# Humming and Buzzing
# Acoustical Features of Annoying Mosquito Noises

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## Introduction

Mosquitoes can transmit diseases like malaria or dengue and are difficult to monitor due to their tiny sizes ranging from 3-15 millimeters, depending on the species [1]. A method of documenting the population and occurrence in special areas is the acoustical analysis of species-specific wing beats, which allows a rough interpretation of species and sex [2]. In Germany and Austria, mainly the species Culex Pipiens is native and widespread [3].

For humans and animals, only the bigger, female mosquitoes are dangerous as they are the only ones sucking blood. With their wings, females produce a buzzing sound of around 300-400 Hz, while the wing frequency of male mosquitoes is above 600 Hz [2], [4]. These differences in pitch range can help to estimate the bite ability of mosquitoes. For example, a free online tool [5] allows recording any mosquito noise and roughly recognizes from signal composition, if it‘s a biting, female mosquito or not.

## Research Question

Until now, there is no study that examines specifically the sound of mosquitoes and how these buzzing sounds are perceived by humans. This study therefore investigates:

Which timbre characteristics are responsible for mosquito buzzing being considered *annoying* and *dangerous*?

## Method and stimuli

15 buzzing sounds with lengths between 4 and 6 s were taken from the Boom and the Blastwave FX library, and equalized in loudness (26.6 sone).

These stimuli were rated in an online questionnaire on the scales *annoyance* [not annoying – extremely annoying, 4-point likert-scale] and estimated *bite probability* [0 – 100%, slider]. 59 participants‘ (26 ♂, 31 ♀, 2 ⚥; aged 18-80; Ø: 40 years) assessments were evaluated. Besides the ratings of the buzzing sounds, sociodemographic data and attitudes towards general *annoyance* of mosquitoes, frequency of mosquito bites [never – constantly] and fear of bites were collected.

Audio features related to pitch, partial strengths, roughness, frequency/amplitude modulation and other timbre attributes were extracted and analyzed using MIRtoolbox [7], CREPE [8] and PyTimbre [10].

## Results

The estimated bite probability is strongly related to the rated annoyance ($r = 0.939$, $p < 0.001$). Bite probability ratings are influenced by participants‘ general specified mosquito exposure in everyday life, with frequently or constantly stung individuals assigning higher probabilities ($t_{(57)} = 3.310$; $p < 0.001$) (Fig. 1).

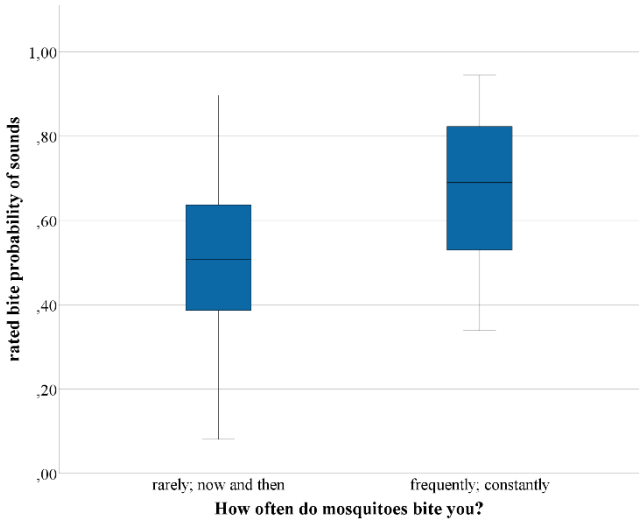


**Figure 1:** Rated bite probability of heard sounds [Ø] in terms of experienced sting frequency in participants ($p < 0.001$).

### Sound composition

Addressing timbre characteristics of buzzing, estimated annoyance and bite probability of buzzing sounds correlate with

- the minimum pitch of the sound
  ($r_{annoy} = 0.828$, $p < 0.001$; $r_{bite} = 0.940$, $p < 0.001$).
- the strength of the first partial
  ($r_{annoy} = 0.539$, $p = 0.038$, $r_{bite} = 0.770$, $p < 0.001$).
- the roughness (according to Vassilakis)
  ($r_{annoy} = -0.531$, $p = 0.042$, $r_{bite} = -0.607$, $p = 0.016$).
- the frequency modulation hub
  ($r_{annoy} = -0.661$, $p = 0.007$).

Minimum pitch of the sound means the lowest mosquito humming pitch that could be measured in the respective sound sample. The strength of the first partial is collected by extracting the positions of all partials included in one signal and calculating how much of the overall signal's energy lies within the filterband of the first partial. Roughness was calculated via MIRtoolbox [7] using ‘Vassilakis’ weighting [9]. This includes summing the sensory dissonance contributions of all pairs of sinusoidal components in a sound, which are calculated as a weighting of the partials’ amplitude product and a function of their frequency separation (peaking

around 1/4 of the critical bandwidth). The frequency modulation hub finally describes the extent or strength of a frequency modulation.

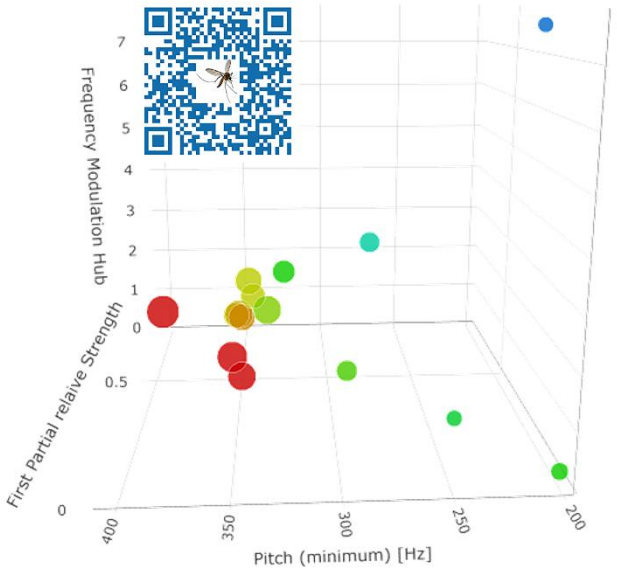


**Figure 2:** Audio features that are connected to the annoyance of mosquito buzzing: the redder the dots, the more annoying the mosquito buzzing was perceived to be; the estimated likelihood of being bitten rises with the size of the dots. (Interactive plot at: https://muwiserver.univie.ac.at/gnats)

Based on these main findings regarding the sound components, a linear regression model for perceived "annoyance" of mosquito buzzing sounds was trained and tested using the holdout method, which shows a fit of $R^2 = 0.968$ on the training set (n = 10) and $R^2 = 0.836$ on a previously separated test set (n = 5). All of the three variables significantly contribute to the model ($p < 0.001$).

In the formula above, standardized regression coefficients are

$$\textbf{Annoyance} = 1.643 \cdot \text{pitch (min)} - 1.096 \cdot \text{first partial strength} - 0.461 \cdot \text{frequency modulation hub}$$

displayed. Please note that although first partial strength shows a positive relation to annoyance in bivariate analysis, the multivariate regression model assigns a negative coefficient to it. This is likely due to the high intercorrelation between first partial strength and minimum pitch (r = 0.885), which introduces multicollinearity. The regression coefficients represent the unique contribution of each variable after controlling for the others. Therefore, the negative coefficient does not contradict its overall positive relation with annoyance, but indicates that, once the shared variance with pitch is accounted for, the strength of the first partial contributes in the opposite direction. The model shows a high fit also on the test set, suggesting that the multicollinearity, while influencing interpretability does not impact predictive performance.

**Minor differences in age and gender**

Interestingly, the self-estimation of how frequently someone is generally bitten by mosquitoes depends on age, a connection which has already been studied with different outcomes. For example, a questionnaire-based study indicated correlations of the estimated probability, which is higher rated with increasing height in men as well as with increasing BMI in women, but there was no significant influence of age or other collected sociodemographic data [6].

In this study, comparing younger subjects' (≤ 40 years; n = 31) estimation of mosquito bites in general and those of older participants shows that younger people experience being stung more frequently ($t_{(57)} = 2.992$; $p = 0.004$) (Fig. 3).

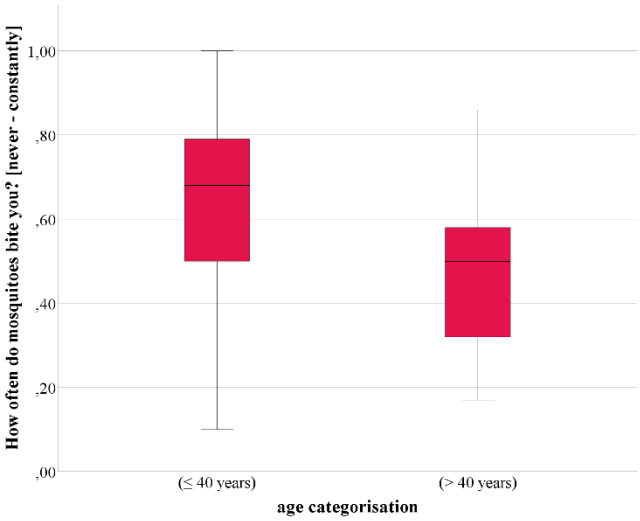


**Figure 3**: Experienced mosquito sting frequency [never – constantly] in terms of younger (≤ 40 years) and older participants (> 40 years).

Analyzing subgroups of ratings, there is also an effect of age regarding timbre characteristics, where in addition to pitch ($r_{annoy} = 0.805$, $p < 0.001$) and the strength of the first partial ($r_{annoy} = 0.566$, $p = 0.028$), the absence of roughness ($r_{annoy} = -0.544$, $p = 0.036$) in sounds seems to be related to a stronger annoyance perception by younger listeners, while the frequency modulation hub does not play a statistically relevant role (Fig. 4).

Although no significant differences regarding gender of participants and ratings were observed, a lower dynamic complexity seems to play a stronger role in the annoyance ratings of the 31 female listeners ($r_{annoy} = -0.584$, $p = 0.022$), see Fig. 5.

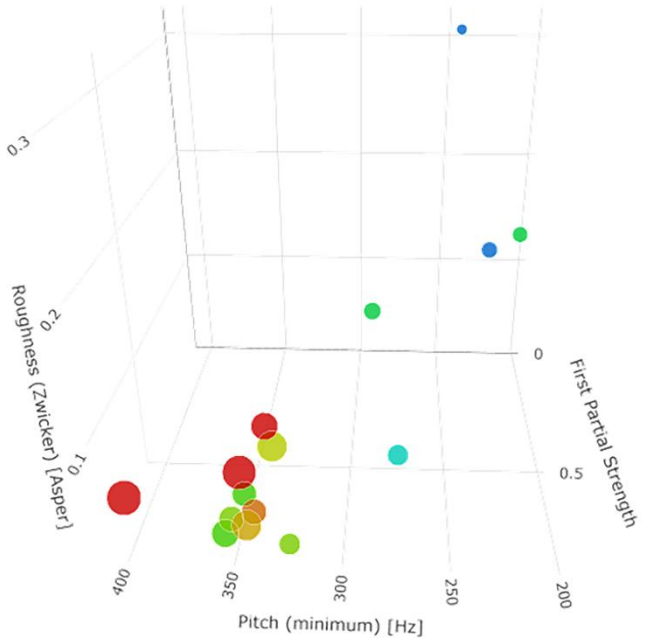


**Figure 4:** Audio features that are related to the annoyance of mosquito buzzing for **younger listeners**: the redder the dots, the more annoying the mosquito buzzing was perceived to be; the estimated likelihood of being stung rises with the size of the dots. (Interactive plot at https://muwiserver.univie.ac.at/gnats/young)

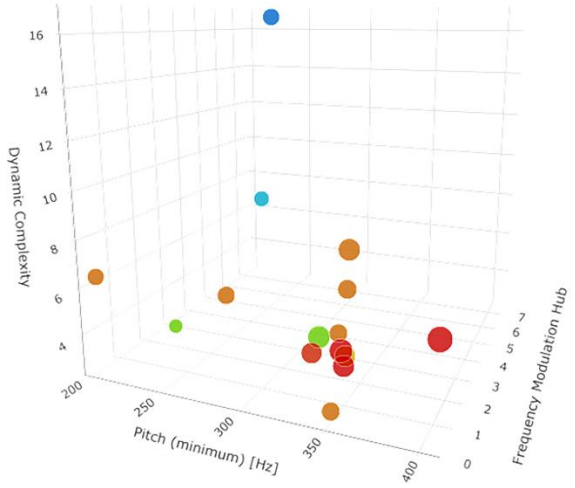


**Figure 5:** Audio features that are related to the annoyance of mosquito buzzing for **female listeners**: the redder the dots, the more annoying the mosquito buzzing was perceived to be; the estimated likelihood of being stung rises with the size of the dots. (Interactive plot: https://muwiserver.univie.ac.at/gnats/female)

## Limitations and Conclusion

In this pilot study, relations between both the perceived annoyance of tested mosquito buzzing sounds and the estimated bite probability associated with these sounds were observed to (minimum) pitch, the strength of the first partial, roughness and frequency modulation hub.

The strongest relationship seems to exist with pitch, indicating that the higher the frequency, the more annoying and dangerous mosquitoes are perceived. This is a surprising result, considering the wing frequency of the (more dangerous) female mosquitoes is actually in a lower frequency range than that of male mosquitoes. This might be related to estimated proximity of the sound source.

It has to be considered, however, that these preliminary findings are based on a stimuli set of very limited size (15 sounds). Therefore, further research is needed to validate the results.

## References

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