# **Tap Dancing Frogs*:* Posterior Toe Tapping and Feeding Behavior in *Dendrobates tinctorius***

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**Abstract**

Animals have myriad adaptations to help them hunt in the most efficient and effective manner. One mysterious behavior suspected to be related to hunting is the posterior toe tapping behavior of some frogs. Biologists and hobbyists alike have long noticed this behavior, but there is little empirical data to explain its function. To test the hypothesis that tapping is related to feeding we conducted a series of related experiments in the Dyeing poison frog, *Dendrobates tinctorius*. We suspected mechanostimulation of prey through vibrational stimuli from tapping might induce prey movement and thereby facilitate prey detection by frogs. First, we confirmed that tap rate was higher during feeding. We next asked whether frogs tapped more under conditions when vibrational contact between frogs and prey was possible. Finally, we asked whether *D. tinctorius* tap more on more vibrationally responsive surfaces and whether prey capture success was higher when tapping. While previous studies have noted an association between toe tapping and feeding behavior our work here is the first to do so quantitatively and experimentally, confirming the impressive speed with which frogs perform the behavior.

**Key words:** anuran, Dendrobatidae, pedal luring, prey capture, feeding behavior

## Introduction

The toe tapping of various species of amphibians is an intriguing behavior that has attracted attention from researchers and pet owners. Variably referred to as toe tapping, twitching, wiggling, and trembling, this curious behavior is the subject of YouTube videos, TikToks, and Twitter threads [1]. Yet despite being readily observed and widely documented, the functional role of toe tapping remains poorly understood.

Among amphibians, toe tapping falls under the general umbrella of pedal luring, which ranges from ostentatious movements of the entire limb to subtle tapping of digits (reviewed in [2,3]). Under this umbrella, a related set of similar-looking toe movements have been broadly discussed in the context of visual and vibrational communication. Toe tapping has been argued to function in prey capture [1,4–6], mate attraction and courtship [7,8], aggression [9,10], and has been suggested to be a 'displacement behavior' with no functional relevance [10,11].

We regularly observe Dyeing poison frogs (*Dendrobates tinctorius*) in our lab tapping their posterior toes (Movie S1 & S2). Toe tapping has been documented in various species of poison frog (family Dendrobatidae) [2], likely with some bias toward increased observations in this group resulting from the fact that these brightly colored, diurnal frogs are popular pets [1]. Poison frogs have dietary specializations for small prey items [12], and in the wild *D. tinctorius* feed on a variety of arthropod prey [13]. Their prey is small and quick, and prey movement is key for detection and capture.

The essential role of prey movement for prey capture in amphibians was demonstrated by studies showing that toads readily strike at any object of the appropriate size and moving in the correct direction [14]. These studies garnered frogs and toads the reputation of being stereotyped in their hunting strategies, with sensory constraints limiting their ability to plastically adjust behavior. However, recent years have seen a growing number of studies cataloging the ability of these animals to integrate complex, multi-modal sensory information (e.g. [15–21]).

Though primarily explored in the context of predator evasion and conspecific communication (e.g. [21–23]), the exquisite vibrational sensitivity of anurans may also play a role in prey capture [4]. Vibrational communication and seismic stimuli through surfaces have also been shown to be sensed by amphibian's arthropod prey [24].

Given the importance of prey movement for prey capture, we reasoned that toe tapping might result in vibrational stimuli that startle prey and increasing hunting efficiency. Under these assumptions, we predicted that *D. tinctorius* would adjust their tapping behavior based on environmental context. We performed a series of experiments to test these ideas. First, we confirmed that *D. tinctorius* do indeed tap more while feeding. Second, we asked whether frogs tapped less under conditions with visual, but no vibrational, contact between frogs and prey. Third, we tested whether *D. tinctorius* tap more on vibrationally responsive surfaces and asked whether prey capture success was higher when tapping. While previous studies have noted an association between toe tapping and feeding our work here is the first to do so quantitatively and experimentally.

## Methods

### *(a) Animals*

*D. tinctorius* were housed in our animal facility at the University of Illinois Urbana-Champaign. Terraria contained soil, moss, leaf litter, live plants, coconut shelters, and a small pond. Terraria were maintained at 70-100% humidity and 22-24ºC on a 12L:12D light cycle. We fed frogs *Drosophila hydei* or *Drosophila melanogaster* dusted with vitamins three times weekly. All animal care and experimental procedures were approved by the University of Illinois Animal Care and Use Committee (IACUC protocol #20147).

### *(b) Experiment 1: Tapping while feeding versus non-feeding*

In the first experiment, we tested if *D. tinctorius* tap more while feeding versus not feeding. For feeding trials, we dropped ½ teaspoon of *Drosophila* into the frogs' terrarium. Once frogs began hunting, we took one minute of slow-motion video (240 frames per second). For non-feeding trials, we took one minute of slow-motion video while frogs were not feeding. All trials took place between 11:00 and 14:00. We also recorded partner proximity (frogs are housed in pairs) during filming. Videos were analyzed as described below. N=12 feeding and N=10 non-feeding trials.

*(c) Experiment 2: Tapping when prey is inaccessible*

In the second experiment we tested whether tapping behavior was affected by prey being on a different surface and inaccessible to the frogs. We placed *Drosophila* inside a small, clear petri dish so that the frogs could see the prey but not feed on it, and the prey was not on the same surface as the frog. Petri dishes were placed in frogs home terraria during normal feeding time, and we performed N=5 trials following data collection procedures described above.

*(d) Experiment 3: Tapping across surfaces*

In the third experiment, we asked whether tapping rate depended on substrate type. We set up terraria with four substrate types: soil (a natural, unpliable surface), leaf litter (a natural, pliable surface), gel (1% agar; an unnatural, pliable surface), and glass (an unnatural, unpliable surface). We chose these surfaces to obtain a variety of pliability and familiarity. We placed frogs singly into test terraria and gave them one-hour acclimation to the novel environment. Following acclimation, we fed frogs and collected data as in Experiment 1. In addition, we recorded the number of strikes frogs made in attempts to catch prey, and how many of these strikes were successful. We performed all trials one day after last feeding to control for satiety status. Each individual performed one trial on every surface, apart from two individuals performing two on each

surface. N=13 trials per surface. All trials were analyzed for tap rate. For strike and success rate, three trials were excluded from analysis due to video loss.

*(e) Data Analysis*

We quantified tap number from slow motion video and standardized data for each frog. To calculate the number of taps per minute, we divided the number of taps on each foot by the number of seconds the foot was visible to obtain taps per second. We then multiplied that by 60 to calculate taps per minute for each foot and added the two feet together to get total taps per minute. For experiment three, we calculated success rate by dividing the number of successful strikes by the total number of strikes.

We used R v4.4.2 [25] in Rstudio v 3.1.446 [26] for all statistical analyses. For Experiment 1, we tested for differences in tap rate using a linear mixed model that included feeding status and partner presence as fixed effects and frog ID as a random effect. In the second experiment, we used the same approach to compare frogs feeding on free flies (data from Experiment 1) to frogs feeding on flies confined to a petri dish. In the third experiment, we included substrate type as a fixed effect and frog ID as a random effect. Finally, we tested for a substrate-dependent relationship between prey capture success and tapping, where capture success rate was predicted by surface type, tap rate, and their interaction. For all linear models, we evaluated significance via ANOVA followed by Tukey corrected post hoc testing. We tested for correlations between tap rate, strike rate, and strike success using Spearman correlations.

## Results

*(a) Frogs tap more when feeding*

Frogs tapped significantly more when feeding versus non-feeding (main effect of feeding: $F_{1,17} = 116.65$, $p < 0.0001$) and this effect was more pronounced in proximity of another frog

(feeding*partner interaction: $F_{1,18} = 7.36$, $p = 0.0143$) (Fig. 1a). The average tap rate was 389 taps/min (range: 305 - 468) when feeding alone, 684 taps/min (range: 492 - 997) when feeding near a partner, 50 taps/min (range: 4 - 149) when not feeding away from a partner, and 43 taps/min (range: 5 - 92) when not feeding but near a partner.

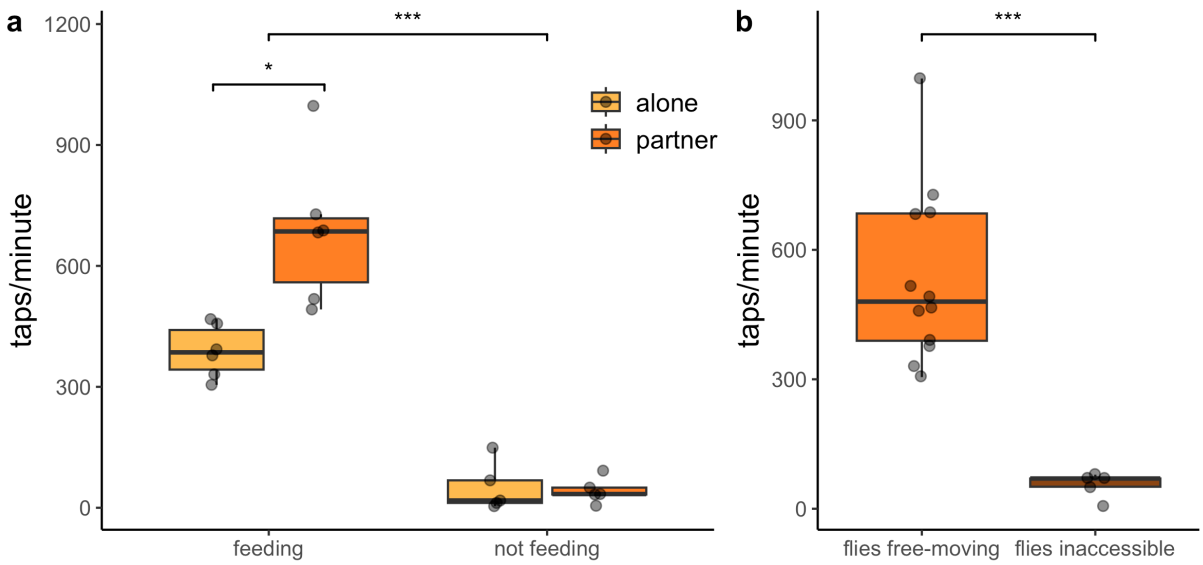


**Figure 1**: Increased tapping when feeding on accessible prey. **(a)** Frogs tapped significantly more when feeding versus not feeding, and this effect was more pronounced in the presence of another frog (dark orange) than when alone (light orange). **(b)** Tap rate was significantly lower when flies were on a different surface than frogs and inaccessible (inside a petri dish). Feeding data in (a) and free-moving fly data in (b) are from the same trials.

*(b) Frogs tap more when on the same surface as prey*

Tap rate was significantly lower when frogs were on a different surface than their prey ($F_{1,15} = 27.17$, $p = 0.0001$) (Fig. 1b). The average tap rate when frogs could see, but not access, flies was 55 taps/min (range: 6 - 79); significantly lower than the 519 taps per minute while feeding on free moving flies (Fig. 1b). Importantly, we observed this difference in tap rate even though frogs attempted to catch prey under both conditions.

*(c) Tap rate depends on surface type*

There was a significant difference in tap rate between surface types ($F_{1,40.6} = 6.21$, $p = 0.0014$) (Fig. 2a). Average tap rates were 98 taps/min for soil (range: 0 - 417), 255 taps/min for leaf (range: 24 - 528), 118 taps/min for gel (range: 0 - 440), and 64 taps/min for glass (range: 0 - 211). Post hoc comparisons revealed that frogs tapped more on leaves than all other surfaces (gel: $t_{38.4} = 2.87$, $p = 0.0317$; glass: $t_{38.4} = 4.01$, $p = 0.0015$; soil: $t_{38.4} = 3.30$, $p = 0.0107$) (Fig. 2a). Tap rates in experimental tanks (Experiment 2) were on average lower than when frogs were in their home terraria (Experiment 1), but still higher than when not feeding in home terraria.

While tap rate differed between surface types, there was no difference in the total number of strikes ($F_{3,28} = 1.41$, $p=0.259$) or success ($F_{3,28} = 0.81$, $p = 0.497$) based on substrate. Strike rate increased with tap rate ($r=0.318$, $p=0.045$); however, tap rate did not significantly predict prey capture success overall (tap rate main effect: $F_{1,30} = 2.29$, $p = 0.142$) or based on surface type (tap rate*surface interaction: $F_{3,28} = 1.43$, $p = 0.254$) (Fig. 2b).

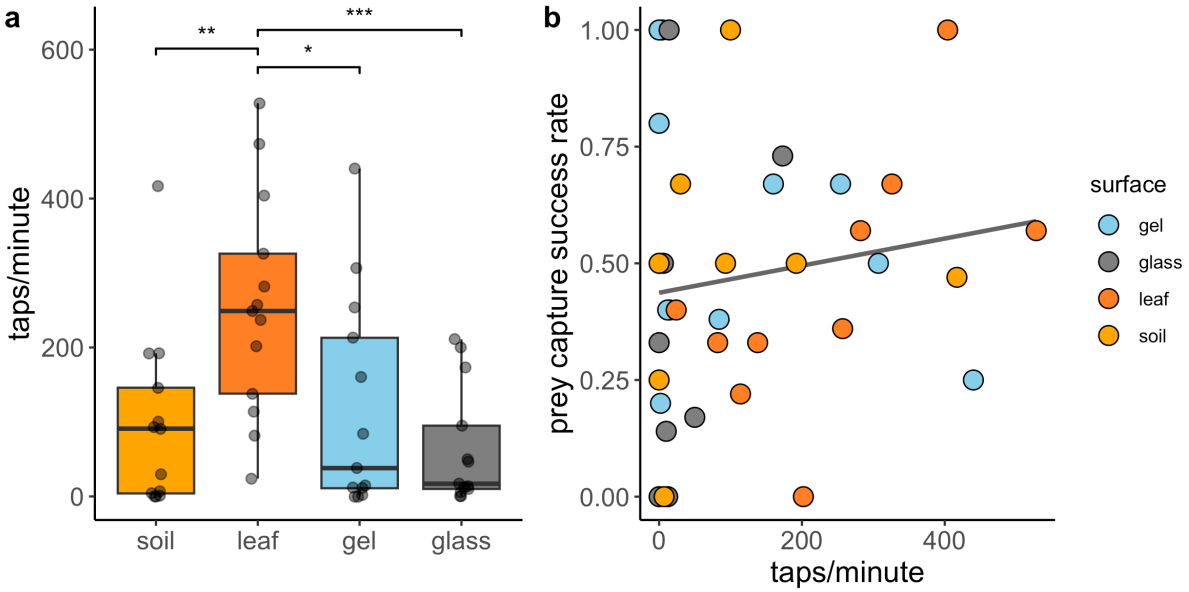


**Figure 2.** Tap rates differ based on surface. (a) Tap rate was higher on leaves (orange) as compared to soil (yellow), gel (blue), or glass (grey). (b) Prey capture success rate did not differ between surface types and was not predicted by tap rate.

## Discussion

Taken together, our findings demonstrate that tapping is associated with feeding and tap rate is modulated by prey accessibility and surface characteristics in *D. tinctorius*. In line with our predictions, we found that the frogs tapped more while feeding, when on the same surface as prey, and on a vibrationally responsive surface. Counter to our expectations, we did find a relationship between tap rate and prey capture success.

An association between feeding and posterior toe tapping has long been noted by researchers and hobbyists; however, to our knowledge, our study is the first to quantify this relationship. Experiment 1 confirmed that tapping is associated with feeding, with frogs increasing their tap rate up to 10-fold in the presence of prey. We highlight that – at a maximum of almost 500 taps per toe per minute – this behavior is incredibly fast for any vertebrate muscular movement [27]. In brief, our findings demonstrate an association between tapping and feeding and provide interesting avenues for further study.

Given the vibrational sensitivity of both frogs and their arthropod prey, and the importance of prey movement for prey detection, we hypothesized that toe tapping could function as a vibrational stimulus that facilitates prey capture. To test this idea, we examined the relationship between tapping and surface type. When frogs could see but not capture flies, frogs tapped significantly less but *still hunted.* We suggest that this change is most likely related to changes in vibrational stimuli as visual signals were not obscured. This observation suggests that frogs might alter their tapping behavior based on whether prey respond to tapping vibrations.

To test this idea further, we asked whether *D. tinctorius* modulated tapping based on surface type. Frogs tapped at a significantly higher rate on the leaf surface, aligning with our prediction that tapping would be enhanced on vibrationally responsive surfaces. We were concerned that tapping might be impacted by the naturalness and familiarity of each surface and the test terraria. Tap rate was overall lower in the experimental terraria than in home terraria; however, frogs hunted on all test surfaces, with no differences in prey capture attempts or prey

capture success. Additionally, we found that frogs tapped less on soil than leaves, despite both surfaces being familiar to frogs. Taken together, these observations demonstrate that frogs modulate tapping behavior based on substrate type and independent of prey capture attempts.

We expected higher tap rate to be associated with increased prey capture success; however, this prediction was not supported - in general or based on surface type. Nor did we find a difference in prey capture success across surface types. We suspect this may be an artifact of our feeding method in the lab, where frogs are provided a large number of flies and prey capture success is artificially high. While this possibility requires further study, our demonstration of an association between tapping behavior, capture attempts, and surface type is suggestive and opens the door for further experiments.

Additional work is also needed to definitively rule out alternative hypotheses for toe tapping. One alternative explanation for tapping is a generalized displacement and/or excitatory response [10,11]. Under this assumption, tapping has no functional role but is a reflex to food or movement, akin to a dog wagging its tail. We consider the unlikely, given our finding that frogs modulate tapping based on surface type and independent of feeding success. Another alternative is that tapping may be involved in social communication between frogs, in an agonistic and/or affiliative manner [7,8,10]. While we did indeed see an increase in tapping while feeding in the presence of another frog, we note that this social modulation occurred only when food was present and that frogs also tapped in the presence of food when they were alone. These observations suggest that any social function – be it cooperative or antagonistic – is in addition to a feeding-related role. In sum, while other non-mutually exclusive roles for posterior toe tapping may exist, our data support a functional connection between tapping and feeding in *D. tinctorius*.

*Conclusions*

Taken together, our findings confirm an association between toe tapping and feeding, and demonstrate that *D. tinctorius* modulate tapping based on environmental context. The observation

that frogs alter their tapping frequency – but not their strike rate – based on substrate type suggests that tapping has a functional, context dependent role. We suggest that tapping may stir small arthropods via substrate vibrations and thereby help *D. tinctorius* detect prey. Future studies characterizing tapping biomechanics, measuring substrate vibrations caused by tapping, and testing the vibrational sensitivity of both frogs and prey will further our understanding of tap-dancing toes.

**Acknowledgements**

We would like to thank Samta Oza for help with data collection and members of the Fischer Lab for feedback on previous version of the manuscript. Thanks to Phil Anderson for advice and assistance with high-speed filming.

**Funding**

TQP was supported by a Dr. Kirk and Mrs. Shannon Moberg Scholarship and a Robert H. Davis Undergraduate Research Prize. EKF was supported by start-up funding from the University of Illinois Urbana-Champaign.

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