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The vocal repertoire of Blue Jays (*Cyanocitta cristata*): Spectrographic snapshots and suggested nomenclature

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ABSTRACT—Blue Jays (*Cyanocitta cristata*) are known to have large vocal repertoires, although no peer-reviewed study had thoroughly overviewed what vocalizations comprise such repertoires. Using 7,153 vocalizations, most of them recorded in central Kentucky, I document 36 Blue Jay vocalization types, provide spectrographs of 31 of them, and present their relative frequency of use. I suggest a hierarchical nomenclature that can be used to classify Blue Jay vocalizations and that can also be used to classify the vocalizations of other corvids. My depiction of the vocalizations of Blue Jays, and suggestion for a generalizable approach to nomenclature establishment, could help advance our knowledge of the functions of Blue Jay vocalizations and of the evolutionary history of them, especially in relation to the New World jay group. *Received 25 October 2019. Accepted 10 February 2022.*

Key words: avian, bird, calls, communication, corvid, vocalization.

Repertorio vocal de la chara *Cyanocitta cristata*: instantáneas espectrográficas y nomenclatura sugerida

RESUMEN (Spanish)—la chara *Cyanocitta cristata* son conocidas por tener amplios repertorios vocales, si bien no hay un estudio arbitrado que haga una reseña exhaustiva de qué vocalizaciones componen dichos repertorios. Usando 7,153 vocalizaciones, la mayoría grabadas en Kentucky central, documento 36 tipos de vocalizaciones de esta chara, presento espectrogramas de 31 de éstas y presento su frecuencia relativa de uso. Sugiero una nomenclatura jerárquica que puede ser usada para clasificar las vocalizaciones de esta chara y que también puede ser usada para clasificar las vocalizaciones de otros córvidos. Mi caracterización de las vocalizaciones de esta chara, y la sugerencia de un enfoque generalizable para establecer su nomenclatura, podrían ayudarnos a avanzar nuestro conocimiento de las funciones y la historia evolutiva de las vocalizaciones de esta chara, especialmente en relación al grupo de charas del Nuevo Mundo.

Palabras clave: aves, aviar, comunicación, llamados, vocalización.

Most bird vocalizations studied have been songs, which generally function to attract mates and defend territories (Catchpole and Slater 2008). Calls are often structurally simpler than songs, tend not to be learned, and have a greater variety of functions. Corvids (Family: Corvidae), noted for exceptional cognitive abilities (Emery 2004, Heinrich and Bugnyar 2005), are songbirds that primarily utilize calls rather than songs. New World jays (genera: *Aphelocoma*, *Calocitta*, *Cyanocitta*, *Cyanocorax*, *Cyanolyca*, *Gymnorhinus*, and *Psilorhinus*) display a variety of vocal repertoire sizes that may be related to their degree of sociality (Rosa et al. 2016, Fernando et al. 2017). Interspecific comparisons within this group, however, are limited by the degree to which vocal repertoires of species have been described.

Blue Jay (*Cyanocitta cristata*) vocalizations have only been described in non-peer-reviewed sources (e.g., Edwards 1969, Conant 1972, Cohen 1977). These descriptions were done before the creation of modern spectrographic software and used different names for the same vocalization types, which impedes our ability to understand those types. Therefore, an updated description of Blue Jay vocalizations that utilizes a modern, replicable classification approach is required.

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Numerous methodological approaches of various complexities, which I have grouped into 3 categories, have been employed to describe vocal repertoires. In the "human observer" approach, human observers have been used exclusively to classify vocalization types based primarily on their visual appearance on spectrographs (e.g., Sandoval et al. 2015, Tanimoto et al. 2017). Extending upon this method, using a "hybrid" approach, others (e.g., Grieves et al. 2015) have classified vocalizations visually and then quantitatively evaluated the accuracy of these classifications. Using a "quantitative approach," yet others have attempted to completely avoid human-derived classification of vocalizations, and associated bias, by choosing a clustering method based on one of a variety of relatively complex procedures (some of which are described by Gamba et al. 2015, Fischer et al. 2017). Of these 3 general approaches, I chose to utilize the "hybrid" approach. Namely, I used spectrographs to visually classify Blue Jay vocalizations based on a set of well-defined nomenclatural rules and then evaluated my classification system quantitatively. As such, my approach is relatively easy to replicate for most investigators and can be evaluated objectively.

Herein, I characterize Blue Jay vocalizations through spectrographic images and provide a nomenclatural approach, synthesized from and expanding upon previous efforts, that could also be used to describe vocalizations of other corvids. To provide additional context about the vocalization types that I have defined, I also report relative frequency of their use.

Methods

Recording details

I recorded Blue Jay vocalizations during December 2014–July 2015 and during January and February 2016. Recordings occurred at 18 locations, of which 16 were in the state of Kentucky (KY), USA (mean size of recording plots approximately 9 ha, range = 0.09–21.5). The borders of recording locations were separated by at least 600 m, a distance that was shown to preclude mixing between groups of nonmigrating individuals during the nonbreeding season (Racine and Thompson 1983). I visited 12 locations during both the breeding and nonbreeding seasons, with a mean of 5.2 and 3.8 visits to locations per season, respectively. Most vocalizations (85% of total) were recorded in Richmond, KY and at the nearby Bluegrass Army Depot (BGAD; 37.71°N, 84.25°W, elevation 290 m). The BGAD primarily consisted of interspersed cover types including mowed areas surrounding munitions storage facilities, cattle-grazed pastures, and second-growth forest. A smaller percentage of the vocalizations in this study were recorded at a predominantly forested site 60 km northeast of Richmond (9% of total; 37.89°N, 83.98°W), at a site 160 km west of Richmond in an agricultural/forested setting (5% of total; 38.09°N, 85.53°W), and in 2 residential yards about 450 km NNW of Richmond (1% of total; 41.79°N, 86.51°W).

During my recording sessions, which occurred between sunrise and sunset, I attempted to maintain visual contact with focal birds. I remained at least 10 m away from recorded individuals to minimize effects upon their behavior. Focal birds were not banded, so I could distinguish only among groups of Blue Jays based on the location where they were recorded. I noted the minimum number of Blue Jays that could have been present (detected at same time) for each recording session. During the breeding season, I assumed that mated pairs tended to concentrate activity around nests and that no Blue Jays had home ranges with a diameter of more than 600 m. I followed and recorded Blue Jays for a total of 1,865 min, with 927 min occurring during the breeding season (18 Mar–31 Jul) and 938 min during the nonbreeding season (1 Aug–17 Mar). I defined breeding and nonbreeding seasons based upon personal observation at the study sites and the observations of Hardy (1961).

I primarily used a solid-state recorder (Marantz Professional, Model PMD620MK II, Kanagawa, Japan) with a shotgun microphone (Audio-Technica Telemike, Model ATR55, Machida, Japan) set to a cardioid pattern. For less than 10% of calls recorded, I used a Tascam Linear PCM recorder (Model DR-05, Montebello, California, USA). Recordings were made as WAV files with a sample rate of 44.1 kHz and a bit rate of 1411 kbps.

Using Audacity (Audacity Team 2019), I first high pass filtered (1 kHz, rolloff = 6 dB) and then normalized to –0.1 dB calls used to create spectrographic images (each recorded at about 10–20 m from the focal bird). To make spectrographs for visual analysis, I used Raven Pro

Table 1. All epithets, and classes described by at least one epithet, used to describe non-imitated Blue Jay vocalizations or imitated American Crow vocalizations (which were commonly uttered) in Kentucky. I note via an "X" what position (primary, secondary, and tertiary) epithets occur and in parentheses which classes they describe (j = jay, s = squeaky-gate, c = crow, b = bell, r = rattle, g = growl). Epithets refer to the dominant frequency.

Class	Epithet	Prim	Sec	Tert	Notes about meaning
Jay	–	–	–	–	Stacks of narrow (~300 Hz) frequency bands
Squeaky-gate	–	–	–	–	Rapid series of brief notes (<0.2 s), wide frequency range (up to 3 kHz), no up-slur, >1 note; musical to human ear
Crow	–	–	–	–	Resembles an American Crow call
Bell	–	–	–	–	Entire call nearly a pure tone; like a chiming bell to human ear
Rattle	–	–	–	–	A trill of rapid clicks with a frequency range of at least 1 kHz
Growl	–	–	–	–	Broadband (3 kHz +) noise; high spectral entropy lacking distinct frequency bands
–	Descend. (j)	X	–	–	Highest frequency >150 Hz higher than end frequency
–	Flat (j)	X	–	–	Highest frequency approximately the same (within 150 Hz) as end frequency
–	Bell-like (j)	X	–	–	Portion of call is nearly a pure tone; like a chiming bell to human hear
–	Burry (j, b, c)	X	X	X	High spectral entropy within a narrow frequency band (~300 Hz); constitutes at least half the duration of call
–	Harsh (j)	–	X	–	Rapid up-slur at beginning of "n" shaped note
–	Hoarse (j)	–	X	–	Similar, but distinct, frequency bands that together create a strident sound
–	Smooth (j)	–	X	–	Note with no up-slur and shaped like "\"
–	Juvenile (j)	–	X	–	Only immature birds utter; tend to be a higher frequency than similar adult calls
–	Inverted (j)	–	X	–	Curve of call opposite of other "jay" calls, similar to a "v"
–	Whine (j)	X	–	–	Relatively high-pitched (~4 kHz), undulating frequency band; whiny quality to human ear
–	Short (j, g, c)	X	X	X	At most half as long as another call with same class and preceding epithet(s)
–	Partial (s)	X	–	–	Less than 4 notes, greater than 1 note
–	Segment. (r)	X	–	–	Notes grouped at regular intervals
–	Contin. (r)	X	–	–	Regular spacing of notes, no grouping

(Bioacoustics Research Program 2019) with default settings, except that I adjusted brightness to "57," contrast to "80," and window size to "678." Percent overlap was 50%.

Vocalization nomenclature

Based on spectrographic images, I classified all Blue Jay vocalizations as a particular "type." Additionally, to provide a broader level of classification, I also assigned each vocalization to a general "class." During the process of classification, I first classified vocalizations as belonging to a class—based on structural characteristics—and used one or more well-defined epithets, if necessary, to distinguish between types within each class. My hierarchical nomenclature places the class last and epithets as necessary preceding the class, with "primary" epithets immediately preceding class, "secondary" epithets immediately preceding primary epithets, etc. (Table 1). Thus, a vocalization type name consists of all used epithets, if any are necessary, and the class name. Having more epithets of a higher order (highest = "primary") in common indicate that vocalization types of the same class are more similar. Common epithets, and how they are used to build a vocalization type name, are displayed in Figure 1. The following classes included multiple vocalization types, and so required epithets to define at least some types: "jay," "squeaky-gate," "crow," "bell," "rattle," and "growl" (Table 1). The remaining, non-imitated classes—such as "whistle"—also serve as vocalization type names given that no other types occurred within them and so no epithets were required to distinguish between types. "Imitated," followed by a species name,

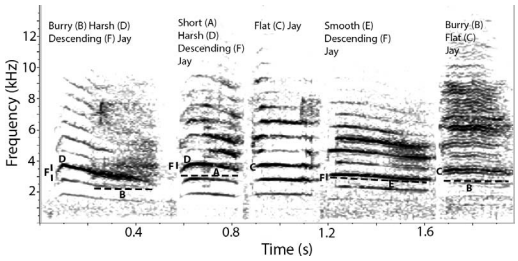

Figure 1. Commonly used epithets for the "jay" class based on spectrographs from the repertoire of Blue Jays in Kentucky. Letters denote epithet name and dashed lines denote the portion of the call that the associated epithet refers to. A = short, B = burry, C = flat, D = harsh, E = smooth, F = descending. The same vocalization type instances in this figure are used in Figure 2 (where from left to right they are labeled as J, F, B, K, O) and are also represented in the supplemental audio files.

indicates that Blue Jays appeared to be imitating a vocalization of another species. For the "Yurp-bout" and "Peep-bout" vocalization types/classes, "bout" indicates a cluster of similar notes, and that these notes are sometimes uttered singly.

I did not include behavioral functions in the names of Blue Jay vocalization types. Rather, I assigned names based upon the way that vocalizations appeared or sounded to me or, in some cases, to previous investigators, e.g., "Squeaky-gate" and "Bell."

Statistical analyses

To test the validity of my nomenclature, I conducted a linear discriminant function analysis (LDFA) using the *lda* function of the *MASS* package (Venables and Ripley 2002) in R 3.6.0 (R Core Team 2019). The grouping variable was vocalization type as I determined via my classification approach. The non-correlated independent variables included 3 parameters (duration, peak frequency, average entropy in bits) that I chose a priori based on the characteristics I used to visually classify vocalizations. I measured these parameters in Raven Pro (Bioacoustics Research Program 2019). To ensure independence of observations, I chose a single, quality instance (clearly visible on a spectrograph with a high signal to noise ratio) of each vocalization type at a given location for measurement. I only included vocalization types that were recorded at high quality at a minimum of 6 locations to maintain an adequate ratio (at least 2:1) between sample size and independent variables.

For each vocalization type ($n = 10$, representing 5 classes) recorded at a sufficient number of locations ($n = 6$), I measured 6 vocalizations randomly chosen from the locations where they occurred and log-transformed as necessary to achieve normality. Using leave-one-out cross validation for this subset of vocalizations, I determined the degree to which my approach to vocalization classification agreed with quantitative classification. Thus, I assessed the general validity of my nomenclature. Pearson correlation coefficients were determined using R 3.6.0 (R Core Team 2019). Reported variation is standard error.

Results

I assigned 7,153 vocalizations to 1 of 36 particular types. These vocalization types were grouped into 18 classes, including 6 classes that contained more than one type. The "jay" class included the most vocalization types ($n = 14$). The other 5 classes that included more than 1 vocalization type (squeaky-gate, crow, bell, rattle, and growl) included 2 types. All of the vocalization classes and types that I documented are listed in Supplemental Table S1. I documented a total of 4,172 vocalizations in the breeding season and 2,981 in the nonbreeding season. The mean number of different vocalization types documented for each location was 9.6 ± 1.4 (range = 1–19), with a significant positive correlation between the number of different vocalization types documented and the number of times locations were visited ($r = 0.57$, $P = 0.013$). The relationship between number of different vocalization types documented and mean number of birds observed at a location was not significant ($r = 0.26$, $P = 0.29$). Of the 3 locations that I visited at least 10 times, 1 location had no new vocalization types documented after being visited 10 times (16 visits total), and 2 locations had at least 1 new type described during the last visit (12 visits total and 15 visits total; Supplemental Fig. S1).

The vocalization types that I recorded at all 3 of these locations were: Harsh Descending Jay (A), Flat Jay (B), Burry Descending Jay (C), Squeaky-gate (D), Short Harsh Descending Jay (F), Partial Squeaky-gate (G), Yurp-bout (H), Smooth De-

scending Jay (K), Burry Bell (P), and Imitated Red-tailed Hawk (*Buteo jamaicensis*; V; letters in parentheses indicate labels in Fig. 2). Aside from the Imitated Red-shouldered Hawk (*Buteo lineatus*) call, all vocalization types recorded distant (>50 km) from Richmond, KY were also documented in or near to Richmond, KY.

For the 10 vocalization types classified via LDFA, that method tended to classify vocalizations as I did (Supplemental Fig. S2). Leave-one-out cross validation classified vocalizations the same as I did for 72% of instances (43/60; Fig. 2, Supplemental Table S2). Of the 17 disagreements (Supplemental Table S2), only 3 resulted in assignment to a different class between methods and 10 disagreements occurred for 2 vocalization types (Burry Descending Jay and Smooth Descending Jay).

I provide spectrographic images of 31 vocalization types recorded during this study, the number of times that I documented each vocalization type, the number of locations at which I documented these vocalization types, and when applicable the number of times LDFA classified instances of a type the same as I did (Fig. 2). Each vocalization presented in Figure 2 is representative of approximately mean vocalization type characteristics. Original amplitudes of vocalizations, before normalization, are available (Supplemental Table S3). The recordings of rattle types were not of high quality, although were sufficient to spectrographically show basic structural differences (Continuous Rattle consists of broad-band, rapid repetition of notes whereas Segmented Rattle consists of clusters of 2 or 3 notes).

Two vocalization types, "Cry" and "Grunt" (DD and Z in Fig. 2), were only uttered when individuals were in or near the hand. Vocalizations documented, but not recorded during observation sessions or recorded insufficiently, include "Twitter" (musical twittering by nestlings; $n = 29$; called "Juvenile Peeping" by Edwards 1969), and apparent imitations of a Red-shouldered Hawk ($n = 7$; called "kee-aah" by Dykstra et al. 2020), a Broad-winged Hawk (*Buteo platypterus*; $n = 3$; called "kill-e-e-e" by Matray 1974), a Bald Eagle (*Haliaeetus leucocephalus*; n not counted; called "chatter calls" by Verner and Lehman 1982), and a Cooper's Hawk (*Accipiter cooperii*; $n = 4$; called "cak-cak-cak" by Rosenfield and Bielefeldt 1991). Species that were apparently imitated by Blue Jays in this study, for which I recorded the calls (Fig. 2), were American Crow (*Corvus brachyrhynchos*; called "short" and "rough" calls by Tarter 2008) and Red-tailed Hawk (called "ke-eeee-arrr" by Preston and Beane 2020). Audio files which correspond to each row of Fig. 2 are available online (https://doi.org/10.5281/zenodo.6024784).

Discussion

I found that Blue Jays have a relatively large repertoire of vocalization types compared to the repertoires of most birds, which typically range from 5 to 14 distinct types (Gill 1995). I documented and formally named 36 distinct Blue Jay vocalization types, compared to 19 by Edwards (1969), 20 by Conant (1972), and 15 by Cohen (1977). Unlike previous investigators, I tended toward "splitting" rather than "lumping" vocalization types so that future investigators can consult my spectrographs (Fig. 2) and pare down vocalization types as they see fit for their purposes. Based on my observation that Blue Jays recorded far (>50 km) from my main site (Richmond, KY) only uttered 1 vocalization type (Imitated Red-shouldered Hawk) not uttered at or near the main site, it appears that the results of my study are likely applicable to many populations of Blue Jays. At 2 of the 3 sites that I visited at least 10 times, I documented at least 1 new vocalization type during my last visit (Supplemental Fig. S1). Therefore, I may have documented more (uncommon) vocalization types study-wide had I made additional recordings.

My approach to classifying Blue Jay vocalization types builds upon and supplements the approaches used by previous investigators (overviewed in Table 2). My precise system avoids assigning behavioral functions to names, which will minimize bias during future investigations of the functions of Blue Jay vocalization types and/or classes. The use of a general class, e.g., "jay," when describing a vocalization—followed by assignment of well-defined epithets to further specify—could be utilized when describing vocal repertoires of other species, especially other corvids. For example, my approach could be applied to the Steller's Jay (*Cyanocitta stelleri*) and perhaps augment the original vocal description by Hope (1980). Meta-analyses such as by Rosa et

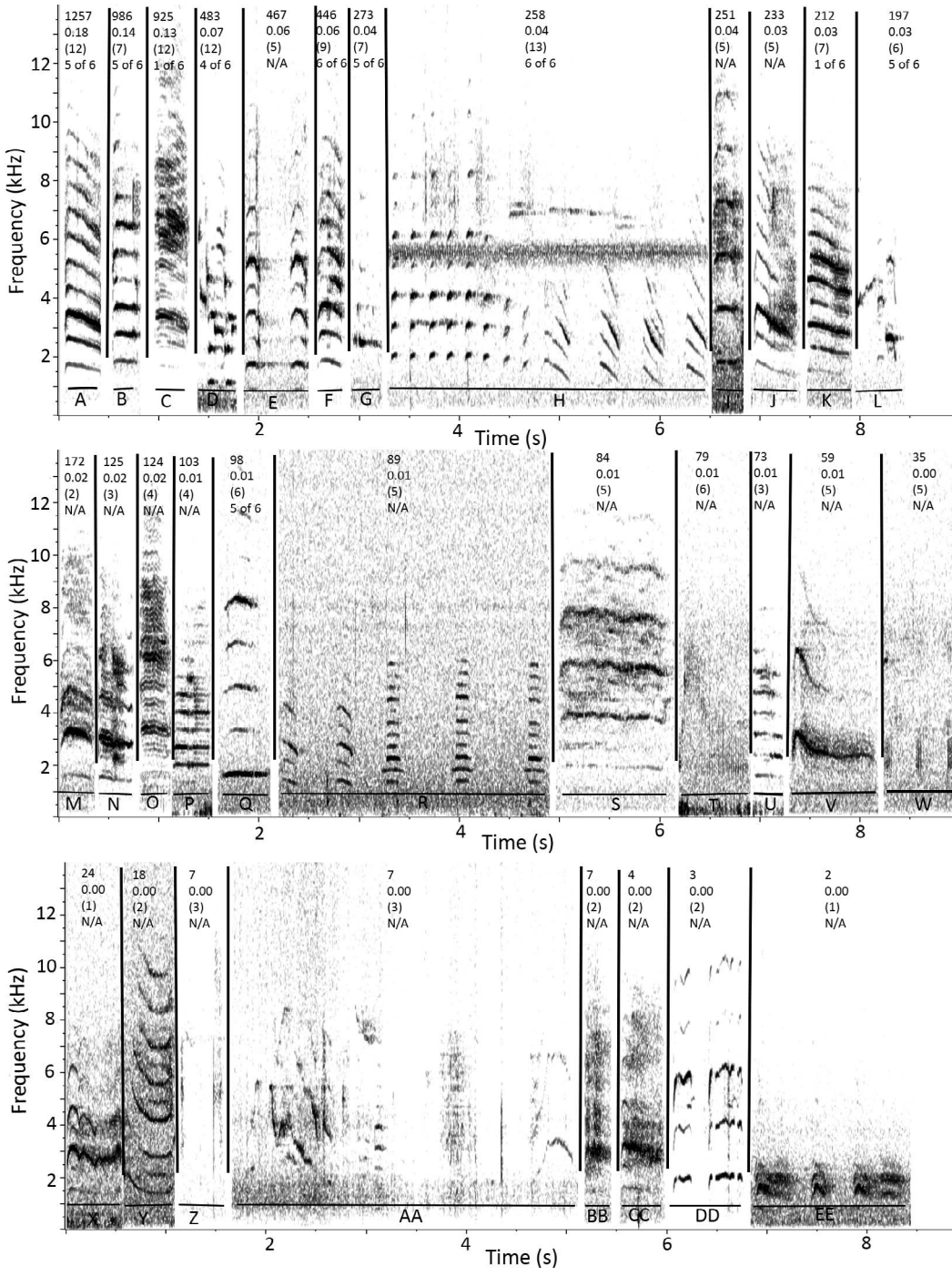

Figure 2. Spectrographs of 31 Blue Jay vocalization types from Kentucky ordered by relative frequency. Vocalization types are specified by letters. For each type, the top number indicates the number of times it was documented, the second number from top indicates the proportion it constitutes of all vocalization instances documented, and the third number (in parentheses) indicates the number of locations where particular vocalization types were recorded. The bottom numbers indicate the results of LDFA and leave-one-out cross validation (e.g., 6 of 6 = perfect agreement between LDFA and my

Table 2. Nomenclatures of Blue Jay vocalizations. Comparison of all non-imitated, post-nestling vocalization types as named in current study and the most similar types named in unpublished works (two PhD dissertations [Conant 1972, Cohen 1977], a master's thesis [Edwards 1969]) and the *Birds of The World* summary (Smith et al. 2020).

Current study	Cohen (1977)	Conant (1972)	Edwards (1969)	Smith et al. (2020)
All "Flat Jays" and Bell-like Jay	Monotonal Jay	Flock Contact	Monotone Cry	Monotonal Jeer
All adult "Descen. Jays"	Ditonal Jay	Alarm	Jeer Cry	Ditonal Jeer
Short Growl	N/A	N/A	Chuck?	N/A
Growl	N/A	N/A	Growl?	N/A
All "Bells"	Bell	Bell Song	Monotone Pump Handle	Bell
Peep-bout	N/A	N/A	Peeping	Peep Call
Yurp-bout	Yurp, Begging?	Begging Keu (soft, loud)	Chirping, Whirring	Kuet Kuet, Kueu-Kueu
Squeaky-gate	N/A	Wheedle Bell Song?	Quiet Pump Handle?	Squeaky Gate, "lo-hi-lo"
Partial Squeaky-gate	Squeaky Gate	Wheedle Bell Song?	High-Low Pump Handle	Squeaky Gate, "hi-lo"
Whistle	N/A	Triple Descen. Whistle?	N/A	N/A
All "Rattles"	Rattle	Rolling Click, Descen. Whistle?	Rattle	Rattle
Cry	Squack	Distress	N/A	Squack
Grunt	N/A	N/A	N/A	N/A
Song	Chortling	Song	Random Jabber	Whisper Song
All Adult "Whine Jays"	N/A	N/A	Kueu Cry	N/A
Juv. Descend. Jay	Begging	Young Food Begging 1?	Juv. Waa, Jeer Cry	N/A
All "Juv. Whine Jays"	Begging, Swallowing	Young Food Begging 2	Juv. Keu Cry	N/A

al. (2016) would benefit from common nomenclatural approaches and therefore could better elucidate evolutionary causes for vocal differences between closely related species.

My ability to quantitatively validate my nomenclature was limited by the number of locations where Blue Jays were recorded. However, based on the subset of vocalization types that I could analyze, I found that 70% of types were classified the same for at least 5 of 6 instances (Supplemental Table S2) by my classification approach and by LDFA. For those instances when vocalizations were not classified the same by both methods, classifications tended to agree with respect to class. Had I been able to use more parameters to classify vocalizations, e.g., if I had recorded at more locations or banded individuals, then classification likely would have improved with respect to vocalization types such as Burry Descending Jay and Smooth Descending Jay. However, with respect to these vocalization types that lacked support by LDFA and those types that were not analyzed, future investigators should practice caution. Generally, though, my nomenclature does appear to objectively classify the majority of Blue Jay vocalization types, especially to the class level. Future investigations are warranted which examine the gradations between the vocalization types I have described herein using, for example, "fuzzy clustering" techniques (Fischer et al. 2017).

←
method, N/A = not analyzed). A = Harsh Descending Jay, B = Flat Jay, C = Burry Descending Jay, D = Squeaky-gate, E = Short Imitated Crow, F = Short Harsh Descending Jay, G = Partial Squeaky-gate, H = Yurp-bout, I = Short Juvenile Whine Jay, J = Burry Harsh Descending Jay, K = Smooth Descending Jay, L = Whistle, M = Juvenile Descending Jay, N = Hoarse Descending Jay, O = Burry Flat Jay, P = Burry Bell, Q = Bell, R = Peep-bout, S = Juvenile Whine Jay, T = Continuous Rattle, U = Bell-like Jay, V = Imitated Red-tailed Hawk, W = Segmented Rattle, X = Whine Jay, Y = Inverted Whine Jay, Z = Grunt, AA = Song, BB = Short Growl, CC = Growl, DD = Cry, EE = Burry Imitated Crow.

It is possible that previous investigations, such as by Dahl and Ritchison (2018), may have discovered additional vocalization-context associations of Blue Jay vocalizations if the more extensive nomenclature of the current study were used. Likewise, future studies seeking to determine functions of Blue Jay vocalizations could benefit from and advance findings of my study. For example, all species imitated by Blue Jays in my study were predators of adult Blue Jays or nestlings, which is consistent with imitation being used by this species to indicate danger (Hailman 2009). Playback experiments could test this hypothesis.

In closing, I would like to note that I agree with Smith et al. (2020) that "the vocabulary of Blue Jays is immense and precludes precise categorization," with gradations likely occurring between most described vocalization types. My description provides investigators a starting point for decoding the exceptional variability present in the repertoire of Blue Jay vocalizations.

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