

A melodious passage to sketch the development of verbal communication in songbird

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Abstract: Many people have always been captivated to bird song because of its aesthetic and alluring aspects. However, because bird song represents an evolutionary apex of vocal sophistication, it also holds enormous interest for behavioral and evolutionary biologists. Only human, cetacean (whales and dolphins), and bat species have shown evidence of vocal learning, which is the copying of sounds used in communication, among lower vertebrates and mammals. Interesting evidence of vocal learning in pinnipeds has also been found. In contrast, three major groups of almost 5,000 bird species—parrots, hummingbirds, and oscine songbirds—including both tropical and temperate species—learn their songs or calls. The oscines exhibit vocal learning and are found all over the world. The convoluted musculature of the syrinx, the vocal organ, serves as the taxonomic basis for the oscines. Nearly all of these bird species sing and are diurnal.

Keywords: *bird song; call; vocal learning; communication; syrinx*

I. INTRODUCTION

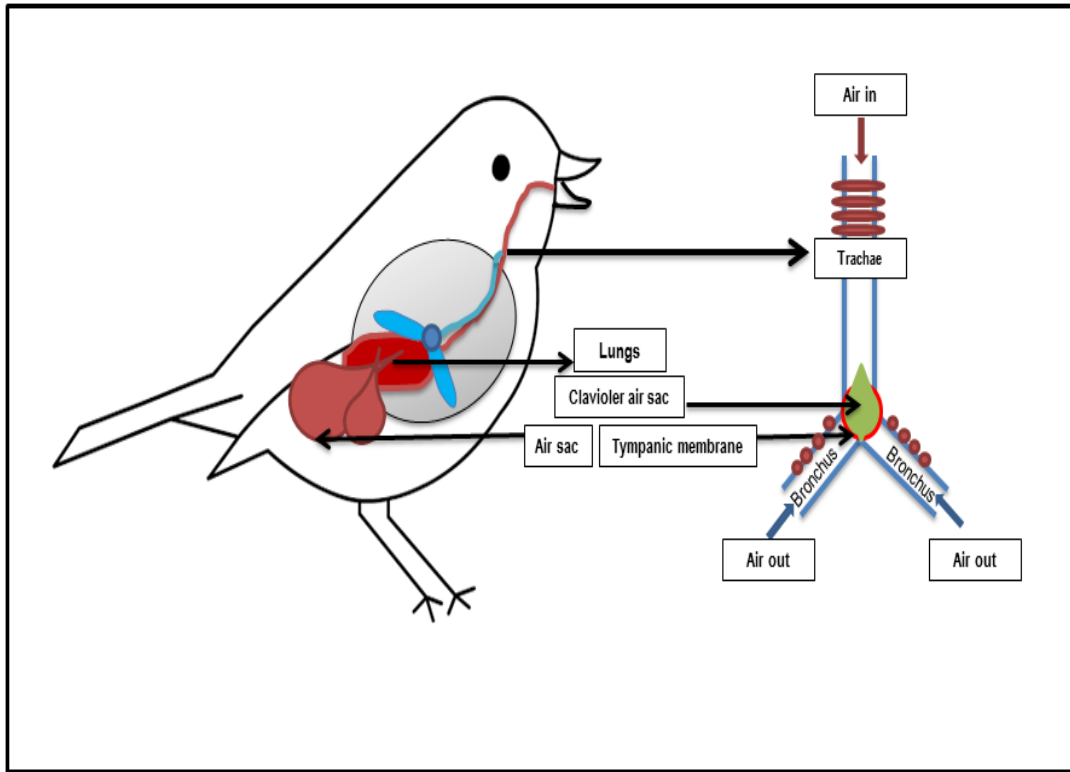
The melodious beauty and complexity of birdsong have long attracted amateurs, naturalists, and scientists alike. In spite of the almost ubiquitous existence of birdsong in both natural and anthropogenous environments, a small amount of people is aware that birdsong is one of the most intricate aural communication and coordination in the animal kingdom. A feature of bird song that has drawn remarkable interdisciplinary scientific study from naturalists, biologists, psychologists, and linguistics is its fundamental, unique, and nearly incomparable 9 likenesses to human speech. Just as in human speech vocalization and verbal interaction by the songbirds are essential for the development of songs. (Catchpole and Slater, 1995). In earlier stage, there is a responsive period in which the basic species-specific structure is acquired. The organization is almost similar to that of humans that is established during the development of language in the first few years of life. Another well-established instances of communication in animal kingdom in which learning plays such a central role in signal acquisition are found in parrots, hummingbirds, bats, and some of the marine mammals (Janik and Slater, 1997).

Birdsong and calls are the best studied vertebrate communication system among all levels of scientific investigation, from ecology to evolutionary biology, from behavior to biodiversity. Evolution of birdsong into its current form has been used as a paradigm for explaining fundamental biological processes that links between learning and communication. (Alcock, 2001; Campbell and Reece, 2001; Barnard, 2004; (Kroodsma, 2004). Only the males sing in the majority of songbird species that breed primarily in temperate zones. Their songs serve to both attract and stimulate females for breeding as well as to protect the territory against rival males. (Catchpole and Slater, 1995). However, there is an enormous variation in song structure and pattern, development and delivery machinery. Songbirds, hummingbirds, and parrots are among the bird species whose vocalizations can be learned through imitation, similar to how people learn to speak. Vocal learning in songbirds is now known to be mediated by a specialized neural pathway, the anterior forebrain pathway, the development of which depends on birds' auditory experiences. Many tropical birds have far simpler songs than their counterparts in temperate species, which are frequently much more complicated. The way and time that songbirds in the tropics sing differs from that of songbirds in temperate zones; singing is more common among females and tends to happen all year round. Amazingly, some of the paired individuals can combine their songs into seamless duets. (Hall, 2004). Even for a skilled human listener, the speed and accuracy of duets' time synchronization produce a composite signal that sounds like a single person's song. The current communication will mainly concentrate on male voice calls and the formation of songs in an effort to explain general songbird vocal communication concepts.

II. CONTRAST BETWEEN BIRDSONG AND BIRD CALL:

Birdsong may be easily distinguished from the other songbird vocalizations, which are typically referred to as bird calls. Bird calls have been defined on the basis of distinguishable structural and functional criteria. Calls, typically made by both sexes, have a simple structure, and frequently depend entirely on the surroundings and circumstances in which they are made, such as begging calls or warning cries (Marler, 2004). Calling happens all year round, unlike songs, which are normally only transmitted during breeding season. Vocal learning has traditionally been regarded to have little impact on calls (Scharff and Nottebohm, 1991). The number of research on call learning has increased, though, and it now seems that there is much more developmental flexibility than was previously thought. The warning calls made in reaction to predators have drawn particular attention among the many calls made by various birds. The calls may gradually change in intensity in accordance with the gravity of the threat and may even contain functionally relevant information. The characteristic that has long been thought to be unique to human language controls the specific calls. A typical bird syrinx for sound production is shown in Fig.

III.



VERSATILITY AND ADAPTABILITY WHILE SINGING:

Fig: A typical avian syrinx for sound production

III. ADAPTABILITY AND VERSATILITY DURING SINGING PERFORMANCE:

Collective structure and versatility of a birdsong vary greatly, ranging from highly simple songs (like those of grasshopper warblers, *Locustella naevia*), which have only one repeated component, to extremely complex songs (like those of nightingales, *Luscinia megarhynchos*), in which each male sings about 200 different song types, each of which is made up of different components. Six birds have been divided into continuous and discontinuous singers in earlier research (Hartshorne, 1973; Catchpole and Slater, 1995). Reed Warblers (*Acrocephalus scirpaceus*), a continuous singer, produce lengthy, nearly continuous streams of song components. A continuous vocalist typically recombines the song repertoire's component parts in a variety of ways, making each new sequence just moderately different from the ones before it. However, the majority of male songbirds, particularly those in the temperate zone, are discontinuous singers, meaning they switch between songs. Such songs are uniquely created by fusing a number of song components with silence intervals. There are two different singing types among several species of discontinuous singers. Males of several temperate species will repeatedly sing the same type of song before transitioning to a different form of song. The species whose males typically have a small to medium repertoire of various song kinds (a catalogue of 2 to 10 acoustically distinguishable songs/male) are those where this mode of singing is most prevalent. On the other hand, male Carolina wrens (*Thryothorus ludovicianus*) have a repertoire of roughly 40 distinct song types, but they deliver their repertoire with more variation. Birds following this repetitive mode are generally said to be singing with ensuing diversity [song sparrows (*Melospiza melodia*), yellow hammers (*Emberiza citrinella*), chaffinches (*Fringilla coelebs*), and great tits (*Parus major*)]. In other species, males rarely sing the same song type in consecutive pattern but, instead, change to a different song type in their repertoire after finishing each song. These birds, like mockingbirds (*Mimus polyglottus*) and European blackbirds (*Turdus merula*), have a greater song repertoire and are known for their instantaneous variety display 5 style of singing.

IV. DEVELOPMENT OF SONG PATTERN:

Songbirds have an incomparable and remarkable ability for vocal learning. According to Eriksen (2011), song learning is divided into two phases: acquisition and production. The ability to memorize music patterns is a key feature of the sensory phase of the acquisition phase. The production learning phase, according to Podos et al. (2009), is the sensorimotor learning step of the complicated motor pattern during song delivery. These two processes' timing throughout development vary depending on the species and environment; it can range from closely overlapping to wholly independent.. In most songbird species, the acquisition process is frequently constrained to a delicate stage during the first year of life, around the time of maturation (Nottebohm, 1992). No further learning is observed in this process after the first breeding season, as in the case of chaffinches or zebra finches (*Taeniopygia guttata*). Learning may last a lifetime in some species, such as canaries (*Serinus canaria*) and starlings (*Sturnus vulgaris*). Age-related repertoire size growth is a common result of this process (Nowicki et al., 2000.).

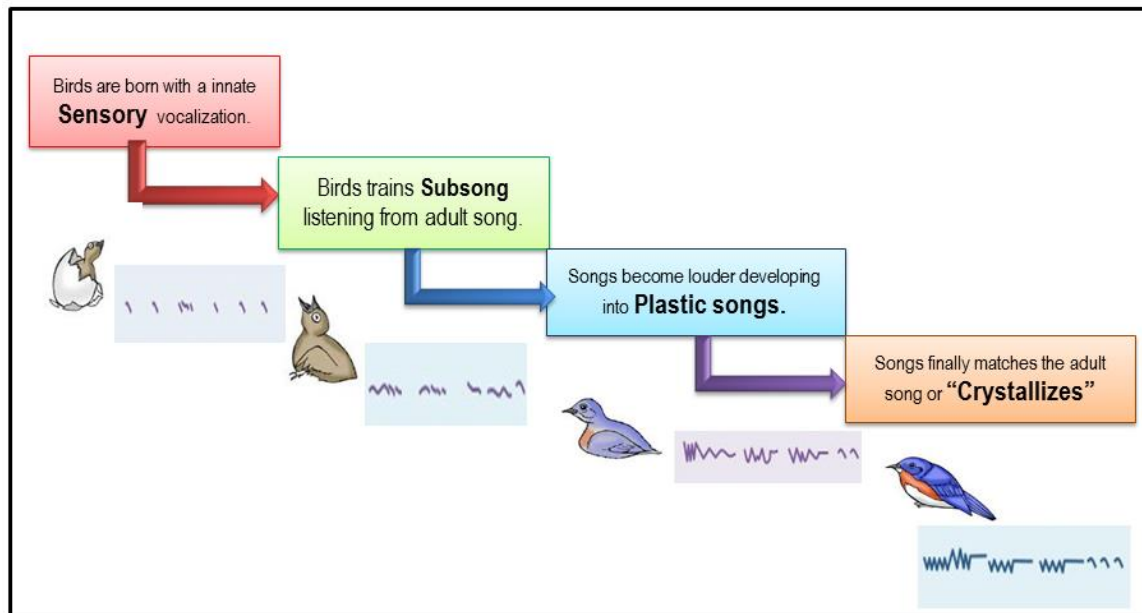


Fig: Stages of avian song development

It is also known as channeled or pre-programmed learning and appears to occur at a sensitive phase without superficial external reinforcement (Riebel, 2003). Unlearned biases determine which vocalizations are learned preferentially, and this usually changes with the distinctiveness of the vocalizations between species. The sensory learning phase comes before the motor learning phase, and the earliest sound memories are often formed during the first two weeks of life, frequently around the time that the young birds fledge from the nest. In migratory birds, this might not happen for several months after the young bird first heard the adult bird's song. Early singing starts off as a subsong or a faint, amorphous warbling that develops into a more diversified, structured song over time. While the final change, to the totally glazed music, might happen quickly—within a few days to a week—the previous two phases can persist for several weeks. Changes in particular sex steroid levels, which are brought on by photoperiod in both temperate and/or tropical zones, are correlated with the beginning of motor practice and song crystallization. However, tropical non-seasonal species show fewer distinct annual patterns. When song and testosterone levels are seasonal, even in adult birds, a brief subsong phase is seen prior to the start of the breeding season (Riebel, 2006).

A rough early template determines the sensory predispositions that filter the kinds of auditory stimuli that are recorded as individual song memories or templates during the final learning phase of the sensory-motor model during song learning. The song prototype is modified by learning and is crucial to the ensuing sensory-motor and learning phase, where the whole song is developed (Troyer and Bottjer, 2001). According to observations, young birds without adult song instructors produce song that has species-specific traits but lacks the fine precision of habitual adult song. Auditory response is the determining factor in adjusting the song production until it

matches the template when the motor learning phase begins. The development of song that is even more sparse than the song of birds raised in isolation results from interrupting the acoustic feedback by drowning it out with noise or by blocking the central nerve connections, rendering the bird unable to hear its own song (Troyer and Bottjer, 2001). The original model of song learning has undergone updates and modifications over time, but behavioral and neuro-endocrinal data seem to support the basic tenets of a two-phase process, and this still fits the general pattern seen in most species (Yoder and Vicario, 2012).

Vocal learning has the effect of increasing spatial and inter-individual variation as a result of incorrect song bootlegging. Birds can have regional dialects with distinct differences from those of other members of the same species, just as is the case with human speech. Short bird generation durations and plainly discernible cultural changes in song have been quite well associated to population shifts through time and place. Due to their ability to adapt to diachronic and regional change, such as dialect development, songbirds may be a useful study paradigm for nonhuman genetic modification-behavioral and co-evolution investigations (Woolley and Moore, 2011).

V. SONG PRODUCTION

Although birds have a larynx at the top of their trachea, they use the syrinx, a specialized organ positioned considerably lower down where the two bronchi unite to form the trachea, to vocalize. Numerous theories on potential basic dissimilarities in sound production processes between birds and mammals have been sparked by the tonal nature of numerous bird vocalizations and the discovery of a unique sound-producing organ. Recent research suggests that the fundamental mechanism is the same: periodic opening and closure of the vocal membrane gap results in harmonic sound at the source, which is filtered by the vocal tract. However, unlike a larynx consists of only one pair of vocal folds, there are two sets (one in each bronchus) of each of the several pairs of membranes involved in production of birdsong (Goller and Larsen, 2002).

The two parts of the syrinx are innervated separately, resulting in two possible sound sources that, up to a point, can function solitarily. One side of the syrinx typically predominates over the other in songbirds, and this lateral dominance may even vary from syllable to syllable and even within a phrase. The songbird vocal tract's settings function as a vocal filter, just like in the creation of mammal sounds, including human speech, and movements of the neck, tongue, and beak affect variations in resonance qualities.

VI. NEUROBIOLOGICAL CORRELATES OF SINGING AND SONG LEARNING

The brains of songbirds exhibit unique modifications for song creation and acquisition. The "song system" is made up of several interconnected brain regions that are missing in bird species that are not vocal learners and are sexually dimorphic in species where singing is a behavioral dimorphism. With the aid of conventional tissue staining methods, the implicated brain regions

can be easily distinguished from neighbouring brain tissue due to their high level of specialization. Two main pathways are involved in sound production.

Two cerebral regions exhibit synchronized neuronal activation with singing. The posterior (or motor) pathway descends from cerebral areas to control the syrinx via the hypoglossal nerve (XII). In young bird's lesions in either Area X or MAN interfere with song acquisition, whereas such lesions have no impact on singing in mature birds. The anterior pathway is crucial for song learning. Many songbird species' well-defined sensitive sensory learning periods enable controlled experimental evaluation of the quantity and quality of the sensory input. Thus, studying the neurological foundations of vocal learning and adult neural plasticity (seasonal changes, neurogenesis) makes use of avian song learning as a key paradigm. Our understanding of the delicate neuroanatomical changes involved in learning has substantially progressed because to insights from neurophysiology, neuroanatomy, and studies on the impacts of differential gene expression driving neuroanatomical and functional change (Jarvis, 2004).

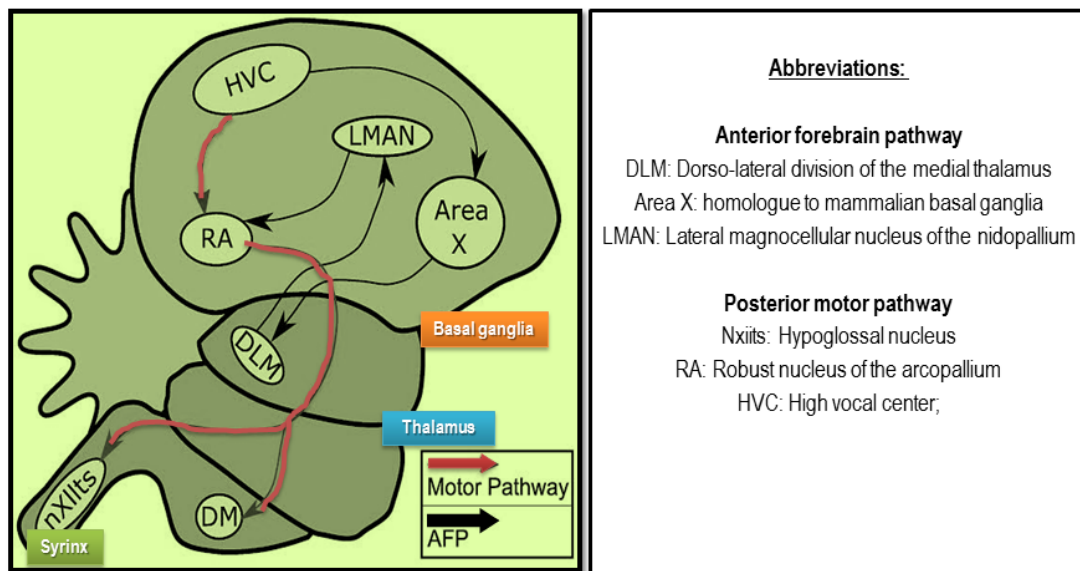


Fig: the neural basis of birdsong production in the brain

VII. EXPERIMENTS ON ZEBRA FINCH VOCALIZATIONS

Female calls affect male song delivery in zebra finches

Male song delivery in zebra finches is influenced by female sounds. Untaught male zebra finch song was continuously recorded for 15 seconds. A distinct variation of each of the seven motifs was sung in that part. The song of a male who was normally reared is depicted in Fig. 1a as five motifs out of a total of ten motifs and three motif variants. b. b. The variation in motif was different amongst ordinarily raised birds and was lower than in untaught birds. Among recordings the frequency of each motif was sung and was tabulated. The plot in the figure illustrates the cumulative proportion of the total number of themes sung. The degree of variation in an adult male's song can be measured by the number of motif variants required to produce 85% of all motifs sung. The diamonds represent a particular pattern of motif variation for a

normally reared male (the 85% level is reached with 2.18 motif variants), the triangles represent the extreme for normally reared males (8.69 motif variants were required to reach the 85% level), and the circles represent a distribution found only in untutored males (21.67 motifs were required to reach the 85% level).

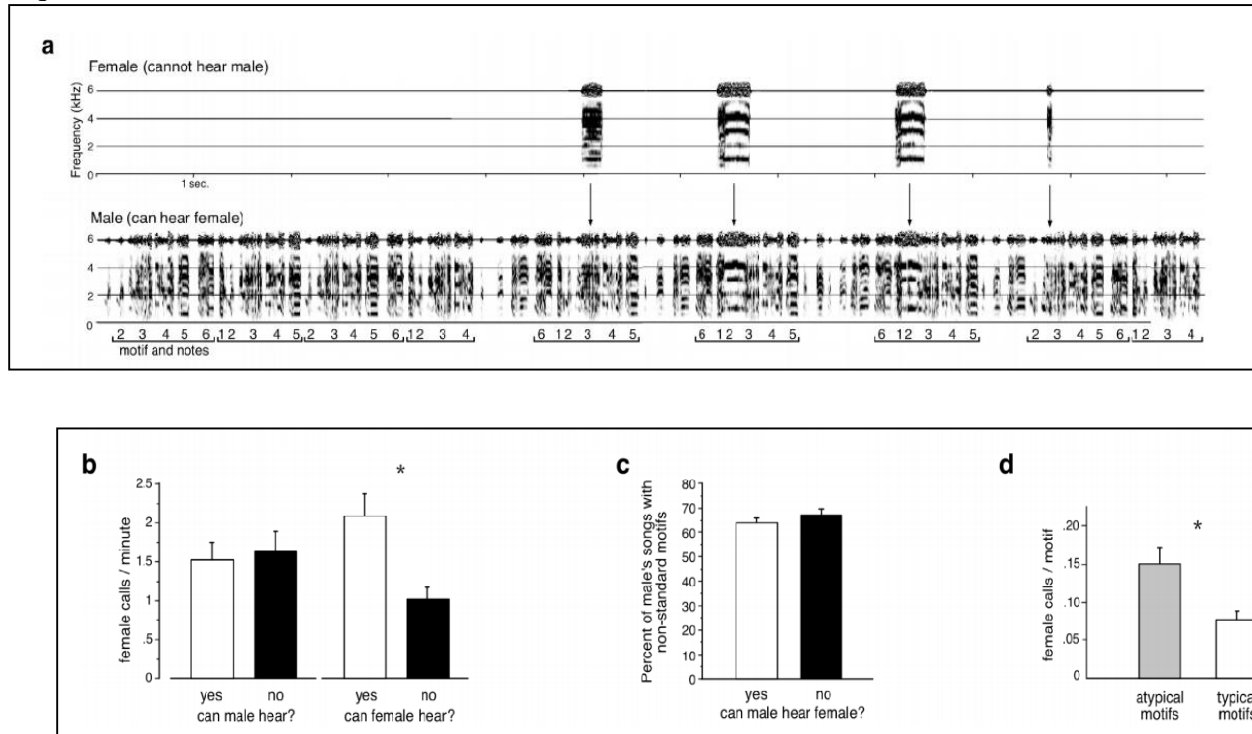


Fig: Undegraded and degraded sound spectrograms and oscillograms of a chaffinch song

Motif variation in tutored and untutored zebra finch song

- a. Zebra finch males and females were separated so they could see but not hear each other through a transparent partition. The experiment showed which bird could hear the other by relaying to a speaker on the other side of the partition. The female's vocalizations were played to the male even though she was unable to hear him. Under the sonogram of the male singer's song, motifs and notes are shown by bars and numbers. Before switching back to a more conventional motif structure, the male repeated the strange cries and singing a number of motifs. b. The average female call rate was unaffected by the males' hearing the calls, but the number of calls considerably increased ($p < 0.05$) when the females could hear the males' vocalizations. c. Whether or not males could hear a female did not have a big impact on how many unusual motifs the males sang. d. The female call rate was considerably greater ($p < 0.05$) during atypical motifs, showing that males were more inclined to sing unconventional motifs when they could hear a female's call.

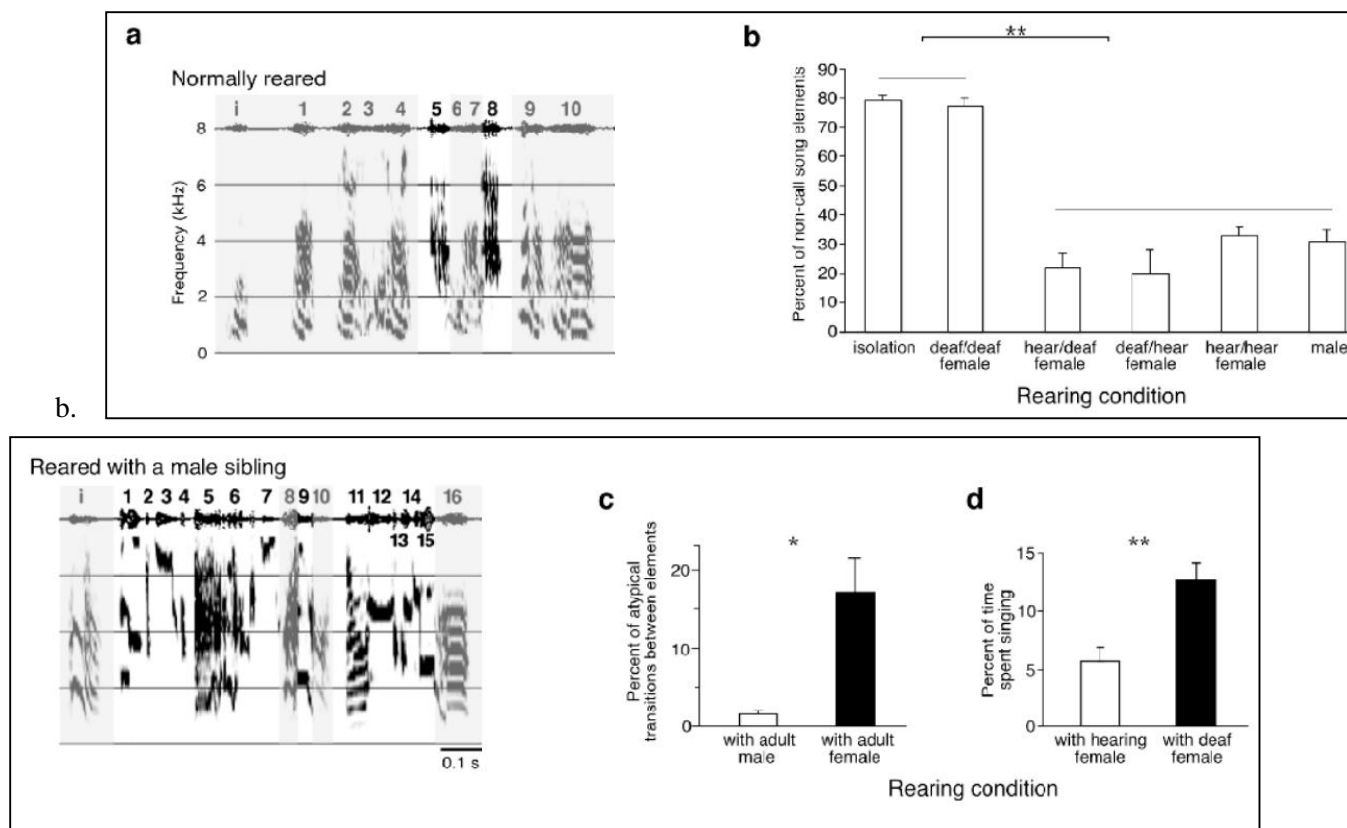


Fig: Sensorimotor calibration of song learning targets in swamp sparrows

VIII. SONG FUNCTIONS

Species Recognition

Birds sing mostly to communicate with other individuals, such as potential mates or rivals, of their own species. Individual birds must have the ability to recognize the songs of their own species and to discriminate such songs from those produced by heterospecifics. Songs indeed have diverged significantly among species, to the magnitude that most species produce songs that can be considered ‘species-specific.’ Interspecific divergence of songs is thought to be driven largely by selection against hybrid mate selection and offspring production. Males that produce species-distinctive songs, and females that are able to successfully identify conspecific songs, will be more likely to achieve conspecific mating and thus avoid costly hybrid mating. Thus, the production and recognition of species-distinctive songs should promulgate along distinctive trajectories in different songbird lineages. Species living in proximity, especially those that are closely related tend to evolve songs that occupy distinct positions in ‘acoustic space’ (Boncoraglio and Saino, 2007). Earlier study on neotropical ant bird songs provides strong support for the sound-environment hypothesis. The study evaluated song similarity within nine species trios, each representing a genus of the ant bird family (Thamnophilidae). Each trio was comprised of a focal species, a closely related species living in sympatry and a closely related

species living in allopatry. It was discovered that the songs of allopatric species pairs were noticeably more similar than those of sympatric species pairs. This finding recommends independent song divergence events within sympatric species, presumably caused by selection favoring the evolution of species-specific song production and song recognition abilities (Macedo et al., 2019). Compared with song features that vary among individuals, song features that do not vary within a species presumably serve as reliable species identification signals. This is especially true for invariant features that are clearly distinct or have little structural overlap from songs of sympatric species. A study was conducted on field sparrows using a series of playback trials to demonstrate the functional significance of multiple invariant song features. Playback stimuli were synthesized in which single invariant features were modified, one at a time, to values outside of the species-typical range. Territorial males were then presented with a choice of modified and control songs. Males were found to approach speakers disseminating control songs more often than speakers distributing modified songs, as expected. Follow-up trials were then performed in which test stimuli expressed modifications in all possible combinations of invariant features.

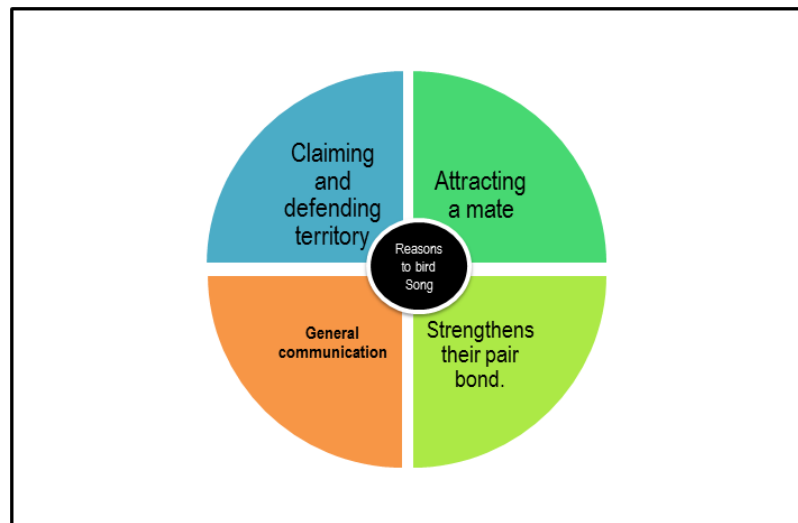


Fig: Functions of bird vocalization

Male communication and territorial function

The majority of passerine birds use song as a territorial signal, i.e., to announce a region that will be guarded from rival males. In a landmark study on the role that bird song plays in bird territorial behavior, Krebs and colleagues (Krebs, 1977) removed male great tits from their homes and territories. Loudspeakers were then placed, and recorded conspecific song, a control sound, or no sound was broadcast via them. It was observed that new males occupied territories earlier when no song or the control song (a tune on a tin whistle) was broadcast than when conspecific songs were. This experiment and others showed conclusively that male song keeps out competing males.. Additionally, field studies and observations of undisturbed singing in various circumstances have demonstrated that males use a rival's song to gather crucial information on which to make their choice of how to reply. Individual-specific information is

crucially important when interactions are repeated, as is the case with all social conduct. Birds can discriminate between known and unfamiliar persons using this information. Males also distinguish between neighbors and outsiders, and when they hear their neighbor's song coming from the other side of their territory, they become more hostile. In this way, knowledge of a song's familiarity is connected to the place where it is typically heard. The 'dear enemy effect' is the term used to describe the lessened response to a neighbor's song when it is heard from the 'right' direction (Stoddard, 1996). While neighbors compete with one another for territory and mates, once a relationship is established, the aggressiveness between the males in the neighborhood decreases. In research utilizing birdsong as a model to investigate communication networks, neighbors can also operate as an early warning system when a stranger starts singing someplace in the territorial region. This problem has garnered particular attention (Naguib, 2005; Peake, 2005).

Males can use a variety of singing techniques to indicate their readiness to escalate a contest during territorial disputes. Which method has which signal value varies depending on the species (Todt and Naguib, 2000). Males may time their songs to overlap those of their rivals during a conversation. Song overlapping is employed and understood as an agonistic signal in practically all species that have been examined to yet. A second strategy for agonistically addressing a rival is to sing a song that is similar to the one the opponent just sang in response. Changes in song rate and the frequency at which different song kinds are played can also indicate arousal levels. The form of the song can be related to testosterone levels in barn swallows (*Hirundo rustica*), and song can therefore be used to forecast fighting vigor. The role that music plays in defending a territory might change depending on the season and the time of day. For example, certain species of temperate-zone songbirds use the dawn chorus, a distinct peak in singing activity early in the morning, to defend their territory. (Staicer et al., 1996).

Function in Mate Attraction

There is now solid evidence that females employ song to get information about male motivation and quality when making pairing and mating decisions. In what are known as "extra-pair copulations," females may select a male partner based on his song then, after mating with him, continue to mate with other males who have more alluring songs. Two lines of research demonstrate how songs influence female preference. Laboratory studies have demonstrated that some song qualities are more receptive to females, while field research have demonstrated links between song traits and paternity and the success of mating. Males of several bird species alter their singing habits after mating, indicating that the purpose of song varies throughout the mate attraction phase and the period thereafter. After mating, the singing activity of many warblers drops noticeably, while nightingales and other nocturnal songbirds stop singing the day after a female has moved into their area (Amrhein et al., 2002). Sedge warbler (*Acrocephalus schoenobaenus*) males become paired earlier when they have large vocal repertoires, suggesting that repertoire size is a trait used by females in mating decisions. Females of great reed warblers (*Acrocephalus arundinaceus*) respond to complicated songs with greater display behavior than

simple ones, and it has been seen that they will only mate with nearby males who have a wider song repertoire than their social mate. Male Dusky Warblers (*Phylloscopus fuscatus*) who sing their song elements more fervently receive more extra-pair mating than do males who sing their song elements "less well." Additionally, research has revealed that males typically produce more song when their mate vanishes or is removed artificially. Additionally, investigations conducted in well controlled lab settings have demonstrated that females exhibit considerable preferences for particular song features. When exposed to larger song repertoires than when exposed to smaller, less sophisticated song repertoires, as in the case of great reed warblers, females exhibit greater copulation solicitation displays. In canaries, a complex syllable category inside the song's substructure has been identified as a "sexy syllable" that females pay particular attention to. It is now possible to examine female preference for song in greater detail thanks to more recent experiments that have included operant approaches, in which females were permitted to peck a key to release playback of songs of various complexity (Riebel, 2003).

IX. SUMMARY AND CONCLUSION

The primary impetus and impulsion of bird song is a modified version of vocal learning. The adult bird song, however, is the process's culmination. It is possible to understand the trajectory of song development retrospectively using adult song, and manipulations that skew the results of the process, such as raising young birds without a song model, help us better understand what is necessary for appropriate song learning. However, the physiologically significant functions that have been formed by natural and sexual selection—primarily territory defense and mate advertisement—are played by the typical adult song. A modified form of vocal learning serves as the main inspiration and driving force behind bird singing. The process's apex, however, is the song of the mature bird. Through the use of adult song, it is possible to comprehend the trajectory of song development in the past. Manipulations that skew the results of the process, such as raising young birds without a song model, can aid in our understanding of the prerequisites for effective song learning. The average adult song, on the other hand, performs the physiologically important roles that have been shaped by natural and sexual selection—primarily territory defense and mate marketing.

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