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Conservation of Lapping Mechanism in Marsupials

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[Conservation of Lapping in Marsupials]

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Honors Research Project

Submitted to

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ABSTRACT

The oral behavior of drinking includes interactions between the tongue, jaw, and liquid being ingested to provide hydration to the animal. Different mechanisms may be used to ingest liquid such as lapping, licking, or sucking. The objective of the study was to compare the mechanism of lapping across marsupial species through comparison of the length of gape cycle, and the amplitude of jaw pitch and tongue protraction between the two marsupial species, *Didelphis virginiana* and *Monodelphis domestica*. I hypothesized that there would be no differences in any of the variables for the lapping mechanism between species. Previous work demonstrates that carnivorans have a conservation of the lapping mechanism between species, which led to the basis of my hypothesis that I believe marsupials will lap in a similar manner to each other as well. The results show that each of the variables, when compared between species, did not have statistically significant differences, which suggests that the lapping mechanism between marsupials may also be conserved.

INTRODUCTION

Hydration is important for survival of animals, therefore different strategies for fluid consumption have evolved. Some animals can use different means of hydration such as absorbing liquid through the skin (Bentley and Yorio, 1979), however the majority will rely on drinking (Withers et al., 2016). Especially in animals that live on land, they must use the oral behavior of drinking to ingest liquid from various bodies of water, often against the force of gravity. Liquid can be taken in through lapping (Thexton and McGarrick, 1988), licking (Weijnen 1998) or sucking movements using the tongue and lips (Thexton et al., 1998). Different

animals use different mechanisms, often associated with their anatomical structures. Mammals with complete cheeks use the mechanism of suction to bring the liquid into their oral cavities and then use the tongue to further transport it. However, those with incomplete cheeks are unable to perform suction and must solely use their tongue to ingest liquid (Thexton et al., 1998). The use of the tongue to bring liquid into the oral cavity can be defined as either lapping or licking, depending on how deep the tongue goes into the body of water (Reis et al., 2010).

The previous studies regarding the lapping mechanisms of other mammals, such as dogs and cats, show similarities in lapping mechanism. These studies specifically compare the scooping mechanism thought to be used by dogs (Crompton and Munisky, 2011; Gart et al., 2015), and adhesion mechanism used by cats (Reis et al., 2010) and determine that both species use the same adhesion mechanism. This comparison and similarity in lapping mechanism between two different mammal species poses the question whether there may be a difference in lapping mechanism between *Didelphis virginiana* and *Monodelphis domestica*, two marsupial species that are commonly used in laboratory experiments. Further, there are studies done on the infant suckling mechanism of the *Didelphis virginiana*, the same species which will be studied in this project. This study focuses more specifically on infant stages and the transition from the suckling to lapping movement (German and Crompton, 1996). However, this study expands the data on this species and compare the lapping movement performed by the adult *Didelphis virginiana* to adult *Monodelphis domestica*.

Marsupials are a type of mammal, particularly characterized by their means of giving birth and lactation. Most living species of marsupials are found in Australasia and South America. A few species are found in Northern America, one of which being the *Didelphis virginiana*. Both *Didelphis virginiana* and *Monodelphis domestica* are in the marsupial cohort of

Ameridelphia and the order Didelphimorphia and within the subfamily Didelphinae (May-Collado et al., 2015). While these species are evolutionarily similar, they are in different geographic locations with the *Didelphis virginiana* inhabiting Northern America and *Monodelphis domestica* inhabiting Southern America.

The goal of the study was to determine if the lapping mechanism is conserved across marsupial species, specifically the *Monodelphis domestica* and *Didelphis virginiana*. If this was observed, this may help determine if lapping was the ancestral behavior for mammals. The lapping mechanism between species was compared using X-ray reconstruction of moving morphology (XROMM: Brainerd et al., 2010) with soft tissue markers in the tongue. Jaw kinematics can be viewed in 3D during both eating and drinking movements using this technology.

For the purposes of the present study, only the lapping portion of the data was used to compare the lapping mechanism. Behaviors such as licking the lips or paws and obvious swallows were excluded from analysis. The variables important to the mechanism of lapping include the amplitude of the up and down rotational movement of the jaw (jaw pitch), duration of gape cycles, and amplitude of protraction and retraction of the tongue (Olson et al., 2021). These variables are different between lapping and sucking. Sucking is characterized by long cycle durations, low jaw pitch amplitudes, and low tongue protraction amplitudes, which is opposite of what is observed for lapping (Olson, 2020). The differences between these variables were compared between species to determine the conservation of the lapping mechanism in these marsupials.

I hypothesized that the oral behavior of lapping will produce a similar duration of gape cycle across marsupial species, specifically the *Monodelphis domestica* and *Didelphis*

virginiana. My second hypothesis is that there will be a similar magnitude of jaw pitch between species. My final hypothesis is that the magnitude of tongue protraction and retraction will occur at similar times relative to the gape cycle in both species. Similarities found between mammal species in previous studies suggested that lapping mechanism may be conserved across various species which leads me to hypothesize that components of lapping mechanism, such as magnitude of jaw pitch, tongue protraction and retraction and duration of gape cycle, will be similar between marsupial species.

The study provides a greater understanding of the diversity of jaw and tongue kinematics within mammalian species by comparing jaw and tongue movements during the oral behavior of drinking. Possible questions in comparative anatomy and evolutionary biology between marsupials can be answered along with data gained about the lapping mechanism in mammals.

MATERIALS AND METHODS

The variables of jaw pitch, length of gape cycles, and protraction and retraction of the tongue were compared using the 3D imaging technology, X-ray Reconstruction of Moving Morphology (XROMM), (Brainerd et al., 2010). XROMM was used to create a 3D model which was used to view an animated model of the drinking movements through a combination of CT scans and X-ray videos (Fig. 1). This model is then used to extract biologically meaningful variables.

The movements of the jaw were quantified using marker based XROMM. Markers were surgically implanted in the skull and jaw and XROMM data was collected. After withholding water for 2 hours, XROMM data was collected while animals freely drank from a container at their home institution. All data collection was in accordance with IACUC #15-U011 (Ohio

University) and #72476 (University of Chicago). One animal of each species was used to collect the data.

Both animals were lab raised and healthy middle-aged adults at the time the data was taken. The animals were CT scanned using an Epica Vimago L CT scanner at the University of Chicago (*Didelphis virginiana*) or a TriFoil Imaging

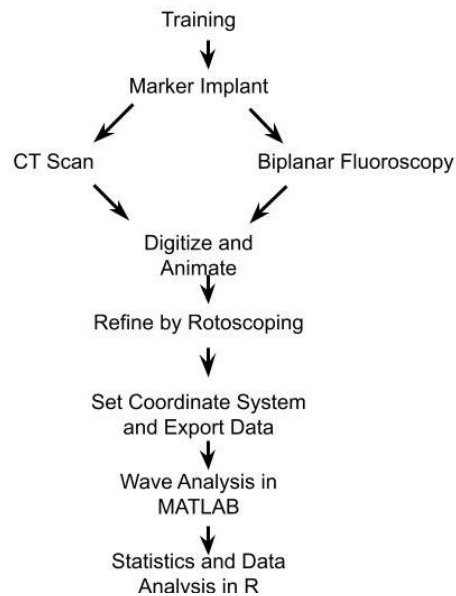


Fig. 1. Overall Process for XROMM and data analysis. Overview of the process used to collect, process, and analyze data used in the study.

eXplore CT120 microCT scanner at Ohio University (*Monodelphis domestica*) in 2018 and 2019. This data was collected in a typical experimental plexiglass enclosure for XROMM which consists of a large enough area for movement with no restraint. The XROMM animations were produced using these CT scans after creating bone mesh models using VGSTUDIO MAX 2.2 (Volume Graphics GmbH).

The XROMM data on the *Monodelphis domestica* and *Didelphis virginiana* while performing drinking actions had been previously collected and processed in Maya (Autodesk Inc., San Rafael, CA, USA). For my part of the project, the XROMM data was analyzed using Scientific Rotoscoping (Fig 2.), which created an animated video which can be used to view the lapping movement. This process was

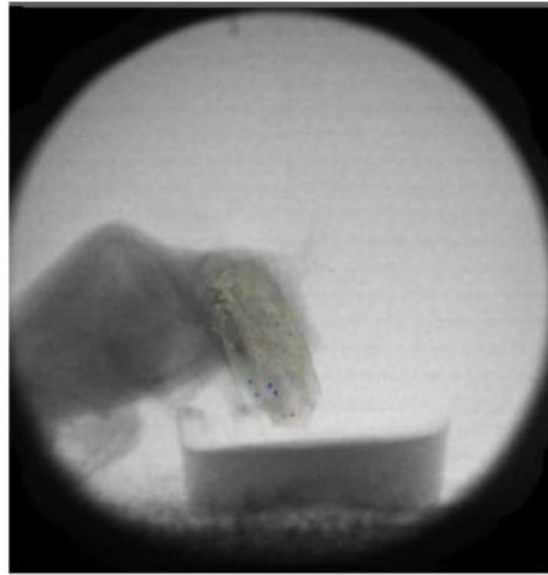
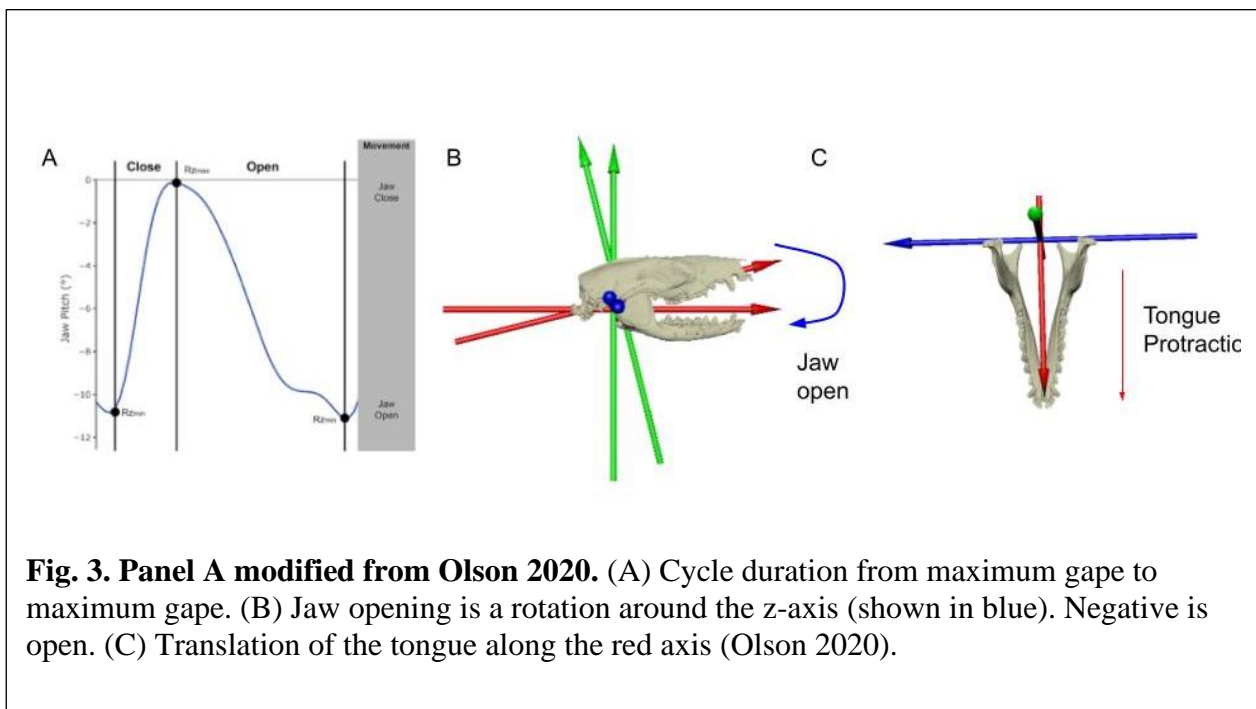


Fig. 2. Bones aligned to biplanar fluoroscopy video. Example of camera used to align bones to biplanar fluoroscopy video during scientific rotoscoping.

completed through manually aligning and adjusting markers within the CT scan to the shadows of the X-ray video drinking movement (Gatesy et al., 2010). The use of these 3D models and videos can allow a fuller picture into the mechanisms of lapping between the species when compared to 2D data (Fig. 3). The models provide an accurate and precise recreation of the movements which occur *in vivo* which were used to measure the variables of interest.

Markers implanted in the bones and tongue were used to calculate variables to compare drinking between the two species. The opening and closing of the jaw, or jaw pitch, is created by a rotation around the temporomandibular joint (Fig 3B). The use of markers and precision thresholds was used to determine differences in this rotation and movement of the jaw. The length of the gape cycles was measured (Fig 3C). Tongue protraction and retraction was measured using a marker in the tongue tip to determine the amount that the tongue protrudes or retracts during drinking movements (Fig 3A).



All the cycles were analyzed, and data exported (Fig. 4) using a custom MATLAB script and data from individual cycles (Fig. 5) were also exported into the statistical analysis software R. After the data processing, statistical analysis was run in RStudio to compare the variables in a quantitative manner. This analysis consisted of exporting and comparing variables, creating any error bars, running statistical tests, and creating any supplementary figures needed for the report.

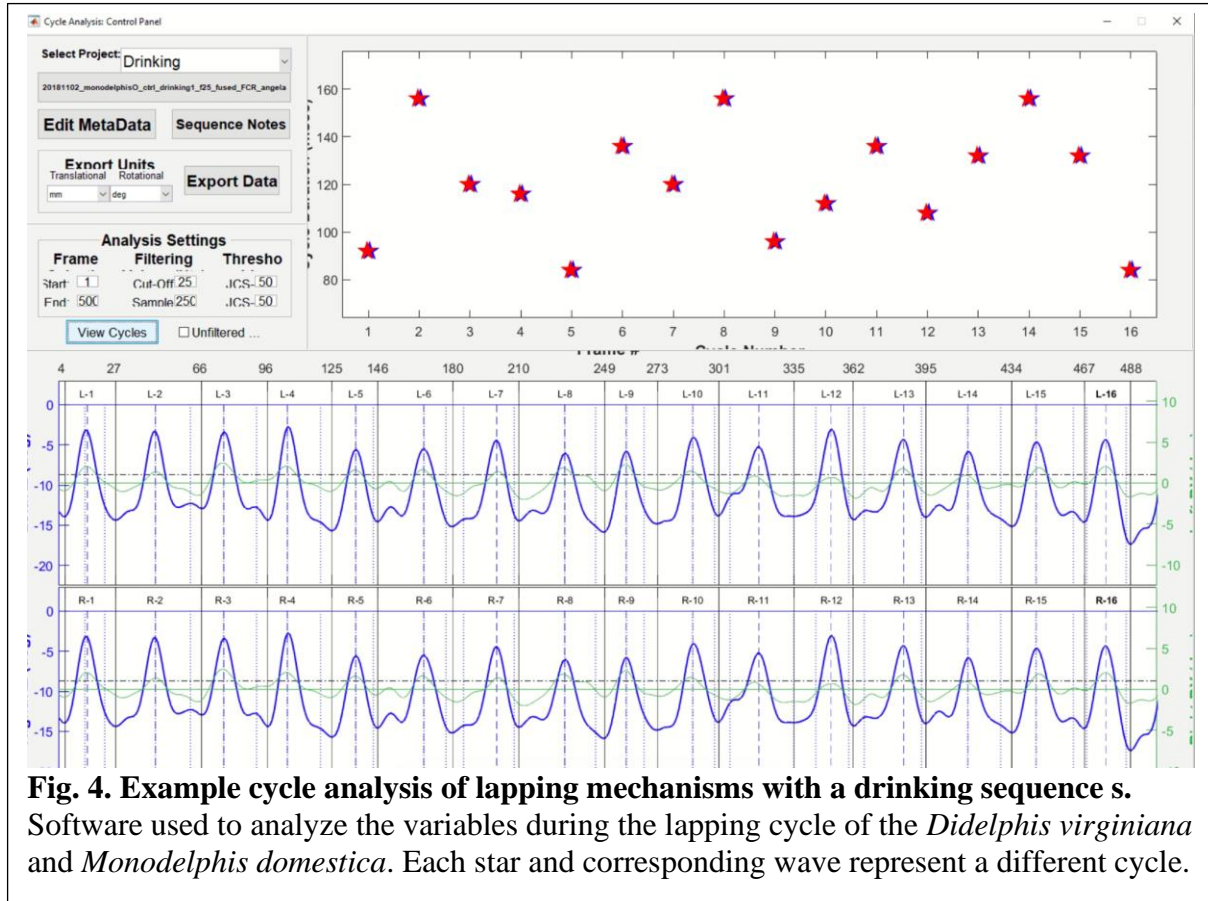


Fig. 4. Example cycle analysis of lapping mechanisms with a drinking sequence s. Software used to analyze the variables during the lapping cycle of the *Didelphis virginiana* and *Monodelphis domestica*. Each star and corresponding wave represent a different cycle.

Statistical analysis

was performed on the variables of cycle duration, jaw pitch amplitude, and tongue protraction amplitude (normalized to jaw length as a proxy for body size) to compare the differences in these variables between the two species. During the

statistical analysis it was necessary to correct protraction data to body size which was done by

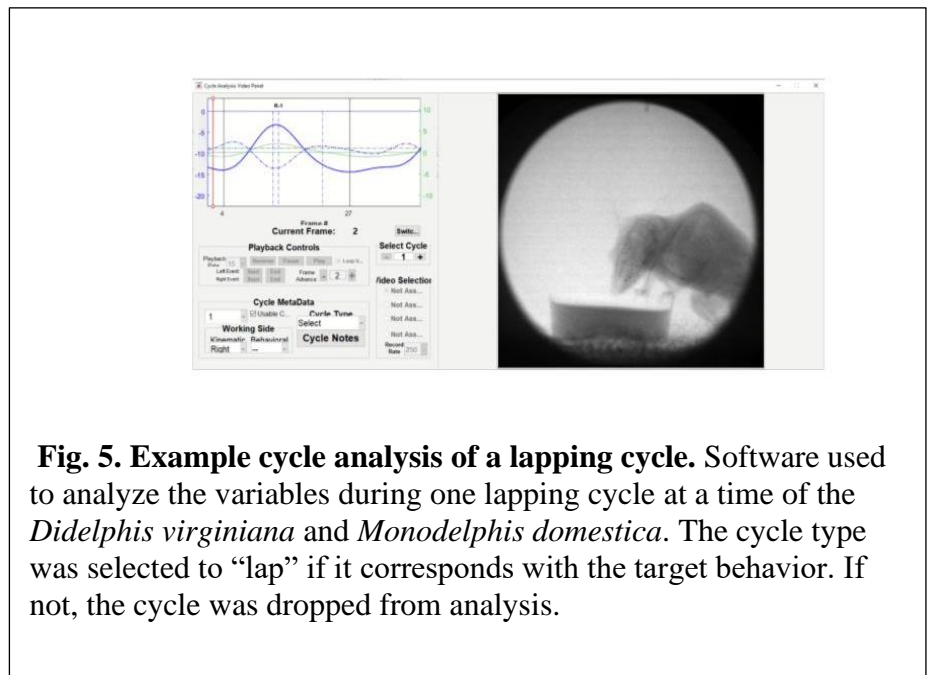


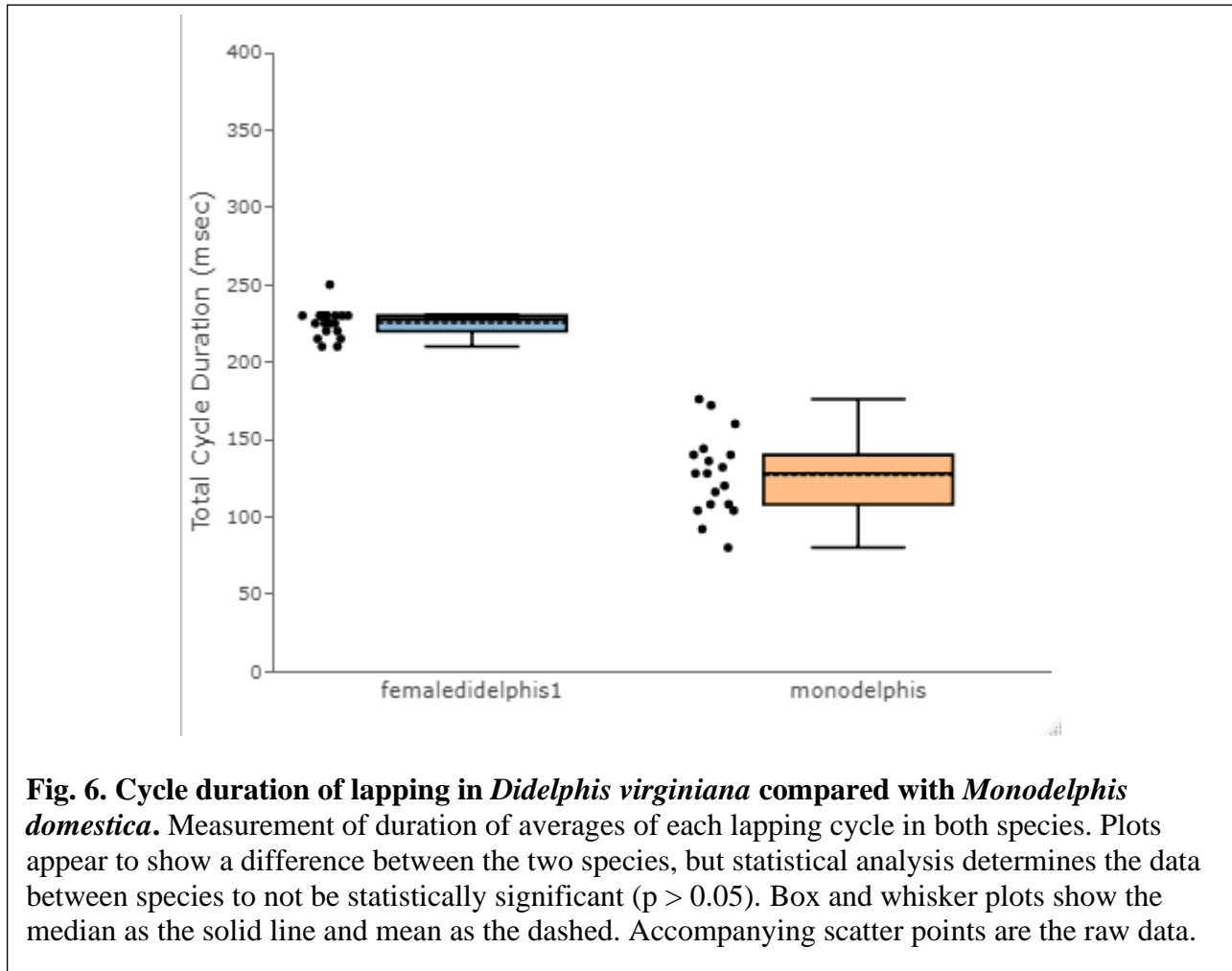
Fig. 5. Example cycle analysis of a lapping cycle. Software used to analyze the variables during one lapping cycle at a time of the *Didelphis virginiana* and *Monodelphis domestica*. The cycle type was selected to “lap” if it corresponds with the target behavior. If not, the cycle was dropped from analysis.

correcting the data as a percentage of jaw length. The jaw was measured at the right hemimandible in centimeters for both species and the percentage of jaw length was determined, and the data was adjusted. Due to unequal sample size effects in statistical analyses, I used one sequence of similar length (1 drinking bout, 20 cycles) from the female *Didelphis virginiana* taken in March 2019 at University of Chicago dataset to compare with my rotoscoped sequence from my male *Monodelphis domestica* (1 drinking bout, 18 cycles) taken in November 2018 at Ohio University. Statistical analyses were run in the package lme4 in R using the lmer function, with the variable of interest as the response variable, species as a fixed variable, and the individual as a repeated measure nested within species to conservatively estimate p-values. P-values <0.05 were considered statistically significant. Degrees of freedom are reported at the individual and cycle levels.

RESULTS

Cycle Duration

Cycle duration of lapping did not differ between the two species (p-value = 0.063). The mean length of cycle duration for the *Didelphis virginiana* was 225.5 ± 9.0 milliseconds. The mean length of cycle duration for the *Monodelphis domestica* was 127.1 ± 26.1 milliseconds. While the results appear to show a difference between the two species due to the scale of the graph being in milliseconds (Fig. 6), when the linear mixed effects model with repeated measures was performed it was determined that there was not a significant difference between the cycle durations between the two species (t-value = 1.86, df = 1,37, p-value = 0.063).



Jaw Pitch

The amplitude of jaw pitch in degrees of rotation did not differ between the two species (p -value = 0.55). A linear mixed effects model was run and determined that there was no significant difference found between the jaw pitch of the two species (t -value = -0.6, $df = 1,37$, p -

value = 0.55). The mean amplitude of jaw pitch for the *Didelphis virginiana* was 8.2 ± 0.3 degrees. The mean amplitude of jaw pitch for the *Monodelphis domestica* was 9.7 ± 1.2 degrees.

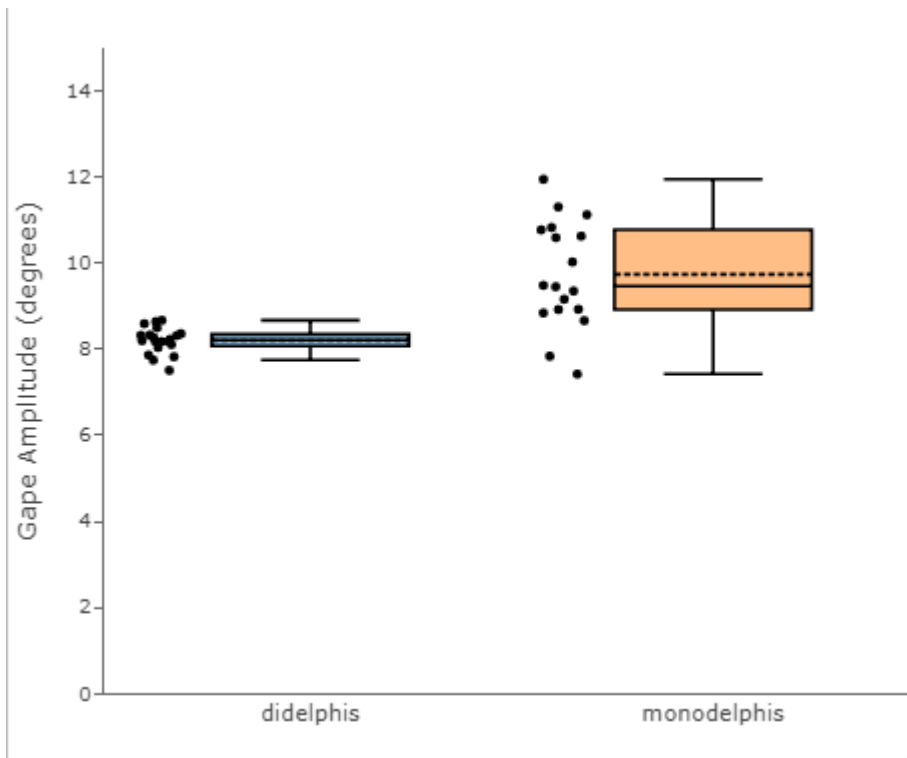
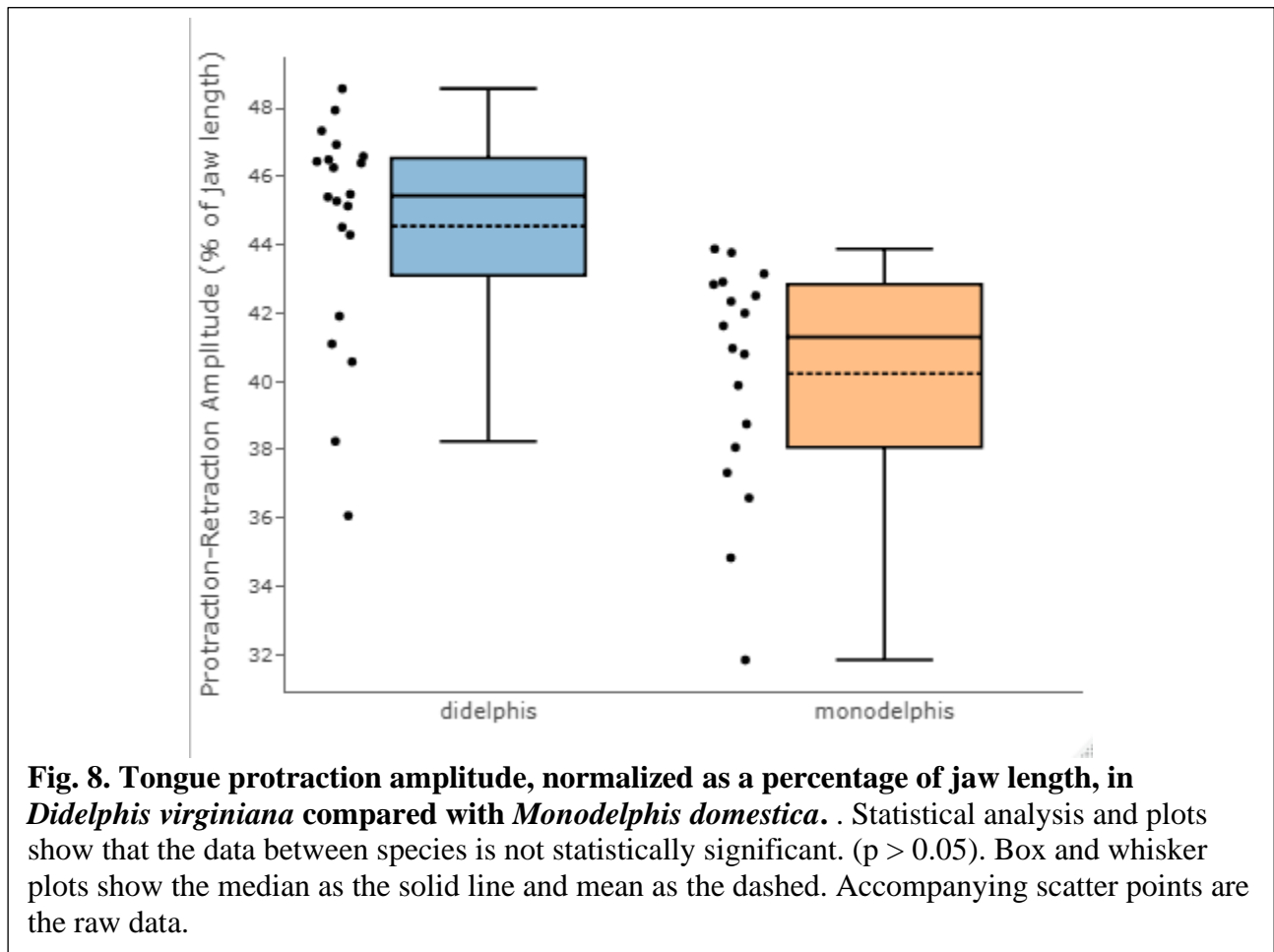


Fig. 7. Jaw pitch during lapping in *Didelphis virginiana* compared with *Monodelphis domestica*. Measurement of the average degree of pitch amplitude during lapping in both species. Statistical analysis and plots show that the data between species is not statistically significant. ($p > 0.05$). Box and whisker plots show the median as the solid line and mean as the dashed. Accompanying scatter points are the raw data.

Tongue Protraction

The amount of tongue protraction, or how much the tongue is sticking out relative to the jaw, did not differ between the two species (p -value = 0.33). This measurement was conducted by comparing anterior tongue marker translation amplitude, normalized to jaw length, and expressed as the percentage relative to jaw length. It was hypothesized that the tongue protraction will be similar between the *Monodelphis domestica* and *Didelphis virginiana* species,

once adjusted for body size. A linear mixed effects model fit by maximum likelihood was run and determined that there was no significant difference found between the tongue protraction of the two species (t -value = 0.97, df = 1,37, p -value = 0.33). The mean adjusted amplitude of tongue protraction for the *Didelphis virginiana* was $44.5 \pm 3.3\%$ of jaw length. The mean adjusted amplitude protection for the *Monodelphis domestica* was $40.2 \pm 3.3\%$ of jaw length.



DISCUSSION

Cycle duration of *Monodelphis domestica* and *Didelphis virginiana* was not significantly different. Therefore, the hypothesis that cycle duration between the two marsupial species would

be similar was supported by the results. However, the data shows a trend to different cycle durations as seen in Fig. 6 and is supported by the p-value of $p=0.06$. With a larger balanced sample size, this relationship will likely become significant. However, with the sample size used the results were not found to be significantly different. This result could be initially thought to be contrary to what is expected due to the difference in body size between the species. In previous studies observing the uptake of water by Felidae and *Canis familiaris*, the lapping frequency measured was scaled with log body size of the animals being studied (Reis et al., 2010; Gart et al., 2015). However, the evolutionary relatedness and similarities in mechanism of lapping between the two species may explain why the duration of the lapping cycle is similar in length.

The hypothesis stating that jaw pitch between the two marsupial species is similar was additionally supported by the results. It was found that the amplitude of pitch did not have a significant difference between *Monodelphis domestica* and *Didelphis virginiana*. The similarity in amplitude of jaw pitch suggests a similarity in the mechanism for the oral behavior of drinking between species. This result is predicted and corresponds to previous studies as the animal opens its mouth wide to place the tongue into the fluid, then closes its mouth to bite off the fluid column (Reis et al., 2010; Gart et al., 2015). This behavior was observed during the fluoroscopy, matching previous studies observations. This again can likely be explained by the evolutionary similarities and similar mechanisms of lapping between the two species.

The final hypothesis that the amplitude of tongue protraction between species would be similar was also supported by the results as there was no significant difference found. While the data had to be adjusted for correcting for the larger size of the *Didelphis virginiana* by measuring protraction data as a percentage of the jaw length, there was no significant difference once this correction was made. This result is predicted and supports previous studies as the animals again

need to protract and retract their tongues to reach fluid for intake, a behavior that matches what was observed during the fluoroscopy videos (Reis et al., 2010; Gart et al., 2015). The similar amplitude of tongue protraction further suggests that the lapping mechanism between marsupial species is conserved as all the variables which were compared did not display any significant differences between species.

Cycle duration, jaw pitch, and amplitude of tongue protraction are variables which can be used to determine relatedness in lapping mechanism between species. The lack of significant difference in each of these variables between *Didelphis virginiana* and *Monodelphis domestica* display the similar mechanism mentioned. Further, evolutionary similarities were another explanation for the lack of significant difference in the variables mentioned. The species *Didelphis virginiana* and *Monodelphis domestica* are closely related on the phylogenetic tree as they are in the marsupial cohort of Ameridelphia and the order Didelphimorphia and within the subfamily Didelphinae (May-Collado et al., 2015). This evolutionary similarity can explain why the variables used to compare species did not yield any significant differences and could be further supported through broader sampling of more individuals of these species, as well as in other marsupials.

CONCLUSION

The comparison of cycle duration, jaw pitch and tongue protraction between *Monodelphis domestica* and *Didelphis virginiana* were used to determine if the mechanism of lapping between these marsupial species is conserved. Despite differences in geographical location, body size, diet and other factors, the data collected suggests that the mechanism for lapping is similar between the two species. It had been previously shown that lapping

mechanisms in dogs and cats both use adhesion (Crompton and Munisky, 2011; Reis et al., 2010; Gart et al., 2015), despite any differences between the species. This suggests that the lapping mechanism could be conserved for marsupial species, which can be explored in further research. It is possible that lapping could have been a mechanism for drinking which was used by early mammals, therefore a greater sampling of different species of mammals would further add to this research. Specifically, marsupials and mammals with complete cheeks should be sampled in order to gain greater insight into the mechanism for drinking used in early mammals.

References

- Bentley, A. J., & Yorio, T. (1979, April 1). *Do Frogs Drink?* The Company of Biologists.
<https://journals.biologists.com/jeb/article/79/1/41/22617/Do-Frogs-Drinks>
- Brainerd, E.L., Baier, D.B., Gatesy, S.M., Hedrick, T.L., Metzger, K.A., Gilbert, S.L. and Crisco, J.J. (2010). X-ray reconstruction of moving morphology (XROMM): precision, accuracy and applications in comparative biomechanics research. *J. Exp. Zool.*, 313A: 262-279. <https://doi.org/10.1002/jez.589>
- Crompton A. W. and Musinsky C. (2011). How dogs lap: ingestion and intraoral transport in *Canis familiaris*. *Biol. Lett.* 7882–884. <http://doi.org/10.1098/rsbl.2011.0336>
- Gart, S., Socha, J. J., Vlachos, P. P., & Jung, S. (2015). Dogs lap using acceleration-driven open pumping. *Proceedings of the National Academy of Sciences of the United States of America*, 112(52), 15798–15802. <https://doi.org/10.1073/pnas.1514842112>
- Gatesy, S. M., Baier, D. B., Jenkins, F. A., & Dial, K. P. (2010). Scientific rotoscoping: a morphology-based method of 3-D motion analysis and visualization. *Journal of experimental zoology. Part A, Ecological genetics and physiology*, 313(5), 244–261. <https://doi.org/10.1002/jez.588>
- German, R. Z., & Crompton, A. W. (1996). Ontogeny of suckling mechanisms in opossums (*Didelphis virginiana*). *Brain, behavior and evolution*, 48(3), 157–164. <https://doi.org/10.1159/000113194>
- May-Collado, L. J., Kilpatrick, C. W., & Agnarsson, I. (2015). Mammals from 'down under': a multi-gene species-level phylogeny of marsupial mammals (Mammalia, Metatheria). *PeerJ*, 3, e805. <https://doi.org/10.7717/peerj.805>
- Olson, R. A., Montuelle, S. J., Chadwell, B. A., Curtis, H., & Williams, S. H. (2021). Jaw

- kinematics and tongue protraction-retraction during chewing and drinking in the pig. *The Journal of experimental biology*, 224(7), jeb239509. <https://doi.org/10.1242/jeb.239509>
- Olson, R. A. (2020). *Biomechanics of the Mammalian Tongue: Kinematic Analysis of Tongue Movements and Deformations during Feeding and Drinking* [Doctoral dissertation, Ohio University]. OhioLINK Electronic Theses and Dissertations Center.
- Reis, P. M., Jung, S., Aristoff, J. M., & Stocker, R. (2010). How cats lap: water uptake by *Felis catus*. *Science (New York, N.Y.)*, 330(6008), 1231–1234. <https://doi.org/10.1126/science.1195421>
- Thexton, A.J., Crompton, A.W. and German, R.Z. (1998), Transition from suckling to drinking at weaning: A kinematic and electromyographic study in miniature pigs. *J. Exp. Zool.*, 280: 327-343. [https://doi.org/10.1002/\(SICI\)1097-010X\(19980401\)280:5<327::AID-JEZ2>3.0.CO;2-Q](https://doi.org/10.1002/(SICI)1097-010X(19980401)280:5<327::AID-JEZ2>3.0.CO;2-Q)
- Thexton, A. J., & McGarrick, J. D. (1988, January 1). Tongue movement of the cat during lapping. *ScienceDirect*. <https://www.sciencedirect.com/science/article/pii/0003996988900660>
- Weijnen J. A. W. M. (1998, October 1). Licking Behavior in the Rat: Measurement and Situational Control of Licking Frequency. *ScienceDirect*. <https://www.sciencedirect.com/science/article/pii/S0149763498000037?via%3Dihub>
- Withers, P. C., Cooper, C. E., Maloney, S. K., Bozinovic, F., and Cruz-Neto, A. P. (2016). *Ecological and Environmental Physiology of Mammals*. Oxford University Press.