PUT SOME MUSCLE INTO LEARNING

Mary A. Bush
Charles Fortes Elementary School
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Charles N. Fortes Elementary:
I study the physiological basis of animal movement. I am interested in how the most basic mechanical properties of muscles define locomotor speed, power, and cost. This work is motivated by both an interest in how muscle and tendon properties have shaped the evolution of the musculoskeletal system, as well as an interest in providing a fundamental understanding of musculoskeletal function for application to problems of human health.”

Thomas J. Roberts
Associate Professor
Ph.D., Harvard University
Completed publications:


Key Concepts:

**Force** - a push or pull that can cause an object with mass to change its velocity to accelerate.

**Power** is the rate at which work is performed or energy is transmitted.

**Power Amplification** - measures power that goes above and beyond the expected maximum power outputs.

**Elastic potential energy** is stored in objects that are stretched, compressed, bent, or twisted.

**Mechanical work** is the amount of energy transferred by a force.
Dissection Tools

XROMM is an x-ray imaging and computational process that produces precise and accurate 3D movies of skeletal movement.

High Speed Video
**Tools of the Trade:**

*In vi-tro - in an artificial environment rather than inside a living organism, e.g. in a test tube*

**Sonometric crystals** used to measure instantaneous length change in muscle.

**Ergometer** An instrument for measuring muscle power or the amount of work done by a muscle.

**Computers** – Used in *every* aspect of the process.
Tools of the Trade:

Programming software used for scientific graphing, data analysis, and image processing.

**Force Plate** measures vertical, medial lateral and fore-aft forces of stepping and jumping.

**Graphs:**
- **Vertical**
- **Medial Lateral**
- **Fore-Aft**
Elastic mechanisms as a determinant of anuran jumping performance: do toads bounce?

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Abstract
Anuran jumping performance varies widely among species. Biomechanical studies have proposed that some of the best jumpers use an elastic mechanism to generate power outputs that exceed their muscular capacity. Most studies of frog power have focused on leaping species, but it is unclear whether species with limited muscle expansion potential use an elastic mechanism. To better understand frog jumping performance and explore alternative mechanisms, we studied the mechanics of towel toad (Lithobates catesbeianus; formerly Bufo catesbeianus), a species with limited muscle expansion potential. We recorded the animal’s full 3D kinematics and muscle strains from the foot and hindlimb muscles and their location and growth. We found that towel toad jumping is powered by an elastic mechanism that stores and releases elastic strain energy to generate peak power. This mechanism can achieve peak power outputs that exceed their muscle capacity. Our results suggest that towel toad jumping is an example of an elastic mechanism that can be used to generate power outputs that exceed the animal’s muscular capacity.

Introduction

Some of the best jumpers develop power outputs that exceed the capacity of their hindlimb muscles. It has been proposed that this supra-maximal power output results from the rapid release of energy stored in elastic elements (Bennett-Clark, 1977; Pepeleøwski and Marsh, 1997; Marsh and John-Alder, 1994).

We sought to determine whether power amplification by an elastic mechanism is common to anurans of varying jumping abilities.

Materials and Methods
We employed three species in our study: 6 Cuban tree frogs (Osteopilus septentrionalis), 4 Northern leopard frogs (Bufo pipiens) and 4 cane toads (Bufo marinus). Animals were placed on a custom built, 3 axis force plate in an enclosed arena at 22-25°C. They were motivated to jump by a spray of canned air. Force data were used to calculate instantaneous velocity, acceleration, work and power. The best jumps for each individual, as determined by peak power output, were selected for analysis. Power and work measurements were determined on a muscle-specific basis. The total hindlimb muscle mass was measured in 3 cane toads and 2 leopard frogs. Cuban tree frogs hindlimb muscle mass was obtained from Marsh (1994).

Peak isometric power output was measured in vitro using a muscle servor to measure muscle force and velocity. A nerve cuff was used to stimulate maximum contraction. Measurements were taken for 6 to 8 contractions over a range of velocities. Peak power was calculated from a Hill-type fit of force-velocity data from these contractions.

Results
Species comparison of muscle mass-specific power outputs

Figure 1. Power profiles from representative jumps show substantial variation in muscle mass-specific power output among the three species. The dashed line indicates the highest published value for peak isometric power output for frog muscle at 20°C (Lanniøergen et al., 1982).

Figure 2. Cuban tree frogs developed much higher power outputs per unit muscle mass than did leopard frogs or cane toads. Peak in vivo power output (species’ left) was much higher than peak in vitro power output (species’ right) measured in isolated muscle for the Cuban tree frogs, while in leopard frogs and cane toads, in vitro and in vivo power outputs were not significantly different. R. pipiens and B. marinus in vivo data is from plante- rials by Gary and Marsh (1993) for sartorius muscle at 28°C.

Figure 3. During the takeoff phase of jumping, time of contact was shortest in O. septentrionalis than R. pipiens and B. marinus.

Figure 4. Work per unit hindlimb muscle mass was greater in O. septentrionalis compared with R. pipiens and B. marinus.

Figure 5. O. septentrionalis jumped farthest.

Figure 6. Data for a modeled muscle/ tendon-foot system indicates that storage of muscle work in elastic elements can produce an asymptotic power profile. Power is low early in the jump as muscle (red) work is stored as tendon (green) strain energy. Power is high late in the contration as muscle and tendon power are released to the body. Figure taken from Roberts and Marsh (2003).

Conclusions
• Supramaximal power outputs in O. septentrionalis provide evidence for an elastic mechanism in this species.

• R. pipiens and B. marinus in this study develop power outputs in a jump that are within their muscles’ capacity for power production.

• The absence of supramaximal power output in poor jumpers suggests that an elastic mechanism for muscle power amplification may not be common to all anuran jumpers.

Acknowledgments
Supported by National Science Foundation NSF-0046428 to T.J. Roberts. We thank Manny Asai for his generous help and counsel with the in vitro experiments. Additional thanks to all helpful frog wranglers volunteers.

References
Jumping Frogs: Finding Force & Power

**Question and Hypothesis:**

The power amplification in the *Rana pipiens* (leopard frogs) was less than expected in Emily’s research.

In her study the *R. pipiens* developed power outputs in their jumps that were within their muscles' capacity for power production but significantly lower than expected.

We sought to find out if we could get more pronounced results from the *R. pipiens*. 
Methods:

We used 2 groups of 4 *R. pipiens*. The first group had been held in captivity for approximately 6 mo. The second group were new arrivals.

Each frog was weighed in. Snout-vent lengths ($L_{sv}$) and hind limb lengths ($L_{hl}$) were taken.

Frogs were placed on a 3 axis force plate in an enclosed area. They were motivated to jump by a quick grabbing motion or by a spray of canned air.
A 24cm barrier was added to encourage more powerful jumps.

Using IGOR, force data were used to calculate the power. Power and work measurements were determined on a muscle-mass specific basis.

The best 5 jumps for each individual frog, as determined by peak power output, were selected for analysis.
Results:

Maximum Power Output

![Graph showing power output over time.](image-url)

- Power (w/kg - muscle mass)
- Time (s)
The *R. pipiens* in this study developed power outputs in jumps that exceeded their muscles' capacity for power production.

Therefore, *R. pipiens* are good jumpers because they have proven to use power amplification.
Calaveras County:

Calaveras Jumping Frog Jubilee Records

Year

triple jump distance (m)

1920 1940 1960 1980 2000 2020
Calaveras County:

Maximum Temperatures Calaveras County Frog Jumping Contest

\[ y = 0.0122x + 4.3965 \]

\[ R^2 = 0.019 \]
Classroom Implications:

Scientific Method

▪ Ask a Question
▪ Do Background Research
▪ Construct a Hypothesis
▪ Test Your Hypothesis by Doing an Experiment
▪ Analyze Your Data and Draw a Conclusion
▪ Communicate Your Results
Classroom Implications: for Younger Children

The process of science learning is what really counts with young children, not the content.

- Observe
- Compare
- Sort and organize
- Wonder, predict, and hypothesize
- Experiment, test, and explore
- Gather and record results to show understanding
- Extend, expand, and apply
References & Acknowledgements

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Let's Investigate! Spark interest in science with these seven steps to successful studies.  
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