Automatic Classification of African Elephant (*Loxodonta africana*) Follicular and Luteal Rumbles

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INTRODUCTION

Recent research in African elephant vocalizations has presented evidence for acoustic differences in the rumbles of females based on the phase of their estrous cycle (1). One reason for these differences might be to attract males for reproductive purposes because rumbles can be heard over a distance of several kilometers because of their low fundamental frequency. This research exploits differences in rumbles to create an automatic classification system that can determine whether a female rumble was made during the luteal or follicular phase of the ovulatory cycle. This system could potentially be used as the basis for a noninvasive technique to determine the reproductive status of a female African elephant.

The classification system is based on current state-of-the-art human speech-processing systems. Standard features and models are applied with the necessary modifications to account for the physiological, anatomical, and language differences between humans and African elephants. The long-term goal of this research is to develop a universal analysis framework and robust feature set for animal vocalizations that can be applied to many species.

The vocalizations used for this study were collected from a group of three female captive elephants. The elephants are fitted with radio-transmitting microphone collars and released into one of three naturalistic yards on a daily basis (2). Although this data collection setup is good for determining the speaker of each vocalization, it suffers from many potential noise sources such as RF interference, passing vehicles, and the flapping of the elephant's ears against the collar.

FEATURE EXTRACTION AND MODEL DETERMINATION

As is common in speech-processing systems, features are extracted from the rumbles using a moving Hamming window. The window size used here was 300 ms with one-third overlap between each window. In each frame, a modified set of 10 Mel-frequency cepstral coefficients (MFCCs) was calculated (3). The first change from standard MFCCs is that the fast Fourier transform of the window is zero padded to four times its original size in order to interpolate and smooth the magnitude spectrum in the lower frequencies. The other change is that the Mel-frequency-spaced filter banks are compressed to span the range from 10 to 150 Hz. This change was made to compensate for the much lower range of frequencies rumbles reside in compared with that of human speech (about 100-4,000 Hz).

Three-state hidden Markov models (HMMs) were used to model the rumbles from each phase of the African elephant ovulatory cycle. The states of the HMMs are represented by a Gaussian distribution of 10 cepstral coefficients. One HMM was trained for each class of rumble using the Baum-Welsh expectation maximization algorithm (4, 5). During evaluation, the Viterbi algorithm (6) was used to find the likelihood of each test vocalization coming from each trained HMM.

For this experiment, three different HMMs were trained for three different phases of the female African elephant ovulatory cycle. The elephant ovulatory cycle is unique among mammals in that it is characterized by an 8-11 wk long luteal phase followed by a period of follicular activity. The follicular period is characterized by two distinct phases of follicular growth. Both phases of the follicular growth are terminated by a surge in luteinizing hormone, but the first is anovulatory while the second ends with ovulation. In order to determine if and how the vocalizations vary between each hormonal phase, three classes were used for classification: luteal, anovulatory follicular, and ovulatory follicular. The training and testing vocalizations for the luteal class were chosen from rumbles made ±6 days from the midpoint of the luteal phase, and the vocalizations chosen for the follicular classes were chosen from rumbles made ±6 days from each hormonal peak. An additional HMM was trained to model the silence before and after each vocalization.

	Anovul.	Ovul.	Luteal
Anovul.	8	7	4
Ovul.	6	19	6
Luteal	3	3	12

FIGURE 1. Confusion matrix for 3-class classification.

	Foll.	Luteal
Foll.	40	10
Luteal	5	13

FIGURE 2. Confusion matrix for 2-class classification.

RESULTS

Experiments were performed on 68 female African elephant rumbles. The rumbles were made in various behavioral contexts, suggesting that errors could result from the fact that some rumbles in the dataset were not meant to attract a male at all but for other signaling purposes. Leave-one-out verification was used to generate confusion matrices for each of the three classes of rumbles. The confusion matrix of the 3-class classifier is in Figure 1. As seen from the matrix, the two classes of follicular rumbles are easily confused. However, the confusion between the two follicular classes and the luteal class is small. This would seem to imply that although rumbles made in the two follicular phases are similar, they differ significantly from rumbles made in the luteal phase.

In order determine how similar the two follicular classes are, the two follicular classes were collapsed into a single class. The confusion matrix of the two-class classifier is shown in Figure 2. The classification accuracy of the 2-class classifier is similar to that of the 3-class classifier (77.9 vs. 76.5%). This supports the assumption that the rumbles from the two follicular classes are extremely similar.

DISCUSSION

By using an automatic classification system based on current state-of-the-art speech recognition systems, the hormonal status of female African elephant rumbles was determined with 77.9% accuracy. Rumbles made during both follicular phases are extremely similar, but follicular rumbles can be easily separated from rumbles made during the luteal phase.

There are many advancements being made to the current classification framework. Although MFCCs performed well for this experiment, it is generally agreed that fundamental frequency contours and the harmonic structure of animal vocalizations contain important perceptual information. Therefore, algorithms are being developed to extract the fundamental frequency and harmonic information as features in order to improve classification accuracy. Another advancement being investigated is the addition of noise correction algorithms. Noise correction can be applied to the actual waveform or to the extracted feature vectors. Numerous algorithms developed for both types of noise correction can be found in human speech-processing literature.

The underlying goal of this research is to develop a universal analysis framework and robust feature set for animal vocalizations that can be applied to many species. This successful application of the framework to the classification of female African elephant rumbles shows the potential of such a framework.

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