1985, Ficken 1990). Both female Red-winged Blackbirds and chickadees form composite vocalizations by combining different sequences of individual notes in much the same manner that humans combine different sequences of letters to form different words (Hailman et al. 1985). Patterns of individual note types are also similar between Black-capped Chickadees and female Red-winged Blackbirds, with both species' non-song repertoires containing several note types forming a graded series, and a group of harsh-sounding notes that are distinct from all other note types (Ficken et al. 1978, Nowicki and Nelson 1990). Determining whether this pattern is a general phenomenon will require additional data from other species.

The categorization of the notes typically used to construct composite vocalizations is the first step in a detailed analysis of the information content of female Red-winged Blackbird calls. Because of the tremendous variation in individual notes among females, unusual notes were omitted from the final analysis and, thus, some information was lost due to simplification. The categorization presented here is, however, the first step in analyzing the syntax of female Red-winged Blackbird vocalizations. My next step will be to look for correlations among the syntax of composite calls, the behavior of the female, and the social context in which calls are given. This functional analysis may provide information on the relationship between the structure and function of a female's vocalizations, and may ultimately help us understand how Red-winged Blackbirds perceive these complex vocalizations.

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APPENDIX. Sample sizes for each note type by female. Sample sizes for note types included in analyses may differ from these data because of deletion of cases with missing values. Calls equal the number of separate composite calls from which notes were sampled.

Female	Calls	*Check*	*Chit*	*Hee*	*Ti*	*Teer*	*Check-chit*	*Chit-hee*	Banded	Unknown	Totals
03	32	32	27	18	18	18	0	0	0	9	122
#4	35	30	30	19	6	30	0	10	0	14	139
12	30	32	30	15	24	33	0	2	0	1	137
22	50	18	20	25	0	15	2	16	0	0	96
23	61	26	30	29	0	32	0	2	0	1	120
31	33	20	30	27	10	9	11	2	3	0	112
43	51	30	30	27	19	30	0	4	10	0	150
45	25	31	31	12	7	24	1	21	2	0	129
46	37	30	26	11	9	3	0	7	8	4	98
47	44	30	19	23	0	28	4	8	0	0	112
50	17	20	25	3	0	0	5	7	0	0	60
51	38	32	0	24	10	15	8	4	6	3	102
52	25	8	23	16	1	2	6	0	0	2	58
65	30	19	30	4	12	2	7	0	0	0	74
Totals	508	358	351	253	116	241	44	83	29	34	1,509