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Dominant frequency characteristics of calling songs in cicada *Chloropsalta smaragdula* Haupt, 1920 (Hem: Cicadidae) and its relationship with body length, width, and weight.

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Abstract
To study the calling songs in cicada *Chloropsalta smaragdula* and its relationship with body length, width, and weight, a research was conducted in the Iranian city of Mobarakeh, Isfahan Province, in 2011-2012. Different sound samples were taken under field and laboratory conditions. Throughout the sampling period, the calling songs of nine male cicadas were recorded and studied. The sound of each individual cicada was separately analyzed by MATLAB Software, and the size of its main parameter (i.e., dominant frequency) was determined and recorded. The results showed that this cicada species have a mean dominant frequency of 9.121 kHz. Moreover, the correlation coefficients indicated that there is a positive relationship between the dominant frequency for the audio signal of the calling songs with body width and weight, and is significant at $p<0.0001$ probability level, thus, indicating that dominant frequency increases as body width and weight increase.

Keywords: body morphological characteristics; calling song; cicada; dominant frequency

1. Introduction
Sound is a phenomenon produced from the vibration of an object, and human being may hear it through some physiological interactions in the auditory system [6].A large number of animals, including many insects, have a hearing range with a sound sensitivity higher than that of human beings [9]. The sounds of insects were first recorded by Greek scientists, like Aristotle [3]. Most insect groups have specialized sound production and receiver systems being used for intraspecies and interspecies communication [3]. Some insect species communicate through sounds to attract the opposite sex. In the process of sound production, male sex is often the producer and female sex acts as the receiver [11]. Cicadas are among the insects that use sound to communicate with each other. Male cicadas can produce sounds with an organ called tymbal on the lateral abdomen part of their abdominal segment [3].
Some cicada species produce very special sounds whose frequency analysis may help us to differentiate them from others [7, 8]. Cicadas produce a set of audio signals that differ based upon behavior and time pattern. Sometimes, time pattern and the set of varying signals are quite different in various species [13]. Moreover, differences in audio signals by cicadas, including the genera *Magicicada sp.*, *Okanagana canadensis*, and *O. rimosa* [2] and the genus *Tibicina* were observed [11]. Sueur *et al.* (2010) [8] studied the calling songs in *Cicada orni* and *Cicadatra atra* species. The results from their study showed that dominant frequencies of sound production in *C. orni* and *C. atra* are 2.13 kHz and 10.23 kHz, respectively. Studies on morphological characteristics and qualities of calling songs (i.e., spectral and temporal characteristics) in some insects revealed that there is a relationship between these two parameters. For example, the studies on *Gryllotalpa major* Saussure suggested that there is a statistically significant relationship between the male's body length and its two calling parameters, namely chirping songs and dominant frequency [4].
Moreover, research on the sounds of three cicadas *Cyclochila australasiae*, *Macrotristria angularis*, and *Magicicada cassini* showed that there is a significant relationship between their body lengths and sound frequency features in these species [1]. Based upon the studies on the cicadas in Cicadidae, Song pressure level and song alarm have increased along with the body weight increase. It is probably due to the larger size of tymbal muscles in larger species [10].

Thus, the purpose of this research was to study the calling songs in the cicada *Chloropsalta smaragdula* and their relationship with body length, width, and weight.

2. Materials and Methods

This experiment was conducted in 2011-2012 in the vineyard of Hassanabad Village at Tang Bidakan Rural District of the Iranian city of Mobarakeh in Isfahan Province, situated 15 kilometers southwest of the city, being at longitude 32´, altitude 32´, and 1,750 meters above sea level. The region had a cold climate and semi-arid warm weather. Studying the environmental conditions and the region under experiment was required to take samples. Therefore, the data related to the present time of the cicada in the region as well as the locality and time of its sound production were gradually recorded from the early June of 2011.

There were masses of short vine trees in the experimental region. According to the observations, *C. smaragdula* selects vine trees to produce its calling songs. Thus, a powerful instrument was required for taking sound samples of the male cicada. A digital Japanese sound recorder, model ICD-Sx713, with a sampling frequency range of 16 bits, and 44.1 kHz linear PCM, and a frequency response of 40 – 20,000 Hz was used to take the samples. Then, sampling was started by observing the cicadas on the vine trees and listening to their sounds. The sound recorder was turned on and quietly placed on a small basis in a distance of one meter from the cicada. After recording the needed sound of each individual cicada, it was collected with an insect net for further morphological measurements in the laboratory. This study was conducted on 30 individual cicadas, and 10 minutes of the recorded sound were analyzed for each one. A precise analysis of frequencies was obtained using MATLAB Software. However, due to poor sound quality, some samples were removed from the experiment. Thus, the dominant frequency feature was obtained only for the sound of nine individual cicadas. Morphological characteristics (i.e., body length, width, and weight) as well as the parameter attained from all the samples were analyzed by SAS Software (ver.9.1) and Pearson correlation coefficient.

Since every cicada species has a different sound structure, it was required that the regional cicadas be identified in order to study the relationship between their sounds and morphological body characteristics. Hence, a pair of male and female cicadas was sent to the Insect Taxonomy Research Department (ITRD) affiliated with the Iranian Research Institute of Plant Protection (IRIPP), and the cicada *C. smaragdula* Haupt, 1920 (Hem.: Cicadidae) was identified.

3. Results and Discussion

In this study, the dominant frequency related to the audio signal of the calling song of the species *C. smaragdula* was identified and measured to be compared with its morphological body features (i.e., length, width, and weight) (Table 1). The studies on the audio signal features of the calling songs revealed that this cicada has a mean dominant frequency of 9.121 kHz. The results from analyzing the dominant frequency features showed that the cicada has a specific mean dominant frequency, which is different from that of other species. In addition, its dominant frequency falls within a range between those of other cicada species. However, mean dominant frequency was found to be 4.51 kHz in *Cicada orni* [12], 10.78 kHz in *Cicadatra atra*, 6.57 kHz in *Lyristes plebejus* [12], and 10.2 kHz in *Psalmocarias alhageos* [15].

The results obtained by other researchers thus confirm the results of the present research.

Of the data derived from analyzing the calling songs, the minimum and maximum dominant frequencies were 8.139 kHz and 9.789 kHz, respectively (Table 1). Therefore, a difference of about 1.5 kHz was observed between minimum and maximum dominant frequencies for all individuals, indicating the experiment accuracy. Moreover, close distances between the frequencies are likely because the male individuals have to use close frequency ranges to attract the females. The higher the frequency, the more females it probably invites for mating.

The statistical results of the data through analyzing Pearson correlation coefficients for all the variables related to the audio signal characteristics of the calling songs and morphological features (e.g., body length, width, and weight) are shown in Table 2. The results showed that there are relationships between some of the morphological parameters and the dominant frequency of calling songs at $p<0.0001$ probability level (Table 2). For instance, there was a positive relationship between the dominant frequency of the calling song with body width and weight (Figs. 1 and 2). In other words, dominant frequency increases as body width and weight increase. However, the relationship between this sound parameter and body weight was positive but not significant.

In other words, with increasing body width and weight, the volume of body muscles also increases; therefore, a sound with greater range is produced. For example, the results illustrated that the collected sample No. 9, with the highest weight (0.55 gram) and the highest body width (10.6 mm) had the greatest dominant frequency (Figs. 1 and 2). Indeed, a larger muscle mass has more energy that may be used as a stimulus to produce a more powerful sound. Higher muscle energy is gained when the insect's body weight and size increase because of proper nutrition and other factors so that it can produce a better sound to attract its opposite sex. The results reported by Young and Josephson (1979) [14] showed that the increase of tymbal muscle tissue leads to increase in the sound pressure level in the species *Cystosoma saundersii*. MacNally and Young (1981) [5] also stated that bodyweight increase in *Cystosoma saundersii* is the reason for its production of a more powerful sound.

Our research on the relationship between the calling song feature (i.e., dominant frequency) and morphological characteristics (i.e., body length, width, and weight) in the cicada *C. smaragdula* is a start for more accurate and detailed studies on the other parameters of its calling song and behavior as well as comparing them with morphological characteristics. Moreover, it is essential that the calling songs of the other species in the genus *Chloropsalta sp.* be studied and compared with one another, so more comprehensive and accurate studies, especially in viewpoints of ethology and taxonomy are recommended.

Table 1: Measured parameters related to audio signal features of calling songs in the cicada *Chloropsalta smaragdula*

Sample No.	Dominant Frequency Hz
1	8.139
2	8.584
3	8.646
4	8.859
5	9.374
6	9.445
7	9.561
8	9.689
9	9.789

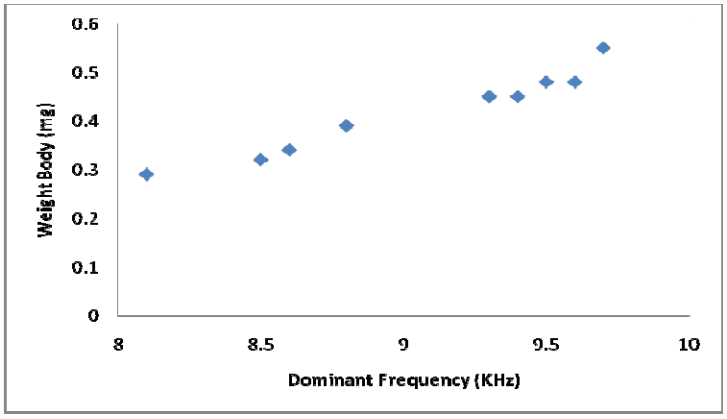

Fig 1: Relationship between dominant frequency and body weight in the cicada *Chloropsalta smaragdula*

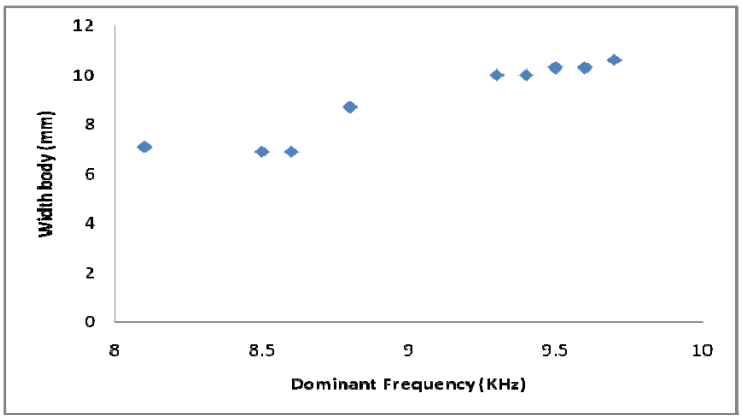

Fig 2: Relationship between dominant frequency and body width in the cicada *Chloropsalta smaragdula*

Table 2: Correlation coefficients between morphological characteristics and calling song parameter in the cicada *Chloropsalta smaragdula* ($p<0.0001$)

Calling song feature	Body length (mm)	Body width (mm)	Body weight (mm)
Dominant Frequency (Hz)	0.22631 ^{ns}	0.94914*	0.97751*

*: significant; ns: not significant

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