VIBRATION FREQUENCIES OF PASSERINE BIRD SONG[1]

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THE recording of bird songs on film produces a medium from which sounds can be studied objectively; hence we need no longer rely entirely on aural impressions. There, on the film, is printed in black and white, on a sound track of varying density or varying area, depending on which of two methods of recording has been used, the picture that the physical vibrations have made upon the sensitized film. The number of these vibrations per second determines the pitch of a sound. For example: a sound of 4096 vibrations per second is pitched at the highest note of the piano keyboard (C_7) and is said to have a frequency of 4096. Bird songs may also be recorded directly on wax, from whence phonograph records can be manufactured. This method, while satisfactory for purposes of reproduction, is not so accurate as film for objective study. In 1934 in Germany, and in 1935–37 in England, Ludwig Koch recorded bird songs directly on wax. He reports on the pitch of some ten passerine bird songs (Nicholson, E. M., and Koch, Ludwig, 'Songs of Wild Birds,' London, p. xxviii, 1936). The data are, however, fragmentary; he gives only the highest and lowest frequencies found. Those he reports on are lower, so far as the highest notes are concerned, than the results of my studies would indicate for American birds. The highest frequency he mentions is 5500 for the Yellow-hammer (*ibid.*, p. 3). But one gathers from what he writes that it is unlikely that he is getting all the highs present in bird song; probably somewhere in his apparatus he loses or partially suppresses them. There are a number of places where this loss is likely to occur. Unless microphone, amplifiers and recorder are very carefully coordinated and specially constructed, this is inevitable; in addition, it is doubtful whether it is practical to construct a disk recorder such as Koch uses, that will reproduce much over 5000 vibrations per second. In other words, songs containing frequencies over 5000 vibrations would probably be reproduced only in part in disk recording. On film, however, we have recorded in Nature, bird and insect sounds of a frequency of over 10,000 vibrations, and we have made laboratory tests up to 17,000. It is therefore unsafe to include these European recordings in our calculations, at least until numerically far more studies have been made than are yet reported, and until we have definite proof that these recordings include the higher frequencies.

In almost every case my studies were made from original negative film, produced by either the variable-density or the variable-area recording

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method. Perhaps half a dozen studies were made from positive prints. Variable-area and variable-density films give essentially similar results, with the main difference that varying-area track produces more visual detail than one of varying density. As at present we are concerned with the pitch-giving frequency of the songs of birds, either type of recording is satisfactory for study. Were we discussing the important factor of bird song, quality, or what musicians call timbre, we should find variable-area film more valuable for study. But thus far, in most of the studies, I have not attempted to analyze the sound further than to discover the main or pitch-giving frequency; and these remarks are restricted to pitch. The study of quality is highly involved, requiring in most cases a study of complicated wave shapes in order to determine the overtones or harmonics. This necessitates intricate mathematical calculations. It is agreed that quality—that which enables us to recognize a Meadowlark's note immediately, and not to confuse it with, let us say, a warbler's note given on the same pitch—is of fundamental importance. At some future time I hope to have sufficient material to offer the results of investigations on that phase. For the present, let us restrict our considerations to the main pitch-giving frequency.

In the past few years, in the Laboratory of Ornithology at Cornell University, we have studied intensively under a low power of magnification (25 diameters), several hundred pieces of film comprising the songs and calls of about one hundred species of birds. In order to simplify matters, I am in this paper, considering songs only. That is, I have taken what is generally accepted as song, and given the results; and in order to simplify further, I shall consider only passerine song. Thus I have reduced the results so that we have studies of fifty-nine passerine bird songs. The families and the number of species included are as follows: Tyrannidae, six; Corvidae, one; Paridae, one; Troglodytidae, three; Mimidae, one; Turdidae, six; Bombycillidae, one; Sturnidae, one; Vireonidae, three; Compsothlypidae, sixteen; Icteridae, six; Thraupidae, one; Fringillidae, thirteen. These species were selected at random and give a fair general sample of passerine song.

Almost no bird notes remain on the same pitch from instant to instant. That is, birds almost invariably slur either upward or downward, and often in both directions. I have attempted to estimate the bird songs on what appears to be the approximate mean of all frequencies in a note, and also the mean of the song.

Though a note may contain a very short portion (sometimes 0.002 seconds in duration) of either excessively high or rather low frequency, I have attempted to approximate the main pitch of the note, which in many cases, is the pitch of longest duration and sometimes the pitch which is

loudest. In many notes the pitch is changing constantly, and in these cases I have, as nearly as possible, estimated the average. While it is possible to count accurately the frequencies, these estimates are merely approximations. However, they are correct within, let us say, two or three per cent. Thus a note which I have called a frequency of 5000 vibrations might be 4850 or 5150, but the error will rarely be greater than that, and in most cases is considerably less. These differences are so slight as to be negligible, being less than one-quarter of a note. Errors may occur, in the following ways. In making a recording, the motor that drives the film through the recorder may occasionally be slightly slow or fast. However, this is very carefully watched, and it rarely happens that the film speed is not accurate; and when it is not, the difference is so slight as to be negligible. In estimating frequencies by inspection no attempt is made at absolute accuracy. Here again the introduced error is very slight. This has been proved a number of times by estimating independently, on separate days, the results of the studies of successive songs of the same bird. The results of these checks are always the same. The introduced error of estimation is very small; often two separately made counts give absolutely identical results. We thus have assurance that the method used is accurate for all practical purposes.

Of the fifty-nine songs included in this study we find, by the method described, that the average pitch of passerine birds' song is 4280 vibrations, or a quarter note higher than C_7, the highest note of the piano keyboard. This is about an octave and a half higher than the highest note that an operatic coloratura soprano can reach. The average of 4280 for fifty-nine species gives, I believe, a fairly correct estimation of all passerine song. However, there is great variation within the group. The average of Wood Warbler songs is considerably higher: for the sixteen species included in these studies, it was found to be 5350, or a shade higher than the E above the highest note on the piano keyboard. This is two notes higher than the average of passerine song. In the thrush group, of which the songs of six species were studied, the average was about 2890, which is a shade under the highest F sharp on the piano, or F sharp $_6$, approximately three notes lower than the average. Icterine song also is comparatively low, and we found in the six species studied, exactly the same, i.e., 2890, as in the Turdidae. Fringilline bird song on the whole is high, although it includes the Cardinal whose clear, whistling tune averages lower than one would presume. The Cardinal song is 2800, or a shade above the highest F (F_6) of the keyboard. The songs of thirteen fringilline species studied, showed an average of 4800 or just under D sharp $_7$, the D sharp above the highest note (C_7) of the keyboard.

The highest song studied was the Black-poll Warbler's. Its average note

was 8900 or over an octave above the highest note on the piano. It is midway between C sharp $_8$ and D_8. The Blackpoll also produced the highest avian frequency studied, 10,225, a note about a quarter under E_8. Other high averages were counted for birds in the following order: Grasshopper Sparrow, 8600; Cedar Waxwing, 8400; Blue-winged Warbler, 7675; Blackburnian Warbler, 7300; Black and White Warbler, 6900. The difference in frequency between the first three, Blackpoll, Grasshopper Sparrow and Cedar Waxwing, is only about a half a note, and is so small and the pitch so high, that an ear would have to be remarkably accurate to recognize the pitch difference.

COUNT OF PITCH OF PASSERINE BIRD SONGS

For further reference for those interested in the subject, the following table gives figures for all songs reported on in this paper. The birds are listed under their common names as given in the fourth edition of the A. O. U. 'Check-list,' grouped by families in systematic order.

	No. of songs studied	*Approximate mean*	*Highest note (about)*	*Lowest note (about)*
TYRANNIDAE				
Eastern Kingbird	1	6225	6225	5850
Eastern Phoebe	2	4300	5200	3300
Alder Flycatcher	3	3300	4750	1925
Little Flycatcher	1	3500	5125	2375
Eastern Wood Pewee	1	4125	4375	3650
Olive-sided Flycatcher	1	3100	3850	2375
CORVIDAE				
Eastern Crow	1	1500(?)	1650	1450
PARIDAE				
Black-capped Chickadee	1	3300	3700	3025
TROGLODYTIDAE				
Eastern House Wren	1	4100	7125	2050
Eastern Winter Wren	1	5000	8775	3300
Long-billed Marsh Wren	1	4400	5475	1925
MIMIDAE				
Catbird	1	3000	4375	1100
TURDIDAE				
Eastern Robin	1	2800	3300	2200
Wood Thrush	1	2750	4025	1825
Eastern Hermit Thrush	1	3000	4375	1475
Olive-backed Thrush	1	2925	3850	2000
Veery	1	3300	4750	2375
Eastern Bluebird	1	2550	3100	2200
BOMBYCILLIDAE				
Cedar Waxwing	1	8400	8950	7675

	No. of songs studied	*Approximate mean*	*Highest note (about)*	*Lowest note (about)*
STURNIDAE				
Starling	1	3475	8225	1100
VIREONIDAE				
White-eyed Vireo	1	2800	3825	1925
Yellow-throated Vireo	1	2750	3825	2325
Red-eyed Vireo	1	3600	5850	2375
COMPSOTHLYPIDAE				
Black and White Warbler	1	6900	8050	5300
Blue-winged Warbler	1	7675	8050	7125
Tennessee Warbler	1	6600	9150	4025
Eastern Yellow Warbler	1	5900	8775	3475
Black-throated Green Warbler	2	6025	6750	5125
Blackburnian Warbler	1	7300	8775	5475
Chestnut-sided Warbler	1	5125	8775	3100
Black-poll Warbler	4	8900	10225	8050
Northern Pine Warbler	1	4150	5125	3300
Oven-bird	2	4000	5850	3300
Northern Water-Thrush	1	2925	3850	2000
Louisiana Water-Thrush	1	4000	6600	2475
Mourning Warbler	1	3300	5125	2375
Yellow-breasted Chat	1	2600	4400	1275
Hooded Warbler	1	4000	5850	2925
American Redstart	1	6200	7300	4400
ICTERIDAE				
Bobolink	1	3000	6950	?
Eastern Meadowlark	1	4400	6025	3150
Western Meadowlark	1	2500	3475	1475
Yellow-headed Blackbird	3	2000	?	?
Eastern Red-wing	1	2925	4375	1450
Baltimore Oriole	1	2500	3825	2050
THRAUPIDAE				
Scarlet Tanager	1	2925	3625	2200
FRINGILLIDAE				
Eastern Cardinal	1	2800	4375	2200
Indigo Bunting	1	5700	8875	3250
Eastern Goldfinch	1	4100	7400	2750
Eastern Savannah Sparrow	1	5000	8775	3300
Eastern Grasshopper Sparrow	2	8600	9500	7675
Eastern Henslow's Sparrow	3	4200	6200	3425
Eastern Vesper Sparrow	2	4800	6600	2750
Slate-colored Junco	1	4750	5500	3850
Eastern Chipping Sparrow	3	5000	8400	3475
Western Chipping Sparrow	1	4000	5500	3300
Eastern Field Sparrow	1	4100	5100	3650
Swamp Sparrow	2	5250	7500	2925
Eastern Song Sparrow	4	4700	7700	1900

To summarize: I believe that these studies are sufficiently comprehensive to warrant the conclusion that passerine song averages above 4000 vibrations per second or around the highest note of the piano keyboard.

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