

AUDIO-SPECTROGRAPHIC ANALYSIS OF THE SONG
OF THE CONE-HEADED GRASSHOPPER,
NEOCONOCEPHALUS ENSIGER (HARRIS)

(ORTHOPTERA: TETTIGONIIDAE)

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The song of *Neoconocephalus ensiger* has been described as consisting of a rapid series of somewhat lipping notes that sound like *chwi* (Scudder 1874), *tsip* (Allard 1911), or *zick* (Cantrall 1943). Pierce (1948, p. 195) states that the notes have a frequency of 13,700 cycles per second (a pitch very near the second A above the highest note on the piano), and are 0.033 sec. in length separated by silent intervals 0.052 sec. in length. This writer cannot hear frequencies as high as 13,700 cps, yet has no difficulty in hearing the song of this insect; it would thus appear that something is wrong with Pierce's figure of 13,700 cps.

On August 24, 1953, a male of this species was collected in a grassy field in Bremen Twp., Lincoln Co., Maine; the insect was caged and later the same day a recording was made of its song. The recording was made with a Magnemite tape recorder, using a tape speed of 15 in. per sec; the insect was about 8 in. from the microphone. The specimen and the recording are in the writer's collection.

THE AUDIO-SPECTROGRAPH

The audio-spectrograph used in this study was a Vibralyzer, which was made available to the writer through the kindness of Dr. J. Allen Hynek, of the Department of Physics and Astronomy, The Ohio State University; the writer is indebted to Mr. William M. Protheroe, of the same department, for assistance in the operation of this instrument. The nature and use of the Vibralyzer is described by Borror and Reese (1953).

Two types of graphs can be made with the Vibralyzer. In one type frequencies are portrayed on the vertical axis and time on the horizontal axis, and variations in intensity appear as corresponding variations in the darkness of the mark on the graph. A second type of graph, called a section, shows (for any selected point in time) frequencies on the vertical axis and intensity on the horizontal axis. The graphs are made electrically on facsimile paper; frequencies are portrayed over a vertical distance of about 4 in. and time over a horizontal distance of 12½ in. The frequency range of the instrument, and the degree of time and frequency resolution, depend on the tape speed of the recorded signal fed into the instrument, and on the settings on the instrument. With the proper settings, frequencies can be determined from the graphs with an accuracy within 2 percent of the frequency range covered by the graph.

RATE OF PRODUCTION OF THE NOTES

The notes in the song of *N. ensiger* are uttered too rapidly to count, but can be counted if the recording is played at a reduced tape speed. Two sections of the song were recorded; in the first section the song is continuous, but in the second there are two places where the insect paused momentarily between notes; the three portions of the second section which are set off by these pauses may be designated 2a, 2b, and 2c. Data on the number of notes and their rate are given in table 1.

FREQUENCIES IN THE NOTES

Figure 1 is a graph of 20 successive notes in the first section of the recording. It is evident that the frequency distribution in each note is continuous within

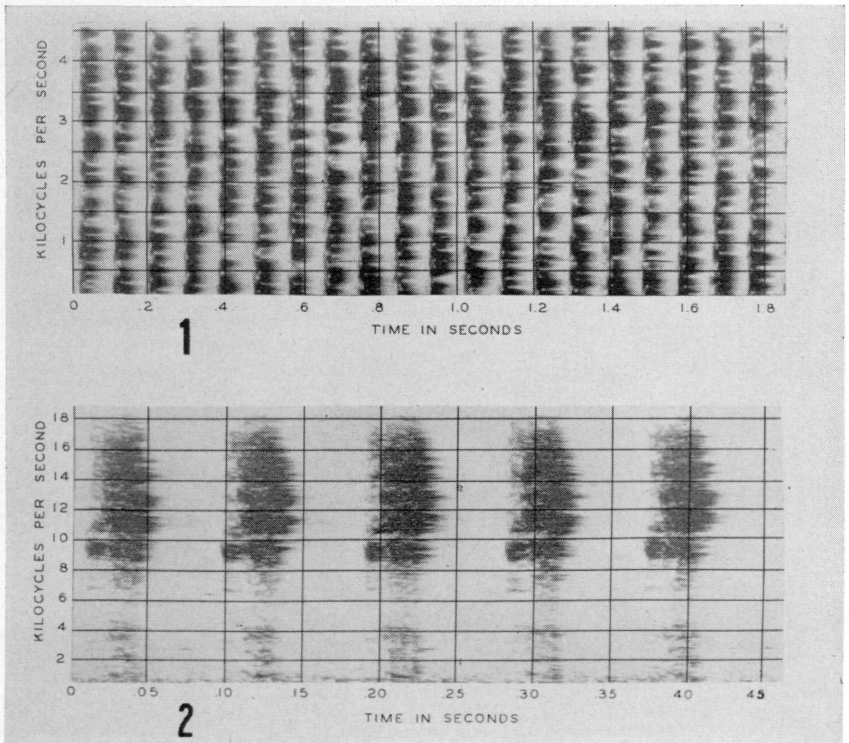
the range of the graph (40 to 4,500 cps); the abrupt cut-off at the top of the graph suggests that the notes contain frequencies higher than 4,500 cps. The various notes are by no means exactly alike as regards the relative intensities of the different frequencies within this range, but the rate with which the notes are uttered is quite regular.

Figure 2 shows five successive notes in the first section of the recording; this graph was made to bring out a greater range of frequencies than is shown in figure 1. While there are weak frequencies below 8,000 cps, the most intense frequencies in each note lie between approximately 8,500 and 17,500 cps. Practically all frequencies between 8,500 and 17,500 are present, but there are four or five groups

TABLE 1
Rate of the notes in the song of N. ensiger

Section	Number of Notes	Length (sec.)	Notes per Second	Average Length of Note + Interval
1	513	45.60	11.25	0.089 sec.
2a	321*	29.55	10.86	0.092 sec.
2b	177*	16.30	10.86	0.092 sec.
2c	124	11.25	11.02	0.091 sec.
Total	1135	103.70	10.95	0.091 sec.

*Each long note and double note (see fig. 8) was counted as one note.

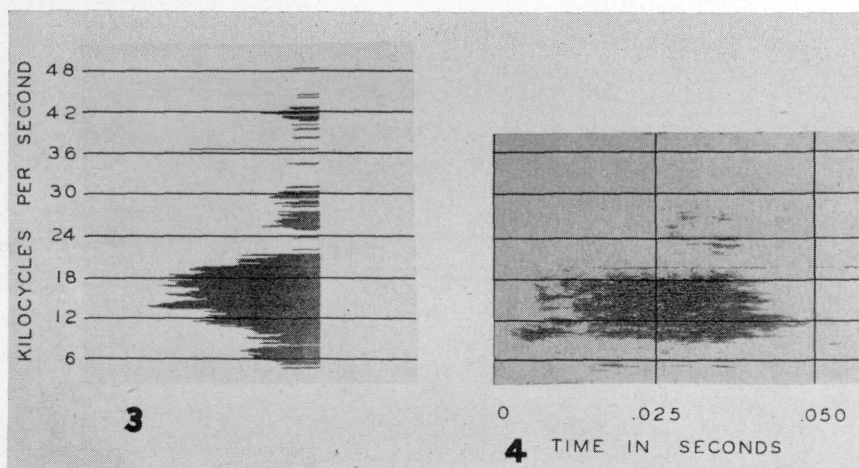


FIGURES 1-2. Audio-spectrographs of the song of *N. ensiger*. These graphs were made to give a maximum degree of frequency resolution; both were made from the first section of the recording. The difference in the darkness of the mark below 4,500 cps in the two figures is due to the different instrument settings when the graphs were made.

of more intense frequencies in this range. Again, the successive notes are very much alike, though not absolutely identical.

Figure 4 shows a single note, and covers a much greater frequency range than either of the first two figures. Here the most intense frequencies appear to consist of a band between about 9,000 and 18,000 cps. Frequencies below 4,500, distinctly shown in figure 1, are barely perceptible in figure 4; an instrument setting which gives a good graph for the more intense frequencies between 9,000 and 18,000 cps scarcely shows the frequencies outside this range. This graph does not portray a very wide range in intensity, but it suggests that there are frequencies in the note much higher than 18,000 cps.

By making a section graph through one of these notes it is possible to portray a greater range in intensity than is possible in a graph like that in figure 4. Such a section, taken at about the middle of a note, is shown in figure 3. The length of the mark at any given frequency level in this figure is proportional to the decibel value of that frequency. Additional data will be needed before a definite decibel value can be given for any particular note or frequency. Figure 3 shows that the note contains frequencies up to almost 50,000 cps.



FIGURES 3-4. Audio-spectrographs of the song of *N. ensiger*, made from the first section of the recording. Figure 3 is a section through the middle of a note. Figure 4 has the same frequency scale as figure 3.

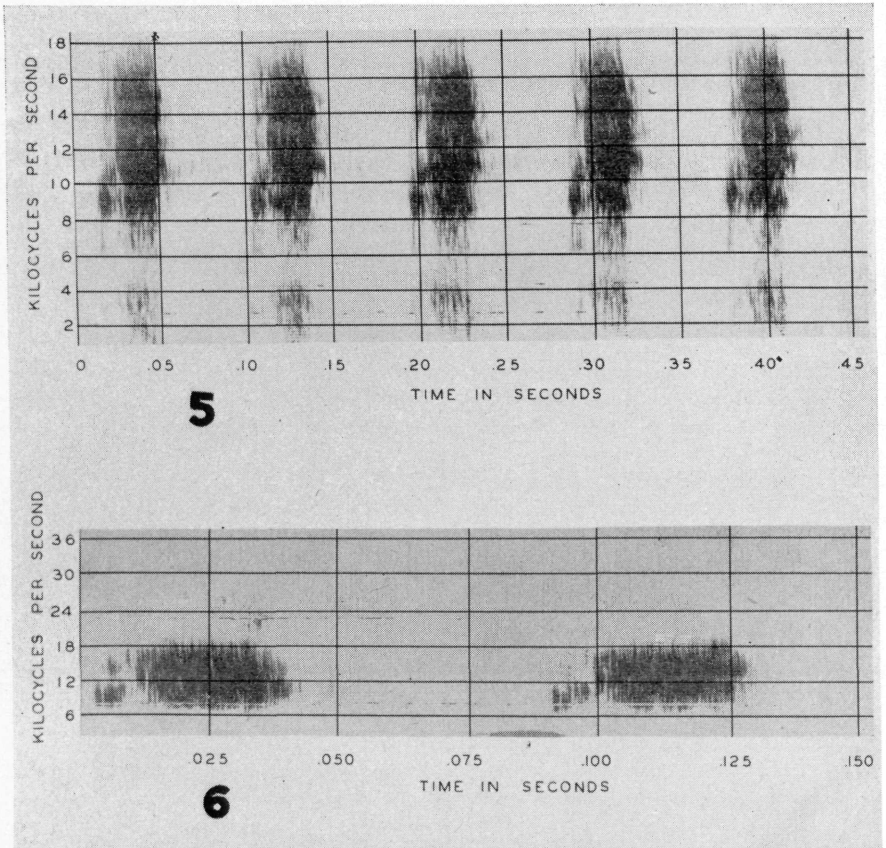
Since the notes of this insect contain a wide band of frequencies they are noise-like rather than musical, that is, they cannot be assigned a particular pitch. How they sound to the ear will depend on how well that ear can detect the higher frequencies present. To this writer, whose hearing falls off very rapidly above about 10,000 cps, the notes sound somewhat rasping; to a person with a normal hearing range (up to 15,000 or 16,000 cps) the higher frequencies will be more evident, and the notes will sound more lisping. The figure of 13,700 cps given by Pierce (1948) probably represents an average of all the frequencies present. Pielmeier (1946), using a sound level meter in which the frequencies measured could be varied, found no output peaks above 20,000 cps in the song of this species. Figure 3 indicates that the intensity of the frequencies above 20,000 cps is quite low, in general lower than that of the frequencies below 8,000 cps.

LENGTH AND CHARACTER OF THE NOTES

The graphs in figures 1 to 4 were made using a narrow band filter, to give maximum frequency resolution; the remaining figures were made using a wide band filter, to give maximum time resolution.

Fig. 5 shows that the individual notes are not steady tones, but consist of a very rapid series of pulses. Each note begins with a series of pulses whose most intense frequencies lie between about 8,000 and 11,000 cps, as shown by the little "blurb" at the lower part of the dark area representing the note's loudest frequencies. One second covered about 22 in. on the original of this graph.

Figure 6 shows two successive notes in the first section of the recording; here we have a high degree of time resolution, with about 66 in. on the original graph representing one second. The "blurb" at the beginning of each note is shown more distinctly here. A number of graphs of this sort were made, and the indi-



FIGURES. 5-6. Audio-spectrographs of the song of *N. ensiger*, made from the first section of the recording. These graphs were made to give a maximum degree of time resolution.

vidual notes varied in length from 0.037 to 0.041 sec., averaging 0.039 sec. Since the average length of the note plus the interval between notes is 0.091 sec. (table 1), the interval therefore averages 0.052 sec. (the same figure given by Pierce). The pulses in the note are slightly irregular, but there are about 40 per note.

THE MECHANISM OF SONG PRODUCTION

When this insect sings the front wings are elevated slightly and moved laterally (outward and inward), at a rate that is too fast to count or to determine what part of the movement actually produces the notes. The notes are produced by the

rubbing of the scraper of one wing (a specially modified portion of the anal edge of the wing) over a file-like ridge on the other wing. There is a file on both wings, but since the file is on the lower surface of the wing, and at rest the base of the left wing overlaps the base of the right wing, apparently only the file on the left wing is used in producing the song.

The file on the left wing is a little over 3 mm. in length and contains about 100 teeth; one wing studied contained 100 teeth in 3.2 mm., and Pierce (1948 p. 195) gives the figure of 108 teeth in a file 3.15 mm. in length. The file on the right wing is shorter and contains about 70 teeth. The teeth of the file on the left wing are not evenly spaced; they are somewhat closer together in the inner (or posterior) half of the file than in the outer half, and the teeth from about the fifteenth to the twentieth from the outer end are somewhat closer together than those adjacent to them. The teeth project from the wing at about a right angle; the inner side of each tooth is nearly straight, while the outer side is slanted.

How much of this file is used to make a note is not known. It was stated above that each note contained about 40 pulses; it seems probable that each of these pulses represents a tooth being struck. If this is the case, then only about 40 percent of the file teeth are used in making each note, and the teeth are struck at the rate of from 1,000 to 1,200 per second¹, with the scraper moving at the rate of about $2\frac{1}{2}$ in. per sec.

An interesting question might be raised at this point—is it the outward or the inward movement of the wings that produces the sound, or do both movements produce it? Allard (1929) and others believe that the notes are made only by the inward movement, but to the writer's knowledge this never been conclusively demonstrated. Information on the rate of the wing movements during singing would help to answer this question, but such information is not at present available; perhaps some light may be thrown on this question by a consideration of audio-spectrographs of the song and the structures by which the song is produced.

If the pulses in each note represent individual teeth being struck, then only about 40 percent of the teeth in the file are struck in producing each note. Of the total time from the beginning of one note to the beginning of the next—about 0.09 sec. (table 1)—the note itself takes on the average 0.039 sec., or just a little over 40 percent. If the scraper moves from one end of the file to the other and at a uniform rate (and this is certainly a big "if"), it would appear that the note is produced during that portion of this movement when the scraper hits the teeth of the file. This would not allow any time for return movement of the wings without sound, and would indicate that a note is produced by *both* the outward and inward movements of the wings.

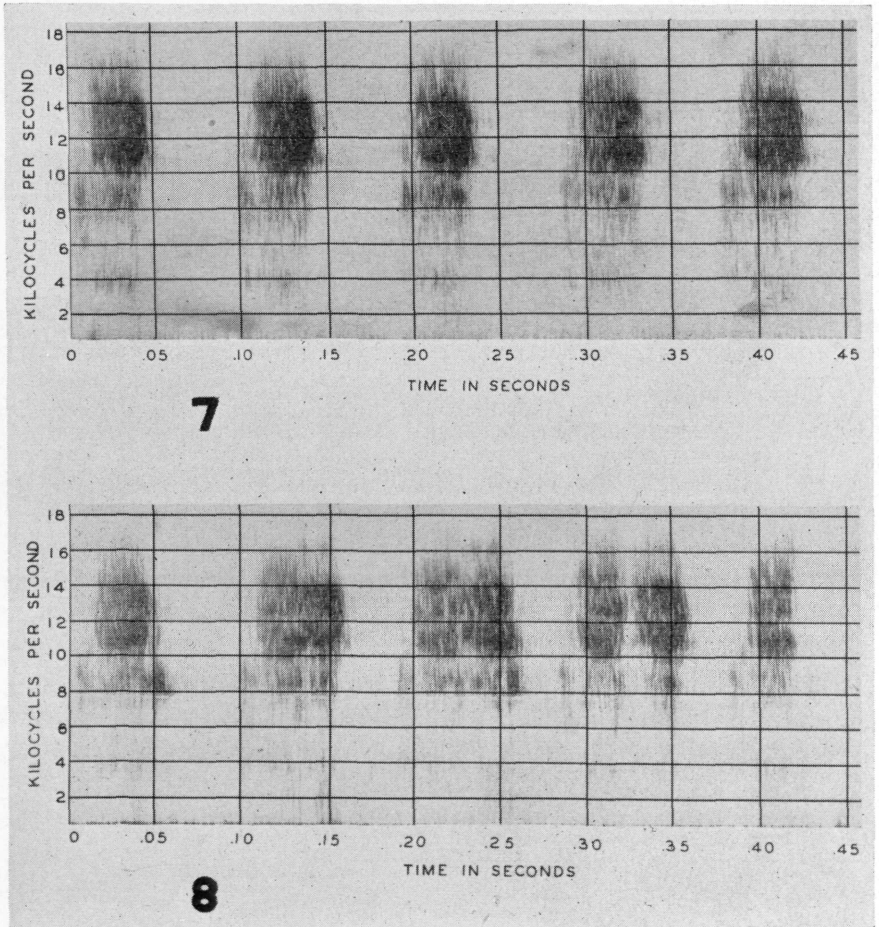
It seems likely that the insect would stop singing with its wings in a closed position, hence if a note is produced by both the outward and inward movements of the wings then each period of song would contain an even number of notes. Only one portion of our recording can possibly be considered a complete period of song, namely, section 2b. This section contains an *odd* number of notes (177), which might indicate that the notes are *not* produced by both movements. However, the silent interval at either end of section 2b is very short, about 0.1 sec., or only about twice the usual interval between notes; hence this section may not represent a complete song period of the insect.

The shape of the file teeth suggests that if a note was produced by both the outward and inward movements of the wings, these two notes would probably be slightly different. In the graphs discussed so far, which were made from the first section of the recording, there is no indication that alternate notes are more alike than successive notes; the notes are all essentially alike. It would thus

¹Pierce's figures (op. cit., p. 196) on the number of teeth struck per second range from 286 to 875, averaging 588, a figure Pierce believes to be too high.

seem that either all the notes are made by the scraper moving in the same direction, or that in spite of the shape of the teeth both movements of the wings (outward and inward) produce a similar sound.

If it is assumed that each note is made by the scraper moving in the same direction over the file, with the backstroke silent, it might be argued that since the wing movements are so fast and the clearance between scraper and file on the backstroke probably small, the scraper might occasionally hit the file on the backstroke. If this occurred, then we would get an extra note, and the extra note



FIGURES. 7-8. Audio-spectrographs of the song of *N. ensiger*, made from section 2b of the recording. Figure 7 shows a series of normal notes; the series shown in figure 8 contains three unusual notes.

might be expected to be a little different from the preceding and following notes. Furthermore, if such backstroke notes were produced we would expect them to be irregular, and this contact of the scraper with the file on the backstroke would probably slow down the wing movements and result in a slightly slower rate of the regular notes.

There is no indication of such "backstroke notes" in sections 1 and 2c of our recording, but in sections 2a and 2b there are. The note rate in these two sections

(see table 1) is slightly lower than that in the other two sections. There are several examples of such notes in section 2a and 2b; figure 8 shows some from section 2b. A group of normal notes in section 2b is shown in figure 7; figures 7 and 8 were made with similar instrument settings for ready comparison.

The second and third notes in figure 8 are longer than usual, and the fourth note is double. The little "blurb" at the beginning of the normal notes appears also at the *end* of the second part of the third and fourth notes (fig. 8, at the .25 and .35 sec. lines), where it is stronger than the "blurb" at the beginning of the first part of these notes. There is no very distinct break in the middle of the second long note, and practically no break at all in the first long note; if these two long notes represent both the normal stroke and the backstroke, then the wings were stopped and reversed almost instantaneously.

There is another possible explanation of the long and double notes shown in figure 8. In the case of the long notes, it is possible that the scraper simply struck more file teeth than usual; the absence of a distinct break in the middle of the note suggests this possibility. In the case of the double notes it may be that the scraper "bounced," and for some reason the last teeth struck were struck harder than the others, thus producing the little "blurb" at the end of the double note.

SUMMARY

A tape recording of the song of *Neoconocephalus ensiger* (Harris) was analyzed by means of an audio-spectrograph. The song consisted of a series of similar notes uttered at the rate of 10.86 to 11.25 (average 10.95) per sec., the notes averaging 0.039 sec. in length. The notes in most of the recording were very much alike, and each consisted of about 40 pulses; these pulses probably represent individual teeth of the file being struck. The notes are noise-like rather than musical, and contain a wide band of frequencies; the most intense frequencies lie between about 8,000 and 17,500 cps, but each note contains a band of frequencies below this range down to at least 40 cps, and frequencies above this range to nearly 50,000 cps.

Each note of the song is probably produced by one movement of the scraper of the right wing over the file of the left wing. The length of the note and the number of teeth struck, in relation to the length of the silent interval between notes and the total number of teeth in the file, suggest that a note may be produced by both the outward and inward movements of the wings. On the other hand there are indications that only one of these movements produces the note; (1) what appears to be a complete period of song contains an odd number of notes, and (2) the structure of the file teeth suggests that the notes made by the scraper moving in different directions would be different, yet the graphs indicate that successive notes are as much alike as alternate notes. The occasional long or double notes that appear in the song suggest that the scraper *does* occasionally strike the file on the backstroke, but that normal notes are made only by one movement of the wings.

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