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Size and temperature information in bullfrog calls. P17

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1. Introduction

•A database of a total of around **1,000 calls**, from **31 bullfrogs** was recorded in the swamps of Missouri (Bee and Gerhardt, 2001, *J. Comp. Psych.*).
•Along with the calls, information about the **mass** and **length** of the frogs and the **air** and **water temperature** at the time they were recorded.
•Most of the bullfrogs were recorded on at least **two** occasions, when the air and water temperature were different.
•We analysed the data to find the effect of frog size and temperature on several features of the calls. Research in this area is ongoing, with the goal of better understanding the sound production mechanism of the bullfrog and how information about frog size is encoded in the call.
•This study sets the groundwork for further investigation of the physics of the bullfrog's calling mechanism.

2. Features – Three Timescales (see fig. 1)

•**Microstructure.** We look for a change in the **fundamental frequency (f_0)** of the call with changing temperature and frog size. The software *PRAAT* was used to extract the fundamental frequency of the stable central portion of each note in the data set using an autocorrelation method.
•**Individual note.** The **rise time**, **fall time** and **inter-note interval** were measured using a simple model which modelled the amplitude envelope of the call as roughly triangular, fitting straight lines to the onset and offset of the call.
•**Whole Call.** The **number of notes in a call** were counted and information in **the distribution of note amplitudes** across the call gathered. We summarise information in the amplitude distribution of notes using a single quantity: the **envelope peak rating (EPR)**. The motivation: to see if large frogs advertise themselves with a call made up of a different distribution of notes than a smaller frog. The envelope peak rating (EPR) is the ratio of call duration to the FWHM of the normalised call envelope.
•**Is the variation on each scale dominated by a random instability in the calling mechanism, or is a systematic effect depending upon other factors such as conscious control by the frog, or its size and temperature?**

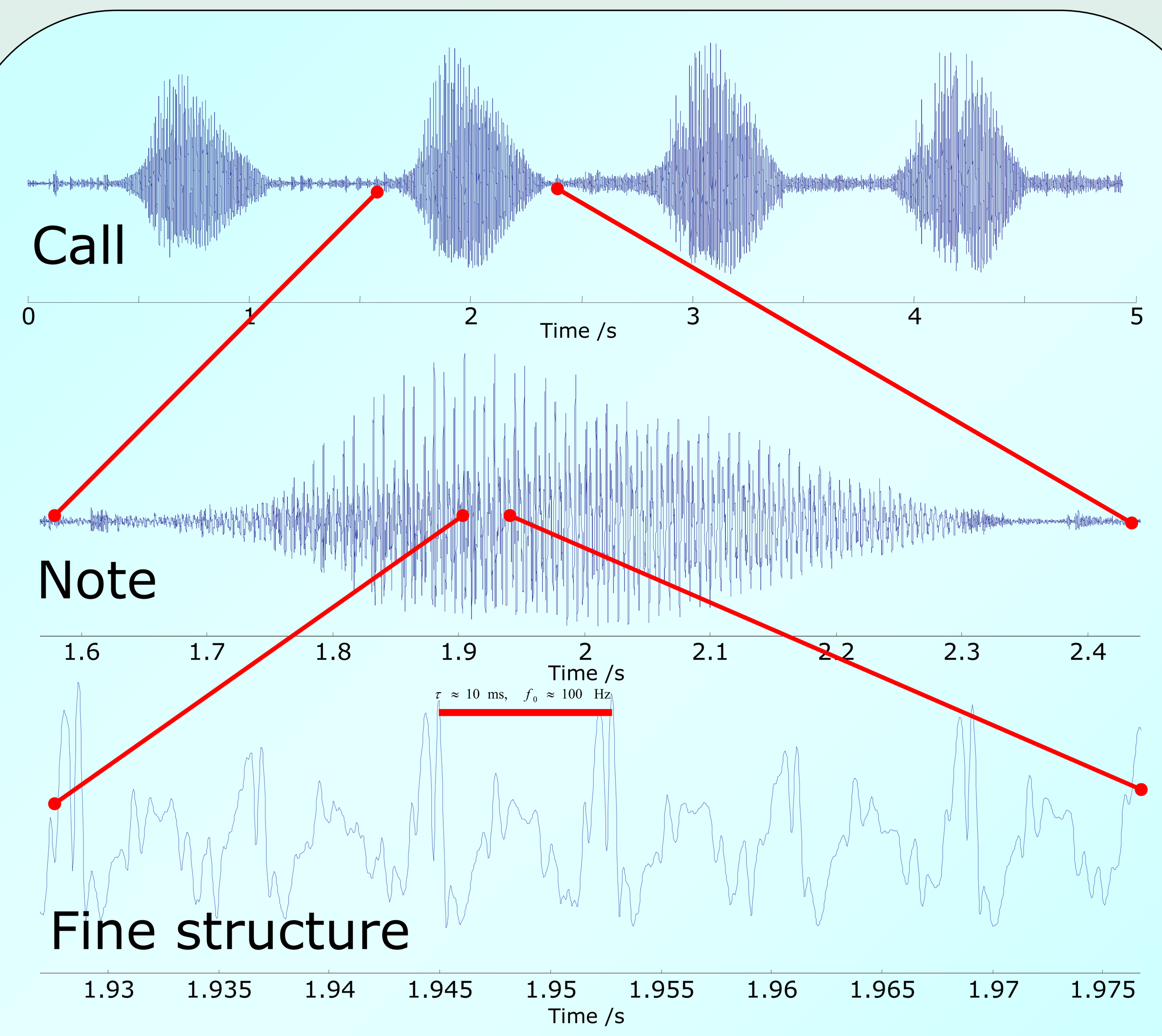

Figure 1: Terminology: A bullfrog ***call*** consists of a series of between one and around seven 'croaks', hereafter known as ***notes***. A set of calls, recorded on a particular occasion (and thus with a particular air and water temperature) is called a ***cut***.

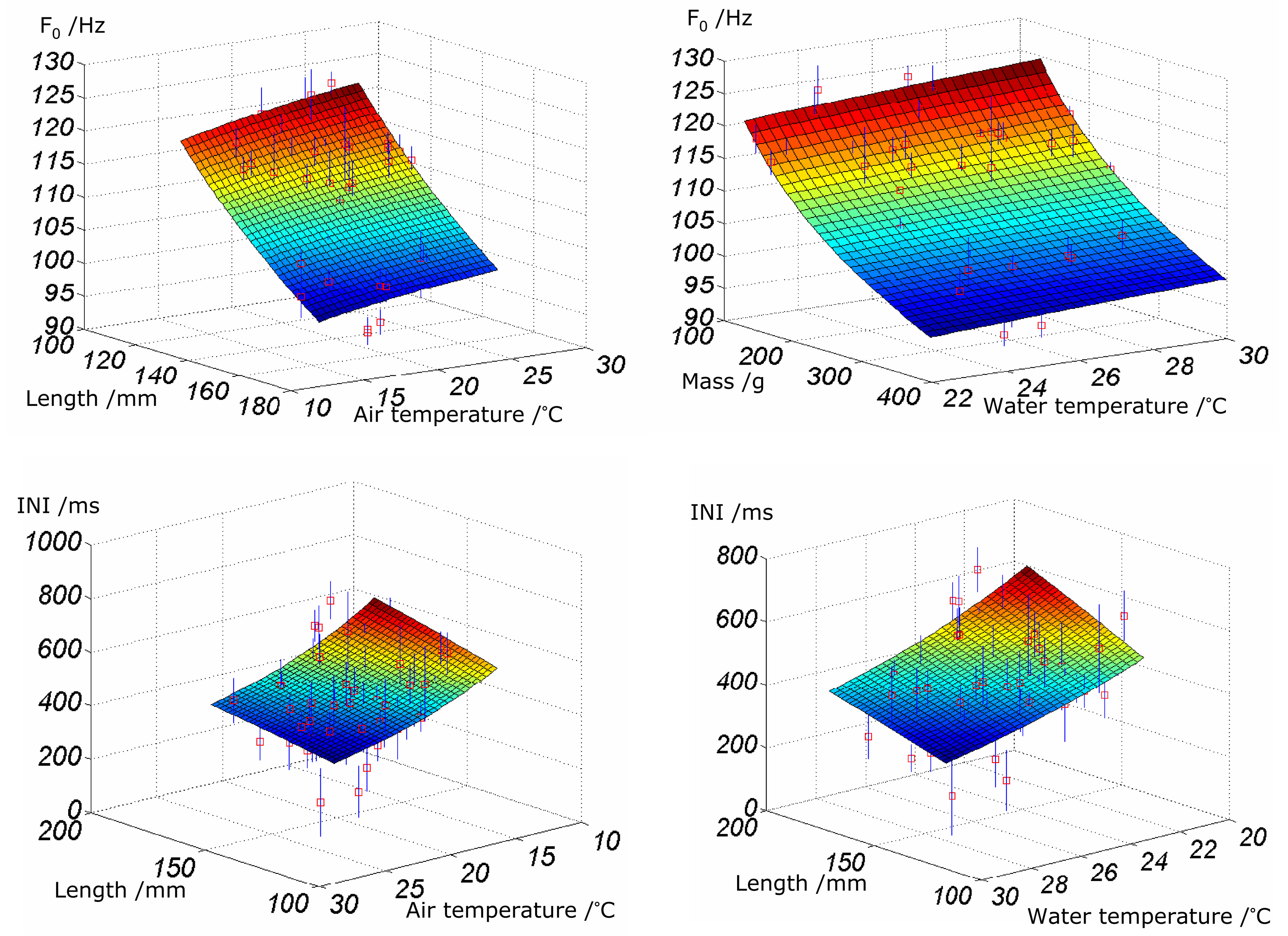

Figure 2: The top row shows surfaces displaying the effect of temperature and size on the **fundamental frequency**. The bottom row shows the effect of air and water temperature on the **inter-note interval**. The blue lines show one standard deviation on the data points.

3. Size-temperature trade-off

•The database contains information about the effect of two independent variables: the frog **size** (which is manifested in mass and length) and the **ambient temperature** at the time of recording (manifested in the air and water temperatures) .
•We wished to analyse the effect of these two variables on each of the measured features. The best visual representation of a function of two variables such as this is a **surface** riding above the **size-temperature plane**.
•The configuration of this surface defines the trade-off between the effect of the two variables on the feature in question.
•Each surface is **interpolated** from a number of points, each point summarises the feature for a cut.
•The model employed is of a **power-law** relationship between the feature of the call we are looking at and the temperature and mass variables:

$$f = AT^n M^m$$

•Where f is the **feature** we are investigating, T is the **temperature** variable, raised to some power, n; M is the **mass** variable, raised to some power, m and A is a **constant**. To **linearise** the equation we take the natural logarithm. This is used in the later stages.

$$\ln f = \ln A + n \ln T + m \ln M$$

•A **maximum likelihood** model was then employed to find the best set of parameters to fit the data

4. Results (see fig. 2)

•Four surfaces were fitted for each variables of interest, with combinations of mass, length, air temperature and water temperature. Of these, the surfaces which were of greatest interest were the $\mathbf{f_0}$ and the **inter-note interval** surfaces.

•**The $\mathbf{f_0}$ surfaces** show that the fundamental frequency of a large frog is lower than that of a smaller frog.
•The dependence on body length is $f_0 \propto L^{-0.5}$, RSD=5% and is stronger than the dependence on mass: $f_0 \propto M^{-0.2}$, RSD=5%. The greater dependence upon length would suggest that the frog is not using a vocal-fold structure, but some sort of vibrating membrane. Previous work (Purgue, 1995) suggests that it is actually vibrations of the tympanic membrane and/or the vocal sacs that are responsible for radiating sound energy.
•The temperature dependence is weak, $f_0 \propto \text{temperature}^{0<x<1/10}$, with only a slight tendency for the f_0 to increase with increasing temperature. This is helpful for those making size estimates of the frog from the fundamental frequency, as the effect of temperature is probably not noticeable.

• **For the inter-note interval**, INI, air temperature, AT, and water temperature, WT, are the governing variables. $INI \propto (AT)^{-0.7}$, RSD=17% and $INI \propto (WT)^{-1.5}$, RSD=18% compared to $INI \propto M^{0.2}$, RSD~35% and $INI \propto L^{0.6}$, %RSD~20%. RSD values for all parameters suggest the relationships given are significant.
•Generally, average metabolic rate decreases with increasing size, and if the timing of the call is locked onto this, we would expect fewer calls in a given time interval for larger frogs. Similarly, the effect of temperature, which appears to scale approximately as $(AT)^{-0.7}$ and $(WT)^{-1.5}$, is probably through its impact on metabolic rate: frogs are cold-blooded and thus the ambient temperature controls their metabolic rates and internal timing mechanisms.

5. Conclusions

•By far the most conclusive evidence for size information is in the **fundamental frequency** of the call. This information is unlikely to be masked by the effects of a change in temperature
•Previous work (Bee and Gerhardt, 2002) has found the $\mathbf{f_0}$ to be the **major cue** in caller recognition in bullfrogs. The fact that the relationship between f_0 and length appears to follow a simple **power law** so closely may help in modelling the calling mechanism.
•Size information in the **interval in time between notes** fits well with the hypothesis that the frog calling mechanism is locked onto some **internal timing mechanism**, based on **metabolic rate.** The strong temperature dependence is also consistent with this hypothesis.
•From a communication perspective, the influence of temperature probably prevents note spacing acting as a size cue to other frogs.
•**The consistency in these results serves to confirm our confidence in the maximum likelihood approach and its quantitative predictions regarding the $\mathbf{f_0}$.**

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Acknowledgments

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