Observing and Measuring the Drinking Mechanism in Cats

by

Anthony Jones

SUBMITTED TO THE DEPARTMENT OF MECHANICAL ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

BACHELOR OF SCIENCE IN ENGINEERING
AT THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
AUG 14 2008
LIBRARIES

JUNE 2008

Signature of Author: ______________________
Department of Mechanical Engineering
May 9, 2008

Certified By: ______________________
Roman Stocker
Doherty Professor of Ocean Utilization

Accepted By: ______________________
John H. Lienhard V
Professor of Mechanical Engineering
Chairman, Undergraduate Thesis Committee

Observing and Measuring the Drinking Mechanism in Cats

by

Anthony Jones

Submitted to the Department of Mechanical Engineering
on May 9, 2008 in partial fulfillment of the
requirements for the Degree of Bachelor of Science in Engineering
as recommended by the Department of Mechanical Engineering

ABSTRACT

This study explores the characteristics of the lapping mechanism in domestic cats (*Felis catus*). Using high-speed video, digital image processing, and weight measurements we quantify data pertaining to the frequency of lapping and the volume of liquid consumed per lap. These observations allow us to suggest a possible mathematical model for cat lapping. The results indicate that cats lap at a rate of 3.54 +/- 0.04 Hz. For the various fluids utilized in this study, the lapping rate was 3.35 +/- 0.05 Hz, 4.11 +/- 0.09 Hz, and 3.64 +/- 0.06 Hz for tuna, water, and yogurt mixtures, respectively. On average, cats were able to ingest 0.14 milliliters of fluid per lap with a standard deviation of 0.04 milliliters. These results show no indication of scooping behavior, and are inconclusive regarding the role of papillae. In the future, this work could contribute to an understanding of a more universal lapping mechanism utilized by various felids and other animals. The fluid mechanism that cats utilize to consume liquid could potentially be applied to a number of engineering applications in the developing field of biomimetics.

Thesis Supervisor: Roman Stocker
Title: Doherty Professor of Ocean Utilization

Acknowledgements

I would like to thank Professor Roman Stocker, of the Environmental Microfluidics Group in the Department of Civil and Environmental engineering, for his support and guidance through this project. I would also like to thank Dr. Pedro Reis and Dr. Sunghwan Jung, of the Department of Mathematics, for their assistance and encouragement.

In addition, I would like to thank Meagan Rock and the staff of the Massachusetts Society for the Prevention of Cruelty to Animals Adoption Center. Finally, I would like to thank my feline collaborators: Cutta Cutta, Blackie, Blackie, Barron, Shady, Loretta, Cosmic, Gus, Brazil, and Bella.

Note: No animals were harmed in conducting this study. All cats were merely observed as they lapped in a natural fashion.

TABLE OF CONTENTS

1. Introduction

This experimental study was designed to observe and measure the lapping mechanism utilized by the domestic cat (*Felis catus*) during liquid ingestion. The results of this experiment could have applications in the developing field of biomimetics. However, as the lapping mechanism has not yet been thoroughly studied, specific applications have yet to be identified. In addition, research on lapping in domestic cats could eventually contribute to a greater understanding of lapping in felids and other animals in general.

By using high-speed video and digital image processing, we will quantify the method by which cats lap liquids. We will analyze the frequency of lapping, the speed and trajectory of the tongue, and the volume of liquid consumed per lap. We will use our data to examine the effect of papillae on the surface of cats' tongues. We will also explore how variations in lapping correlate with efficiency of fluid consumption.

2. Background

2.1 Earlier Work

Probably the earliest video to look at cat lapping up close is the 1940 short film Quicker 'n a Wink featuring MIT's Dr. Harold Edgerton[5]. This Academy Award-winning ten-minute black and white film briefly shows the movements of a cat's tongue in slow motion as it laps from a saucer of milk. Edgerton clearly shows that a cat's tongue actually curls down (Figure 1), rather than up, when lapping a liquid. In addition, the video demonstrates that the fluid is not scooped up, but appears to adhere to the tip of the cat's tongue. The cat's tongue extends downward, and skims the surface of the liquid before being retracted. As the tongue travels upward, a column of fluid is formed, as can be seen in Figure 1I. Most of this fluid falls back into the bowl, while a small amount is transported into the mouth to be ingested. This video exhibits an example of the kind of fluid behavior that we would like to study more closely by understanding the motions of the fluid movement as the cat drinks. It is also an early example of the high-speed filming technique that we will employ. Since Dr. Edgerton pioneered high-speed filming techniques, to our knowledge no in-depth quantitative analysis of cat lapping has been undertaken until now.

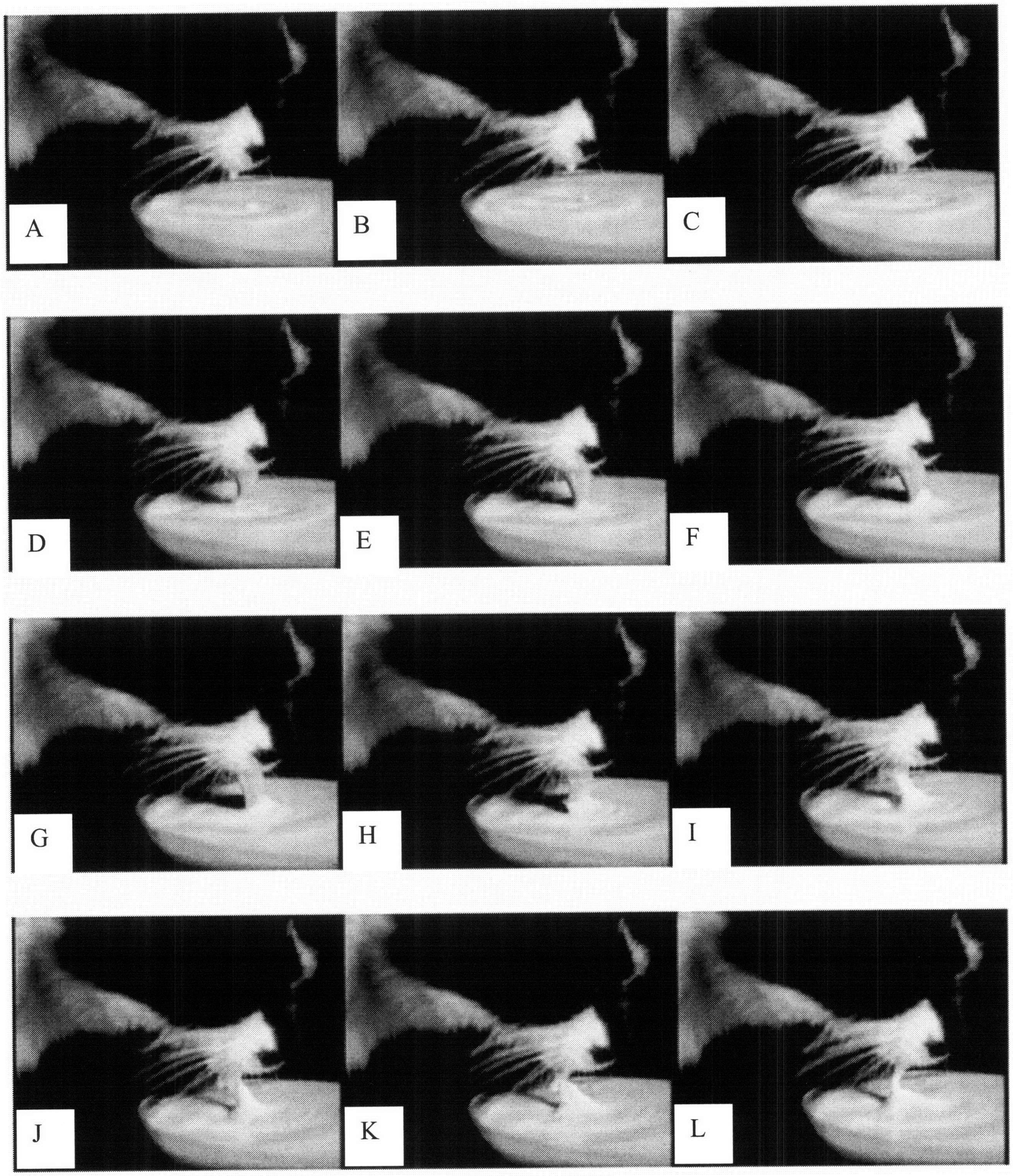

Figure 1: Cat lapping from "Quicker 'n a Wink" (1940)[5].

In addition, researchers at Tilburg University in the Netherlands undertook a study of drinking behavior in rats that could serve as a model for analogous research in cats[7]. This study quantified lapping frequencies and volumes, indicating a typical volume between 4 and 8 microliters, and a licking frequency between 4 and 7.5 Hz, depending on variations in the experiment. The results of the Tilburg University study can offer an idea of the behavior that we might expect in cats.

However, this study differed from our own in important ways. First, the subjects drank from inverted bottles with watering tubes, whereas the cats in our study will be drinking from bowls. Second, the rats' drinking conditions were intentionally modified in order to induce variations in drinking behavior. Our experiment does not seek to induce variations in the drinking mechanism; rather, we hope to observe cat lapping as it occurs naturally, with any natural variations that may occur across subjects.

2.2 Papillae

The surface of a cat's tongue is covered with many fine papillae with a length on the order of 200 micrometers (Figures 2 and 3) that give the tongue a coarse feel. It is unclear whether these papillae have an effect on the manner in which cats lap and the efficiency of lapping. Before commencing research, we hypothesize that papillae could potentially facilitate the adhesion of fluid by adding surface area to the tongue. When the papillae are completely covered, it seems that they would have little effect on the adhesion of the fluid. However, as gravity pulls fluid away from the papillae, a difference in pressure could potentially cause some fluid to collect in the areas between papillae[4]. These hypotheses will guide our research as we attempt to understand the role, if any, that papillae play in helping cats lap.

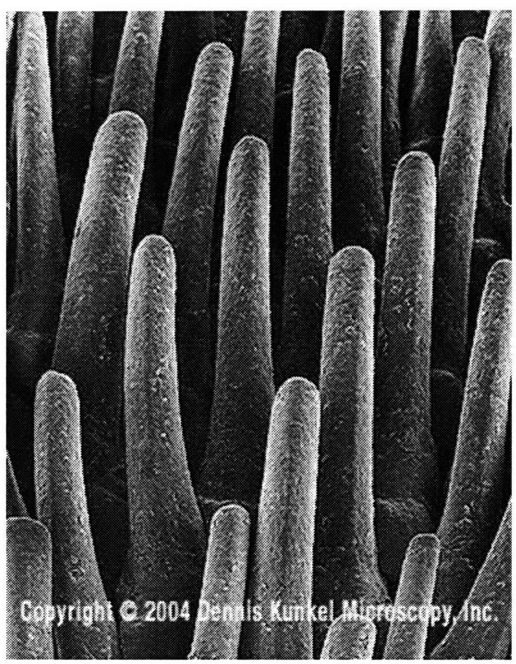

Figure 2: Papillae up close[2].

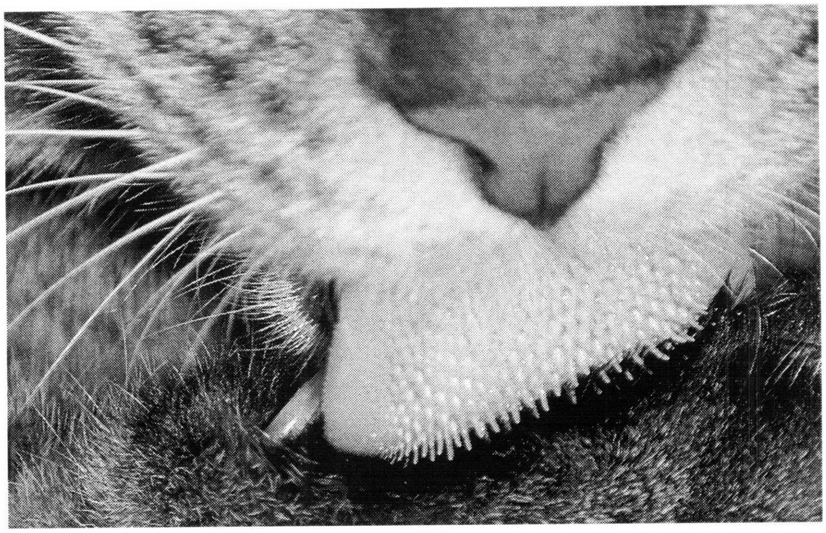

Figure 3: Cat papillae[1].

2.3 Comparative Drinking Behavior

According to Professor Allan Thexton of King's College London[6], one important contributor to an animal's drinking behavior is the presence or absence of well-formed cheeks. For humans, and many other mammals, the presence of complete cheeks allows fluids to be sucked into the mouth and then transported to the stomach through muscle motions in the tongue. The presence of complete cheeks allows these mammals to create a low-pressure cavity within their mouths, thus consuming liquids via suction, rather than lapping.

For many predators, the mouth is used to apprehend prey, and thus complete cheeks would obstruct the hunting process. This is a possible explanation for why the lapping mechanism is necessary, given the absence of complete cheeks.

One inconsistency in this hypothesis is that different prey animals vary in their lapping and licking characteristics. For example, a dog's tongue lacks the coarseness of a cat's tongue even though both are predators with incomplete cheeks. In fact, Professor Thexton notes that the coarseness of a cat's tongue is more similar to the texture of some sub-mammalian species, such as woodpeckers. Such animals mainly use this coarse texture to consume solid foods. Thus, it is possible that the cat's coarse tongue is not ideally suited for lapping up liquids[6]. It is also possible that the coarse texture of a cat's tongue could aid in grooming.

3. Measuring the Lapping Mechanism

3.1 Obtaining Lapping Data

The majority of our data was measured from high-speed video recordings of lapping. Initial observations took place using the thesis advisor's personal pet, Cutta Cutta, as it lapped mixtures of yogurt and water. Since the cat was attracted to the fluid, it was rather easy to induce drinking and thus obtain observations for the purpose of quantifying frequency and qualitatively examining the cat's drinking behavior.

As the scope of the project expanded, subjects included cats at the Massachusetts Society for the Prevention of Cruelty to Animals (MSPCA) adoption center. Dietary restrictions prevented the use of yogurt in observations at the adoption center. For that reason, initial trials at the adoption center were undertaken using tap water. However, the need for greater fluid visibility necessitated the use of food coloring, and it was also discovered that the juices from a can of tuna fish were better able to induce lapping in the adoption center cats without presenting dietary problems. Thereafter, observations were taken at the MSPCA adoption center using a mixture of tap water, tuna juice, and green food coloring. The different fluids used for various observations will need to be taken into consideration because variations in surface tension and viscosity could affect the amount of liquid that the cat is able to retain. In addition, the cat's level of attraction toward the fluid could affect its behavior. These considerations should be investigated in future research.

Using a Sony HDR-SR5 video camera, we recorded a series of laps at a rate of 240 fields per second for a 3 second duration. These videos were slowed to a playback rate of 60 fields per second. In order to quantify lapping information and obtain detailed qualitative observations, the videos were then analyzed frame-by-frame. First, the videos were edited to contain an integer number of continuous lapping events. Then, the number of laps observed were counted, and divided by the duration of the video. This quotient was then multiplied by 4 to represent the real-time frequency of lapping as opposed to the slow-motion playback frequency.

In order to obtain data pertaining to the volume of fluid lapped, cats were presented with the tap water and tuna juice mixture. The weight of the bowl was measured using a digital scale. The cats were then filmed as they lapped from the bowl several times. Afterwards, the bowl was again weighed. The number of laps was noted from the video observations, and the difference in bowl weight was divided by the number of laps to obtain an average amount of liquid consumed per lap. The lapping frequency was measured in the same manner as the other video observations.

3.2 Digital Image Analysis

In addition to being used to quantify lapping frequency, the high-speed video recordings were also used to extract data pertaining to the position and velocity of the cat's tongue. First, the video was converted to a sequence of Bitmap still images. The Bitmap images were then read into a MATLAB M-file. In-house software was developed to track the position of both that cat's jaw and the tip of the cat's tongue. The ginput command in MATLAB was used to keep track of the pixel position of the cat's jaw and tongue throughout the sequence of video frames by reading a mouse click at each position, as indicated in Figure 4. The pixel position was then scaled to convert from pixels to millimeters, and the results were plotted. Figure 5 shows a plot of the vertical tongue position over a sequence of images representing a 3 second period as the cat, Cutta, laps eleven times. The position was measured from the jaw to the tip of the tongue.

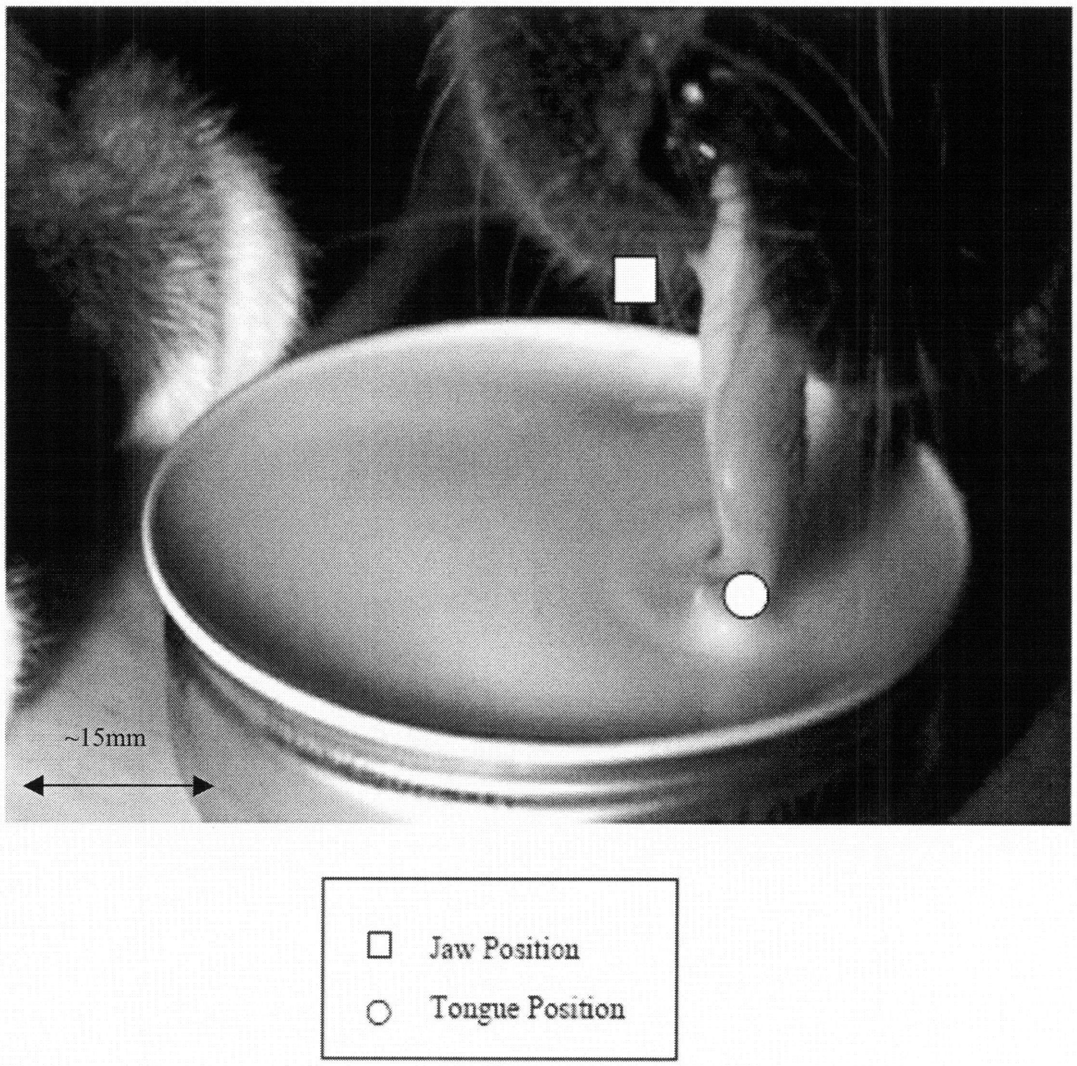

Figure 4: Jaw and tongue position as indicated by mouse clicks.

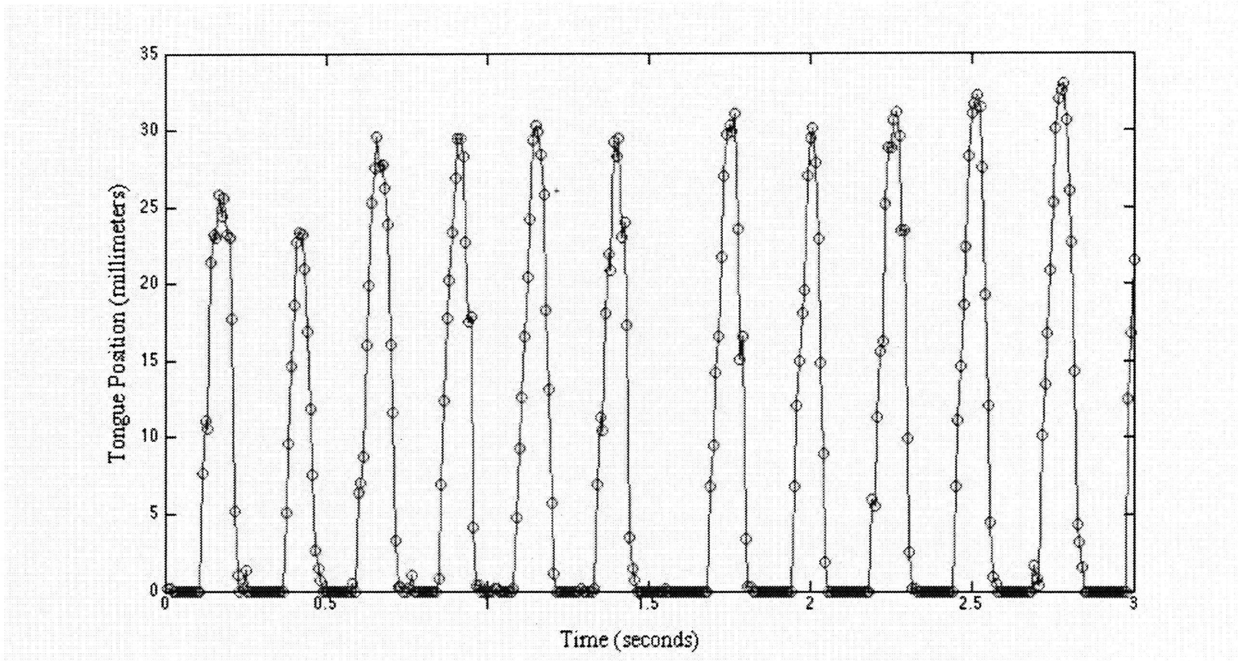

Figure 5: Tongue position over several lapping events; subject Cutta.

Further MATLAB analysis was done to ensemble average these eleven lapping events into a representative average lapping event. Figure 6 shows a plot of the average vertical position and velocity of the cat's tongue over a single average lapping event. Note that each lapping event was shifted on the time axis so that the maximum position sits at time zero. On average, the cat's tongue extended 30 millimeters below the jaw, with a maximum speed of about 500 millimeters per second. Interestingly, the trajectory of the tongue was approximately symmetrical for extension and retraction, despite the tongue's interaction with the fluid.

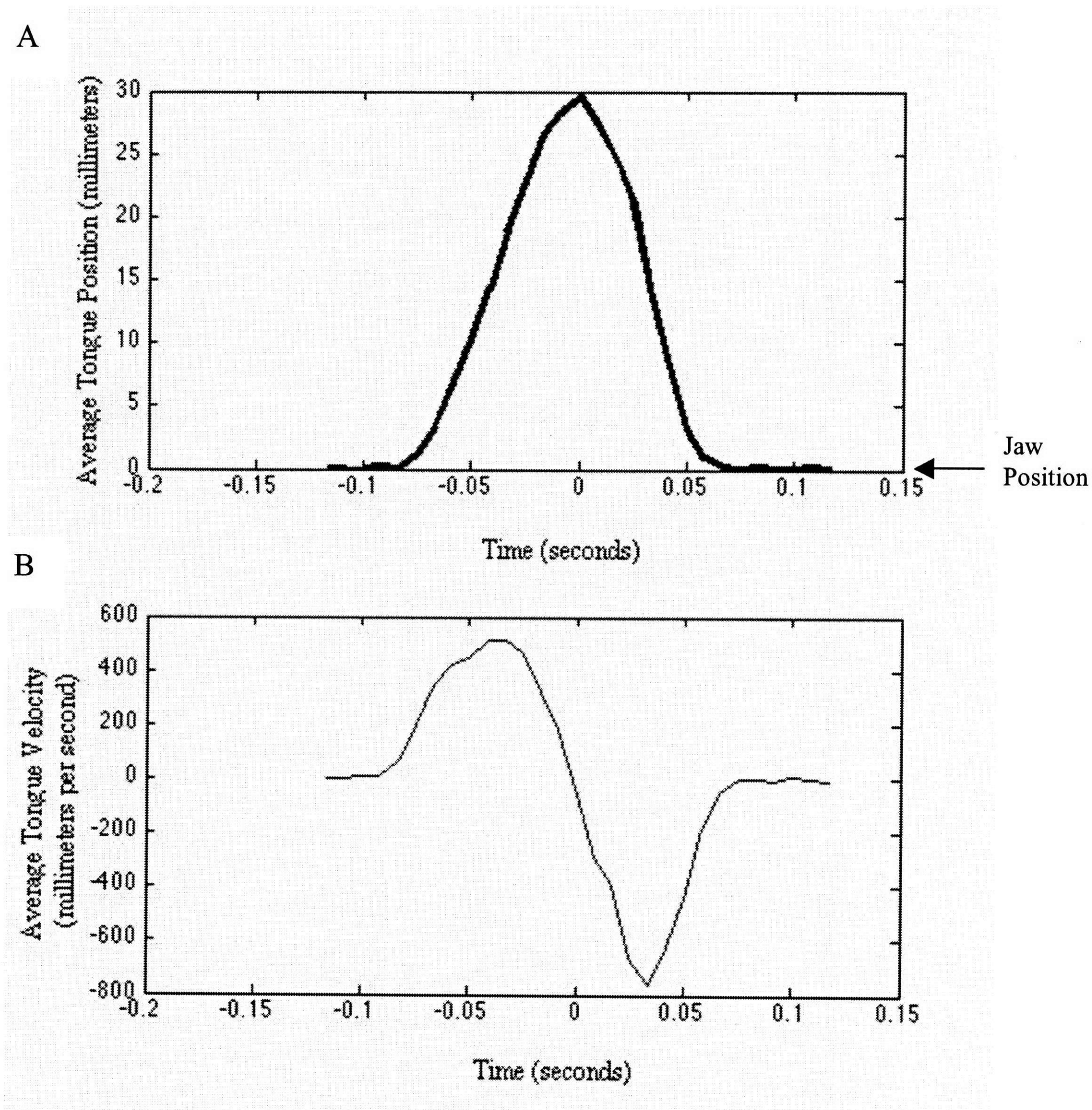

Figure 6: Tongue position and velocity over an average lapping event; subject Cutta.

4. Results and Discussion

4.1 Summary of Lapping Data

Through observation of 10 cats of various ages in 79 videos of lapping, domestic cats lapped at an average frequency of 3.54 +/- 0.04 Hz. The average frequencies were 3.35 +/- 0.05 Hz, 4.11 +/- 0.09 Hz, and 3.64 +/- 0.06 Hz for tuna, water, and yogurt mixtures, respectively. Table 1 summarizes the data collected from our ten subjects.

NAME	AGE (years)	AVERAGE FREQUENCY (Hz)	+/-	FLUID
Blackie	1	3.19	0.08	Tuna water
Blackie II	2	3.57	0.04	Tuna water
Barron	3	3.64	0.07	Tuna water
Shady	3	4.00	n/a	Water
Cutta	5.5	3.64	0.06	Yogurt (various)
Loretta	6.5	3.29	n/a	Tuna water
Cosmic	7.5	3.54	0.11	Tuna water
Gus	9.5	4.06	0.07	Water
Brazil	13	3.10	0.04	Tuna water
Bella	unknown	3.53	n/a	Tuna water

Table 1: Summary of lapping data.

Table 2 shows a summary of data as it pertains to the volume of liquid lapped. On average, the cats lapped 0.14 milliliters of liquid per lap, with a standard deviation of 0.04 milliliters. Note that volume data only pertains to the tuna juice mixture, not yogurt mixture or tap water. Yogurt mixture was not used due to the subjects' dietary restrictions. Water was not used because the tuna mixture was more effective for inducing subjects to drink. The amount of water ingested per lap could be explored in future research.

VOLUME PER LAP (mL)	FREQUENCY (Hz)
0.16	3.49
0.22	3.79
0.13	3.21
0.12	3.43
0.14	3.22
0.12	3.38
0.10	3.63
Avg. Vol.	**0.14**
Std. Dev.	**0.04**

Table 2: Summary of lapping volume data for tuna water.

There seemed to be little correlation between the age of the cats and their lapping behavior. Figure 7 shows a plot of average lapping frequency versus the age of the cat.

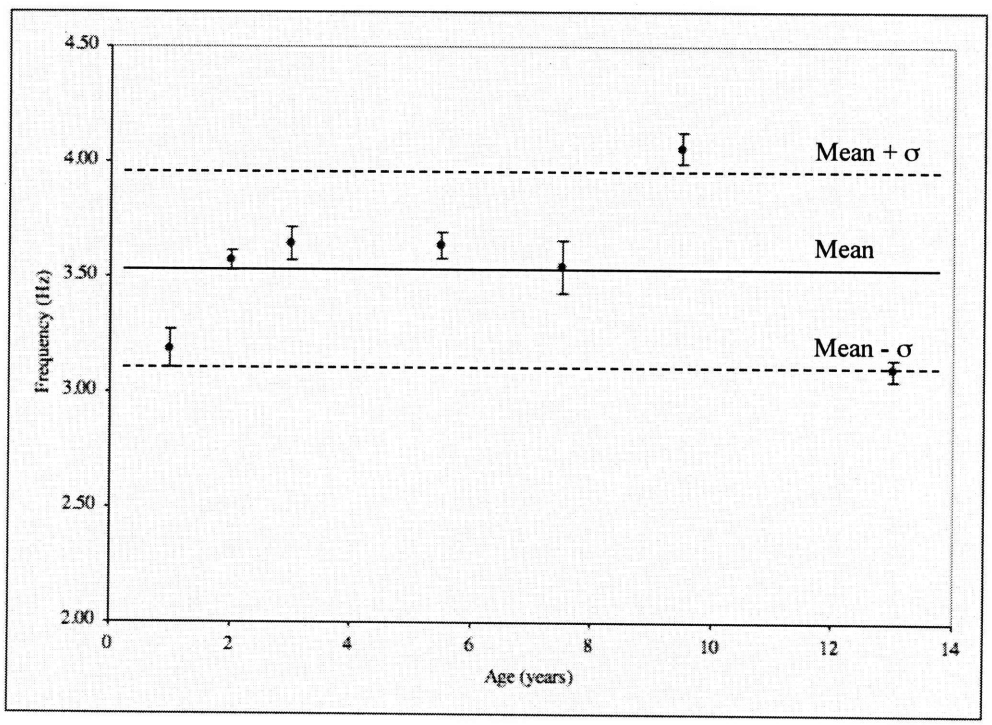

Figure 7: Average lapping frequency versus age of subject.

In addition, there seemed to be little correlation between the lapping frequency and the volume of liquid retained per lap. Figure 8 shows the plot of volume retained per lap versus lapping frequency. All observations fall within one standard deviation of the mean volume per lap, except for one outlier that is two standard deviations above the mean at 0.22 milliliters per lap. There seems to be no obvious explanation for this outlier. However, Weijnen's study of rat drinking indicated a wide range of volumes ingested per lap, so such variations are consistent with earlier research on lapping[7]. Our results show that, although different cats lap at different frequencies, they retain approximately the same volume per lap, on average.

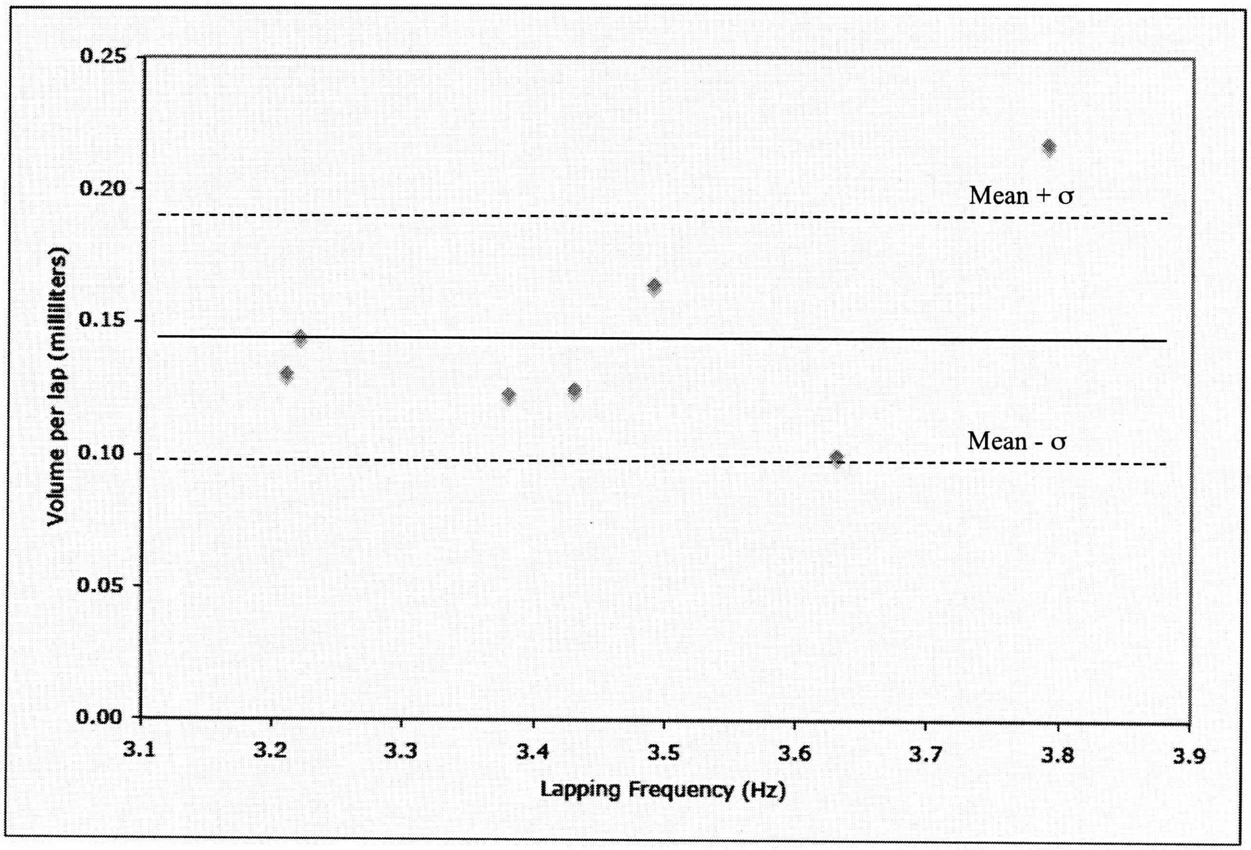

Figure 8: Volume retained per lap vs. lapping frequency.

Furthermore, the histogram in Figure 9 shows the distribution of average frequencies for the 10 subjects observed in this study. Five of the subjects observed fell within the range of 3.5 to 3.7 Hz, while three of the subjects were notably slower and two of the subjects were notably faster. Although each cat's average lapping frequency differed, only one cat (Brazil) fell more than one standard deviation below the mean frequency, and only one cat (Shady) fell more than one standard deviation above the mean frequency.

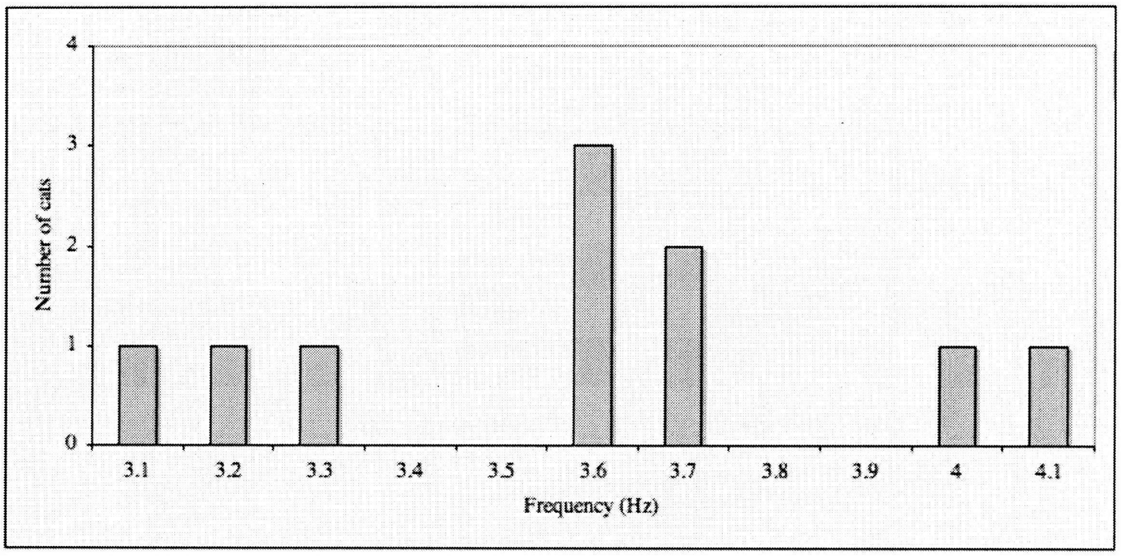

Figure 9: Number of cats versus average frequency range.

4.2 Two Modes of Lapping

In addition to the quantitative data, qualitative observation of the videos suggests two different styles of lapping practiced by different cats. The majority of the subjects observed exhibited a vertical tongue trajectory, like the one shown in Figure 10.

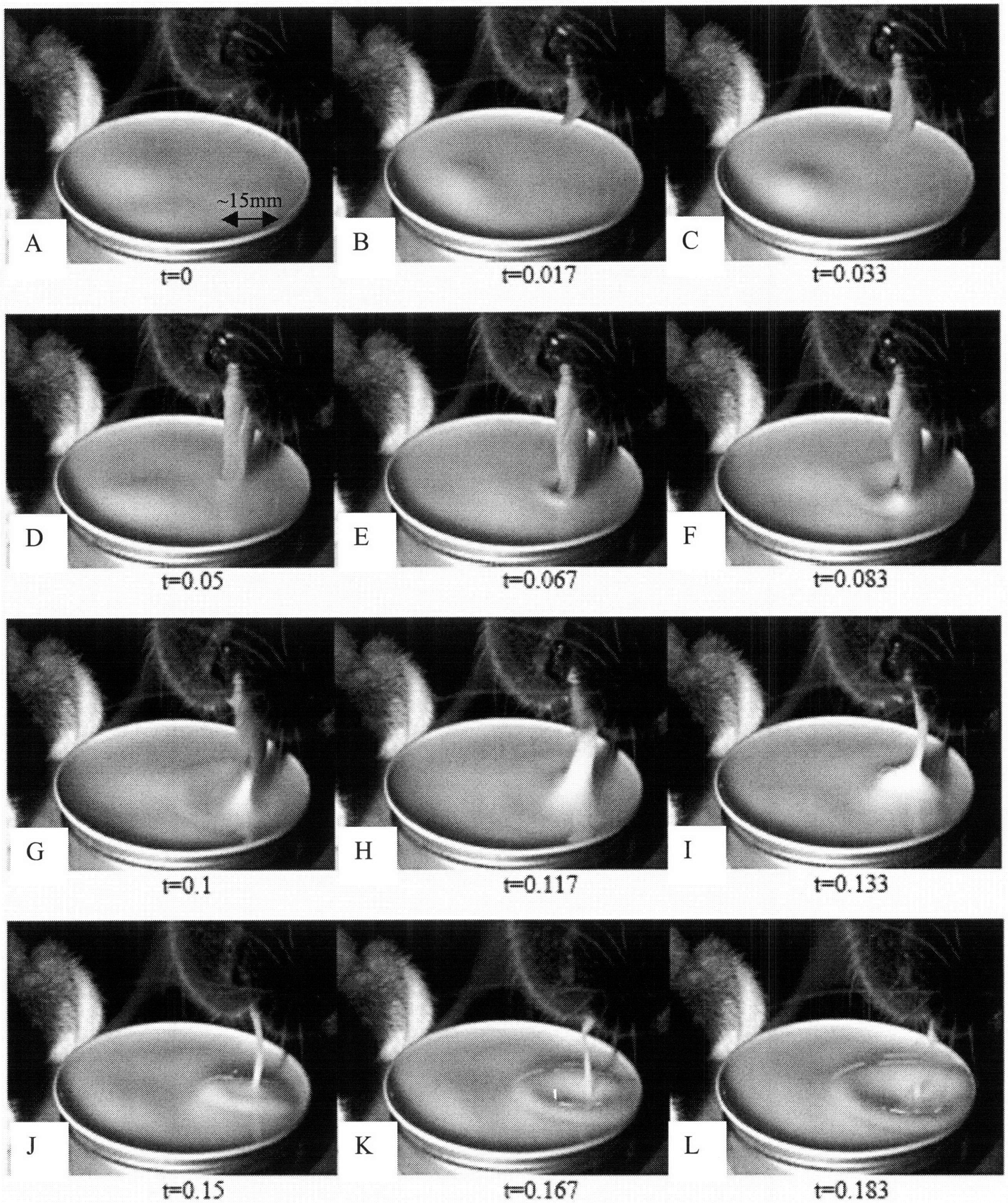

Figure 10: Vertical lapping; time measured in seconds; subject Cutta.

The cat extends its tongue downward and contacts the fluid. The fluid then adheres to the tip of the tongue as the tongue is retracted, forming a fluid column. A portion of the column is then retained as the cat closes its jaw and consumes the fluid. A closer view of the fully extended tongue (Figure 11) shows that no fluid is accumulated on the rear of the tongue. This implies that the tongue does not serve as a scoop to collect fluid, relying only on the adhesion of the fluid to transport liquid to the mouth. These results are consistent with initial research, which suggested that cats do not scoop liquids. In fact, none of the ten subjects exhibited any behavior indicative of scooping.

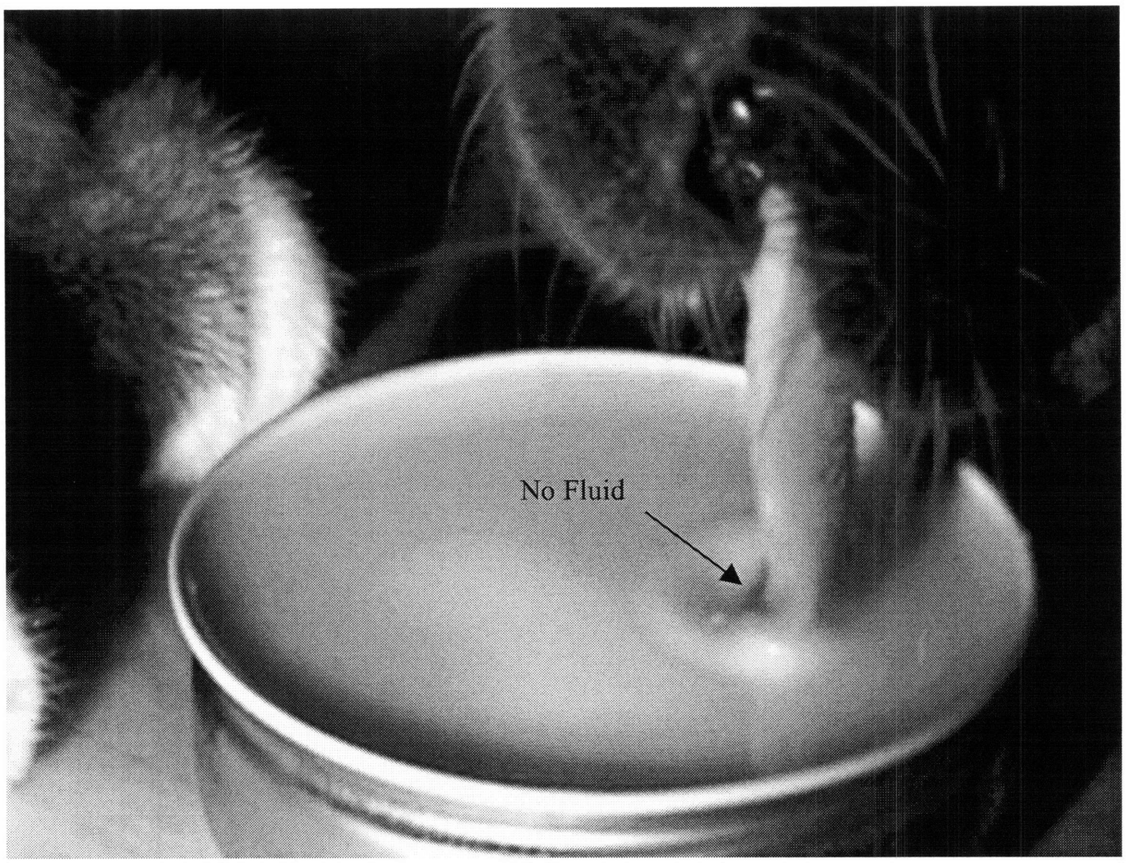

Figure 11: Fully extended tongue.

The second mode of lapping observed exhibits significant motion tangential to the surface of fluid, as shown in Figure 12. This results in a fluid column with significant motion in the horizontal direction that is not captured between the jaws of the cat, presumably decreasing the amount of fluid retained per lap (Figure 12I). Unfortunately, no volume data was obtained to compare vertical lapping retention versus tangential lapping retention, as the most obvious tangential lapper (Blackie) was adopted before measurements could be taken. A study of the quantitative differences between vertical and tangential lapping could be pursued in future research.

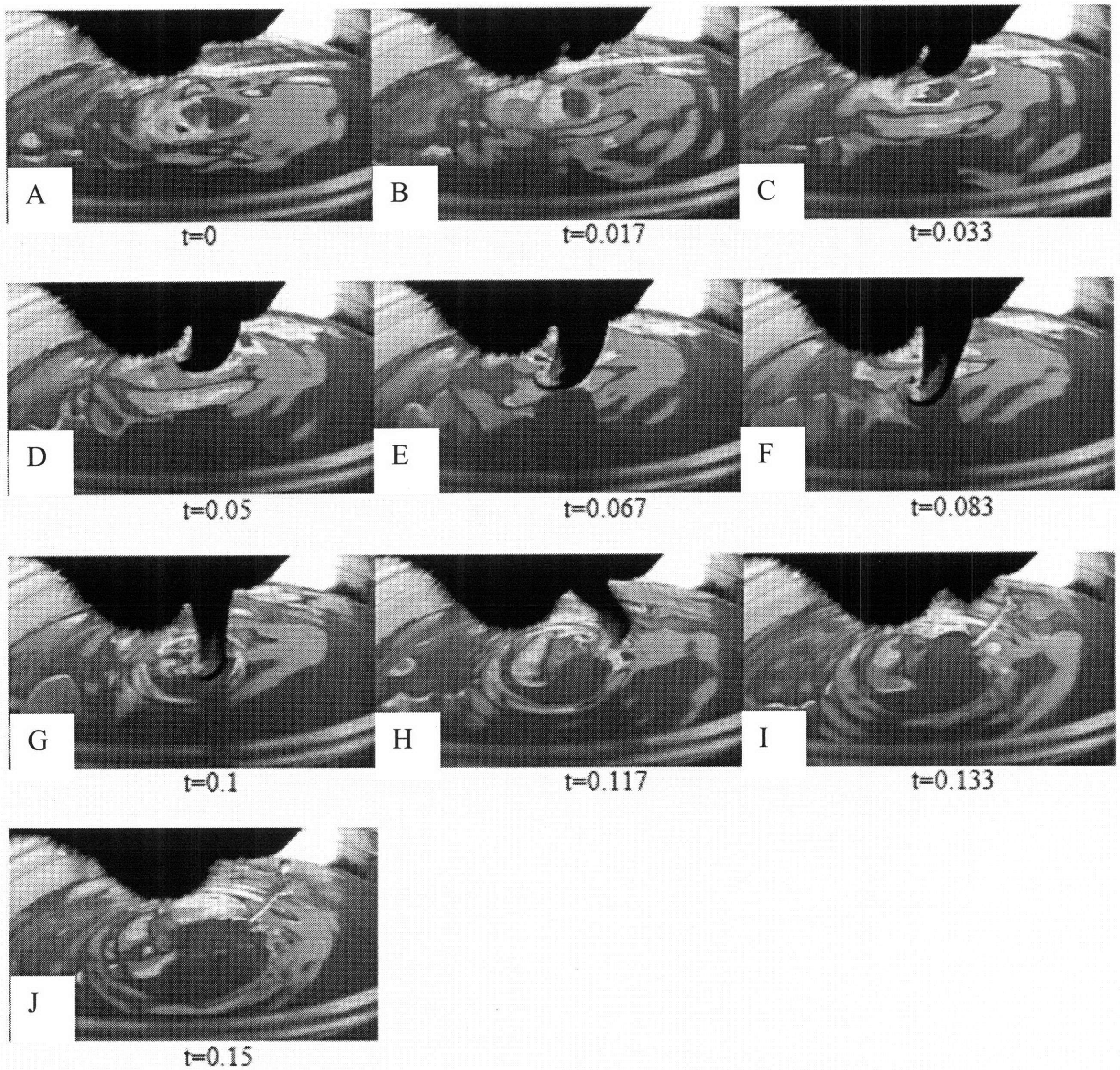

Figure 12: Tangential lapping; time measured in seconds; subject Blackie.

4.3 Proposed Fluid Mechanism

The basic fluid mechanism that we propose to approximate cat lapping is that of a plate interacting at the surface of a liquid, as shown on Figure 13.

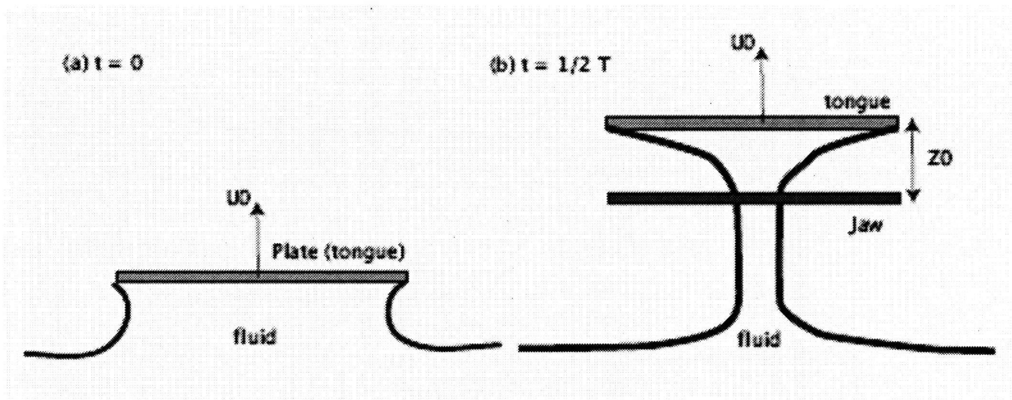

Figure 13: Basic Fluid Model for Animal Drinking[4].

As the plate (analogous to the tongue) is drawn away from the fluid at velocity U_0, a column of liquid is formed between the plate and the surface. When the cat's jaw closes, it brings the portion of the column Z_0 into the mouth to be consumed. This basic behavior can be approximated using Bernoulli's equation:[4].

$$\frac{1}{2}\rho U_0^2 + \rho g z + P_0 + \frac{\sigma}{a} = \frac{1}{2}\rho u_z^2 + P_0 + \frac{\sigma}{r} \quad (1)$$

Where ρ is fluid density, U_0 is velocity of the tongue, g is the acceleration of gravity, z is the height of the fluid column, P_0 is atmospheric pressure, σ is surface tension, a is the radius of the area of the tongue that touches the fluid, u_z is velocity of the fluid at an arbitrary point, and r is the radius of the column of fluid. The left hand side is evaluated near the tongue, and the right hand side is evaluated at the position of the jaw. The Froude number can be approximated using the velocities shown in Figure 5, and the radius a.[3]

$$Fr = U_0^2/ga \quad (2)$$

This calculation will indicate the relative effect of inertial versus gravitational forces. Approximating the velocity to be on the order of 50 cm/s, as indicated in figure 6B, and the radius to be 2 cm, the Froude number is on the order of 1. On the other hand, the Weber number (Equation 3) can be approximated with the same velocity and radius, and surface tension of 60. The Weber number will indicate the relative effect of inertial force versus surface tension.

$$We = \rho U_0^2 a/\sigma \quad (3)$$

Using these approximations yields a Weber number on the order of 80. Since We>>Fr, inertial forces are relatively more important than surface tension, and the effects of surface tension can be ignored for simple calculations.

4.4 The Effects of Papillae

As previously mentioned, we hypothesized that the papillae on the surface of the cat's tongue could potentially aid in the lapping process. As shown in Figure 14, when papillae are completely covered by fluid, it is not possible for them to affect fluid adhesion because of the lack of pressure difference. However, once the fluid begins to fall away from the tongue, pressure differences in the fluid between the papillae and the fluid on the outside of the papillae could cause some fluid to become trapped between the papillae, thus increasing the volume of fluid retained[4].

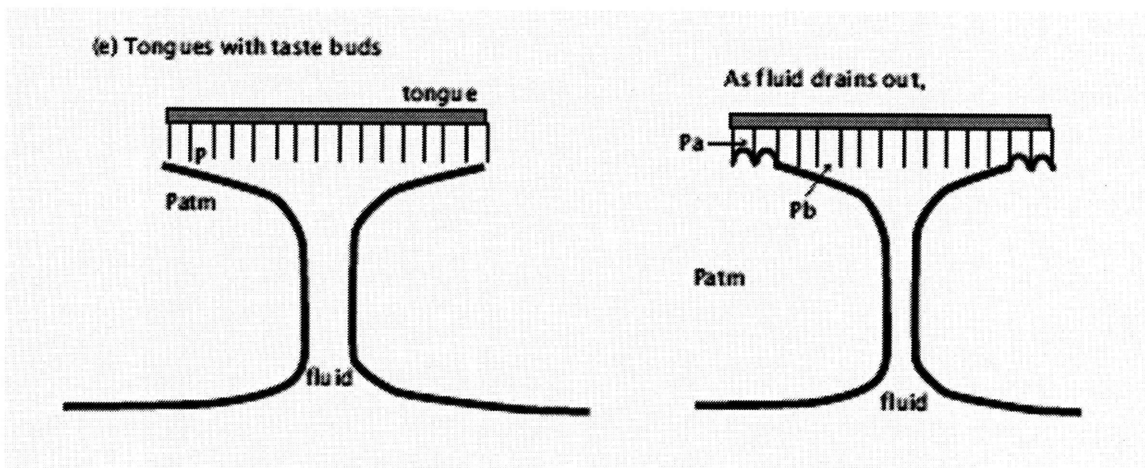

Figure 14: Effect of Papillae on Fluid[4].

However, in practice, it appears that the papillae contribute little to the lapping process in cats. According to Shin-ichi Iwasaki, "in the lingual apex region, typical filiform papillae were not apparent, however, numerous small bulges were seen in this area where many fungiform papillae were found widely distributed."[3] As seen in Figure 15, the area of the tongue that interacts with the fluid column seems to be exactly the area where fine filiform papillae are least prominent. This implies that papillae do not contribute to the lapping mechanism. Further research will need to be undertaken to fully understand the role of papillae.

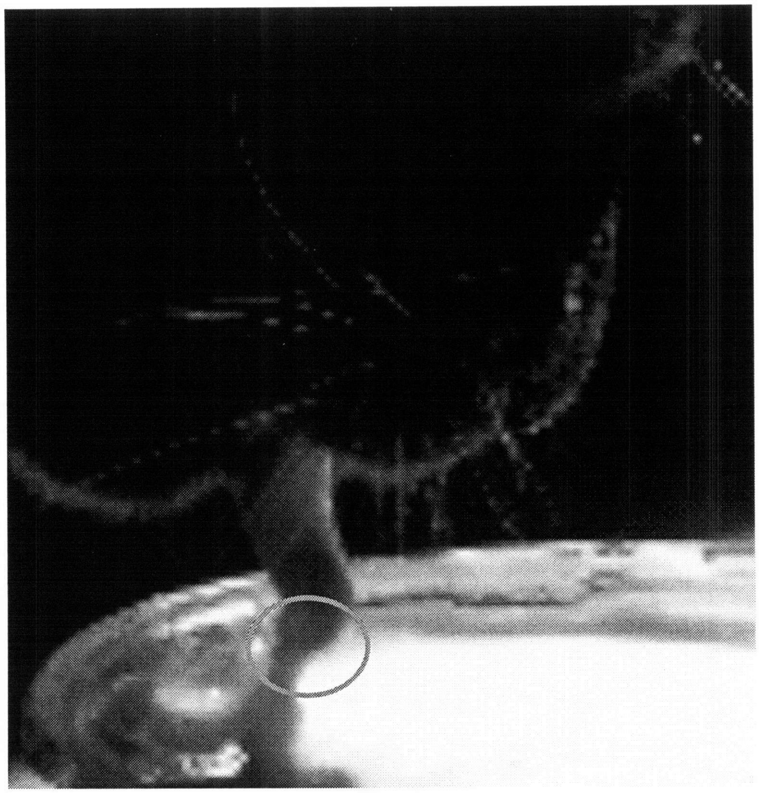

Figure 15: Tip of tongue interacting with fluid column.

5. Conclusions and Recommendations

Using high-speed video techniques, digital image analysis, and weight measurements we were able to determine the average lapping frequency, fluid consumption per lap, and tongue trajectory for a typical housecat (*Felis catus*). Our results indicated two different modes of lapping practiced by domestic cats, one vertical and one tangential. The frequency of lapping and volume per lap seemed to be fairly consistent across subjects, with few exceptions. This means that lapping behavior does not depend on the age or size of the subject. Further research will need to be undertaken to determine the possible differences in lapping efficiency for vertical lappers versus tangential lappers. In addition, results were inconclusive regarding the effects of papillae on lapping efficiency. Physical experiments of the mechanism shown in Figures 13 and 14 will play an important role in determining the possible effect of papillae. Further research should also be undertaken to compare the lapping mechanism observed in domestic cats to that of larger felids, and possibly other animals.

References

1. “Cat’s got the tongue.” Online posting. 26 February 2007. 37primeBlog. 7 November 2007. <http://37prime.com/blog/2007/02/>.
2. “Cat tongue papillae.” Dennis Kunkel Microscopy, Inc. 2004. 17 October 2007. <http://www.denniskunkel.com/DK/Misc._Vertebrates/92621B.html>.
3. Iwasaki, Shin-ichi. “A Study of the Filiform Papillae of the Newborn Domestic Kitten Felis catus by Scanning Electron Microscopy.” Journal of the Mammalogical Society of Japan, Vol. 18, No. 1 (1992): 33-38.
4. Jung, Sunghwan. “Simple explanations of animal drinking.” Personal notes. 17 October 2007.
5. Quicker ‘n a Wink. Dir. George Sidney. Perf. Harold Edgerton and Pete Smith. MGM, 1940.
6. Thexton, Allan. “Re: cat lapping.” Email to Roman Stocker. 30 March 2008.
7. Weijnen, Jan. “Licking Behavior in the Rat: Measurement and Situational Control of Licking Frequency.” Neuroscience and Biobehavioral Reviews, Vol. 22, No. 6 (1998): 751-760.