Identification and characterization of vocalization of the Blue-Throated Barbet (*Megalaima asiatica*)

BY

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2023

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A thesis submitted in the partial fulfillment of the requirements for the degree
of
MASTER OF PHILOSOPHY
IN
PHYSIOLOGY

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2023

“In the name of ALLAH, the Most Gracious, the Most Merciful”

بسم الله الرحمن الرحيم

DECLARATION

I hereby declare that the material contained in this dissertation “Identification and characterization of vocalization of Blue Throated Barbet (*Megalaima asiatica*)’’ is my original work. I have not previously presented any part of this work elsewhere for any other degree.

Muhammad Shafqat

Dedication

First of all, I dedicate my project to Allah Almighty

&

Dedicated to whom the world owes its existence

Prophet Muhammad (Peace be Upon Him)

&

I dedicated my humble efforts to my sweet and loving parents.

&

And all my Aasi caste

ACKNOWLEDGEMENTS

*All praise be to Almighty Allah, the Sustainer, and Cherisher of the worlds, who has bestowed countless blessings upon us and enabled me to present my humble efforts in the form of this dissertation. I extend my heartfelt salutations to the Holy Prophet **Hazrat Muhammad** (Peace Be Upon Him), a beacon of knowledge and blessings for all of creation, who emphasized that the pursuit of knowledge is a divine commandment.*

*I express my sincere gratitude to my esteemed supervisor, **Dr. Irfan Zia Qureshi**, for granting me the freedom to explore the communication behavior of the Adult Blue Throated Barbet in a novel manner. I am grateful for his expertise, valuable suggestions, and the time he dedicated to providing feedback on my writing and research. Sir, your unwavering support, guidance, and generosity have been invaluable.*

*I extend my eternal thanks to my senior, **Dr. Abdul Aziz Khan**, who has always been ready to assist with a warm smile. I am also grateful to my other seniors, Miss **Sumaira Hassan, Miss Haleema Sadia, Ayesha Razzaq**, and **Tariq Aziz**, as well as my fellow lab mates, **Ruqayya Shoukat, Bakhtwer Hina, Hafsa, Izhar, Taimoor,** and **Ikram**, for their moral support and encouragement.*

*I would like to express my gratitude to my exceptional colleagues, **Semab Khadam** and **Momna Nazir**, for their hard work and dedication. Working with them has been a delightful and inspiring experience. Special thanks also go to my friends, **Nazar Hussain, M. Ishaq, Aqeel Ahmed, Hassan Bilal, Adnan Ali, Nadir Ali**, and last but not least, my field companion and best friend, **Safdar Ali**. Special thanks to HS, who supported me throughout my entire journey without any limitations. I owe a great deal to each of them for their contributions.*

*No acknowledgment could adequately convey the depth of my gratitude to my beloved family, without whom I would feel incomplete. Words fall short when expressing my appreciation to my parents. Their love, care, and support have been instrumental in enabling me to achieve my goals in life. I extend special thanks to my brother, **Safdar Abbas**, and my sisters for their ceaseless prayers, unparalleled love, and care.*

Lastly, I offer my sincere regards and blessings to all those who supported me in any way during the completion of this thesis.

"Intelligence without ambition is a bird without wings".

Muhammad Shafqat Aasi

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LIST OF ABBREVIATIONS

NAME	ABBREVIATIONS
ML	Medial labia
LL	Lateral labia
MTM	Medial tympaniform membrane
dB	Decibel
kHZ	Kilohertz
RA	Robusts archistriatalis
P	Pessulus
B	Bronchus
T	Trachea
DM	Dorsomedial
Ram	Retroambigualis
DLM	Dorsolatral thalamic nucleus
TL	Trachea latelaris
ST	Sterno trachealis
dS	Syringealis dorsalis
dTB	Tracheobronchialis dorsalis
ICM	Interclavicular air sac membrane
CMM	Caudomedial mesopallium
CLM	Caudolateral mesopallium
Vs	Syringealis ventrails
CNM	Caudomedial nidopallium
HCV	High vocal center
RA	Robust nucleus of archistraitum
IC	Intercollicular complex
DM	Dorsolateral
rVRG	Rostral ventral respiratory neurons group
IMAN	Lateral part of the magnocellular nucleus of anterior neostriatum
DLM	Dorsolateral thalamic nucleus medial part
Hz	Hertz
NCM	Caudomedial nidopallium

CLM	Caudolateral mesopallium
CMM	Caudomedial mesopallium
CN	Cochlear nucleus
HVC	High Vocal Center
MLd	Mesencephalon dorsal part lateral nucleus
Ov	Mesencephalon dorsal part lateral nucleus
SO	Ovoidalis
LMAN	Anterior nidopallium lateral magnocellular
T	Testosterone
E2	Estradiol
DHT	5a dihydrotestosterone
PMc	Pure Melodious call
Ac	Aggressive call
Tc	Territorial call
Cc	Calling call
Ms	Miliseconds
Av	Nucleus avalanche
RA	robust nucleus of the arcopallium
NCMv	ventral caudomedial nidopallium
F0	Fundamental frequency
F0 min	Minimum fundamental frequency
F0 max	Maximum fundamental frequency
F0 avg	Average fundamental frequency
Pitch m	Pitch mean
Pitch min	Pitch minimum
Pitch max	Pitch maximum
No.of elements	Number of elements
DFA	Discriminant function analysis
DF1	Discriminant function1
DF2	Discriminant function 2

ABSTRACT

Birds primarily communicate through their vocalizations, as their sense of smell is absent because their olfactory system is not as well-developed compared to their vocal capabilities. Birds with extensive and intricate vocal displays also communicate through non-verbal sounds. Determining the range of vocalizations an animal possesses sets a foundation for recognizing the significance of acoustic signals in their courtship and social dynamics. The use of computer software for analyzing bird vocalizations is a powerful and efficient means of conducting such analysis. The vocal patterns of non-passerine members have received limited attention compared to those of singing birds. Singing is absent in non-passerine birds but they rely on calls for the exchange of different information. By studying different calls of non-passerine birds we can learn deeply about bird communication and associated behaviors.

Materials and Methods

The study area for recordings was made by a directional microphone connected with a digital recorder and birds were recorded from Islamabad National capital of Pakistan because in this city dense forests and plains are present which is a suitable environment for many birds. The recordings were analyzed on visual inspection of the spectrogram and other acoustic characteristics. The vocalization rate is also considered. The identification of various call types was achieved through the visual inspection of spectrograms and waveforms of vocalizations and the corresponding behaviors observed in the field in the present study. Characterization of calls is done on the basis of Spectro, acoustic, and statistical parameters. Ten acoustic variables were selected for call characterization.

Results

Calls were characterized into four different categories. Seven out of ten variables are significant by the stepwise regression model, and then significant variables are classified 96.8 % by DFA into predicated call categories which are on the basis of spectrogram analysis.

The first two functions in DFA showed maximum variance (Function1:86%, eigenvalue=13.4; Function 2:13 %, eigenvalue=2) and showed highly significant differences between the different types of calls (Wilks' λ DF1/3 = 0.019, df = 21, P <

0.001 and Wilks' λ DF2/3 = 0.269, df = 13, $P < 0.001$). Using the cross-validated method, DFA classified the vocalizations correctly into the predicted vocal categories that we initially classified on the basis of spectrographic examination. The DFA correctly classified 99% (344/348) of Kutrook-Kutrook type 1, 99% (102/104) Touk calls, 87.3% (96/110) of Kutrook-Kutrook type 2 calls, and 98% (98/100) of Kurrrrrrr calls. The Kruskal-Wallis ANOVA was utilized to determine differences among vocal categories, excluding non-significant variables. Subsequently, a post-hoc Mann-Whitney U-test (2-tailed) was performed for multiple group comparisons. The Holm's sequential Bonferroni procedure with alpha = 0.05 was implemented to adjust the results of the multiple-comparison Mann-Whitney U-test. The data is shown as mean ± S.E. A difference was considered statistically significant if $P < 0.05$.

Conclusion

In the present study, the vocalization of blue-throated barbet is characterized by four different calls. Our results enhance the understanding of the vocalizations of adult Blue-throated Barbets and establish a baseline for future comparative studies with other species of Barbets. Further research should aim to uncover the complete vocal range of Blue-throated barbet and investigate the role of these calls role in courtship, social biology, and individual identification

INTRODUCTION

Introduction

1.1 Vocalization

Vocalization is the physiological ability of animals to produce sounds by vocal apparatus (such as fish by swim bladder, mammals, frogs, reptiles by the larynx, and birds by syrinx (Charif et al., 2006 and 2010, and Gill 2007, Senter, 2008). Phylogenetically tetrapods show that vocalization likely evolved autonomously over most animal groups more than 100 million years ago. (Chen and Wiens, 2020).The animals used Vocalization to exchange information between individuals, or across the same or different species (Barkan and Zornink, 2020)

In animals, it plays a key role in to exchange of biologically related information (Narins et al., 2006; Bradbury et al., 1998; Gerhardt and Huber, 2002). Therefore, Studies of animal communication remain challenging because the meanings of vocal signals depend not on their sound characteristically features, but also on the behavioral state of different species and the environmental context (Vignal et al.,2004; Ljubičić et al.,2016; Ciaburri and Williams, 2019).

Some species of mammals, including humans, elephants, and dolphins are excellent learners(Doupe and Kuhl, 1999), and other mammals like sea lions bats, rodents, lagomorphs, manatees, and also some bird species, such as oscine songbirds, which include hummingbirds, canaries, and finches, as well as non-songbirds like budgerigars and parrots, have ability to produce vocal sounds through learning which is a very unique character(Poole et al., 2005; Goller and Shizuka, 2018)

The only mammals with the ability to express themselves verbally and articulate their words in speech form are humans. In contrast, non-human primates can only learn and make a limited number of innovative vocalizations (Egnor and Hauser, 2004; Jurgens, 2002). Due to sharing common features with humans, other primates are therefore considered to be useful to study animals for studying the neural networks that control the muscles which are used in sound production (Simonyan and Horwitz, 2011).

Bird songs and human language are parallel to each other in many aspects like behavioral, neural, genetic, and developmental processes (Lipkind et al., 2013; Jarvis,2019; Hyland Bruno et al., 2020). Human language hierarchy is constructed from alphabets forming words, words forming sentences, and sentences forming speech, bird songs can also be viewed as a hierarchy of elements, with notes composing syllables, syllables forming phrases, and phrases combining to create songs. An individual bird's song repertoire consists of multiple songs which have many functions (Bowling and Fitch, 2015; Ten Cate and Okanoya, 2012).

Bird vocalizations do not possess the linguistic characteristics of words and syntax or semantics and are not believed to possess any symbolic significance beyond basic reference functions (Bowling and Fitch, 2015; Berwick et al., 2011;).

Birds produce a great variety of voices for communication, including calls, songs, and non-vocal mechanical sounds that can differ in length, complexity, and other factors. These sounds can be long, short, simple, or intricate. Instead of relying on the syrinx of birds, mechanical sounds are intraspecific, modulated audio impulses that consciously regulate physical sounds. When foraging, non-syringeal characteristics like tail feathers, struck wings, or snapped bills frequently produce mechanical noises (Catchpole and Slater, 1995, Charif et al., 2010).

The two suborders of the Passeriformes order are Passerine (oscine songbirds) and Tyranni (suboscine birds) (Barker et al., 2002; Sibley and Alquist, 1990). Innate songs are basic source of communication in Sub-order of oscine birds because they typically lack the ability to learn or acquire any vocal type. (Kroodsma, 1989). In contrast, closely relatives of these order oscine birds have excellent ability to learn and produce songs from intra-species and inter species in very short time (Beecher and Brenowitz, 2005). Due to the variety of musical features and communication approaches, these have also been in-depth explored. The complex vocalization, geographic variation in vocalization, and function of the sub-oscine and non-songbirds have also been studied, and these findings suggest that they share similarities with songbirds in terms of vocal complexity and function. (Falls, 1982; Baker and Cunningham, 1985; Todt and Naguib, 2000).

Songbirds have been the main subject of research on the communication behavior of birds for the past few years (Marler, 2004; Benedict and Krakauer, 2013). Comparatively little research has been done on the communication behavior of signaling systems in non-passerine birds, compared to singing birds. Non-passerine birds normally do not sing, however, these birds do occasionally vocalize in high range of behaviors such as defining territory and coordination of reproductive activity and eating habits avoiding predators and make social aware (Wilson and Evans, 2012; Seddon et al., 2002; Radford, 2003; Baker, 2004; Lefevre et al., 2001; Radford, 2004b; Evans and Evans 2007; Grieves et al., 2014)

Additionally, it is clear that the calls serve as a means of inter-sex communication, breeding status, and group and individual identity (Warrington et al., 2014). Investigating the vocalizations of birds, such as their calls and songs, can reveal much about their behavior, as these sounds serve a diverse range of functions (Keen et al., 2013)

1.1.1 Significance of Vocalization

Birds use acoustic vocalization as a particularly effective means of communication because it doesn't require direct eye contact between sender and receiver, can travel great distances, and can transport the information even in low-light situations like dense forests or at night (Catchpole and Slater, 2008). The spoken language comprises a wide range of components enough for the exchange of information among the animals like danger, food, sexual state and social information (Fitch, 2017; Wirthlin et al. 2019; Jarvis, 2017).

1.1.2 Voice, Speech, Phonation, and Vocalization

Phonation, vocalization, speech, and voice all have unique qualities despite being frequently used interchangeably. The sound made by the vibrating vocal folds is referred to as a voice in a technical sense. The physiological processes connected to the vibrating of the vocal folds that produce sound are technically referred to as "phonation" in this context. Voice production describes taught human behaviors like speaking and singing. While "song" encompasses both semantic and non-semantic elements, "speech" in humans refers to the development of voice with semantic meaning. Some birds, like oscine birds, are taught to sing, but other birds, such as sub-oscine birds, may naturally sing (Simonyan et al., 2012).

Some non-songbirds, such as the open-ended learners known as budgerigars, which are included in this category, can also acquire through hearing (Brittan-Powell and Dooling, 2004). Song learning only happens once, at a vital time, in age-range range learners (bird species), whereas it happens continuously in lifelong learners (Stripling et al., 2003). Unlike the lone chirping of birds, songs contain several syllables. In addition to speech and its constituent parts, non-speech and pre-speech noises created by infants and animals are also referred to as "voice production" (the production of syllables and vowels) (Simonyan et al., 2012).

1.2 Songs and Calls

Vocalizations are frequently divided into calls and songs based on their shape, function, and occasionally other variables such as the taxonomy and whether they are innate or acquired. Typically, the term "songs" refers to the frequently complex, pure-toned vocalizations that oscine passerines utilize to declare territorial boundaries and attract mates (among other functions). "Calls" are all other avian vocalizations; they are typically shorter than songs, have a simpler structure, and frequently emit a larger range of frequencies all at once (such as "chips" and "hisses"). Calls or sets of calls, such as "predator warning calls," "mobbing calls," and "begging calls," etc., are typically associated with specific events or "messages" (Charif et al., 2010, Gill 2007).

There are several ways to tell a bird call apart from a song, though in some species the line between the two may be a little blurry. On the basis of function, the bird songs are often seen as serving a purpose in attracting mates and facilitating reproduction, while calls multiple are viewed as serving a multitude of functions beyond courtship (Spector, 1994). Therefore alternative, classifications use acoustic or other characteristics to separate songs from calls. During the breeding season, mostly males generate songs, which are typically multi-part sounds (Marler, 2004; Smith, 1991; Vicario, 2004). In most song-producing species, the males are the ones who produce the majority of the songs, which are usually stereotypical and employed for territoriality and reproduction. Everyday communication is carried out through calls, which are frequently simpler and mostly have one or two syllables, and both males and females are capable of producing these calls and also by individuals of all ages. A bird's ability to survive depends on its ability to make a variety of calls (Marler, 2004).

Many bird species are required to maintain their social groups, whether it be a pair that has not yet mated or all ages individuals. The majority of birds have vocalization used to keep track of the location of other members of the same species which enables them to coordinate with each other during food searching in noisy or dense environments. When a bird loses contact with its flock, it may emit a separation call, which can occasionally sound similar to a contact call or be completely distinct. A bird's ability to discover food is also essential to its ability to survive, so certain species of birds also produce food signals that signal to invite other individuals of same species to eat nearby. Begging calls are a subset of these calls; they are typically made by chicks soon after they hatch and convince their parents to feed them. These calls frequently help parents recognize their children or other nest members to help parents to identify their children and nest location (Rowley, 1980; Dentressangle et al., 1986, 2016).

In social interactions between individuals, aggressive calls are employed and can often result in settling disputes. Alarm calls, on the other hand, serve to alert others of potential danger, such as the presence of a predator. These alarm calls come in various forms, including distress calls and mobbing calls. When an individual is being attacked by a predator, they will often make a distress call (Stefanski and Falls, 1972; Zachau and Freeberg, 2012).

On the other hand, when any danger has been spotted, and the goal is to gather individuals of the same species to surround and intimidate the danger caused, pressurize by many ways to leave the area mobbing calls are produced. The variations (change in the production of the call number, changes its frequency and pitch) of mobbing calls that indicate the specific type of danger or the level of danger it poses to the individual making the call. Mobbing calls are identified in many other species of birds or even animals species due common danger of predators (Griesser, 2009; Avey et al., 2011; Ellis, 2008; Suzuki and Ueda, 2013; Carlson et al., 2017).

The song of birds is mostly an intricate and sophisticated vocal activity that has many functions but is most common among many different songbirds' species to announce and protect their territory, to draw the attention of female birds for mating purposes, and potentially to encourage reproductive behavior and physiology in female birds (Kroodsma and Miller, 1996). The specific number of elements in the song determines how the song and the bird's collection of songs are performed because the change in the number of elements, song rate and frequency, and pitch have different functions (Marler, 2004; Vicario, 2004).

The manner in which birds present their songs can be quite structured, with a definite rhythm and pattern to the song rate, and through the song, complexity determines the repertoire of birds. A great similarity between animals like humans, whales, and elephants and birds like hummingbirds and parrots in vocal learning (Doupe and Kuhl, 1999).

The birds learn their songs, they must have a natural attraction toward learning and must be exposed to the song during a critical period of development (Brainard and Doupe, 2

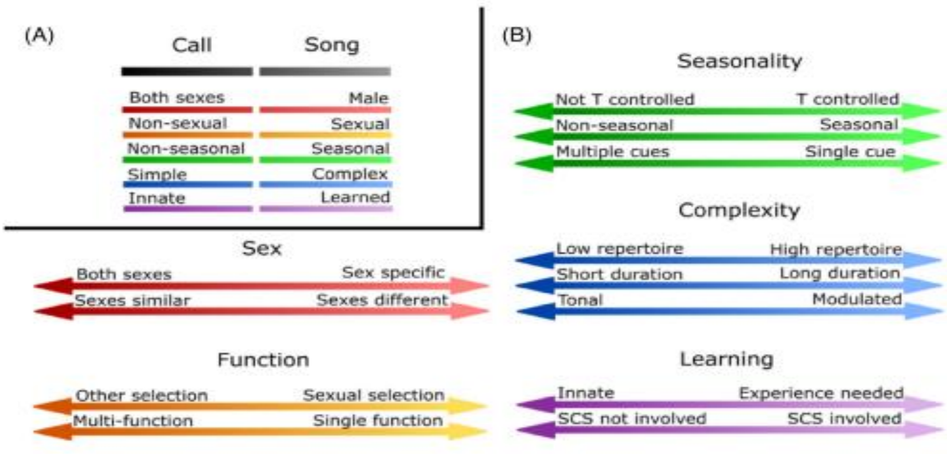


Fig. 1.1 Difference between calls and songs (Evangeline M. Rose et al., 2022).

1.3 Syrinx Avian Vocal Organ

The syrinx has been a topic of interest among researchers since the 18th century and continues to receive attention in the 21st century due to its uniqueness in vocal production (Erdogan et al., 2014; Miller et al., 2008; Düring et al., 2013; Picasso and Carril, 2013; Riede et al.,2015; Zimmer et al., 2008) because all other relatives of birds like reptiles produce vocalizations through larynx (Hall BK., 2012). This unique sound-producing organ is thought to have evolved as a result of the lengthy tracheal system of birds compared to animals, and also has greater resonating capabilities compared to other tetrapods which have a larynx. Its location is the tracheal lower base (Riede et al., 2019).

The sound production in birds requires a syrinx, multi-laryngeal system that requires just not only to cross over the air the is the requirement of high and directional pressure of air to generate the correct sounds which convey basic information to the same or different species (Gans, 1973; Riede et al., 2019). This is the unique vocal organ that is evolved in birds only, which functions as a valve to regulate airflow inward and outward and also control vocal activity (Riede and Goller, 2010; Clarke et al., 2016; Kingsley et al., 2018).

The location of avian vocal organs besides the heart has many differences from animals with reference to anatomy as well as structure. The syrinx is located in the interclavicular air sac, near the junction of the bronchi and trachea in birds. Sound is produced by the oscillations of pairs of labia structures located at the terminal end of each bronchial tube (Suthers and Zollinger, 2004). The basic units of the syrinx are tracheal rings composed of cartilage and paired bronchial half-rings that become calcified as the bird matures. These structures are connected by flexible connective tissues that vibrate when air flows through them, resulting in the production of sounds (Düring and Elemans, 2016). The anatomy of the syrinx varies among different bird taxonomic groups and its position also differs among species (Kingsley et al., 2018).

Bird vocal organ is made up of cartilaginous rings that change each top side and bottom of each bronchus and trachea. These changes are held in place by the paired tracheolateralis and sternotrachealis muscles of the syrinx. The hypoglossal nerve controls these muscles through its tracheosyringeal branch (as shown in Figure 1.2).

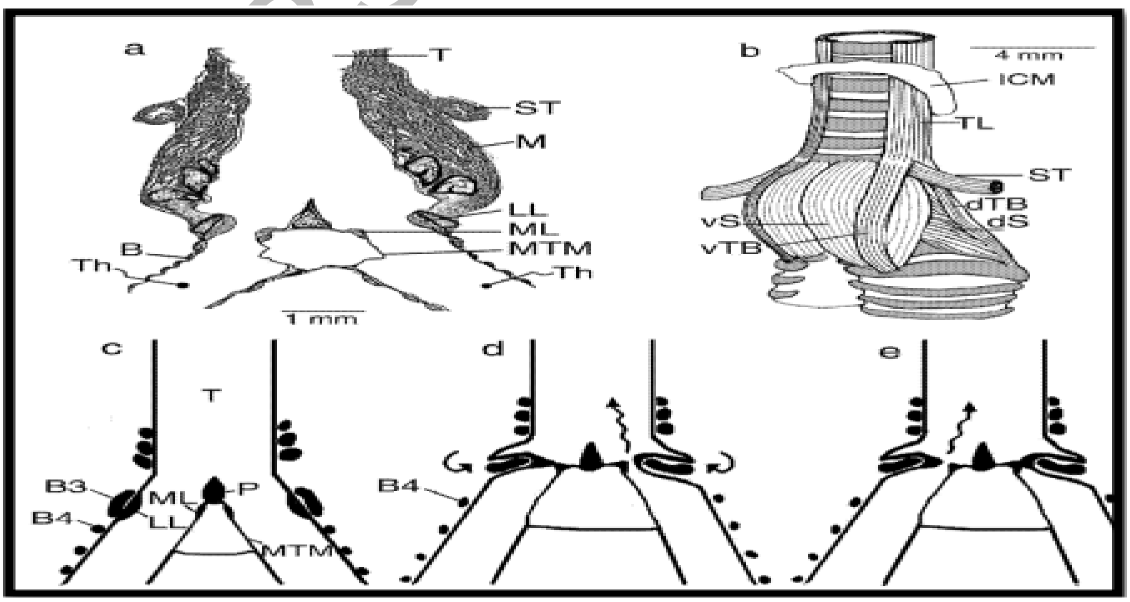


Fig. 1.2 Syrinx is a bipartite structure located at the tracheobranchial junction. (a) A

microbead thermistors (Th) is placed in dual nature of vocal organ of moking bird for recoding airflow; (b) syringial musculature are shown in the syrinx ventrolateral external view; (c) left side shows phonation while the right valve is closed; (d) Phonation on right side while left side valve is closed; (e) syrinx moves roastrad in preparation of phonation. Curved arrows shows branchial cartilage rotation into syringeal lumen by the contraction of ipsilateral dorsal syringeal muscles, labia moves into the air stream where they are set into vibration and producing sound (wavy arrows). Both bilateral (not shown) and unilateral phonation (shown) are present. ABBREVIATIONS: M, syringeal muscles; MTM, medial tympaniform membrane; ST, m. sterno trachealis; P, pessulus: B, bronchus; vTB, m. tracheobronchialis ventralis; T, trachea; B3 and B4, are third and fourth cartilages; vS, m. syringealis ventralis; ICM, interclavicular air sac membrane; ML, medial labium; dTB, m. tracheobronchialis dorsalis; LL, lateral labium; TL, m. trachea latelaris; dS, m. syringealis dorsalis; ST, m. sterno tranchealis (c-e, figures are modified from Suthers and Guller, 1997).

Additionally, the motion and tension of the medial labium (ML) and lateral labium (LL) located at the front end of the bronchi are regulated by the syringeal muscles. The medial tympaniform membrane (MTM), which is a thin membrane, is attached to the caudal end of the medial labium (King, 1989). In birds like parrots and doves that are not passerines, the tissues that produce vibrations are known as tympaniform membranes and in singing birds, they are referred to as labia. The left and right vibratory tissues that produce sound and are independently controlled are positioned at the connection between the bronchi and the syrinx (Goller and Riede, 2012). Based on Miskkimen's findings, the medial tympaniform membrane (MTM) was believed to be the source of sound production. As per these observations, when air was expelled from the syrinx of an unconscious house sparrow (Passer domesticus), the MTM started to vibrate, resulting in chirping sounds (Miskimen, 1951).

1.3.1 Sound Production

The terminology related to the production of sound includes waves, pressure, and medium. Sound waves refer to the variations in pressure within a given medium, with air being the most common medium for avian vocalizations. The intensity of sound is determined by the amplitude or height of the sound waves, which is expressed in decibels (dB) as a logarithmic representation of the pressure ratio. The pitch of sound is determined by the wavelength and is measured in millimeters, representing the length of a complete wave cycle. The frequency of sound, expressed in kilohertz (kHz), provides information about the height of the pitch, with higher frequencies indicating higher-pitched sounds (Catchpole and Slater, 2008).

Birds exposed to human-made noise, such as in urban areas, seem to be able to mitigate the effects of acoustic masking by adjusting their vocalizations in various ways. They may increase the frequency of their songs amplify the volume of their calls and change the timing of their signals (Fuller et al., 2007; Slabbekoorn and Peet, 2003; Wood and Yezerinac, 2006; Hu and Cardoso, 2009; Brumm and Todt, 2002; Brumm 2004; Nemeth and Brumm, 2010)

1.3.2 Song Modulation in Vocal Tract

Song modulation in the vocal tract refers to the process of adjusting and changing the properties of a bird's song as it travels through the vocal apparatus, including the syrinx and the mouth. This modulation can have a significant impact on the quality and character of the bird's song, and can be used to produce a wide range of vocalizations. Some of the ways in which birds can modulate their songs include adjusting the frequency, amplitude, and timing of the sounds, as well as changing the shape of the vocal tract to alter the resonance and harmonics of the song. These modifications can be used to produce specific calls and songs, to communicate with other birds, and to attract mates. Bird vocalizations are produced at the syrinx, but there is a significant distance between the syrinx and the point at which the song exits the bird's body and enters the environment. Birds are renowned for the musical quality of their songs, characterized by their tonal properties (Nowicki et al., 1992). The limited frequency range of pure, melodious bird songs contributes to vocal quality, these are characterized by a lack of overtones and harmonics. However, the source of this refined tonality is unclear, and it is not known whether it is solely due to the sound source or if it is the result of the entire vocal passage. Some researchers suggest that the vocal organ functions not limited as a windpipe but work as a resonator. According to some researchers, the vocal tract in birds may play a role in shaping the final song, similar to how the human vocal tract influences speech. The vocal tract could act as a complex filter that selects certain frequencies and eliminates others, thereby modulating the bird's song. This could explain why some birds of the same species have variations in their songs, even though they share the same neural circuits for song production (Catchpole and Slater, 2008). In avian vocalization, the respiratory system plays a significant role in controlling the rate of airflow and generating enough pressure to produce sounds. The expiratory muscles help regulate the pressure within the air sacs, which in turn affects the rate and frequency of airflow. The respiratory system also contributes to the production of frequencies below 80Hz, which are important for low-pitched vocalizations. These findings highlight the importance of considering the respiratory system as an integral component of avian vocalization and suggest that the interplay between respiratory and vocal systems is critical to generating the complex range of sounds observed in birds (Elemans et al., 2008; Riede et al., 2019). This highlights the importance of the coordination between the syringeal and ventilatory systems in fine-tuning the airflow for vocalization.

1.4 Song Perception

Song perception refers to the process of detecting, analyzing and interpreting vocal sounds produced by birds. Birds have evolved specialized auditory mechanisms that allow them to distinguish between different songs, even in noisy environments. Birds are able to recognize complex song patterns and discriminate between songs of their own species and those of others. Birds are facing problems of urbanization. They adapted themselves in many ways to convey their signal by changing the frequency, pitch, and time of vocalization. By doing so, they can make sure that their songs are still audible and noticeable even in noisy environments. (Slabbekoorn and Peet 2003; Wood and Yezerinac 2006; Hu and Cardoso 2009; Brumm and Todt 2002; Brumm 2004; Nemeth and Brumm 2010),

1.4.1 Hearing

In birds, the auditory system is located in the inner ear and is made up of the cochlea, which is responsible for converting sound waves into neural signals, and the auditory nerve, which transmits these signals to the brain for processing. The sensitivity and frequency range of bird hearing varies among species and is influenced by factors such as age, sex, and habitat. For example, some species have a higher sensitivity to higher frequencies than others, while some species have a broader frequency range than others. This allows birds to hear and respond to the specific calls and songs of their own species while ignoring other sounds in the environment. The structure of the bird's head and the presence of feathers and other features can also affect the perception of sound, including its direction and intensity (Beason, 2004).

One component of the communication system is the ability to produce sound, and the other is the capacity to hear, detect, differentiate, and recognize incoming sounds. Juvenile birds are unable to produce typical songs from the tapes if they do not hear the song of their adult conspecifics through a live teacher or a cassette. To develop a crystallized form of the specific song in young birds, young birds need to have the ability to perceive and learn the song from adult conspecifics during their early developmental stage. During this stage, the bird's auditory system is particularly receptive to the sounds in their environment, allowing them to form a memory of their conspecifics' song model. This process, known as song learning, involves complex neural and behavioral mechanisms that allow the bird to acquire, store, and retrieve the learned song (Sommers et al., 1997).

Several methods are employed to figure out the audio frequencies that birds can perceive. One such method is the neurophysiological technique, in which birds are given a sedative, and the auditory neurons located in the cochlear nucleus are recorded after playing different noises. The behavioral training method, where birds are trained to press a key in response to a sound, is considered to be the most common method. These two methods showed equivalent results in starlings (Konishi, 1970).

Additional research has demonstrated that the threshold curves for most bird species are similar. The most sensitive hearing frequency is estimated to be between 2-3 kHz, with the ideal hearing range lying between 1-5 kHz. The auditory brainstem response, which involves placing electrodes under the scalp, is a more recent technique used to determine a bird's hearing range. This method was utilized to measure the hearing thresholds of budgerigars and canaries while they were nesting, and the results showed that in both species, the hearing threshold reaches maturity at around 20 to 25 days old (Dooling, 2004).

Unlike humans, birds do not have an external ear flap (pinna) and their external auditory canal entrance is covered by feathers for protection. At the end of the auditory canal lies the tympanic membrane, which vibrates in response to pressure changes.

The only bone that transfers these vibrations to the inner ear is the columella. This boned is held by a complex system of ligaments in the inner ear opposite the cochlea (Henry, 1988; Saunders et al., 2000).

1.4.1 Neural Control of Auditory System

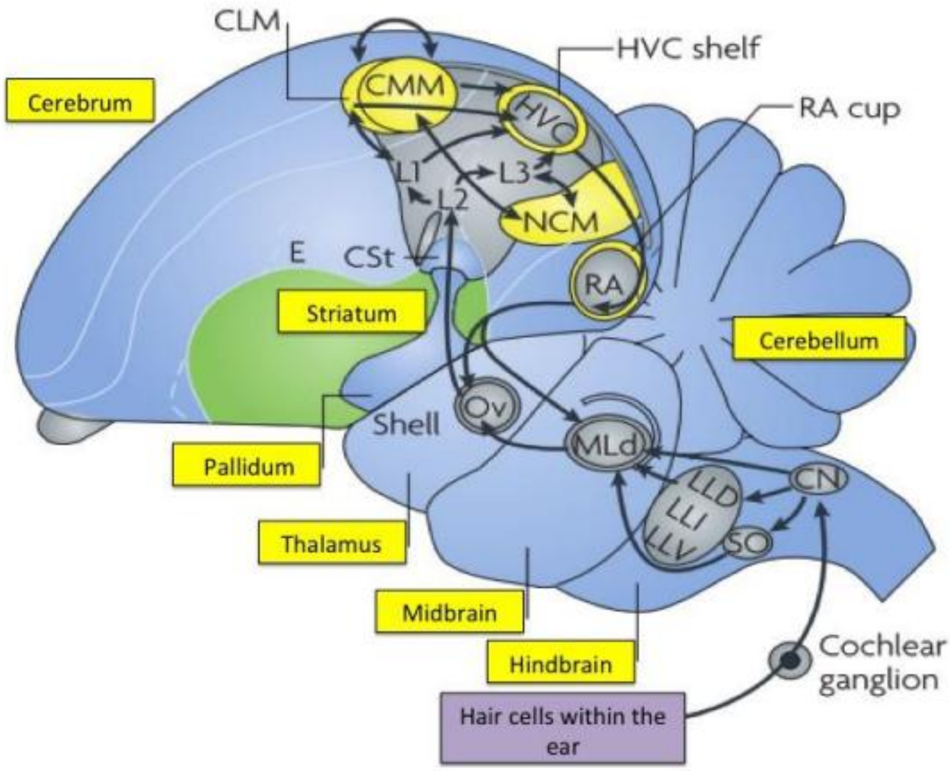


Fig.1.3 Diagram depicting the parasaggital view of the auditory system of the songbird brain. Brain regions that show increased activation when the bird hears song are represented in yellow. CLM, caudal lateral mesopallium; CMM,caudomedial mesopallium; HVC, proper name; L1, L2, L3, subdivisions of Field L; NCM, caudomedial nidopallium; E, entopallium; CSt, caudal striatum; RA, robust nucleus of the arcopallium; Ov, ovoidalis; MLd, dorsal lateral nucleus of the mesencephalon;

LLD, lateral lemniscus, dorsal nucleus; LLI, lateral lemniscus, intermediate nucleus; LLV, lateral lemniscus, ventral nucleus; SO, superior olive; CN, cochlear nucleus. The yellow boxes depict the different subdivisions of the songbird brain, whereas the purple box shows where the sensory information is coming from. Image is adapted from Bolhuis et al., 2010**.**

There is limited research on the brain mechanisms underlying learned calls. Even less research has been done on the brain regulation of call production in several species of birds. The auditory area NCM in budgerigars shows a very interesting plasticity of the complexity of brain in birdsong through hearing complex songs. The auditory area NCM in budgerigar's high neurons activation when examined with complex songs and low when simple song (Gobes et al., 2009; Eda-Fujiwara, Satoh, Bolhuis, and Kimura, 2003; Roach, Lockyer, Yousef, Mennill, and Phillmore, 2016).

1.5 Song Recognition

The ability to differentiate between sounds does not necessarily equate to the subject's recognition of the auditory stimuli. In order to recognize a stimulus, a predictable response is typically required, often involving a previously encountered and remembered stimulus (Mendelson et al., 2012). Individual vocal recognition is common among many species of birds (Falls, 1982; Aubin and Jouventin, 2002). Research on mate recognition and parent-offspring recognition has shown evidence to support this. (Falls, 1982). Many of the species that have been examined in these contexts are considered non-vocal learners, indicating that their vocalizations are not acquired through learning but instead are shared among members of the same species. In these types of species, the recognition of individual vocalizations frequently depends on the distinct characteristics of each individual's sound (Aubin and Jouventin, 2002).

The songbirds which belong to order oscine have the ability of vocal learning, territory defining birds have great approach to the identification of individuals on the basis of vocalizations. Song type has significant role in territory defense behavior, and territorial songbirds often exhibit less aggressive responses to song playback from familiar and established neighbors on the base territory, compared to strangers (referred to as the "dear enemy phenomenon"). This demonstrates the bird's capability to recognize their neighbors (Temeless, 1994; Godard and Wiley, 1995; Brindley, 1991).

Birds that have the ability to learn vocalization can able to recognize the individual on the bases of unique vocal patterns. For example, in different song-producing bird species that have complexity in song types, individual recognition can occur based on these unique songs (Gentner and Hulse, 1998). Basically, song-sharing rates play a major role in the identification that a lower degree of song-sharing can facilitate neighbor (Moser-Purdy and Mennill, 2016), while a higher number of songs from different birds confused the receiver in the identification of the song (Beecher et al. in 1994). It is known that birds identity is not based on learned songs but also on innate calls that play a crucial role in their identity (Beecher et al. in 1994; D'Amelio et al., in 2017; Elie and Theunissen, 2018).

Birds of various species have the ability to differentiate between their own species and different species on the basis of songs. They can easily recognize the same species' songs compared to other species songs (Cynx and Nottebohm 1992; Sinnott et al., 1980; Dooling, 1992). The vocal repertoire plays a vital role in sexual selection. The male fitness is judged by the female on the production of different song types, females are known to be more perceptive at distinguishing between song types (from mockingbirds) and original songs of their species. Similar to other animal species, female birds partner based on their vocal complexity because sexual fitness is linked with the bird repertoire. Bird songs are intriguing in the sense that learned features of a song, rather than inherited ones, are more likely to lead to success in sexual selection (Mooney, 2009).

1.6 The Vocal Control System of Non-Songbird And Songbird

The song control system of oscine birds such as zebra finches and canaries has been well documented, but it is still not clear if this system is present in other species of oscine birds. More research is needed to fully understand the extent and diversity of the song control system in oscine birds (Gregory et al., 2002).

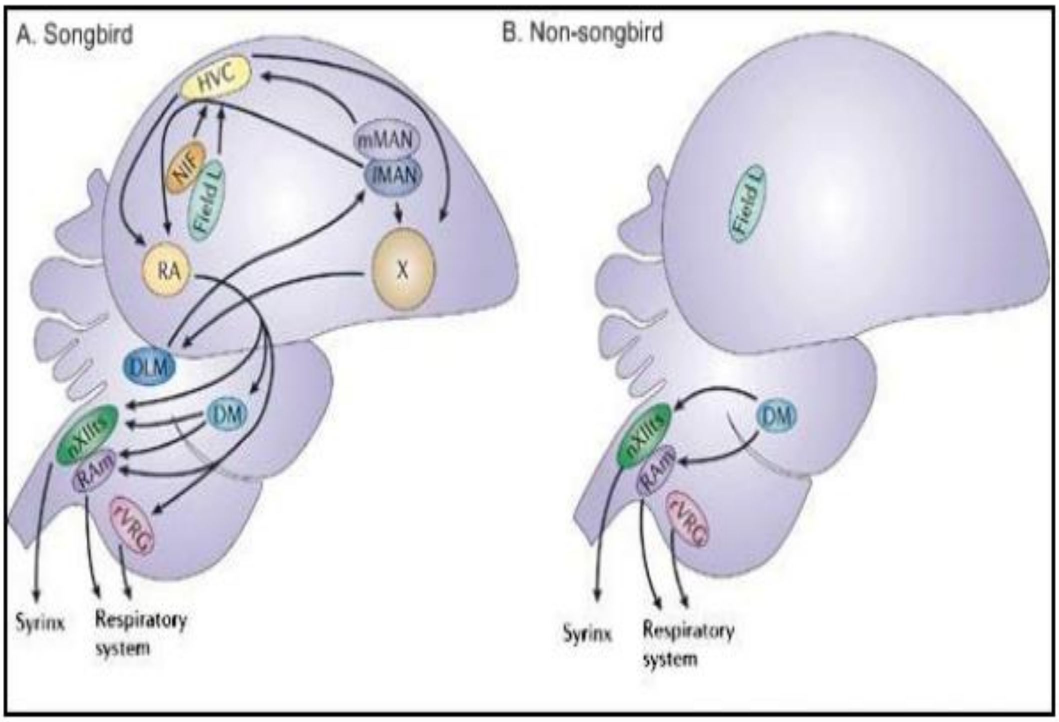


Fig.1.4 Despite having a close taxonomic relationship and being incapable of learning songs, it is very interesting that forebrain networks which are very important for song control are absent in non-song birds (Kroodsma and Konishi, 1991), whereas these components are present in a non-passerine bird the budgerigar, but the nuclei of the forebrain in song and non-song birds are not homologous (Durand et al., 1997; Striedter, 1994). Some characteristics investigated by other researchers revealed that parallels in the structure of forebrain vocal control pathway nuclei were observed in singing birds and budgerigars (Durand et al., 1997).

In both types of bird taxa, archistraital neurons frequently extend from the brainstem nuclei, in particular to nXIIts (Striedter, 1994; Wild, 1997). The nXIIts are thought to be the most prevalent motor nucleus in all bird taxa, despite significant variances in the taxonomy of the structure of syrinx muscles (Ames, 1971). Songbirds have a specialized neural circuit known as the song control system, which is located in the forebrain and is responsible for the learning, production, and maintenance of their complex vocalizations. This system consists of several interconnected brain regions that work together to process auditory input and generate motor commands for vocal output. The birds that don't sing. Although non-songbirds possess Field L and are capable of producing a variety of vocalizations, they lack the network of forebrain nuclei found in songbirds (Gahr, 1998; Gahr, 2000).

1.7 Breeding Versus Non-Breeding Songs

The songs or calls of birds change with time in many ways like number, structure or pattern. There is a deep relationship between singing activity and mating behavior songs are signs of fitness for males in bird species (Catchpole and Slater, 2003). Testosterone is the main hormone that controls song production and song complexity in temperate region birds (Ball and Hahn, 1997; Hahn et al., 1997). The change in the level of testosterone is not limited to spring. Most bird species breed and produce songs in spring so many researchers linked testosterone to the spring season but it has been found a change of testosterone changes in other species which breed after the spring (Schlinger and Brenowitz, 2002; Alward et al., 2013). Many studies show that there link between the testosterone in production of vocalization in the breeding season in temperate region birds (Hahn et al., 2008; Rose et al., 2019).

The magnitude of change in variation in vocalization in different bird species based on regions or breeding's is unknown but both sexes show clear changes in their songs in different seasons (Gahr, 2020). The different factors which are suitable for the young of the birds like the availability of food in birds breed in temperate season. Hypothalamic-pituitary-gonadal axis affects the physiology to determine the duration of the day and to modify their physiological preparation for breeding (Ball and Balthazart, 2002; Sharp, 2005).

The activity in the brain and hormone production change due to an increase in light and temperature known as photo stimulation spring will cause a condition of in temperate zone species and release steroid hormones to enhance gametogenesis and morphological and behavioral changes required for courtship and mating (Nicholls et al., 1988; Goldsmith and Dawson, 1984;).

Long days also trigger a mechanism that causes breeding to stop in preparation for a decline in food supply (Dawson et al., 2001; Nicholls et al., 1988). Then there is a negative effect of light for some period of time on the hypothalamic-pituitary-gonadal axis long time exposure of light even twenty-four hours have no or very little effect (Nicholls et al., 1988). The decrease in day length in autumn restores the effect of light on the HPG known as the photosensitive phase resetting Photorefractoriness to a temporary state that allows the axis to respond to an increase in day length (Sharp, 1996; Dawson et al., 2001).

Different activation states due to light high, medium, and low in temperate species are linked to various degrees of the HPG axis' physiological profiles that are distinct from one another. In many circumstances, the autumnal song of photosensitive birds may be interpreted as an indication of a "breeding" song. In contrast there is no fixed states of activation and inactivation in adaptable, tropical and opportunistic species (Prior & Soma, 2015).

An HPG axis that can start reproducing at any time of the year due to environment stimulus appears to be present in many tropical species. Periodic breeding in these species is typically brought on by energy restrictions (Hahn et al., 2008).

Since they likely continue to experience physiological conditions like those of photosensitivity in temperate photoperiodic species, they have flexibility in breeding with reference to time (Hahn et al., 2008). The hypothalamic-pituitary-gonadal (HPG) axis is impacted by changes in day length in temperate breeding birds. Hypothalamus and its associated produce GnRh which stimulates the pituitary and pituitary releases LH and FSH into the blood which induces spermatogenesis and embryogenesis and also high level of testosterone the also increases the rate of song production and behavioral changes. The lengthy days after some duration cause downregulation of HPG (Evangeline M. Rose et al., 2022).

1.8 Song Learning and Speech

The use of songbirds as a model for studying vocal communication and imitative vocal learning has become increasingly popular in recent years. This is because of their ability to mimic sounds, a rare evolutionary characteristic known as speech pattern acquisition. This ability has independently developed in three avian groups - songbirds, parrots, and hummingbirds - as well as a few mammals (Monte et al., 2020). In oscine passerines, hummingbirds, and parrots, vocal learning plays a significant role in the development of their vocal abilities.

The duration of song learning can vary greatly among the different species in the world (Beechard Brenowitz, 2005). The ability of birds to learn songs is comparable to that of human newborns learning to speak through interactions with adults. Without proper environmental stimulation that allows for the transfer of communicative signals, both human and bird newborns will be unable to develop their speaking and singing skills (Doupe, 1999). Furthermore, humans have been shown to be excellent listeners and social influences can affect perceptual sound learning in non-human primates (Sugiura, 1998).

The process of learning birdsong is typically divided into two phases, the sensory phase and the sensorimotor phase, which can overlap (Brainard and Doupe, 2002; Kroodsma and Miller, 1996). During the sensory phase, the songbird is in a critical period where it is receptive to auditory input. The bird listens to the songs produced by adult birds (known as tutor birds), and its brain processes this input to form a memory template of the song (Marler, 1997; Mooney, 1999).

As a result of the auditory input during the sensory phase, changes occur both in the bird's brain and behavior, leading into the sensorimotor phase. During this phase, the songbird begins to produce its own song based on the template established or activated during the sensory phase. At first, the song is not very accurate or consistent and is often compared to babbling in human infants (Aronoy et al., 2008; Doupe and Kuhl, 1999; Prather et al., 2017).

The auditory feedback the songbird receives allows it to evaluate its performance and make adjustments to its song, until it matches the song template established during the sensory phase (Konishi, 1965; Fee and Goldberg, 2011). Songbirds can generally be categorized into two groups: open-ended learners and closed-ended learners (Brainard and Doupe, 2002; Catchpole & Slater, 2008; Slater, 2003). Early experiences play a crucial role in song learning, and disruptions to these experiences can negatively impact song development. The length of exposure to a tutor bird can significantly affect birdsong, with shorter exposure leading to less complex song structures (Baptista and Morton, 1981; Thorpe, 1958). If a bird is acoustically isolated from others during the sensory phase, its song will be simpler, shifted in frequency, and highly variable (Marler, 1981; Marler and Peters, 1977; Shackleton and Ratcliffe, 1993).

Disrupting auditory feedback during the sensorimotor phase by deafening the bird can also have a negative impact on song, leading to shorter songs, delayed singing behavior, or even a complete loss of song (Konishi, 1965; Nottebohm, 1968). However, even when raised in isolation, many species still retain some of the features of their typical songs, suggesting that some song features are partially encoded or that there is an inherent song template guiding song learning from the beginning (Bolhuis and Gahr, 2006; Bolhuis, 2007; Okanoya and Scharff, 2010; Fehér et al., 2009; Marler, 1997; Searcy, Marler et al., 1985).

The timeline for song learning can vary greatly among the thousands of species of songbirds on the planet (Beecher and Brenowitz, 2005). Parrots are also capable of learning new vocalizations through various social reinforcement or changes in their social environment (Treisman, 1978; Rowley and Chapman, 1986; Farabaugh et al., 1994; Brittan-Powell et al., 1997). Non-passerine birds like Budgerigars, which have elaborate, non-stereotypical warble songs and the ability to learn calls, can also learn vocalizations and both sexes are capable of versatile vocal learning throughout their lives (Brittan-Powell et al., 1997; Hile and Striedter, 2000; Hile et al., 2005).

This supports the idea that hearing abilities are unable to learn vocalizations without a specific tutor in birds and humans. Studies on children of humans who were kept in the environment and absence of other people have demonstrated different types of speech patterns when they are deprived of social interactions (Lane, 1976). One well-known example of abnormal speech is the case of Genie, a girl belonging to California who was kept in isolation without any social in activity. These findings highlight the importance of social interaction and exposure to a tutor for the development of vocalization in both birds and humans. Birdsong is a complex vocal behavior that requires the integration of sensory, motor, and neural systems. Researchers study birdsong to gain insights into how animals learn and produce vocalizations, how the nervous system controls the production of complex sounds, and how the auditory system processes and recognizes sounds. By studying birdsong in different species, researchers can also compare and contrast the mechanisms of vocal learning and communication across different taxa. (Fromkin et al., 1974)

Birdsong is also important for communication between individuals of the same species. For example, birds use songs to attract mates, establish territories, and deter rivals. By studying the songs of different species, researchers can gain insights into the evolution of communication and the role of vocalization in the social and reproductive behavior of birds.

Overall, the study of birdsong is a rich and multi-disciplinary field, with contributions from areas such as ethology, neurobiology, psychology, and acoustics. By studying birdsong, researchers can gain a piece of deep information about the biological and neural connections that control vocal activity and patterns of learning in animals, and their ecological and evolutionary implications. (Doupe and Kuhl, 1999; Slater, 2003; Zann, 1996).The calls and songs of many birds characterized and studied like Asian koels (Eudynamys scolopacea), zebra finches, parrots, European starling Sturnus vulgaris, etc.(AA Khan and IZ Qureshi, 2017; Bruno, J. H., and Tchernichovski, O, 2019; Walløe, S et al., 2015; Cabe, 2020).. That makes a lot of sense. Studying the vocalization and behavior of a lesser-known species like the blue-throated barbet can provide valuable information and insights into bird behavior that might not have been discovered otherwise. By studying a species that hasn't been studied extensively before, you have the opportunity to make new discoveries and contribute to the field of animal behavior. Furthermore, this approach also helps to broaden our understanding of the diversity of vocalization and behavior in birds. Therefore, vocalization and associated behaviors of zebra finches.

1.9 Blue-Throated Barbet

Barbets (Capitonidae) are distributed widely throughout the world, spanning three continents: Africa, Asia, and South America. Their range is pan-tropical. While barbets are primarily fruit-eaters, they do consume a significant amount of insects, particularly during the breeding season. Some species also feed on nectar. Competition for food among coexisting species is generally not intense, as they usually gather food from different areas. However, intraspecific competition and aggression is observed within some species.

Barbets typically rely on vocal courtship displays, and males often offer food to females after copulation. They protect their nesting branches from other hole-nesting birds and squirrels. Barbets play a crucial role in the ecosystem and economy as they aid in seed dispersal and cross-pollination of plants, as well as controlling populations of harmful insects, such as termites and teak defoliator caterpillars. However, the reduction of forested areas, removal of roadside trees, decrease in garden space, and extensive urbanization are all detrimental to these beneficial birds (Yahya HAS, 1987,88,89).

Blue throated barbet is medium-sized barbet with blue face and throat, red forehead and hind crown, and black band across the crown. Juveniles have duller head pattern. Incessant calling throughout the day, a rapid Kutrook-Kutrook. Resident in outer Murree foothills, Marghala hills, Islamabad and Azad Kashmir. Its body length is 22-23cms, wing length is 10- 11cms, tail length is 6-6.8cms and bill length is 2.6-3cms. (Non-Passeriformes By T.J. Roberts).

Scientific Classification

Kingdom	Animalia
Phylum/ Division	Chordata
Class	Aves
Order	Piciformes
Family	Capitonidae
Genus	*Megalaima*
Species	*M.asiatica*

(Latham, 1970)

Fig.1.5 Blue throated barbet at Quaid e Azam university Islamabad.

Aim And Objectives of Study

Aim:

The aim of the present was Identification and characterization of vocalization of adult Blue-throated Barbet

Objectives:

1. Categorization of different call types on the basis of spectrogram morphological examination
2. Categorization of different calls on the basis of different acoustic parameters
3. Categorization of different calls on the basis of statistical analysis

MATERIALS AND METHODS

Material And Methods

2.1 Identification

Blue Throated barbet was identified in the field as described by birds of Pakistan by Richard Grimment, Tom Roberts, and Tim Inskip. A binocular (Bushnell 10-50x50 ZOOM, USA) was used during the fieldwork to identify bird species. Medium-sized barbet with blue face and throat, red forehead and hind crown, and a black band across the crown. The bird is very secretive or wants to protect itself from predators and remains hidden 10 to 12 meters above the ground and 1 to 2 meters below the end of the tree. Vocalize at a very high rate and can be heard from a distance of 300 to 500 meters. And the vocalization recorded and compared with all vocalizations of blue-throated barbet uploaded on different libraries

2.2 Ethical Statement

In order to minimize the impact on the natural behavior of the birds and to avoid disturbing other species, all recordings were made in a humane and ethical manner. No special permits were necessary to conduct recordings in open parks and gardens in Pakistan.

2.3 Study Area

The recordings were made from over 100 unmarked adult Blue-throated Barbets in the wild. The fieldwork was conducted for two consecutive years, from 2021 to 2022, at various times of the day, including full-day recordings on Sundays and Saturdays and partial-day recordings on other days in 2021. In 2022, full-day recordings were made in different areas of Rawalpindi and the Capital Territory, Islamabad, Pakistan. The birds were recorded in various parks and gardens, as well as the Margalla hills, which offered a rich habitat with a diverse array of tree species, such as the This abundant habitat attracts many migratory birds during their breeding season, including the Indian Magpie Robin (Copsychus saularis), Indian Robin (Saxicoloides faulicata), and the Purple Sunbird (Nectarinia asiatica)

Fig.2.1 The study sites Location on the Map

2.4 Recordings

For the recordings in wild we use ME67/K6 microphone which is used for the directional recording's product of (Sennheiser, Germany) which is connected to the TASCAM model dr-I00 recorder by (TEAC a Japanese Corporation). To avoid wind and pop noise head of the microphone was covered with a special type of MZW 66 pure foam windshield by (Sennheiser, Germany) which effectively protects against noise during recording. All recordings are done at same setting of the instrument. The sampling rate of 48 kHz and 24bit resolution are set for recordings which is effective to extract shimmer and jitter and all other acoustic parameters that are selected for characterization of the vocalization of blue-throated barbets. Totally recordings are o perched birds there is no vocalization found during flight. Recordings were made whole the day at different times but at dawn (5:30–6:30 a.m., local time) and dusk (17:00–18:00 p.m., local time), as these birds are more active compared to the whole day these times there is the low signal to noise ratio which is effective for analysis of the recording. Moreover, at this time other highly vocal species in the study area, the Asian koels (Eudynamys scolopacea) and the Indian treepie (Dendrocitta vagabunda) were usually found less active. Recordings which are made whole the day except dawn and dusk mostly overlapped with other birds' calls. The overlapped calls were not used for analyses. The recordings were started in January and done from January to December. The recordings are done in all-weather except rain and thunderstorms. During recording, the target bird distance between the bird and the recorder was kept at 10 to 15 meters. The basic aim is to keep a distance to avoid any disturbance to the recorded bird. All recordings are ignored in which the target bird is disturbed by any bird or author. All those recordings are also ignored in which the recording device is disturbed. To avoid the same bird recording more than once 200 to 300 meters distance was kept between two recording birds. If at any place recording was missed we skipped the site. The authors attempted to capture video recordings of the birds, but unfortunately, due to the shy nature of the birds and their habit of hiding in dense evergreen vegetation, they were unable to obtain any reliable video footage.

2.5 Vocal Activity Variation on The Day

The birds exhibit varying levels of vocal activity throughout the day. We counted the number of recordings in the specific area and took the average and presented the data in the graph form.

2.6 Change of Vocal Activity Over Year

In my observations of the blue-throated barbet, I aimed to identify and describe their vocalizations. I discovered that from mid-November to mid-January, there was no vocal activity at all. However, at the end of January, vocal activity started to increase gradually.

We counted the number of recordings in the specific area and took the average of all calls and presented them in the form of a graph.

2.7 Comparison Between A Normal Sunny Day And A Cloudy Day

In normal a sunny day high rate of vocalization as compared to a cloudy day. We counted the number of recordings in the specific area and took the average of all calls and presented them in the form of a graph.

2.8 Spectrographic Analysis

A total of 300 audio recordings were digitized on Dell Inspiron n4030 Core i3 Laptop (Dell Technologies Inc. USA). For the characterization of vocalization into different types on the bases of the morphology of different elements in the call the computer-based software Cool Edit Pro version two a product of (Syntrillium Software Corporation, Phoenix, AZ, USA) was used. The setting of the software is variable you can adjust it to your need.

The contrast and brightness were adjusted to provide clear pictures of the vocalizations and all of the calls were viewed at the 0.5 s zooming level. A total of 1050 calls were extracted during the initial spectrogram analyses.

A total of 388 calls were excluded due to the overlapping of other birds' vocalizations, or the insufficient signal-to-noise ratio of the selected birds. Total 662 good-quality calls were extracted for further analysis from this original dataset of calls. We considered all associated behaviors of vocalization in the field which was noticed. During a morphological analysis of spectrograms, the frequency changes are compared morphologically by counting the number of notes and syllables and comparing them to each other.

These were categorized as:Kutrook-Kutrook type 1 = 348 (contributed by a total of 24 individuals; 24.4±2.04 per individual), Touk call = 104 (contributed by a total of 10 individuals; 10.4±2.18 per individual), Kutrook-Kutrook type 2 call = 110 (contributed by a total of 15 individuals; 7.33 ± 0.68 per individual), Kurrrrrrr call = 100(contributed by a total of 13 individuals; 7.69 ±0.84 per individual), for the deep study acoustic measurements.

2.9 Acoustic Analysis

During the acoustic analysis, measurable factors were used to evaluate ten call parameters for selected vocalizations previously studied in vocal repertoire research.

These parameters included spectral, temporal, frequency, and amplitude characteristics.

All variables which were used for characterization are given in the table. For this analysis, Praat software version 6.0.20 computer-based software was used for all calls. For calculating fundamental F0 contour of the call spectrograms was obtained by individually selecting each call and using the cross-correlation method with the Fast Fourier Transform (FFT) method and a Gaussian window shape.

The analysis utilized a window length of 0.012 seconds, a frequency range of 100-24000 Hz, a pitched floor of 75-700 Hz, a dynamic range of 70 dB, and an intensity range of 50-100 db. The F0 contour was measured based on each syllable, The [Sound: To Pitch (cc)] command was utilized to determine the jitter and shimmer values as a percentage. The metric of shimmer quantifies the differences in amplitude from one cycle to the next, while jitter examines the fluctuations in the fundamental frequency from cycle to cycle. These measurements are frequently employed in voice and laryngeal research as well as to evaluate the speaker's vocal quality.

Table 2.1 The following is a list of abbreviations and descriptions of various acoustic parameters and categorical call variables that were measured for each vocal category.

Abbreviations	Description of Parameter
Dur (s)	The total duration of the call
F0 min (Hz)	The minimum fundamental frequency of the call
F0 max (Hz)	The maximum fundamental frequency of the call
F0 avg (Hz)	Average or mid-point frequency of the call
Pitch m (Hz)	The Mean pitch value across the call
Pitch min (Hz)	The Minimum pitch value across the call
Pitch max (Hz)	The Maximum pitch value across the call
Jitter (%)	The average absolute difference between the consecutive F0 period's frequency values divided by the mean F0 frequency value
Shimmer (%)	The average absolute difference between the consecutive F0 period's amplitude values divided by the mean F0 amplitude value
No. Syl.	Number of syllables in different calls.

2.10 Behavioral Study

Calls were classified based on the similarities and differences in their acoustic parameters, taking into account the accompanying behaviors observed in the field. The spectrogram of each call was analyzed morphologically, counting the number of elements in the call and categorizing them as calling calls, territorial calls, melodious calls, and aggressive calls. By examining the spectrogram and comparing it to field observations, it was possible to easily categorize each call and associate it with a specific bird behavior.

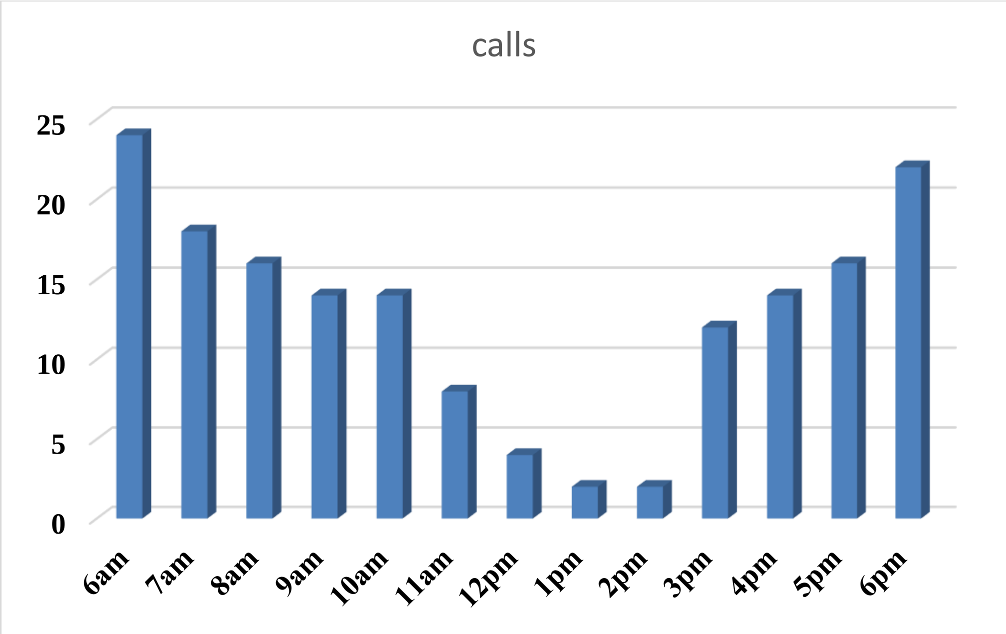
2.11 Statistical Analysis

Statistical analysis is done by IBM SPSS Statistics 20.0 software by (USA). A stepwise regression procedure was employed to evaluate the significance of 10 independent variables, resulting in the exclusion of any non-significant variables. The remaining important variables were then used in a cross-validated discriminant function analysis (DFA). In the DFA, the selected independent variables served as predictors, while the type of call was the dependent grouping variable. The cross-validation method used was the "leave-one-out" classification approach. This statistical analysis allowed for the identification of the most influential variables in separating the different call types and provided insight into the structural differences and similarities among the call types.

The accuracy of the classification of cases into different groups based on the discriminant functions was measured using Wilk's Lambda.

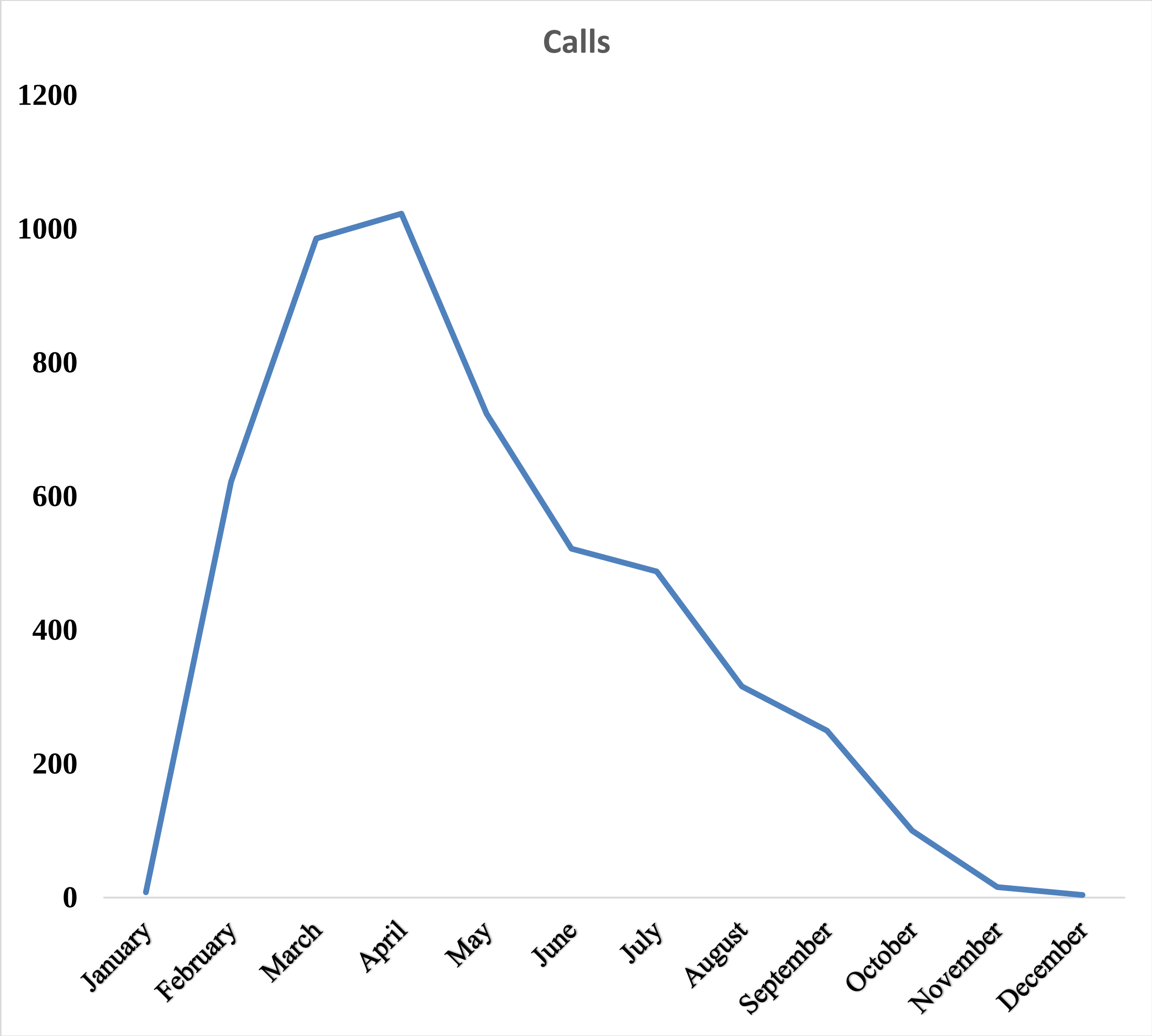
The total three non-significant variables excluded by the stepwise regression model not selected for discriminant function analysis are (F0 min, Pitch max, and Pitch mean). These excluded parameters are further checked by other statistical tests to find results. To determine differences among all the vocal categories, a Kruskal-Wallis ANOVA was performed, followed by post-hoc Mann-Whitney U-tests (two-tailed) for multiple comparisons among the groups. The results of the Mann-Whitney U-tests were corrected for multiple comparisons using Holm's sequential Bonferroni procedure, with alpha set at 0.05. The data is presented as the mean ± standard error, and a P-value less than 0.05 was considered indicative of a statistically significant difference.

RESULTS



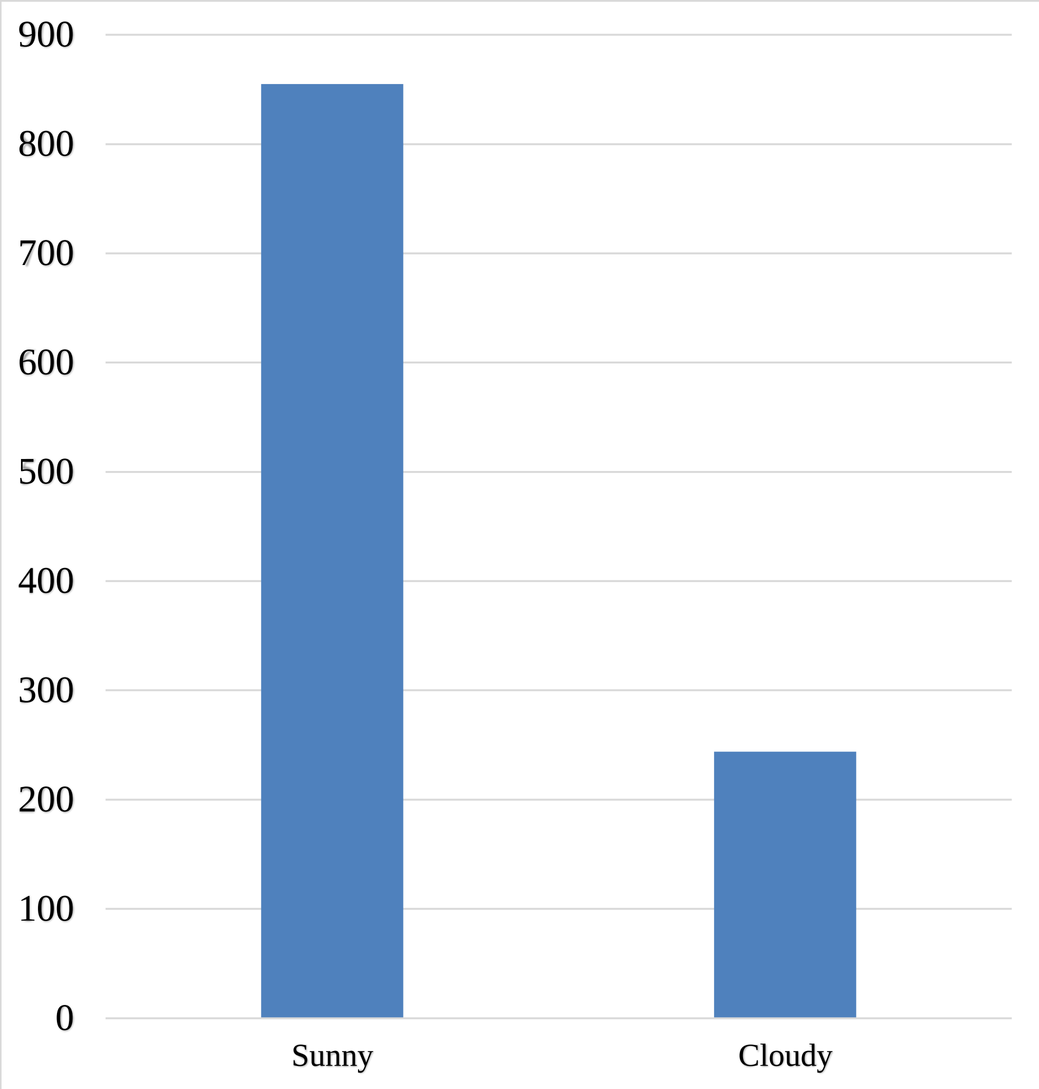
Graph.3.1 Variation in vocal activity over the day

It shows that call rates are very high at early in the morning but decreases with time and become very low and again very high in the evening time.



<u>Graph.3.2 Average variation in vocal activity over the year</u>

The vocal activity starts end of January and is very high in march and April and decreases at June and stop in mid of November



Graph.3.3 Comparison Between good weather and bad weather production of Calls

The bird’s makes high calls in good weather and very small in bad weather.

3.1 Characteristics of Calls

The Blue-Throated Barbet's calls were classified based on spectrograms, visual inspection, waveform analysis, total length duration, the number of syllables in different calls, Dur (s), F0 (Hz), Shimmer (%), F0 max (Hz), F0 e (Hz), F0 min (Hz), Pitch max (Hz) and Pitch m (Hz)

3.1.1 Kutrook-Kutrook Type2 Call (Melodious Calls)

The Kutrook-Kutrook type2 of the Blue-throated Barbet is a distinctive call that the bird uses to announce its presence. Its duration 0.408s or 408 milliseconds it is longer than the touk and Kutrook- Kutrook type1 and shorter than the kurrrr call.

The minimum fundamental frequency for this call is the lowest fundamental frequency for all other calls and the maximum fundamental frequency is also not high than other calls except the kurrrrr call. There are high variationsn in the maximum fundamental frequency of this call.

The average frequency of this call is also lower than other two types of calls but higher than the kurr call. The pitch of this call shows a remarkable variation across the call. The jitter of this call is higher than all other calls.The shimmer is higher than touk call but lower than other calls and all factors showing variation.

The call consists of a single note followed by four syllables, which is different from the calling call which consists of a single note followed by three syllables. The average duration of the melodi call is 0.408 second, or 408 milliseconds. The call has a melodic quality and is often repeated by the bird throughout the day. The frequency and amplitude of the call are moderate compared to other calls produced by the bird.

The first syllable having the highest frequency and then gradually decreasing in frequency with each subsequent syllable is a common pattern in many bird songs and calls. This gradual decrease in frequency is known as frequency modulation and is thought to be important in conveying information about the identity and motivation of the bird producing the call.

They use this call to maintain contact with each other and to strengthen their bond. The frequency pattern of this call is also distinct, which may help individual birds identify their mate's call among a chorus of other bird calls. Additionally, the frequency range of this call is in the optimal range for bird hearing, making it easier for other birds in the area to hear and respond

The variation in the frequency of the blue-throated barbet's trilling call in different environments may be due to the effects of background noise. In noisy environments, the bird may need to raise the frequency of its call to make it more audible and distinguishable from other sounds in the environment. In quieter environments, the bird may be able to use a lower frequency for the call. Because we found frequency differences in different environments.

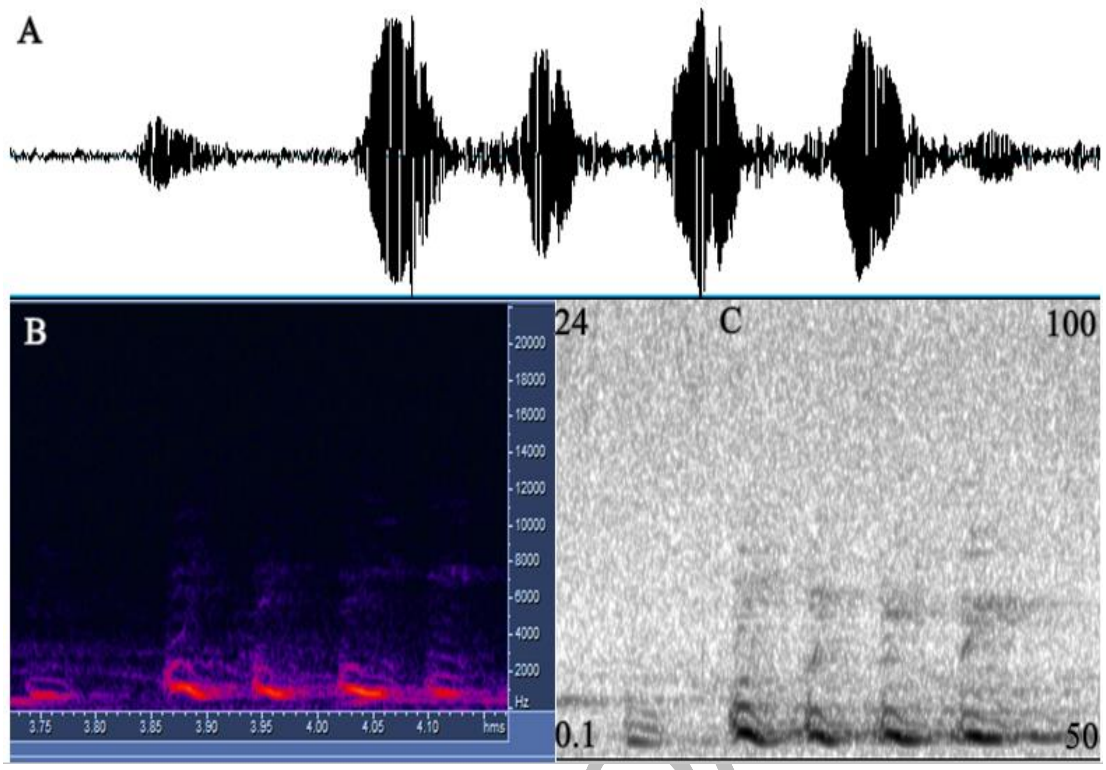


Fig.3.1 Waveform, spectrogram and visual picture of call Kutrook-Kutrook type2

(A) Waveform picture

(B) Spectrogram picture

(C) Visual picture.

These three pictures used for the morphological, spectral, and to measure acoustic variables for this call and categorize into Kutrook-kutrook type2 showing different from all other calls.

3.1.2 Kutrook-Kutrook Type1 (Calling Calls)

Blue-throated Barbet birds have been observed to promote themselves by continuously emitting vocalizations known as Calling calls (Cc) (s). It is produced in very high numbers 52% (348/662) of total analyzed calls. Spectrogram analysis of these calls has shown that they consist of one low-energy note with a low frequency, followed by three syllables with varying frequencies in a high-frequency range. Notably, the second syllable has a lower frequency than the first syllable, while the third syllable has a frequency equal to that of the first syllable. This distinctive pattern of a low-frequency note followed by three syllables with differences in frequency helps to distinguish the Blue-throated Barbet's vocalization from other species and may play a role in many functions.

The duration of this call is 0.336 or 336 milliseconds which is the different duration from all other calls lower than all other calls except kurrrr call. There is a 0.35-second or 350- millisecond gap between two consecutive calls. On average, it produces 75 calls per minute.

The Kutrook-Kutrook type1 call, is also known as the Calling call, because it is heard a whole year except from November to January. It is characterized by a high number of calls as compared to other types of calls, with a gradual increase in frequency from the start to the end and a smooth frequency distribution across the call.

Spectrogram analysis and picture of this call reveal that the distance between the note and the first syllable is greater than that of the following three syllables. Additionally, the spectrogram shows that the first syllable does not have a frequency between 9 to 11kHz, which further distinguishes it from other calls made by the same bird species. These unique acoustic features of the Kutrook-Kutrook type1 call may play an important role in communication.

The first syllable has the highest energy and a frequency between 12 to 14 kHz. The second syllable has a lower frequency range compared to the first syllable. The third and last syllable has a higher frequency range compared to the adjacent syllable. This unique acoustic structure of the Kutrook-Kutrook type1 call is likely important for communication within the bird population.

The minimum fundamental frequency is lower than other types but a little higher than the Kutrook-kutrook type2. The bird produces all calls when perched and moves head in all directions may to see his partner or any danger, and is used to convey information about the bird's energy and fitness state. This call can also be used for duetting, where two or more birds sing together, which may be related to courtship behavior and mate selection. The fact that male and female Blue-throated Barbets are similar in appearance and may have similar vocalizations suggests that both sexes may play a role in duetting and other social interactions. Overall, the Kutrook-Kutrook call is a fascinating example of the complex vocal communication systems used by many bird species.

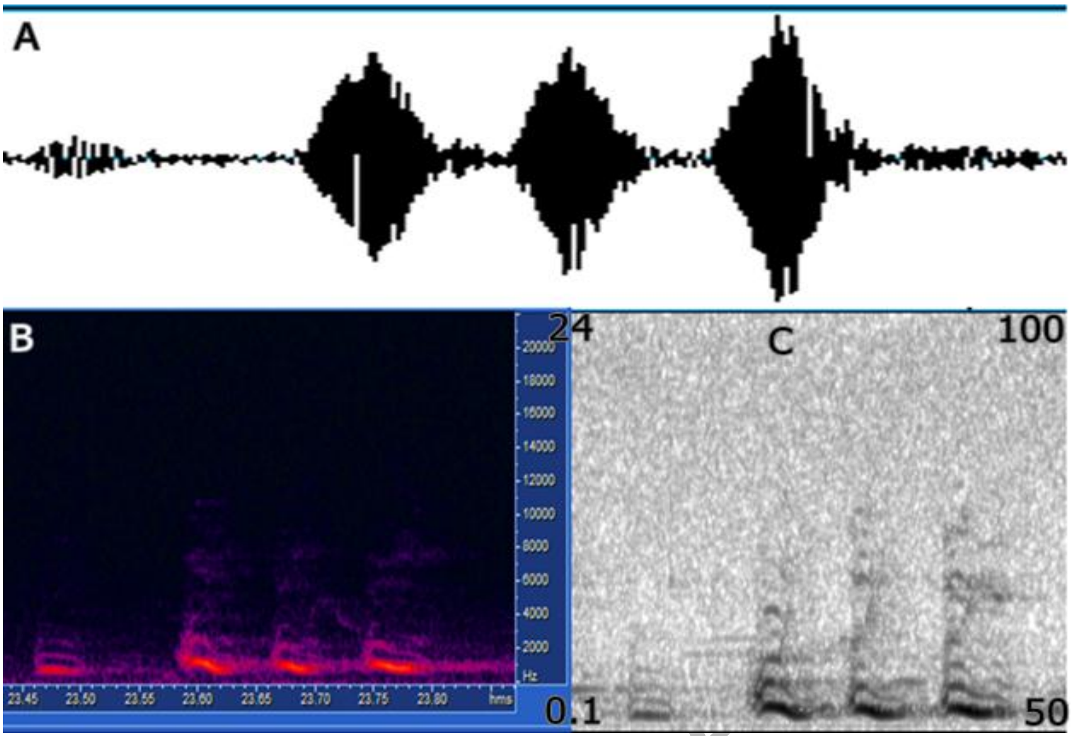


Fig.3.2 Waveform, spectrogram and visual picture of call Kutrook-Kutrook type1

(A) Waveform picture

(B) Spectrogram picture

(C) Visual picture.

These three pictures used for the morphological, spectral, and to measure acoustic variables for this call and categorize into Kutrook-kutrook type1 showing different from all other calls.

3.1.3 Kurrrrr Call (Aggressive Calls)

This is the longest call as compared to all other calls which are produced by blue-throated barbet. It is lowest number of call produced by the bird 15% of all analyzed calls

It is an average of 0.841s or 841ms but a minimum of 0.62s or 620ms and a maximum of 2s or 2000ms which is very long compared to all other calls.

the number of syllables can vary from 8 to 32, and they have equal frequency across the call. The equal frequency distribution across the call indicates that the energy level is constant, and the variation in the number of syllables may convey additional information to conspecifics. The fact that this call is produced after the territorial call suggests that it may be involved in mate attraction or pair bonding or warning or sign of anger.

It sounds like the spectral characteristics of this call are unique and easily distinguishable from other calls produced by the blue-throated barbet. The fact that all syllables have equal energy and frequency suggests that this call may be used to convey a specific message to other birds, perhaps related to mating or territory defense. The short distance between the syllables and the overall structure of the call may also be important in conveying this message effectively.

It seems that the blue-throated barbet uses different vocalizations to convey different types of information. The Touk call, which is short and has a high frequency, may be used to defend the bird's territory or to signal its presence to other birds. In contrast, long calls with more syllables and lower frequency may be used for other purposes, such as attracting a mate or communicating with other members of its species. It's also interesting to note that as the duration of the call increases, the frequency and pitch decrease, suggesting that the bird is using different vocal strategies to convey different types of information.

It sounds like the lengthy aggressive call is referring to is a defense call, which blue-throated barbets use to defend their territory and nest site against intruders. This call is usually produced in response to a perceived threat, such as another bird or predator, and is often longer and more complex than the territorial call. The defense call may also include elements of the other calls, such as the kutrook-kutrook call and duetting calls. It can also be produced by both male and female birds.

In this call there is a higher shimmer than all other calls and lowest jitter than all other calls make it more different from all other calls. The defense call can be a precursor to aggressive behavior and attacking the intruder. It serves as a warning to the intruder to back off and leave the territory. If the intruder does not heed the warning and continues to approach, the defending bird may then resort to physical aggression to protect its territory and nest site. The ratio of aggressive calls is small compared to other calls, suggesting that the blue-throated barbet uses this call sparingly and only when necessary. The fact that the call requires a significant amount of energy to produce, as well as the need for rest between calls, further supports this idea.

It's also possible that the length and complexity of the call serve as a deterrent to potential intruders, signaling that the bird is strong and capable of defending its territory.

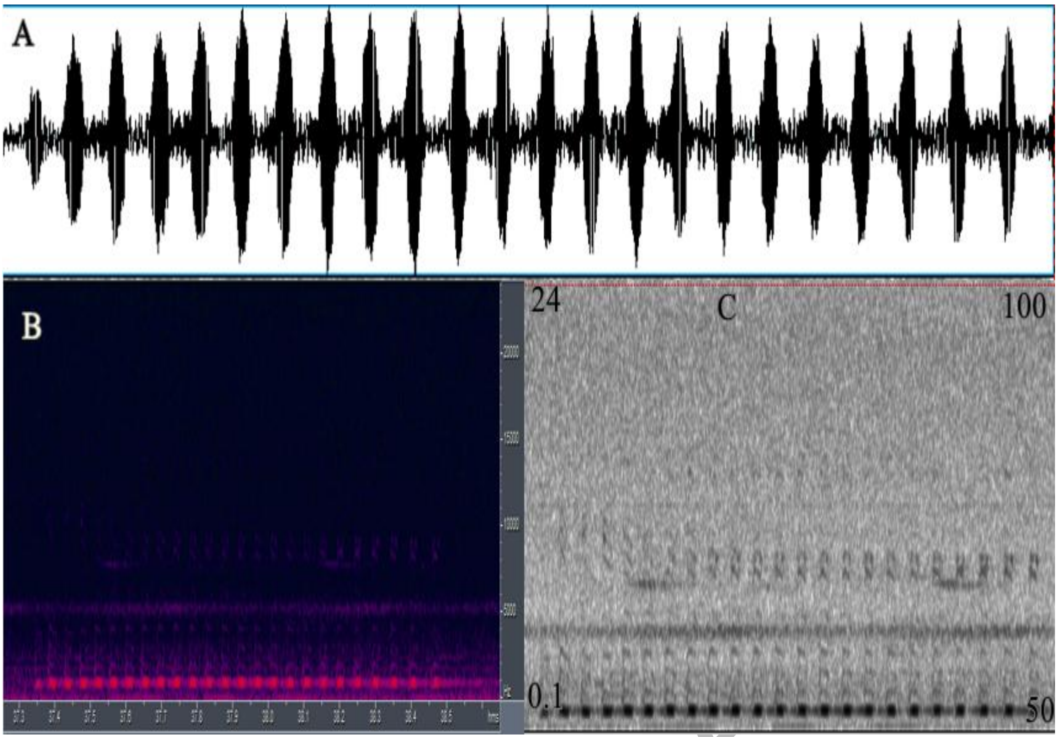


Fig.3.3 Waveform, spectrogram and visual picture of call Kurrrrr

(A) Waveform picture

(B) Spectrogram picture

(C) Visual picture.

These three pictures used for the morphological, spectral, and to measure acoustic variables for this call and categorize into Kurrrrr showing different from all other calls.

3.1.4 Touk Call (Territorial Calls)

This is the shortest call than all other calls its duration is0.112s or 112ms but has highest frequency. The call is typically short in duration, with a single syllable, and is repeated at regular intervals to maintain the bird's presence in the area. The inter-call interval, or the time between calls, can vary depending on the bird species and the situation, but on average it is around 1.72 seconds for the blue-throated barbet.

The pitch in this call is very high compared to all other calls and the jitter is lower than all other calls. The highest frequency and pitch make it more clear and spread in high area. Therefore, we think this is territorial call due to its different acoustic function.

During the breeding season, birds are actively searching for mates and defending their territories against potential competitors. The territorial call is an important means of communication for birds to establish and defend their territory. The short duration and high frequency of the Tc call may also help the bird conserve energy, as producing long or complicated calls can be energetically costly The Tc call is an important aspect of territorial behavior in birds, as it serves to both establish and defend a bird's territory. The high frequency and pitch of the call help to communicate the bird's presence to potential competitors or predators, and the repeated production of the call over time can signal to other birds that the territory is already occupied. In addition to defending the territory, the Tc call can also be used during mating to attract a mate or during nesting to protect young.

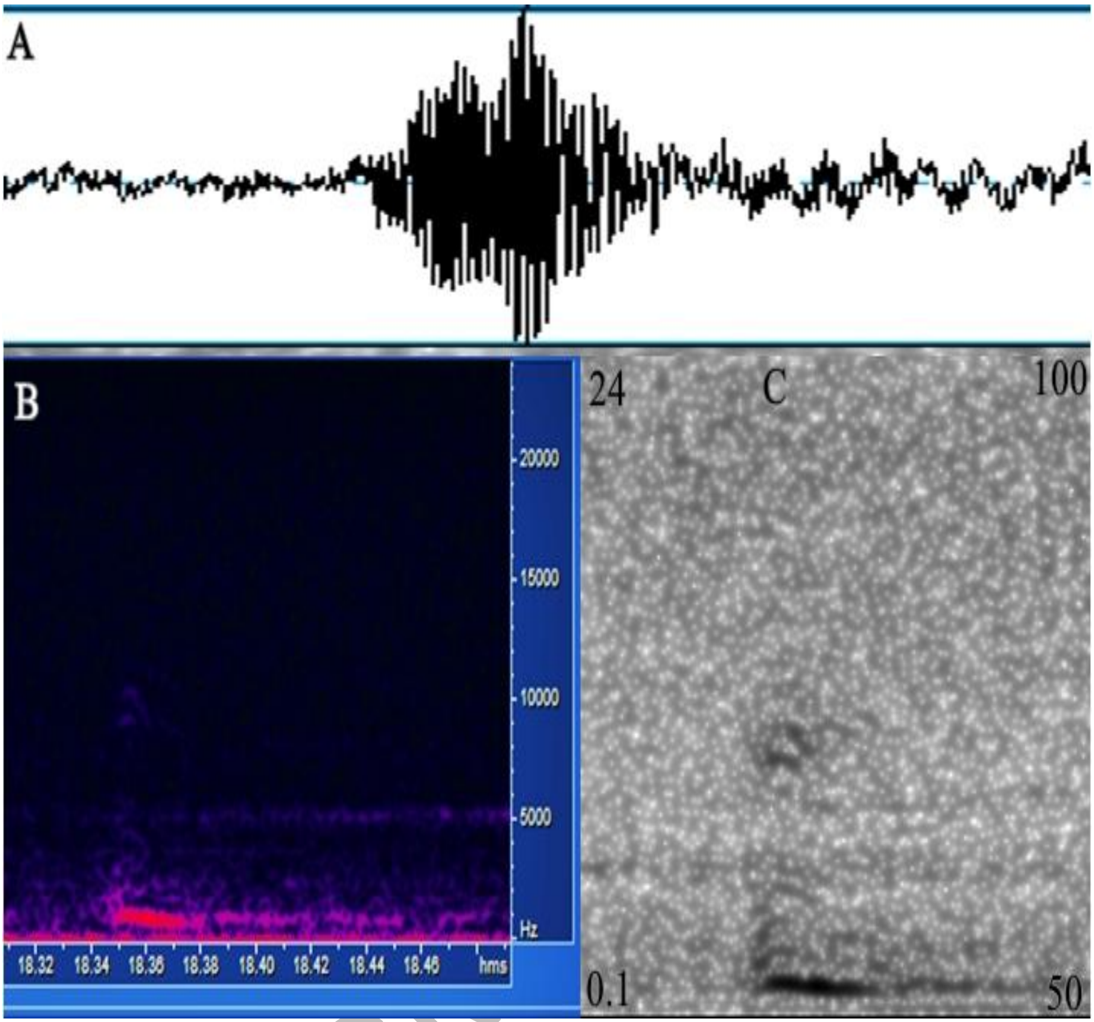


Fig.3.4 Waveform, spectrogram and visual picture of call Touk

(A) Waveform picture

(B) Spectrogram picture

(C) Visual picture.

These three pictures used for the morphological, spectral, and to measure acoustic variables for this call and categorize into Touk showing different from all other calls.

3.1.5 Comparison of All Four Types Of Calls

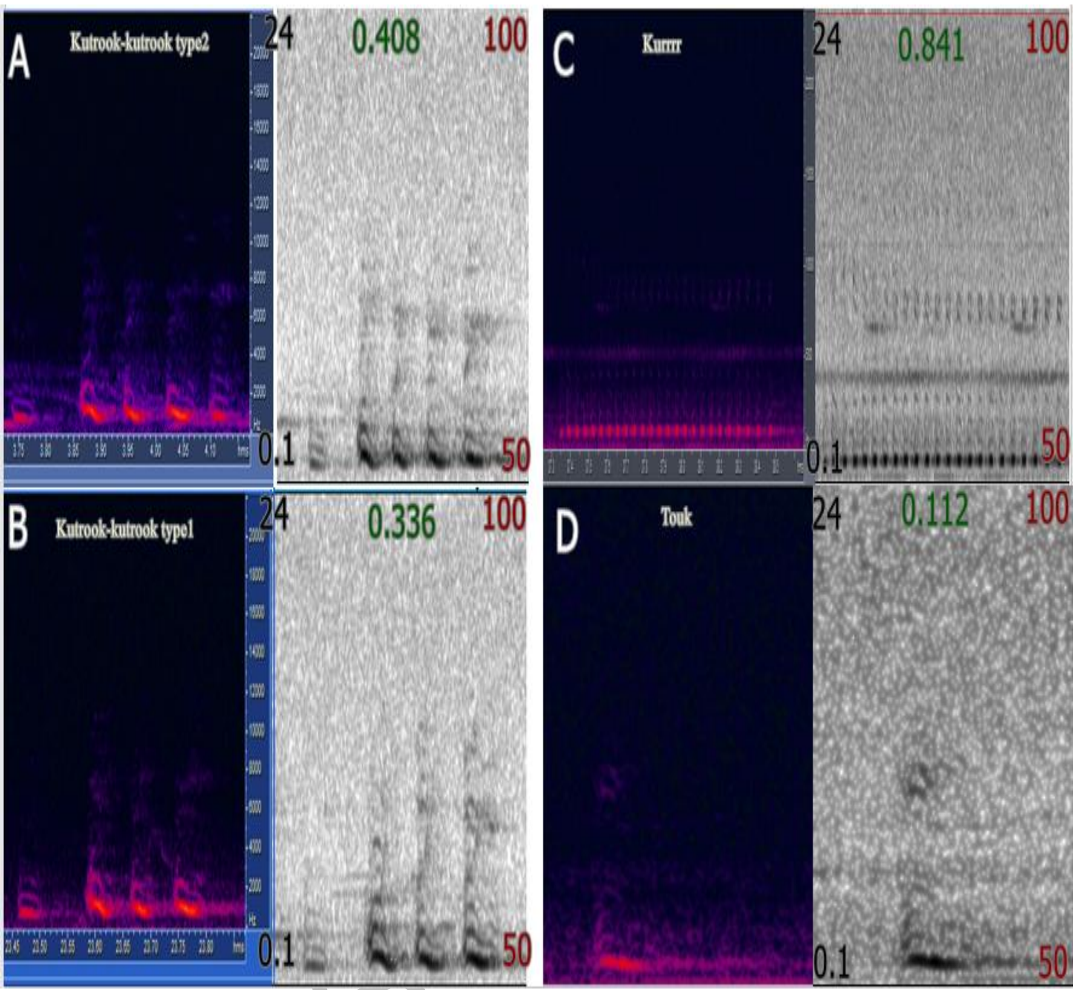


Fig.3.5

i. Kutrook-kutrook type2
ii. Kutrook-kutrook type1
iii. Kurrrr,
iv. TOuk

Black digits show **frequency** (Hz), red shows **intensity** (DB) and green shows **total duration of calls** (s)

Spectrograms were constructed in Praat and cool edit pro, using the Fast Fourier Transform method (FFT), Gaussian window shape, window length of 0.012 s, frequency view range of 700–24000 Hz, pitch floor of 75–700 Hz, dynamic range of 70 dB, intensity range of 50–100 dB, 0.05 s zooming level.

3.2 Statistics Results

The descriptive statistics of acoustic parameters were measured for all four vocal categories.

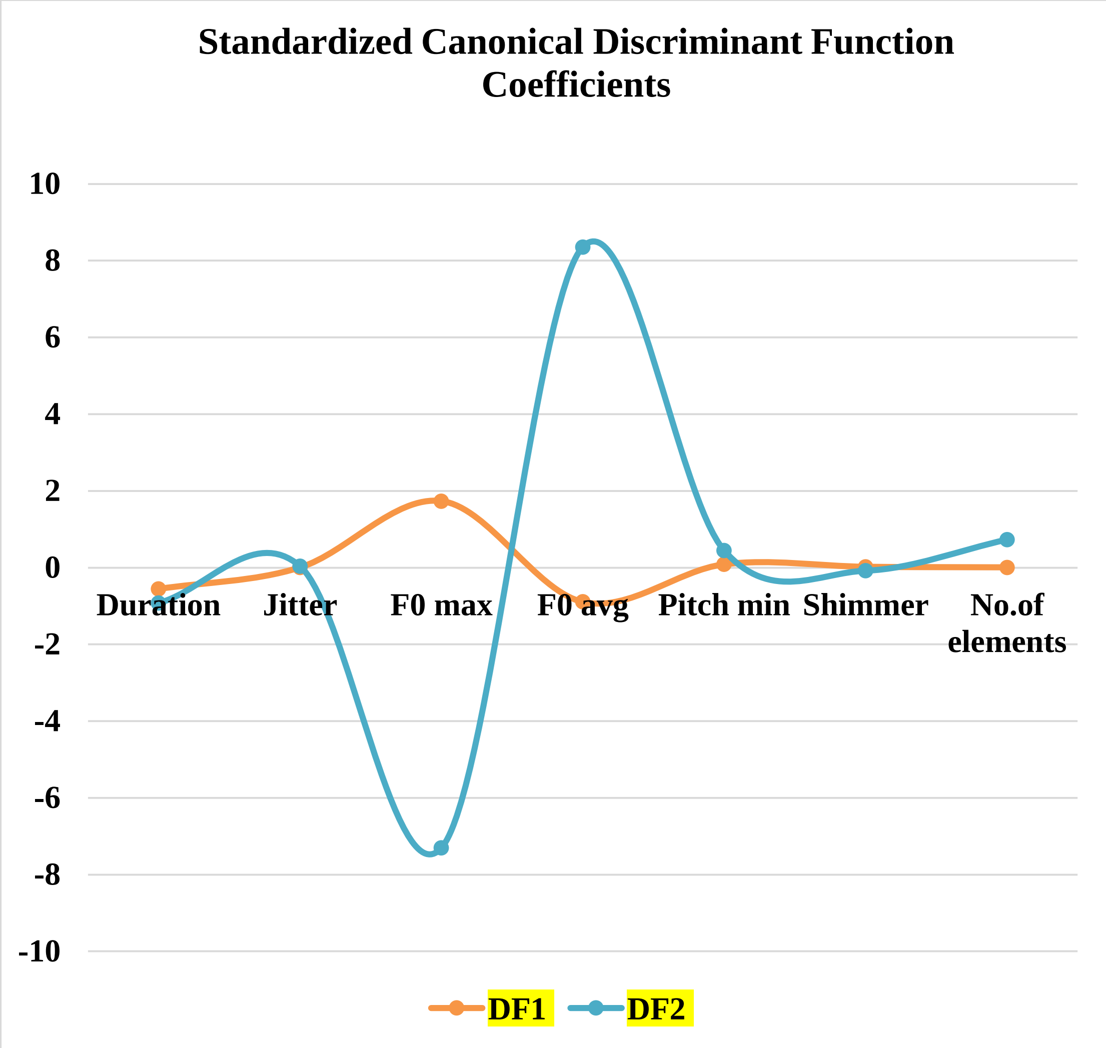
	Vocal category			
Acoustic parameter	**Kutrook-Kutrook type 1 call n=348**	**Touk call n=104**	**Kutrook-Kutrook type 2 call n=110**	**Kurrrrrrr call n=100**
Dur (s)	0.336±0.0008	0.112±0.007	0.408±0.0008	0.841±0.026
F0 min (Hz)	559±2.86	640±3.24	526±4.08	712±6.16
F0 max (Hz)	13170±21.79	14968±42.33	11455±83.32	9723±43.55
F0 avg (Hz)	6864±10.86	7804±21.08	5990±41.65	5217±21.93
Pitch m (Hz)	389±3.77	426±4.87	388±3.62	377±5.76
Pitch min (Hz)	284±5.58	389±8.03	268±7.92	260±10.37
Pitch max (Hz)	475±2.76	455±3.05	470±3.89	462±5.52
Jitter (%)	4.61±0.64	4.70±3.92	5.15±0.13	4.47±0.12
Shimmer (%)	21.31±0.2	17.67±0.57	19.96±0.39	21.35±0.35
No. of elements	4.0±0.00	1.0±0.00	5.0±0.00	16.19±0.73

Table.3.1 Values are presented as mean ± S.E., n = number of calls.

3.3 Stepwise Regression Model And DFA

By applying the stepwise regression model seven out of ten variables which are Dur (s), Pitch min (Hz), F0 max (Hz), F0 avg (Hz), Shimmer (%), Jitter (%), and a number of elements are selected by the regression model. The other three out of ten are excluded by the regression model which is Fundamental frequency min (Hz), Pitch mean (Hz), and Pitch maximum (Hz) are excluded by the regression model.

Seven out of ten variables which are Dur (s), Pitch min (Hz), F0 max (Hz), F0 avg (Hz), Shimmer (%), Jitter (%), and a number of elements are selected by regression model further checked by DFA statistical test. By applying DFA the first two functions in DFA showed maximum variance (Function 1:86 % eigenvalue=13.4; Function 2:13%, eigenvalue=2) and highly significant differences between the different types of calls (Wilks' λ DF1/3 = 0.019, df = 21, $P < 0.001$ and Wilks' λ DF2/3 = 0.269, df = 13, $P < 0.001$).



Graph.3.4 Function 1 showed positive value for F0 max and F0 avg showed a negative value; Function 2 showed a high positive value for F0 avg and high negative value for F0 max.

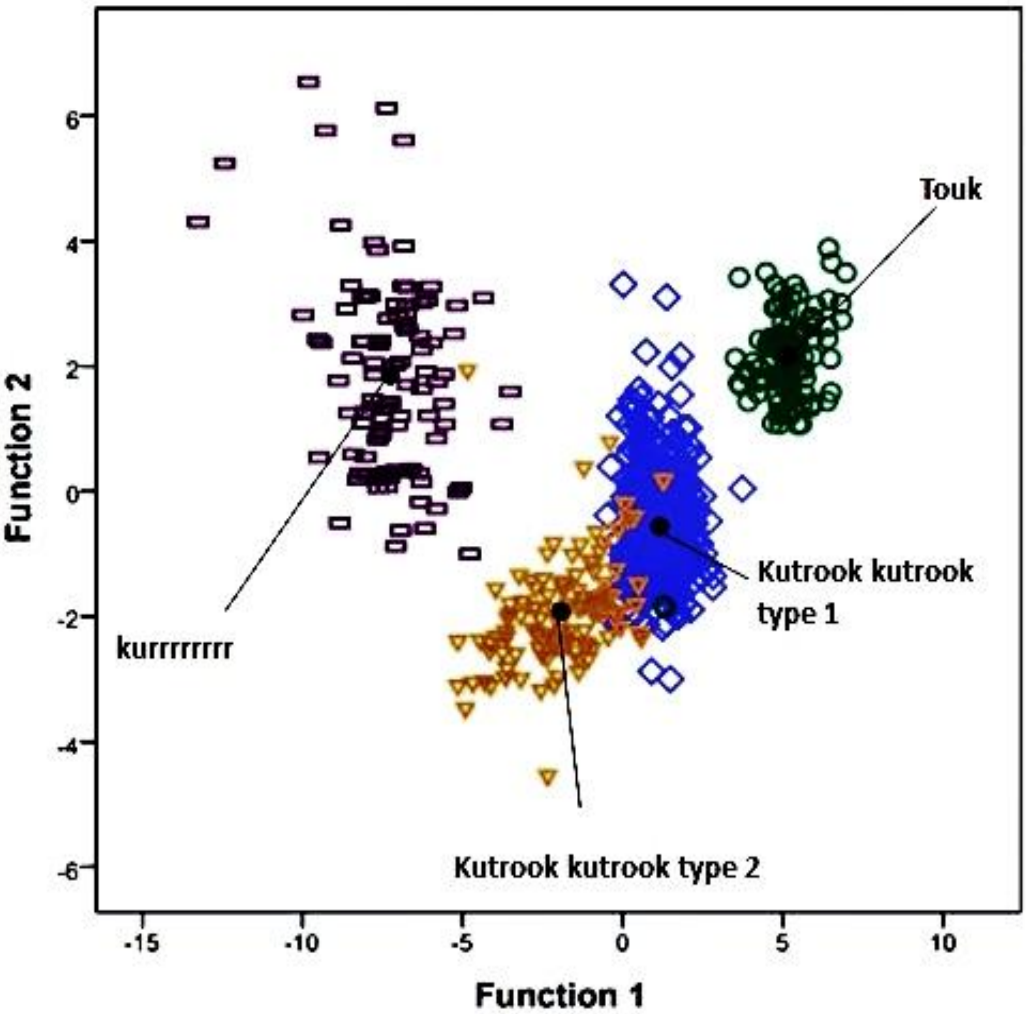
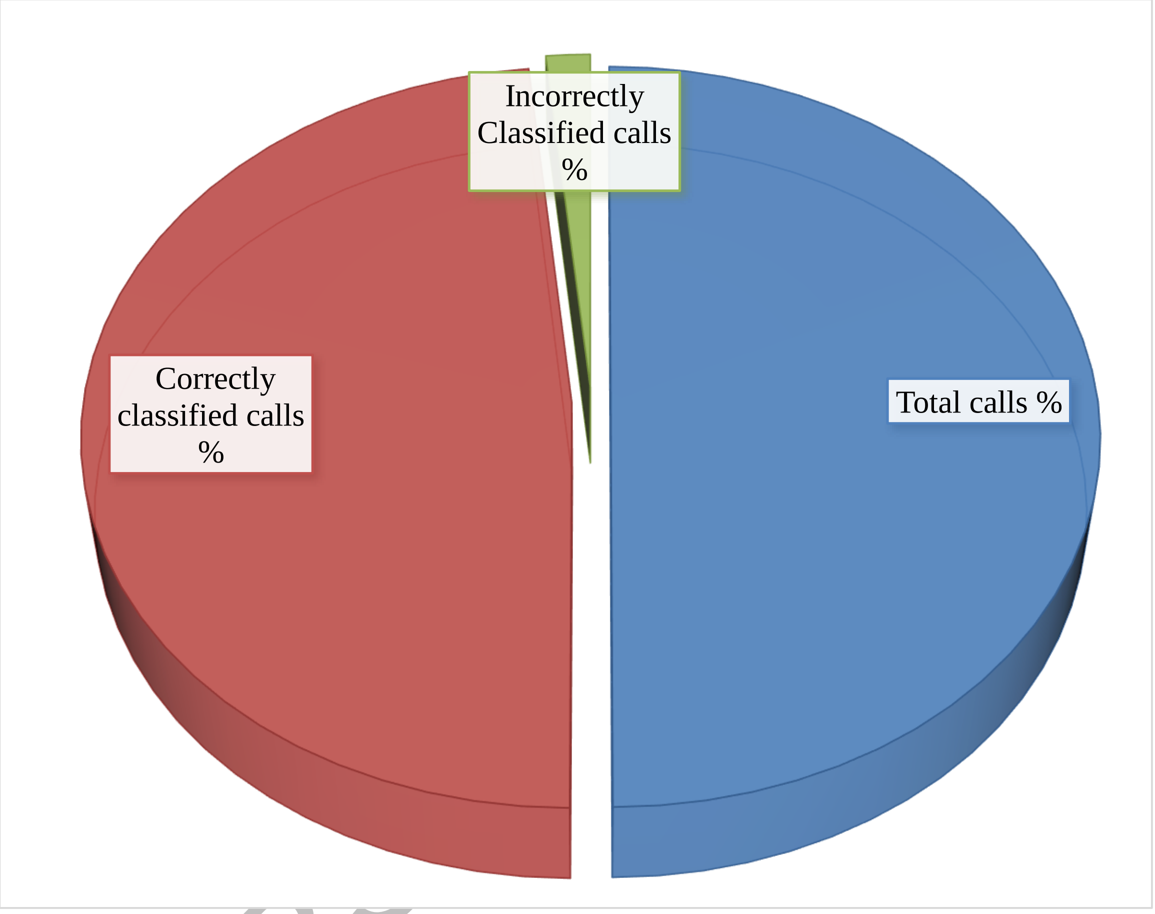
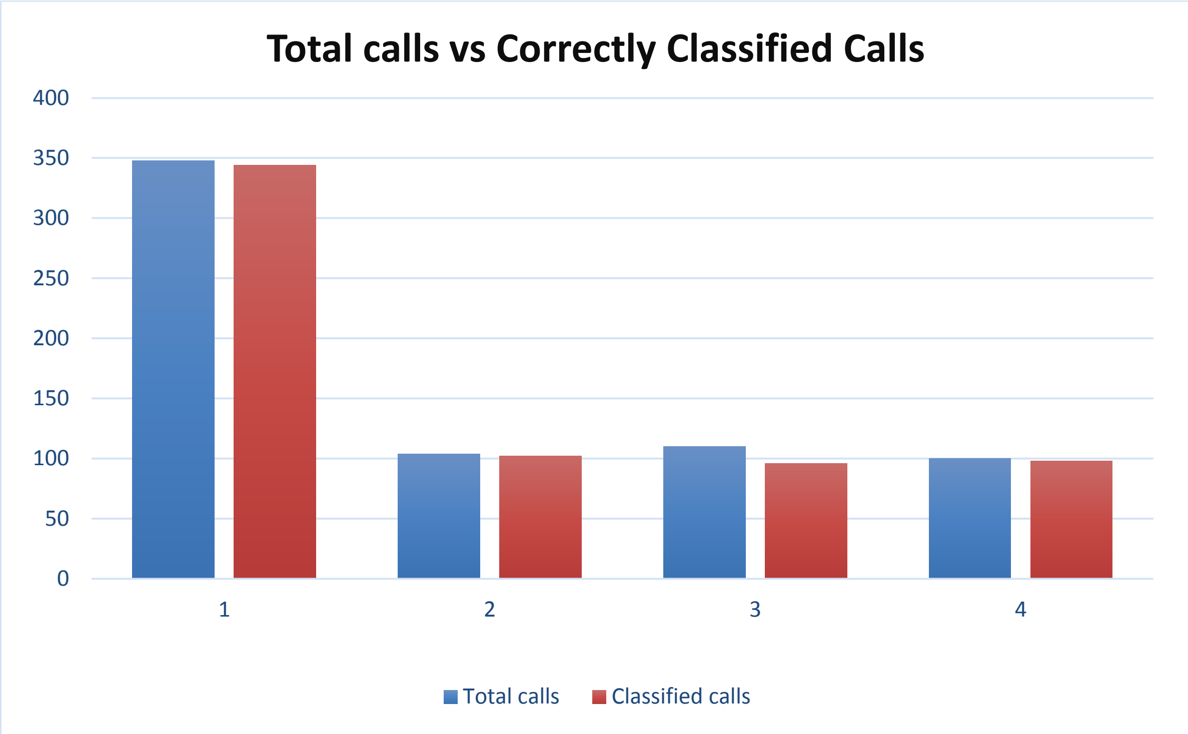


Fig.3.6 The plot of the scores generated by the first and second discriminant functions clearly illustrates a clear differentiation of the adult Blue-throated barbet's vocal types. The centroids of the various vocal categories are represented by black dots.

Cross-Validated method DFA



Graph.3.5 Using the cross-validated method, DFA classified the vocalizations correctly to (640/662)96.8% into the predicted vocal categories that we initially classified based on spectrographic examination.



Graph.3.6 Using the cross-validated method, DFA classified the vocalizations correctly into the predicted vocal categories that we initially classified on the basis of spectrographic examination. The DFA correctly classified from left side 99% (344/348) of Kutrook-Kutrook type 1, 99% (102/104) Touk calls, 87.3% (96/110) of Kutrook-Kutrook type 2 calls, and 98% (98/100) of Kurrrrrrr calls

3.4 Summary Of Statistical Results Of Three Nonnormalized Parameters (F0 Min, Pitch Max, Pitch Mean).

Summary of statistical results										
Vocal category comparison		Acoustic parameter								
		MINUMUM FUNDANENTAL FREQUENCY H=367.29 , df =3, P=0.001			MEAN PITCH H=76.58, df =3, P=0.001			MAXIMUM PITCH H=87.34, df =3, P=0.001		
		U	Z	P	U	Z	P	U	Z	P
1. Kutrook-kutrook type I	Touk	3694	-12.34	0.001	10109	-6.83	0.001	7045	-9.45	0.001
	kutrook kutrook -type 2	10926	-6.81	0.001	15788	-2.77	0.006	16036	-2.56	0.01
	Kurrrrrr	1470	-13.99	0.001	13679	-3.26	0.001	14826	-2.25	0.024
2. Touk	Kutrook-kutrook type 2	247	-12.1	0.001	2459	-7.2	0.001	2660	-6.75	0.001
	Kurrrrrr	1751	-8.18	0.001	2242	-7.01	0.001	3577	-3.85	0.001
3. Kutrook-kutrook type 2	Kurrrrrr	169	-12.13	0.001	4902	-1.36	0.17	5435	-1.47	0.88

Table 3.2 Abbreviations: SEs = Secondary elements, H = Kruskal–Wallis ANOVA, df = degree of freedom, U = Mann- Whitney U -test, z = Wilcoxon W test and P = Probability.

DISCUSSION

Discussion

The vocalization of Blue-throated barbet has been successfully characterized in the current study using spectrogram analysis, acoustic parameters, and statistical analysis along with their associated behaviors which may provide a tool for further research on the communication behaviors of the birds. This study gives an explanation of various call types, call structures, and their behavioral context.

Our main findings are the characterization of bird calls of the blue-throated barbet but we also checked the variation in vocal activity, daily, and monthly and compared vocal activity on a normal sunny and cloudy day.

The variation was also found in the number of calls at different times of the day. The vocalization is very high at dawn and decreases at noon and then also increases at dusk.

We found that they are more active in the production of vocalization in spring. There is no vocal activity found in the winter which starts at the end of January and continues until mid of November. Vocalization rate is very high in summer and low in winter (Avey et al., 2011; Cabe, 2020).

Permanent records of vocalization are kept for future purposes and compare different species and individuals and parameters are selected for in birds census (Gregory, 2004). Computer-based software is used to measure acoustical parameters of vocalization and is also used to convert sound into picture form. We also used Cool Edit Pro Version two to convert the sound into pictures for observation and classification(Catchpole and Salter, 2008)Measuring physical properties which make enables us to differentiate, categorize, and identify different calls and songs produced by the same or different birds (Catchpole and Salter, 2008).

Vocal communication plays a critical role in the lives of individuals, especially in the absence of pheromones and non-verbal cues. It serves as the sole means of communication between individuals, allowing them to exchange information and coordinate their behavior. The sounds produced in the form of calls and songs have the ability to impact the physiology and behavior of those who are within their range of influence (Smith, 2010). This highlights the importance of vocal communication in shaping the behavior and interactions of individuals within a group (Geoff, 1996).

In the present study, we analyzed 662 good-quality calls of Blue-throated barbet and characterized them on the basis of a spectrogram and 10 acoustic parameters into four distinct types which are specific on onomatopoeic and spectrogram analyses names are i) Kutrook-Kutrook type 1 call (calling call), ii) Touk call (Territorial call), iii) Kutrrok-Kutrook Type2 call, iv) Kurrrr call (aggressive call). The classification on the basis of spectrogram and acoustic parameters are significant. Six different calls of adult male Asian koels (Eudynamys scolopacea) are characterized in the breeding season in Pakistan compared to 3 call Koels present in Australia (AA Khan and IZ Qureshi, 2017).

The onomatopoeic names assigned to describe the vocal categories were not based on a functional analysis of the sounds produced. Instead, these names were chosen to imitate the sounds themselves, which is why they are referred to as onomatopoeic. This approach was taken to provide a descriptive and easily recognizable label for each vocal category, rather than relying on more technical or functional terminology. The use of onomatopoeic names can also help to engage people with the research and make it more accessible to those without a scientific background. However, it is important to note that these names may not necessarily reflect the underlying mechanisms or functions of the sounds, and a more detailed analysis is required to fully understand the vocalizations of the animals (Liu WC et al.,2013; AA Khan and IZ Qureshi, 2017).

The vocalization into different calls is done by comparing spectrogram, waveform, and acoustic parameters and all observed associated different behaviors in the field in the present study are checked by vision or visual inspection. The characteristics calls secondary names are given on basis of syllables that are diffused from each other. The onomatopoeic names are kutrook-kutrook type 1, touk, kutrook-kutrook type 2, and kurrrrrr and their names are calling calls, territorial calls, melodious calls, and aggressive calls. These names are given to calls spectrogram presentations and their associated behaviors. Kutrrok-kurook type1 or calling call play role in the sexual selection or fitness of bird and Touk is a territorial call that plays the role to define territory and kutrook-kutrook type2 produced at dawn and dusk and after mating known as a happy or melodious call. Kurrrrr or aggressive call is produced when a bird of the same species or different species is near the nest or not bothering the territorial call (Charrier et al., 2004; Zachau and Freeberg, 2012).

The vocal repertoire of an animal is a crucial aspect of its communication and behavior. It represents the range of sounds that an animal is capable of producing, and serves as a foundation for understanding the role of acoustic signals in their sexual and social interactions. The study of an animal's vocal repertoire can reveal important information about its communication strategies, courtship behaviors, and relationships with other individuals. By examining the different types of vocalizations produced by an animal, researchers can gain insight into the mechanisms underlying their social behavior and the evolution of their acoustic signals. Understanding the vocal repertoire of an animal is thus a crucial step in understanding their communication and social interactions (AA Khan and IZ Qureshi, 2017).

The Kutrook-Kutrook type1 call is very high in number and indicates that it plays a major role in courtship and sexual selection. The variation rate of all acoustic parameters in this call compared to all other call is high It is very high compared to all other calls and one call has many functions by changing its pitch, frequency, and amplitude like food calls, social calls and territorial call (Vignal, 2016).

In our current study, we found that blue-throated barbet produced four types of calls which are (Kutrook-Kutrook type 1 call, Touk call, Kutrrok-Kutrook Type2 call, Kurrrr call) which is harmonically rich and has the same minimum fundamental frequency. Frequencies that occur together in a sound can create complex and rich musical textures, adding melodic content to the sound. The relationship between these frequencies is often described as harmonic and is defined by their relative frequencies. When the frequencies are multiples of a single frequency component, called the fundamental frequency, they are said to be harmonically related. This relationship between the frequencies gives a sound its distinctive timbre and character, making it possible to distinguish one sound from another, even if they are at the same overall volume (Zdenek CN et a., 2015).

Broadcast songs are a widely prevalent form of vocalization among birds. These songs are usually produced by males as part of their mating displays and serve as an advertisement of their presence and fitness to potential mates. Broadcast songs are usually species-specific and help in species recognition, territorial defense, and mate attraction. The frequency, tempo, and structure of these songs vary among species and are often used for the characterization of calls and also used to differentiate between individuals and species of birds (Xia et al., 2013).

The DFA results from 7 call parameters accurately classified 96.8% of the adult Blue throated Barbet calls according to the predicted vocal categories which were identified based on visual examination of spectrograms. These results were relatively higher than the previously reported vocal classification for birds: e.g., 90.5% in case of African penguins (Favaro L et al.,2014), 83.3% in case of great curassows (Crax rubra) (Baldo S and Mennill DJ, 2011), and 74.2% in the case of the smooth-billed anis (Crotophaga ani) (Grieves LA et al., 2015). Furthermore, in the statistical analysis of the three acoustic parameters (Fundamental frequency min (Hz), Pitch mean (Hz), and Pitch maximum (Hz)) both the Mann-Whitney Utest (two—tailed) and Wilcoxon W test results were taken into consideration because the latter one is also considered a different version of Mann-Whitney U-test in SPSS software analysis (Field A, 2009)

In conclusion, our research presents a thorough examination of the acoustic features and statistical analysis of the vocalizations made by adult Blue-throated Barbets over a two-year period. Although the results are limited to a brief period and may not include all the vocalizations of this bird species due to the presence of other birds and background noise, we believe we have recorded all the vocalizations of adult Blue-throated Barbets during the two-year study. We noted that the recordings taken during noon had more noise, possibly due to the heightened activity of other bird species during that time. We conducted a preliminary examination of these recordings to identify any additional vocal categories but found that most were similar to those recorded at other times and were thus omitted from further analysis.

In conclusion, our results enhance the understanding of the vocalizations of adult Blue-throated Barbets and establish a baseline for future comparative studies with other species of Barbets. Further research should aim to uncover the complete vocal range of Blue-throated barbet and investigate the role of these calls in the reproductive selection, social biology, and individual identification.

REFERENCES

REFERENCES

Altonen, B. L., Arreglado, T. M., Leroux, O., Murray-Ramcharan, M., & Engdahl, R. (2020). Characteristics, comorbidities and survival analysis of young adults hospitalized with COVID-19 in New York City. PloS one, 15(12), e0243343.

Alward, B. A., Balthazart, J., & Ball, G. F. (2013). Differential effects of global versus local testosterone on singing behavior and its underlying neural substrate. Proceedings of the National Academy of Sciences, 110(48), 19573-19578.

Amador, A., & Margoliash, D. (2010). Auditory Memories and Feedback Processing for Vocal Learning. In The Auditory Cortex (pp. 561-575). Boston, MA: Springer US.

Aronov, D., Andalman, A. S., & Fee, M. S. (2008). A specialized forebrain circuit for vocal babbling in the juvenile songbird. Science, 320(5876), 630-634.

Aubin, T., & Jouventin, P. (2002). How to vocally identify kin in a crowd: the penguin model. In Advances in the Study of Behavior (Vol. 31, pp. 243-277). Academic Press.

Avey, M. T., Hoeschele, M., Moscicki, M. K., Bloomfield, L. L., & Sturdy, C. B. (2011). Neural correlates of threat perception: neural equivalence of conspecific and heterospecific mobbing calls is learned. PLoS One, 6(8), e23844.

Baker, M. C. (2004). The chorus song of cooperatively breeding laughing kookaburras (Coraciiformes, Halcyonidae: Dacelo novaeguineae): characterization and comparison among groups. Ethology, 110(1), 21-35.

Baker, M. C., & Cunningham, M. A. (1985). The biology of bird-song dialects. Behavioral and Brain Sciences, 8(1), 85-100.

Baldo S, Mennill DJ (2011) Vocal behavior of great curassows, a vulnerable Neotropical bird. J Field Ornithol 82: 249–258

Ball, G. F., & Balthazart, J. (2002). Neuroendocrine mechanisms regulating reproductive cycles and reproductive behavior in birds. In Hormones, brain and behavior (pp. 649-XII). Academic Press.

Ball, G. F., & Hahn, T. P. (1997). GnRH neuronal systems in birds and their relation to the control of seasonal reproduction. GnRH neurons: gene to behavior, 325-342.

Baptista, L. F., & Morton, M. L. (1981). Interspecific song acquisition by a white-crowned sparrow. The Auk, 98(2), 383-385.

Barkan, C. L., & Zornik, E. (2020). Inspiring song: The role of respiratory circuitry in the evolution of vertebrate vocal behavior. Developmental neurobiology, 80(1-2), 31-41.

Barker, F. K., Barrowclough, G. F., & Groth, J. G. (2002). A phylogenetic hypothesis for passerine birds: taxonomic and biogeographic implications of an analysis of nuclear DNA sequence data. Proceedings of the Royal Society of London. Series B: Biological Sciences, 269(1488), 295-308.

Beddard, F. E. (1898). The structure and classification of birds. Longmans, Green, and Company.

Beecher, M. D. (1982). Signature systems and kin recognition. American Zoologist, 22(3), 477-490.

Beecher, M. D., & Brenowitz, E. A. (2005). Functional aspects of song learning in songbirds. Trends in ecology & evolution, 20(3), 143-149.

Beecher, M. D., Beecher, I. M., & Hahn, S. (1981). Parent-offspring recognition in bank swallows (Riparia riparia): II. Development and acoustic basis. Animal Behaviour, 29(1), 95-101.

Beecher, M. D., Campbell, S. E., & Burt, J. M. (1994). Song perception in the song sparrow: birds classify by song type but not by singer. Animal Behaviour, 47(6), 1343-1351.

Benedict, L., & Krakauer, A. H. (2013). Kiwis to pewees: the value of studying bird calls. Ibis, 155(2), 225-228. Seddon, N., Alvarez, A., & Tobias, J. (2002). Vocal communication in the pale-winged trumpeter (Psophia leucoptera): repertoire, context and functional reference. Behaviour, 139(10), 1331-1359.

Benedict, L., & Krakauer, A. H. (2013). Kiwis to pewees: the value of studying bird calls. Ibis, 155(2), 225-228.

Billerman, S. M., Keeney, B. K., Rodewald, P. G., & Schulenberg, T. S. (2020). Birds of the World. *Cornell Laboratory of Ornithology, Ithaca, NY, USA.*

Bolhuis, J. J., & Gahr, M. (2006). Neural mechanisms of birdsong memory. Nature reviews neuroscience, 7(5), 347-357.

Bolhuis, J. J., Okanoya, K., & Scharff, C. (2010). Twitter evolution: converging mechanisms in birdsong and human speech. Nature Reviews Neuroscience, 11(11), 747-759.

BOLHUIS, J. O., & SCHARFF, K. C. (2010)."Twitter Evolution: Converging Mechanisms in Birdsong and Human Speech". Nature Rev. Neurosci, 11.

Bowling, D. L., & Fitch, W. T. (2015). Do animal communication systems have phonemes? Trends in Cognitive Sciences, 19(10), 555-557.

Bradbury, J. W., & Vehrencamp, S. L. (1998). Principles of animal communication

Braus, H. (1900). Die muskeln und nerven der Ceratodusflosse... G. Fischer.

Brenowitz, E. A., Margoliash, D., & Nordeen, K. W. (1997). An introduction to birdsong and the avian song system. Journal of neurobiology, 33(5), 495-500.

Bretagnolle, V. (2019). 9. Acoustic Communication in a Group of Nonpasserine Birds, the Petrels. In Ecology and evolution of acoustic communication in birds (pp. 160-178). Cornell University Press.

Brittan-Powell, E. F., & Dooling, R. J. (2004). Development of auditory sensitivity in budgerigars (Melopsittacus undulatus). The Journal of the Acoustical Society of America, 115(6), 3092-3102.

Brittan-Powell, E. F., Dooling, R. J., & Farabaugh, S. M. (1997). Vocal development in budgerigars (Melopsittacus undulatus): contact calls. Journal of Comparative Psychology, 111(3), 226.

Brumm, H. (2004). The impact of environmental noise on song amplitude in a territorial bird. Journal of animal ecology, 434-440.

Brumm, H., & Todt, D. (2002). Noise-dependent song amplitude regulation in a territorial songbird. Animal behaviour, 63(5), 891-897.

Bruno, J. H., & Tchernichovski, O. (2019). Regularities in zebra finch song beyond the repeated motif. *Behavioural processes*, *163*, 53-59.

Cadman M. D., Sutherland D. A., Beck G. G., Lepage D., and Couturier A. R. (2007). Second atlas of breeding birds of Ontario (2001–2005). Bird Studies Canada, Environment Canada, Ontario Field Ornithologists, Ontario Ministry of Natural Resources, and Ontario Nature, Ontario, Canada

Carlson, N. V., Healy, S. D., & Templeton, C. N. (2017). A comparative study of how British tits encode predator threat in their mobbing calls. Animal Behaviour, 125, 77-92.

Catchpole, C. K., & Slater, P. J. (2003). Bird song: biological themes and variations. Cambridge University Press.

Catchpole, C. K., & Slater, P. J. B. (2008). Bird song: biological themes and variations. Cambridge: Cambridge University Press. 335 p.

Chapman, G., & Rowley, I. (1986). Cross-fostering, imprinting and learning in two sympatric species of cockatoo. Behaviour, 96(1-2), 1-16.

Charif, R. A., Waack, A. M., & Strickman, L. M. (2010). Raven Pro 1.4 user's manual. Cornell Lab of Ornithology, Ithaca, NY, 25506974.

Charrier, I., Bloomfield, L. L., & Sturdy, C. B. (2004). Note types and coding in parid vocalizations. I: The chick-a-dee call of the black-capped chickadee (Poecile atricapillus). Canadian Journal of Zoology, 82(5), 769-779.

Ciaburri, I., & Williams, H. (2019). Context-dependent variation of house finch song syntax. Animal Behaviour, 147, 33-42.

Cuvier, G. L. F. D. (1802). Über den unteren Larynx der Vögel. Reils Archiv Physiol, 5, 67-96.

Cynx, J., & Nottebohm, F. (1992). Testosterone facilitates some conspecific song discriminations in castrated zebra finches (Taeniopygia guttata). Proceedings of the National Academy of Sciences, 89(4), 1376-1378.

Dawson, A., King, V. M., Bentley, G. E., & Ball, G. F. (2001). Photoperiodic control of seasonality in birds. Journal of biological rhythms, 16(4), 365-380.

Deng, Z., Lloyd, H., Xia, C., Møller, A. P., Liang, W., & Zhang, Y. (2019). Components of variation in female common cuckoo calls. *Behavioural Processes*, *158*, 106-112.

DOOLING, R. (2004). Audition: can birds hear everything they sing? In Nature's Music (pp. 206-225). Academic Press.

Dooling, R. J. (1992). Hearing in birds. The evolutionary biology of hearing, 545-559.

Doupe, A. J. (1997). Song-and order-selective neurons in the songbird anterior forebrain and their emergence during vocal development. Journal of Neuroscience, 17(3), 1147-1167.

Doupe, A. J., & Konishi, M. (1991). Song-selective auditory circuits in the vocal control system of the zebra finch. Proceedings of the National Academy of Sciences, 88(24), 11339-11343.

Doupe, A. J., & Kuhl, P. K. (1999). Birdsong and human speech: common themes and mechanisms. Annual review of neuroscience, 22(1), 567-631.

Durães, R. (2009). Lek structure and male display repertoire of blue-crowned manakins in eastern Ecuador. The Condor, 111(3), 453-461.

Düring, D. N., & Elemans, C. P. (2016). Embodied motor control of avian vocal production. Vertebrate sound production and acoustic communication, 119-157.

Düring, D. N., & Elemans, C. P. (2016). Embodied motor control of avian vocal production. Vertebrate sound production and acoustic communication, 119-157.

Düring, D. N., Ziegler, A., Thompson, C. K., Ziegler, A., Faber, C., Müller, J., ... & Elemans, C. P. (2013). The songbird syrinx morphome: a three-dimensional, high-resolution, interactive morphological map of the zebra finch vocal organ. BMC biology, 11(1), 1-27.

Egnor, S. R., & Hauser, M. D. (2004). A paradox in the evolution of primate vocal learning. Trends in neurosciences, 27(11), 649-654.

Elie, J. E., & Theunissen, F. E. (2018). Zebra finches identify individuals using vocal signatures unique to each call type. Nature communications, 9(1), 4026.

Elie, J. E., & Theunissen, F. E. (2018). Zebra finches identify individuals using vocal signatures unique to each call type. Nature communications, 9(1), 4026.

Ellis, J. M. (2008). Which call parameters signal threat to conspecifics in white-throated magpie- jay mobbing calls?. Ethology, 114(2), 154-163.

Erdoğan, S., Sağsöz, H., & Paulsen, F. (2015). Functional Anatomy of the Syrinx of the Chukar Partridge (G alliformes: A lectoris chukar) as a Model for Phonation Research. The Anatomical Record, 298(3), 602-617.

Evans, C. S., & Evans, L. (2007). Representational signalling in birds. Biology letters, 3(1), 8-11.

Evans, C. S., & Evans, L. (2007). Representational signalling in birds. Biology letters, 3(1), 8-11.

Evans, C. S., Evans, L., & Marler, P. (1993). On the meaning of alarm calls: functional reference in an avian vocal system. Animal Behaviour, 46(1), 23-38.

Falls, J. B. (1982). Individual recognition by sounds in birds. Acoustic communication in birds, 2, 237-278.

Farabaugh, S. M., Linzenbold, A., & Dooling, R. J. (1994). Vocal plasticity in budgerigars (Melopsittacus undulatus): evidence for social factors in the learning of contact calls. Journal of Comparative Psychology, 108(1), 81.

Favaro L, Ozella L, Pessani D (2014) The vocal repertoire of the African Penguin (Spheniscus demer1sus): structure and function of calls. PloS one 9(7): e103460. https://doi.org/10.1371/journal.pone.

Field A (2009) Discovering statistics using SPSS. Sage Publications.

Fromkin, V., Krashen, S., Curtiss, S., Rigler, D., & Rigler, M. (1974). The development of language in Genie: a case of language acquisition beyond the "critical period". Brain and language, 1(1), 81-107.

Fuller, R. A., Warren, P. H., & Gaston, K. J. (2007). Daytime noise predicts nocturnal singing in urban robins. Biology letters, 3(4), 368-370.

Gahr, M. (2020). Seasonal hormone fluctuations and song structure of birds. Coding strategies in vertebrate acoustic communication, 163-201.

Gans, C. (1973). Sound production in the Salientia: mechanism and evolution of the emitter. American Zoologist, 13(4), 1179-1194.

Garrod, A. H. (1878, August). Notes on the Anatomy of Passerine Birds. Part IV. In Proceedings of the Zoological Society of London (Vol. 46, No. 1, pp. 143-143). Oxford, UK: Blackwell Publishing Ltd.

Gentner, T. Q., & Hulse, S. H. (1998). Perceptual mechanisms for individual vocal recognition in European starlings, Sturnus vulgaris. Animal behaviour, 56(3), 579-594.

Gerhardt, H. C., & Huber, F. (2003). Acoustic communication in insects and anurans: common problems and diverse solutions.

Gill, F., & Donsker, D. (2015). IOC world bird list (v 5.4).

Godard, R., & Wiley, R. H. (1995). Individual recognition of song repertoires in two wood warblers. Behavioral Ecology and Sociobiology, 37, 119-123.

Goller, F. (2016). Sound production and modification in birds–Mechanisms, methodology and open questions. Comparative Bioacoustics: An Overview (C. Brown and T. Riede, Editors). Bentham Science Publishers, Sharjah, United Arab Emirates, 165-230.

Goller, M., & Shizuka, D. (2018). Evolutionary origins of vocal mimicry in songbirds. Evolution letters, 2(4), 417-426.

Griesser, M. (2009). Mobbing calls signal predator category in a kin group-living bird species. Proceedings of the Royal Society B: Biological Sciences, 276(1669), 2887-2892.

Grieves LA, Logue DM, Quinn JS (2015) Vocal repertoire of cooperatively breeding smooth-billed anis. J Field Ornithology 86: 130–143.

Grieves, L. A., Logue, D. M., & Quinn, J. S. (2014). Joint-nesting smooth-billed anis, Crotophaga ani, use a functionally referential alarm call system. Animal Behaviour, 89, 215-221.

Haecker, V. (1918). Entwicklungsgeschichtliche Eigenschaftsanalyse (Phänogenetik): gemeinsame Aufgaben der Entwicklungsgeschichte, Vererbungs-und Rassenlehre. Gustav Fischer.

Hafner, M. S., & Hafner, D. J. (1979). Vocalizations of grasshopper mice (genus Onychomys). Journal of Mammalogy, 60(1), 85-94.

Hahn, T. P., & MacDougall-Shackleton, S. A. (2008). Adaptive specialization, conditional plasticity and phylogenetic history in the reproductive cue response systems of birds. Philosophical Transactions of the Royal Society B: Biological Sciences, 363(1490), 267-286.

Hahn, T. P., Boswell, T., Wingfield, J. C., & Ball, G. F. (1997). Temporal flexibility in avian reproduction: patterns and mechanisms. Current ornithology, 39-80.

Hall BK, Kerney R (2012) Levels of biological organization and the origin of novelty. J Exp Zoolog B Mol Dev Evol 318:428–437

HARTWIG, S. (2005). Individual acoustic identification as a non-invasive conservation tool: an approach to the conservation of the African wild dog Lycaon pictus (Temminck, 1820). Bioacoustics, 15(1), 35-50.

Hauser, M. D., Chomsky, N., & Fitch, W. T. (2002). The faculty of language: what is it, who has it, and how did it evolve? science, 298(5598), 1569-1579.

Hensch, T. K. 2, 3 1 Department of Psychology, University of British Columbia, Vancouver British Columbia V6T 1Z4, Canada; email: 2 Department of Molecular and Cellular Biology, Harvard University, Cambridge, Massachusetts 02138; email: 3 Canadian Institute for Advanced Research, Toronto Ontario M5G 1Z8. Canada Annual Review of Psychology, 66, 173-196.

Hile, A. G., & Striedter, G. F. (2000). Call convergence within groups of female budgerigars (Melopsittacus undulatus). Ethology, 106(12), 1105-1114.

Hile, A. G., Burley, N. T., Coopersmith, C. B., Foster, V. S., & Striedter, G. F. (2005). Effects of male vocal learning on female behavior in the budgerigar, Melopsittacus undulatus. Ethology, 111(10), 901-923

Hu, Y., & Cardoso, G. C. (2010). Which birds adjust the frequency of vocalizations in urban noise? Animal Behaviour, 79(4), 863-867.

Hyland Bruno, J., Jarvis, E. D., Liberman, M., & Tchernichovski, O. (2021). Birdsong learning and culture: analogies with human spoken language. Annual review of linguistics, 7, 449-472.

Janik, V. M., & Slater, P. J. (1997). Vocal learning in mammals. Advances in the Study of Behaviour, 26(1), 59-100.

Jarvis, E. D. (2004). Learned birdsong and the neurobiology of human language. Annals of the New York Academy of Sciences, 1016(1), 749-777.

Jarvis, E. D. (2019). Evolution of vocal learning and spoken language. Science, 366(6461), 50-54.

Jarvis, E. D., & Mello, C. V. (2000). Molecular mapping of brain areas involved in parrot vocal communication. Journal of Comparative Neurology, 419(1), 1-31.

Jürgens, U. (2002). Neural pathways underlying vocal control. Neuroscience & Biobehavioral Reviews, 26(2), 235-258.

Jürgens, U. (2002). Neural pathways underlying vocal control. Neuroscience & Biobehavioral Reviews, 26(2), 235-258.

Keen, S. C., Meliza, C. D., & Rubenstein, D. R. (2013). Flight calls signal group and individual identity but not kinship in a cooperatively breeding bird. Behavioral Ecology, 24(6), 1279-1285.

King, A. S. (1989). Functional anatomy of the syrinx. Form and function in birds, 4, 105-192.

Kingsley, E. P., Eliason, C. M., Riede, T., Li, Z., Hiscock, T. W., Farnsworth, M., ... & Clarke, J. A. (2018). Identity and novelty in the avian syrinx. Proceedings of the National Academy of Sciences, 115(41), 10209-10217.

Köditz, W. (1925). Uber die Syrinx einiger clamatores und auslandischer oscines. Z Wiss Zool, 126(70), 144.

Kolaczkowski, B., & Thornton, J. W. (2004). Performance of maximum parsimony and likelihood phylogenetics when evolution is heterogeneous. Nature, 431(7011), 980-984.

Konishi, M. (1965). The role of auditory feedback in the control of vocalization in the white- crowned sparrow 1. Zeitschrift für Tierpsychologie, 22(7), 770-783.

Konishi, M. (1970). Comparative neurophysiological studies of hearing and vocalizations in songbirds. Zeitschrift für vergleichende Physiologie, 66(3), 257-272.

Konishi, M. (1985). Birdsong: from behavior to neuron. Annual review of neuroscience, 8(1), 125-170.

Kroodsma, D. E. (1984). Songs of the Alder Flycatcher (Empidonax alnorum) and Willow Flycatcher (Empidonax traillii) are innate. The Auk, 101(1), 13-24.

Kroodsma, D. E. (1985). Development and use of two song forms by the Eastern Phoebe. The Wilson Bulletin, 21-29.

Kroodsma, D. E. (1989). Male eastern phoebes (Sayornis phoebe; Tyrannidae, Passeriformes) fail to imitate songs. Journal of Comparative Psychology, 103(3), 227.

Kroodsma, D. E., & Miller, E. H. (Eds.). (1996). Ecology and evolution of acoustic communication in birds (pp. p-3). Comstock Pub..

Lane, H. (1976). The wild boy of Aveyron (Vol. 149). Harvard University Press.

Lefevre, K., Gaston, A. J., & Montgomerie, R. (2001). Repertoire, structure, and individual distinctiveness of Thick-billed Murre calls. The Condor, 103(1), 134-142.

Leonard, M. L., Horn, A. G., Brown, C. R., & Fernandez, N. J. (1997). Parent–offspring recognition in tree swallows, Tachycineta bicolor. Animal Behaviour, 54(5), 1107-1116.

Lewandowski, B., Vyssotski, A., Hahnloser, R. H., & Schmidt, M. (2013). At the interface of the auditory and vocal motor systems: NIf and its role in vocal processing, production and learning. Journal of Physiology-Paris, 107(3), 178-192.

Lewkowicz, A. G., & Way, R. G. (2019). Extremes of summer climate trigger thousands of thermokarst landslides in a High Arctic environment. Nature communications, 10(1), 1329.

Ligout, S., Dentressangle, F., Mathevon, N., & Vignal, C. (2016). Not for Parents Only: Begging Calls Allow Nest- Mate Discrimination in Juvenile Zebra Finches. Ethology, 122(3), 193-206.

Lipkind, D., Marcus, G. F., Bemis, D. K., Sasahara, K., Jacoby, N., Takahasi, M., ... & Tchernichovski, O. (2013). Stepwise acquisition of vocal combinatorial capacity in songbirds and human infants. Nature, 498(7452), 104-108.

Ljubičić, I., Bruno, J. H., & Tchernichovski, O. (2016). Social influences on song learning. Current Opinion in Behavioral Sciences, 7, 101-107.

Margoliash, D. (1997). Functional organization of forebrain pathways for song production and perception. Journal of neurobiology, 33(5), 671-693.

Marler, P. (1981). Birdsong: the acquisition of a learned motor skill. Trends in Neurosciences, 4, 88-94.

Marler, P. (1997). Three models of song learning: evidence from behavior. Journal of neurobiology, 33(5), 501-516.

Marler, P. (2004). Bird calls: a cornucopia for communication. In Nature's music (pp. 132-177). Academic Press.

Marler, P. (2004). Bird calls: a cornucopia for communication. In Nature's music (pp. 132-177). Academic Press.

Marler, P., & Peters, S. (1977). Selective vocal learning in a sparrow. Science, 198(4316), 519-521.

May, R., Reitan, O., Bevanger, K., Lorentsen, S. H., & Nygård, T. (2015). Mitigating wind-turbine induced avian mortality: Sensory, aerodynamic and cognitive constraints and options. Renewable and Sustainable Energy Reviews, 42, 170-181.

McShane, L. J., Estes, J. A., Riedman, M. L., & Staedler, M. M. (1995). Repertoire, structure, and individual variation of vocalizations in the sea otter. Journal of Mammalogy, 76(2), 414-427.

Medvin, M. B., & Beecher, M. D. (1986). Parent-offspring recognition in the barn swallow (Hirundo rustica). Animal Behaviour, 34(6), 1627-1639.

Mendelson, T. C., & Shaw, K. L. (2012). The (mis) concept of species recognition. Trends in ecology & evolution, 27(8), 421-427

Mendelson, T. C., Fitzpatrick, C. L., Hauber, M. E., Pence, C. H., Rodríguez, R. L., Safran, R. J., ... & Stevens, J. R. (2016). Cognitive phenotypes and the evolution of animal decisions. Trends in ecology & evolution, 31(11), 850-859.

Michael, S. B., & Allison, J. D. (2002). What songbirds teach us about learning. Nature, 417(6886), 351-358.

Miller, E. H., Seneviratne, S. S., Jones, I. L., Robertson, G. J., & Wilhelm, S. I. (2008). Syringeal anatomy and allometry in murres (Alcidae: Uria). Journal of Ornithology, 149, 545-554.

Miskimen, M. (1951). Sound production in passerine birds. The Auk, 68(4), 493-504.

Monte, A., Cerwenka, A. F., Ruthensteiner, B., Gahr, M., & Düring, D. N. (2020). The hummingbird syrinx morphome: a detailed three-dimensional description of the black jacobin’s vocal organ. BMC Zoology, 5(1), 1-15.

Mooney, R. (1999). Sensitive periods and circuits for learned birdsong. Current opinion in neurobiology, 9(1), 121-127.

Mooney, R. (2009). Neurobiology of song learning. Current opinion in neurobiology, 19(6), 654-660.

Morelli, F., Møller, A. P., Nelson, E., Benedetti, Y., Tichit, M., Šímová, P., ... & Tryjanowski, P. (2017). Cuckoo as indicator of high functional diversity of bird communities: A new paradigm for biodiversity surrogacy. Ecological Indicators, 72, 565-573.

Moser-Purdy, C., & Mennill, D. J. (2016). Large vocal repertoires do not constrain the dear enemy effect: a playback experiment and comparative study of songbirds. Animal Behaviour, 118, 55-64.

Müller, J. (1847). Über die bisher unbekannten typischen Verschiedenheiten der Stimmorgane der Passerinen. Gedruckt in der Druckerei der K. Akademie der Wissenschaften.

Myers, J. A. (1917). Studies on the syrinx of Gallus domesticus... Cornell university.

Nemeth, E., & Brumm, H. (2010). Birds and anthropogenic noise: are urban songs adaptive? The American Naturalist, 176(4), 465-475.

Nicholls, T. J., Goldsmith, A. R., & Dawson, A. (1988). Photorefractoriness in birds and comparison with mammals. Physiological reviews, 68(1), 133-176.

Nicholls, T. J., Goldsmith, A. R., & Dawson, A. (1988). Photorefractoriness in birds and comparison with mammals. Physiological reviews, 68(1), 133-176.

Nottebohm, F. (1968). Auditory experience and song development in the chaffinch Fringilla coelebs. Ibis, 110(4), 549-568.

Nottebohm, F. (2005). The neural basis of birdsong. PLoS biology, 3(5), e164.

Nottebohm, F., & Arnold, A. P. (1976). Sexual dimorphism in vocal control areas of the songbird brain. Science, 194(4261), 211-213.

Nottebohm, F., & Nottebohm, M. E. (1976). Left hypoglossal dominance in the control of canary and white-crowned sparrow song. Journal of Comparative Physiology, 108(2), 171-192.

Nottebohm, F., Stokes, T. M., & Leonard, C. M. (1976). Central control of song in the canary, Serinus canarius. Journal of Comparative Neurology, 165(4), 457-486.

Papousek, H., Jürgens, U., & Papoušek, M. (Eds.). (1992). Nonverbal vocal communication: Comparative and developmental approaches. Cambridge University Press.

Picasso, M. B. J., & Carril, J. (2013). The peculiar syrinx of Rhea americana (greater rhea, Palaeognathae).

Poole, J. H., Tyack, P. L., Stoeger-Horwath, A. S., & Watwood, S. (2005). Elephants are capable of vocal learning. Nature, 434(7032), 455-456.

Prather, J. F., Okanoya, K., & Bolhuis, J. J. (2017). Brains for birds and babies: Neural parallels between birdsong and speech acquisition. Neuroscience & Biobehavioral Reviews, 81, 225-237.

Prior, N. H., & Soma, K. K. (2015). Neuroendocrine regulation of long-term pair maintenance in the monogamous zebra finch. Hormones and behavior, 76, 11-22.

Prum, R. O. (1992). Syringeal morphology, phylogeny, and evolution of the Neotropical manakins (Aves: Pipridae). Am. Mus. Novit., 3043, 1-65.

Radford, A. N. (2003). Territorial vocal rallying in the green woodhoopoe: influence of rival group size and composition. Animal Behaviour, 66(6), 1035-1044.

Radford, A. N. (2003). Territorial vocal rallying in the green woodhoopoe: influence of rival group size and composition. Animal Behaviour, 66(6), 1035-1044.

Radford, A. N. (2004). Vocal coordination of group movement by green woodhoopoes (Phoeniculus purpureus). Ethology, 110(1), 11-20.

Rae, L. F., Whitaker, D. M., & Warkentin, I. G. (2015). Variable effect of playback of chickadee mobbing calls on detection probability of boreal forest birds. Journal of Field Ornithology, 86(1), 51-64.

Riede, T., Forstmeier, W., Kempenaers, B., & Goller, F. (2015). The functional morphology of male courtship displays in the Pectoral Sandpiper (Calidris melanotos). The Auk: Ornithological Advances, 132(1), 65-77.

Riede, T., Thomson, S. L., Titze, I. R., & Goller, F. (2019). The evolution of the syrinx: An acoustic theory. PLoS biology, 17(2), e2006507.

Rodewald P. (Editor) (2017). The Birds of North America Online (https://birdsbna.org). Ithaca, NY, USA: Cornell Lab of Ornithology. Accessed 10 Dec 2017

Rose, E. M., Coss, D. A., Haines, C. D., Danquah, S. A., Studds, C. E., & Omland, K. E. (2019). Why do females sing?—pair communication and other song functions in eastern bluebirds. Behavioral Ecology, 30(6), 1653-1661.

Rose, E. M., Prior, N. H., & Ball, G. F. (2022). The singing question: re-conceptualizing birdsong. *Biological Reviews*, *97*(1), 326-342.

Rowley, I. (1980). Parent-Offspring Recognition in a Cockatoo, the Galah, Cacatua Roseicapilla. australian Journal of Zoology, 28(3), 445-456.

Saunders, J. C., & Henry, W. J. (1988). the peripheral auditory system of birds: Structural and functional contributions to auditory perception. Dooling, RJ, Hulse. WM, eds. Contributions to Auditory Perception in Animals. Collingswood NJ: Earlbaum, 31-62.

Saunders, J. C., Duncan, R. K., Doan, D. E., & Werner, Y. L. (2000). The middle ear of reptiles and birds. Comparative hearing: Birds and reptiles, 13-69.

Savart, F. (1826). Mémoire sur la voix des oiseaux. In Annales de Chimie et de Physique (Vol. 32, pp. 5-24).

Schachner, A. (2013). The origins of human and avian auditory-motor entrainment. Nova Acta Leopoldina, 111, 243-253.

Schachner, A. (2013). The origins of human and avian auditory-motor entrainment. Nova Acta Leopoldina, 111, 243-253.

Searcy, W. A., Marler, P., & Peters, S. S. (1985). Songs of isolation-reared sparrows function in communication, but are significantly less effective than learned songs. Behavioral Ecology and Sociobiology, 17, 223-229.

Seddon, N., Alvarez, A., & Tobias, J. (2002).

Seddon, N., Alvarez, A., & Tobias, J. (2002). Vocal communication in the pale-winged trumpeter (Psophia leucoptera): repertoire, context and functional reference. Behaviour, 139(10), 1331-1359.

Seddon, N., Alvarez, A., & Tobias, J. (2002). Vocal communication in the pale-winged trumpeter (Psophia leucoptera): repertoire, context and functional reference. Behaviour, 139(10), 1331-1359.

Seddon, N., Alvarez, A., & Tobias, J. (2002). Vocal communication in the pale-winged trumpeter (Psophia leucoptera): repertoire, context and functional reference. Behaviour, 139(10), 1331-1359.

Senter, P. (2008). Voices of the past**:** a review of Paleozoic and Mesozoic animal sounds.

Setterwall, C. G. (1901). Studier öfver syrinx hos polymyoda passeres. Gleerupska Universitetsbokhandeln.

Sharp, P. J. (1996). Strategies in avian breeding cycles. Animal Reproduction Science, 42(1-4), 505-513.

Sharp, P. J. (2005). Photoperiodic regulation of seasonal breeding in birds. Annals of the New York Academy of Sciences, 1040(1), 189-199.

Sharp, S. P., & Hatchwell, B. J. (2005). Individuality in the contact calls of cooperatively breeding long-tailed tits (Aegithalos caudatus). Behaviour, 142(11-12), 1559-1575.

Sibley, C. G., & Ahlquist, J. E. (1990). Phylogeny and classification of birds: a study in molecular evolution Yale Univ Press. New Haven.

Simonyan, K., & Horwitz, B. (2011). Laryngeal motor cortex and control of speech in humans. The Neuroscientist, 17(2), 197-208.

Simonyan, K., Horwitz, B., & Jarvis, E. D. (2012). Dopamine regulation of human speech and bird song: a critical review. Brain and language, 122(3), 142-150.

Simonyan, K., Horwitz, B., & Jarvis, E. D. (2012). Dopamine regulation of human speech and bird song: a critical review. Brain and language, 122(3), 142-150.

Simpson, H. B., & Vicario, D. S. (1990). Brain pathways for learned and unlearned vocalizations differ

Sinnott, J. M., Sachs, M. B., & Hienz, R. D. (1980). Aspects of frequency discrimination in passerine birds and pigeons. Journal of Comparative and Physiological Psychology, 94(3), 401.

Slabbekoorn, H., & Peet, M. (2003). Birds sing at a higher pitch in urban noise. Nature, 424(6946), 267-267.

Slater, P. J. B. (2003). Fifty years of bird song research: a case study in animal behaviour. Essays in Animal Behaviour: Celebrating 50 Years of Animal Behaviour, 301-313.

Smith, S. M. (1991). The black-capped chickadee: behavioral ecology and natural history. Comstock Pub Assoc.

Sommers, M. S., Kirk, K. I., & Pisoni, D. B. (1997). Some considerations in evaluating spoken word recognition by normal-hearing, noise-masked normal-hearing, and cochlear implant listeners. I: The effects of response format. Ear and Hearing, 18(2), 89.

Sousa-Lima, R. S., Paglia, A. P., & Da Fonseca, G. A. (2002). Signature information and individual recognition in the isolation calls of Amazonian manatees, Trichechus inunguis (Mammalia: Sirenia). Animal Behaviour, 63(2), 301-310.

Spector, D. A. (1994). Definition in Biology: The Case of" Bird Song". Journal of Theoretical Biology, 168(4), 373-381.

Stefanski, R. A., & Falls, J. B. (1972). A study of distress calls of song, swamp, and white-throated sparrows (Aves: Fringillidae). I. Intraspecific responses and functions. Canadian Journal of Zoology, 50(12), 1501-1512.

Stripling, R., Milewski, L., Kruse, A. A., & Clayton, D. F. (2003). Rapidly learned song-discrimination without behavioral reinforcement in adult male zebra finches (Taeniopygia guttata). Neurobiology of learning and memory, 79(1), 41-50.

Sugiura, H. (1998). Matching of acoustic features during the vocal exchange of coo calls by Japanese macaques. Animal Behaviour, 55 (3): 673-687.

Suzuki, T. N., & Ueda, K. (2013). Mobbing calls of Japanese tits signal predator type: field observations of natural predator encounters. The Wilson Journal of Ornithology, 125(2), 412-415.

T.J. Roberts Non-Passeriformes Birds of Pakistan, Oxford Press.

Temeles, E. J. (1994). The role of neighbours in territorial systems: when are they'dear enemies'? Animal Behaviour, 47(2), 339-350.

ten Cate, C., & Okanoya, K. (2012). Revisiting the syntactic abilities of non-human animals: natural vocalizations and artificial grammar learning. Philosophical Transactions of the Royal Society B: Biological Sciences, 367(1598), 1984-1994.

Thorpe, W. H. (1958). The learning of song patterns by birds, with especial reference to the song of the chaffinch Fringilla coelebs. Ibis, 100(4), 535-570.

Todt, D., & Naguib, M. (2000). Vocal interactions in birds: the use of song as a model in communication. In Advances in the Study of Behavior (Vol. 29, pp. 247-296). Academic Press.

Todt, D., & Naguib, M. (2000). Vocal interactions in birds: the use of song as a model in communication. In Advances in the Study of Behavior (Vol. 29, pp. 247-296). Academic Press.

Treisman, M. (1978). Bird song dialects, repertoire size, and kin association. Animal Behaviour, 26, 814-817.

Vates, G. E., Broome, B. M., Mello, C. V., & Nottebohm, F. (1996). Auditory pathways of caudal telencephalon and their relation to the song system of adult male zebra finches (Taenopygia guttata). Journal of Comparative Neurology, 366(4), 613-642.

Vicario, D. S. (2004). Using learned calls to study sensory- motor integration in songbirds. Annals of the New York Academy of Sciences, 1016(1), 246-262.

Vignal, C., Mathevon, N., & Mottin, S. (2004). Audience drives male songbird response to partner's voice. Nature, 430(6998), 448-451.

Vocal communication in the pale-winged trumpeter (Psophia leucoptera): repertoire, context and functional reference. Behaviour, 139(10), 1331-1359.

Walløe, S., Thomsen, H., Balsby, T. J., & Dabelsteen, T. (2015). Differences in short-term vocal learning in parrots, a comparative study. *Behaviour*, *152*(11), 1433-1461.

Warrington, M. H., McDonald, P. G., Rollins, L. A., & Griffith, S. C. (2014). All signals are not equal: acoustic signalling of individuality, sex and breeding status in a cooperative breeder. Animal Behaviour, 93, 249-260.

Warrington, M. H., McDonald, P. G., Rollins, L. A., & Griffith, S. C. (2014). All signals are not equal: acoustic signalling of individuality, sex and breeding status in a cooperative breeder. Animal Behaviour, 93, 249-260.

Wells, K. D., & Schwartz, J. J. (2006). The behavioral ecology of anuran communication. Hearing and sound communication in amphibians, 44-86.

Wilson, D. R., & Evans, C. S. (2012). Fowl communicate the size, speed and proximity of avian stimuli through graded structure in referential alarm calls. Animal Behaviour, 83(2), 535-544.

Wirthlin, M., Chang, E. F., Knörnschild, M., Krubitzer, L. A., Mello, C. V., Miller, C. T., ... & Yartsev, M. M. (2019). A modular approach to vocal learning: disentangling the diversity of a complex behavioral trait. Neuron, 104(1), 87-99.

Wood, W. E., & Yezerinac, S. M. (2006). Song sparrow (Melospiza melodia) song varies with urban noise. The Auk, 123(3), 650-659.

Yip, M. (2013). Structure in human phonology and in birdsong: a phonologist's perspective. Birdsong, speech, and language: exploring the evolution of mind and brain, 181-208.

Yu, A. C., & Margoliash, D. (1996). Temporal hierarchical control of singing in birds. Science, 273(5283), 1871-1875.

Zachau, C. E., & Freeberg, T. M. (2012). Chick-a-dee call variation in the context of “flying” avian predator stimuli: a field study of Carolina chickadees (Poecile carolinensis). Behavioral Ecology and Sociobiology, 66, 683-690.

Zann, R. A., Morton, S. R., Jones, K. R., & Burley, N. T. (1995). The timing of breeding by zebra finches in relation to rainfall in central Australia. Emu, 95(3), 208-222.

Zimmer, K. J., Robbins, M. B., & Kopuchian, C. (2008). Taxonomy, vocalisations, syringeal morphology and natural history of A

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