“My Field for Dummies”: Bat flight and temperature

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Outline

How animals deal with temperature

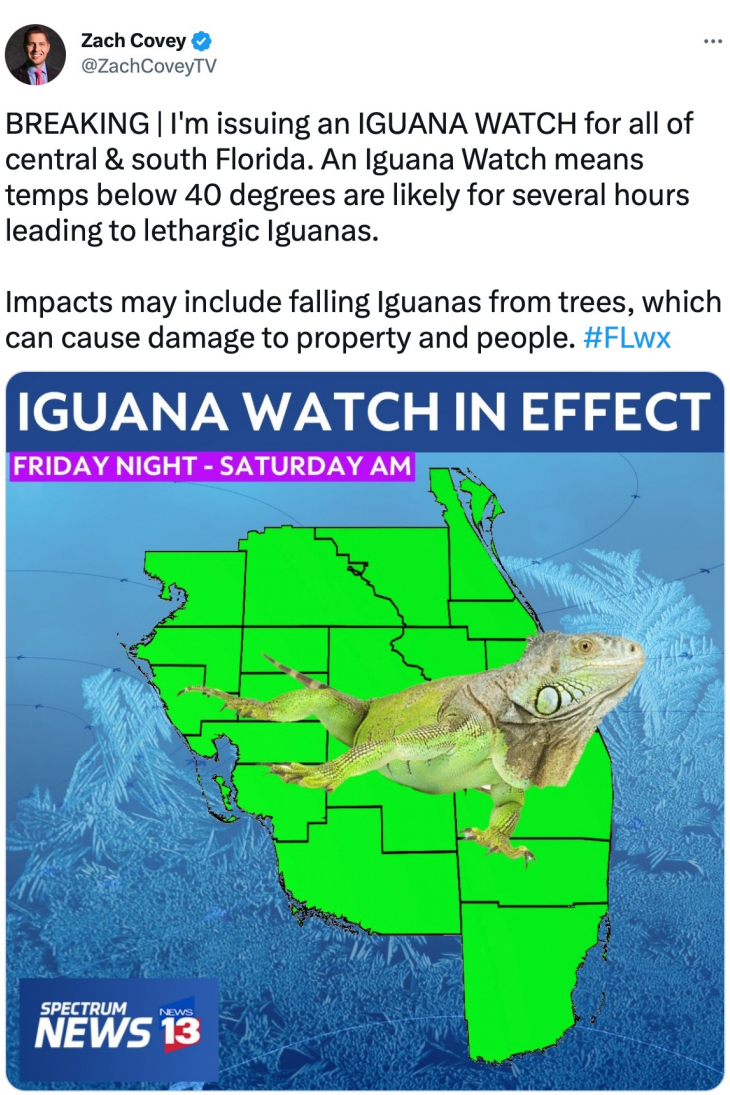
Muscle anatomy and physiology

Why it’s important to integrate thermal biology, muscle physiology, and biomechanics in the study of bat flight

Dromedary camel

Arctic tern

Temperature affects performance



Thermal performance curves

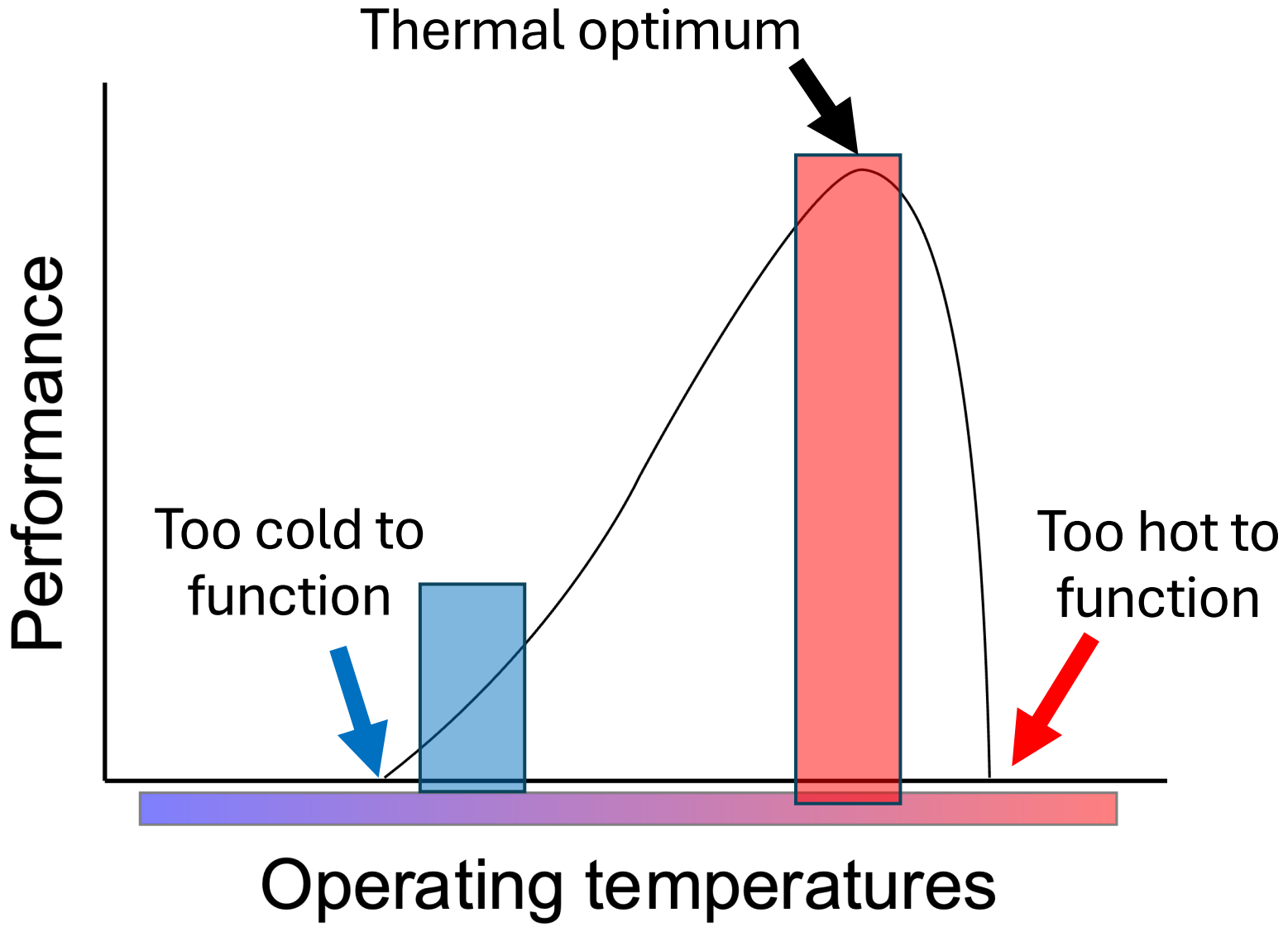
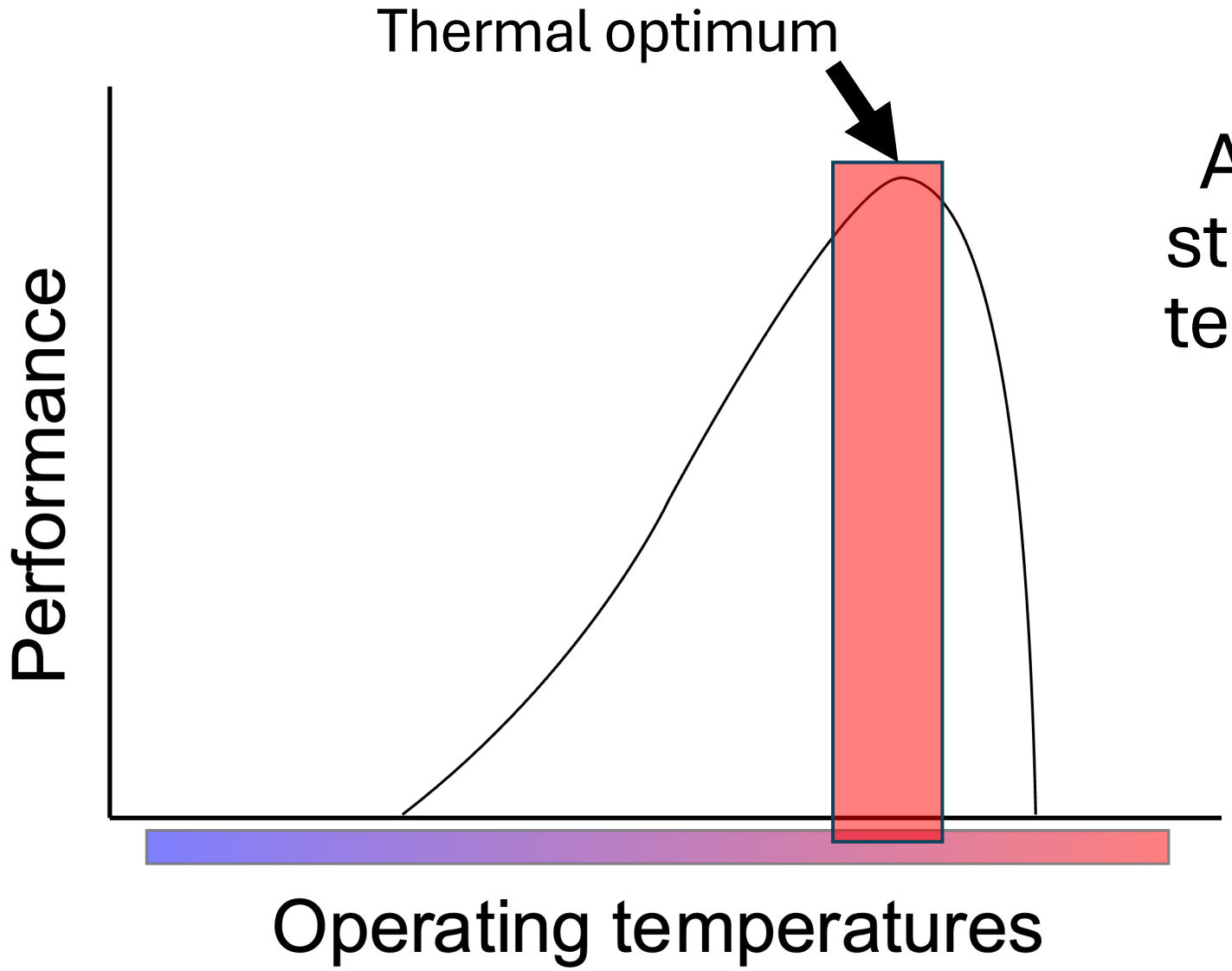


Photo: Nelli Parhomenko

Performance is optimal at an animal's preferred temperature



Animals adopt various strategies to adjust body temperature along these curves

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Thermoregulation

Body temp. maintained via internal heat production

Endotherms

Heterothermy

Body temp. depends on environmental temp

Ectotherms

Temporal heterothermy

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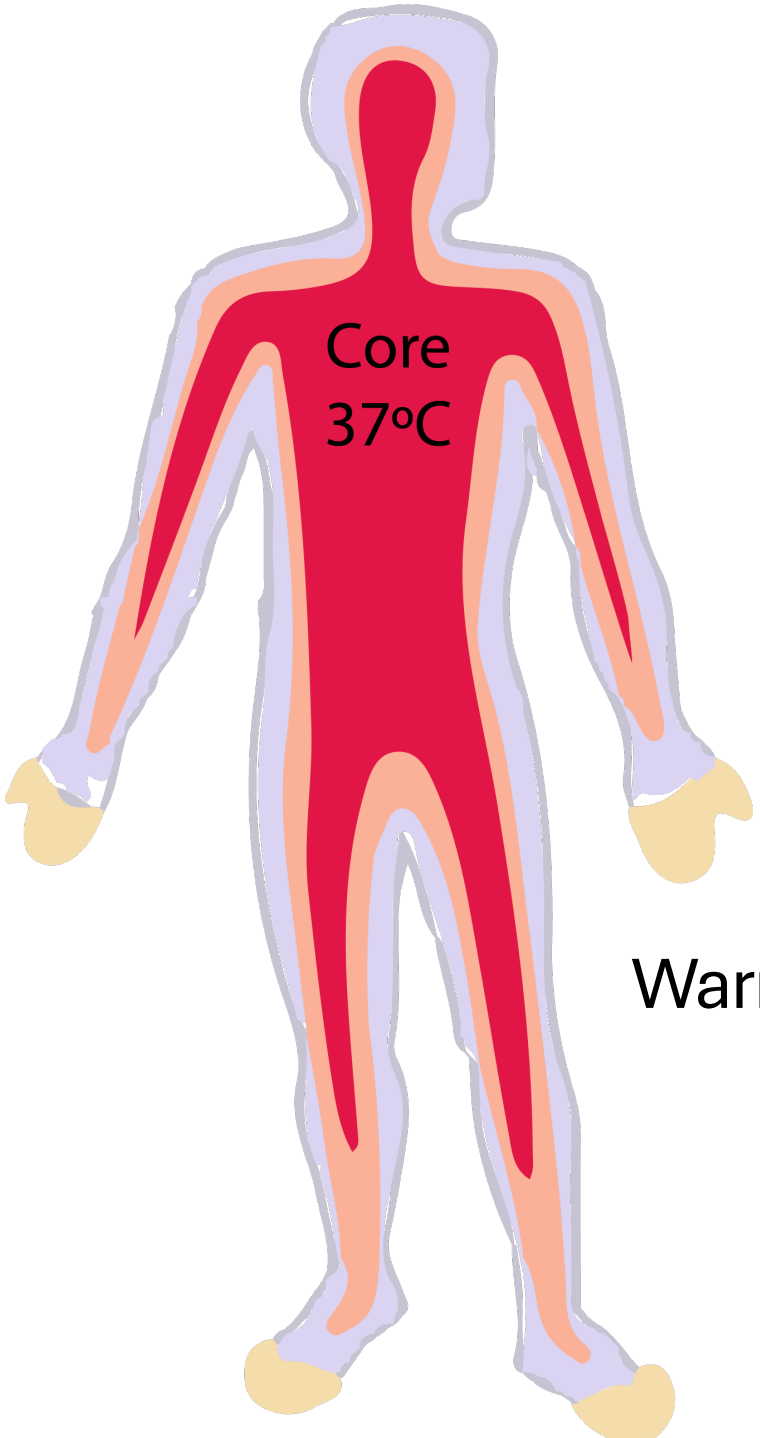
Differences in body temperature across time

Torpor, hibernation

Golden mantled ground squirrel



Regional heterothermy

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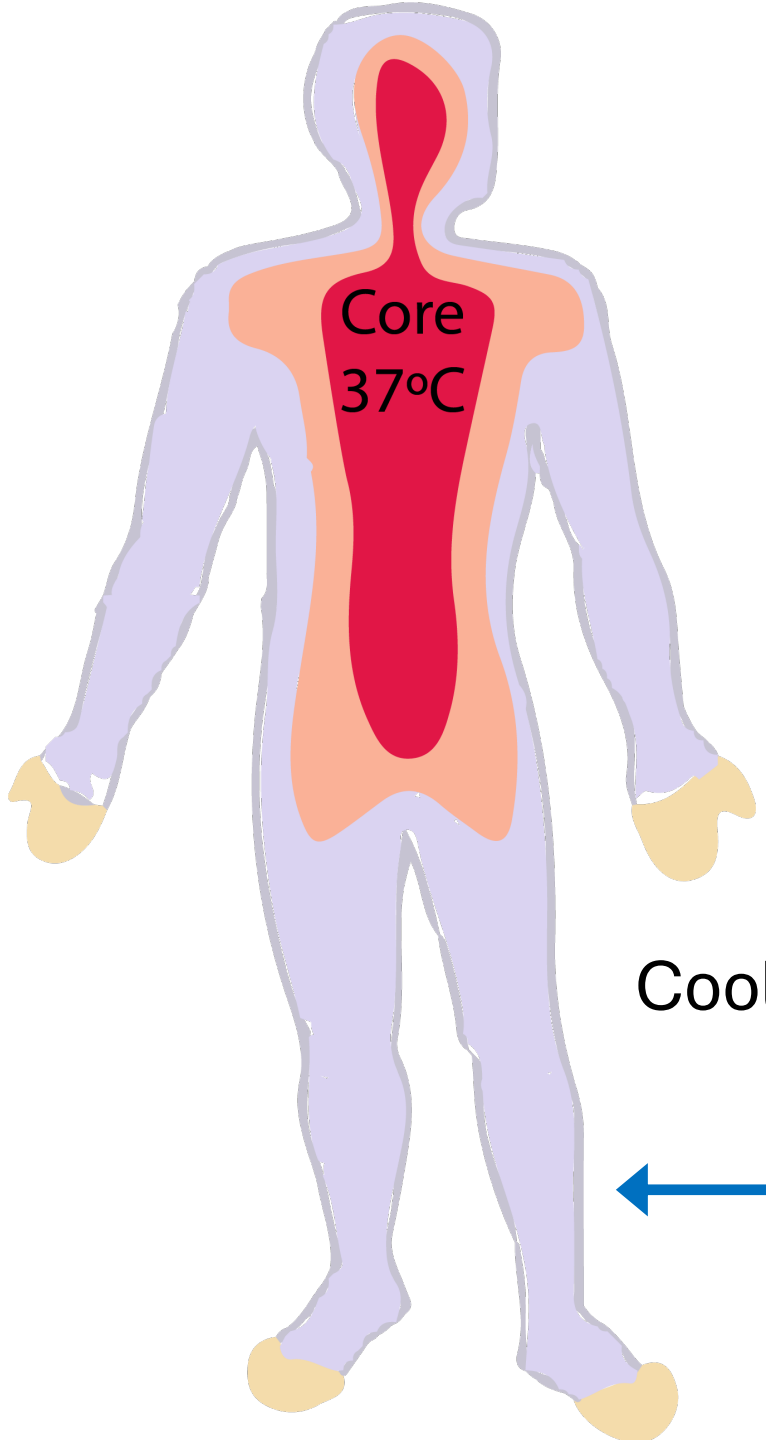
Differences in body temperature across body regions

Warm ambient temperature

White et al. 2011



Regional heterothermy

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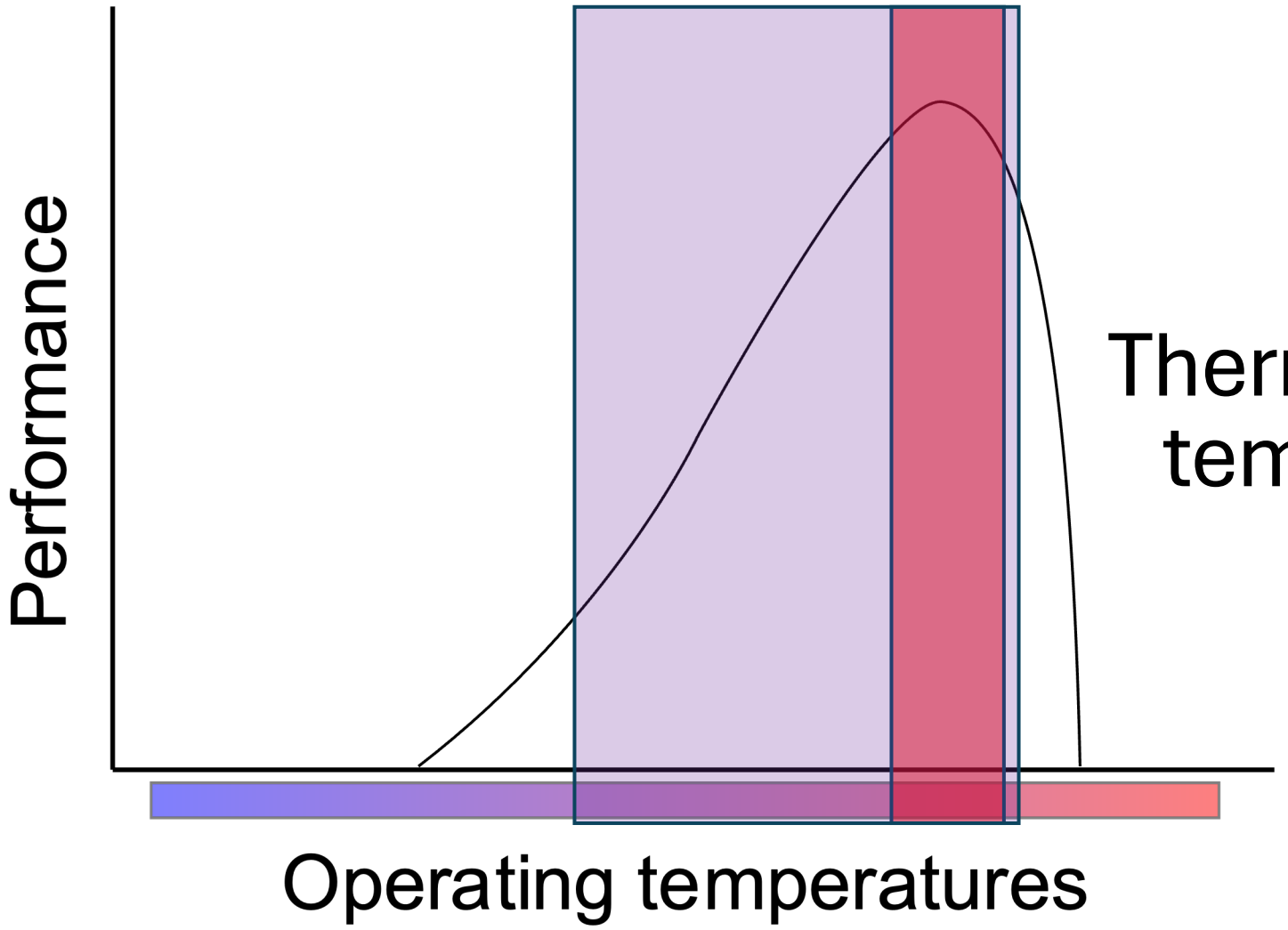
Differences in body temperature across body regions

Cool ambient temperature

Extremities cool while core temp is maintained

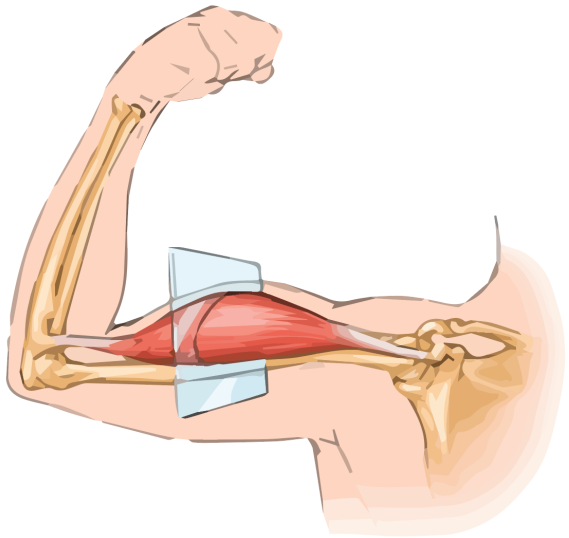
Everybody feels the effects of temperature

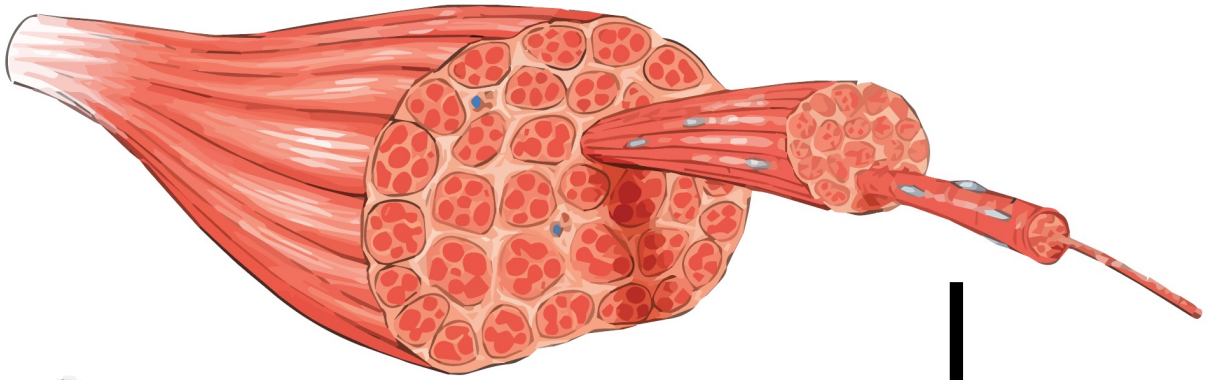


Thermoregulation buffers temperature effects to some extent

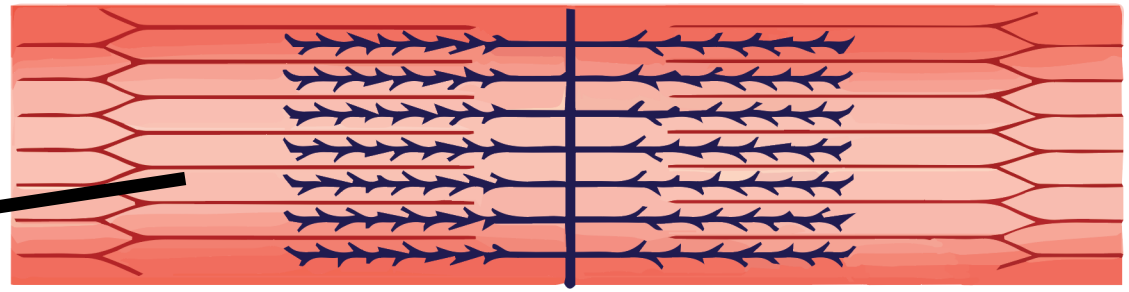
Muscle anatomy and physiology

What's going on inside skeletal muscle?

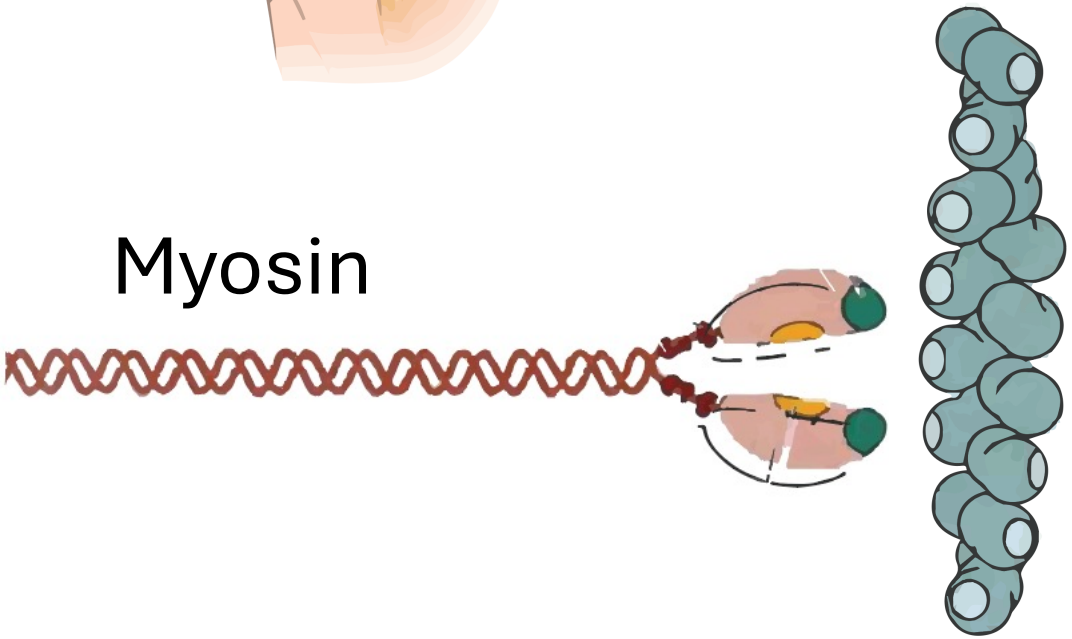




Sarcomere

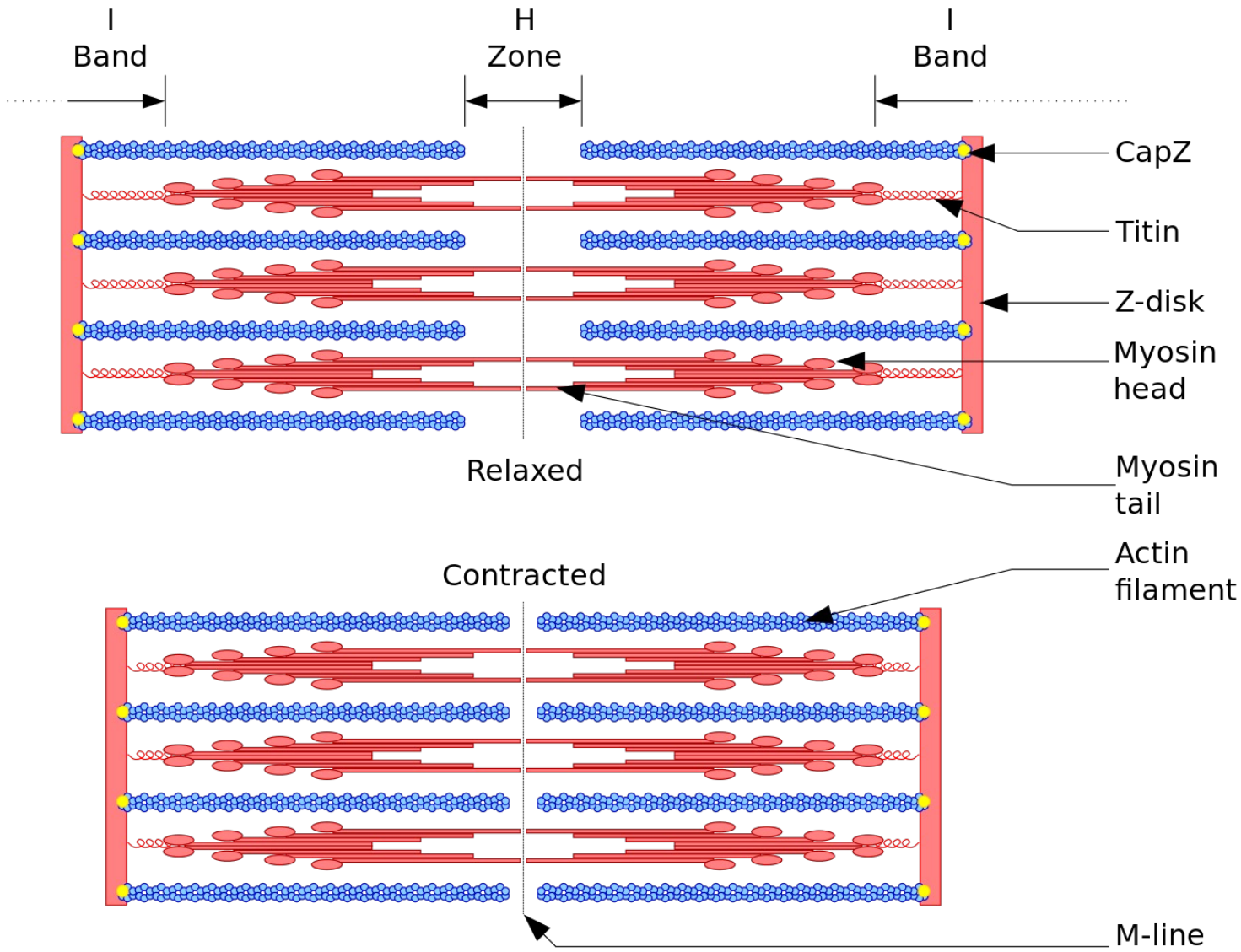


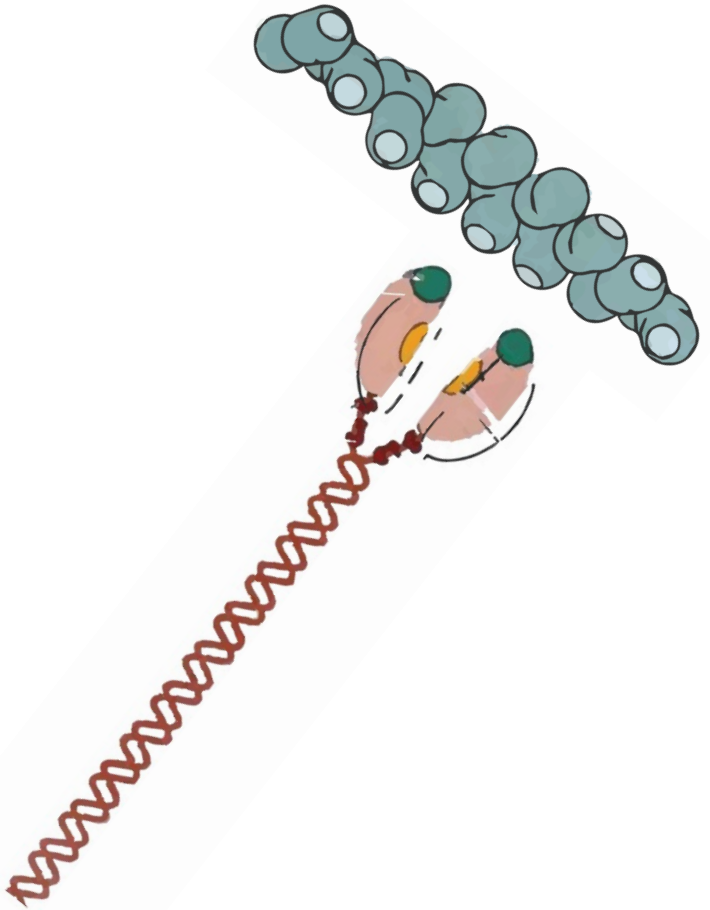
Myosin



Adapted from Dave Carlson

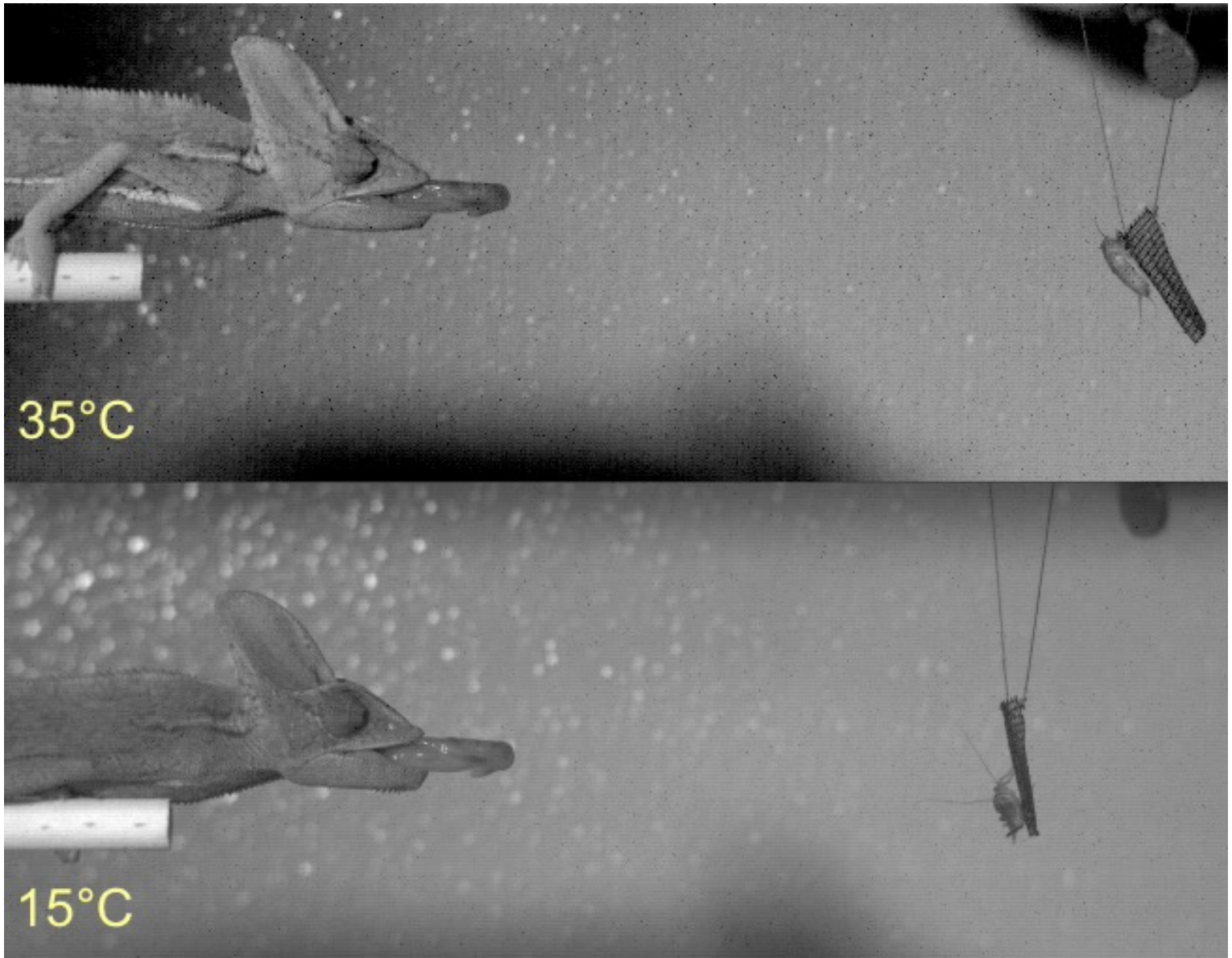
Myosin and actin pull against each other during muscle contraction





David Richfield, Wikimedia

Muscles are extremely temperature sensitive



cold muscles

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slow movements

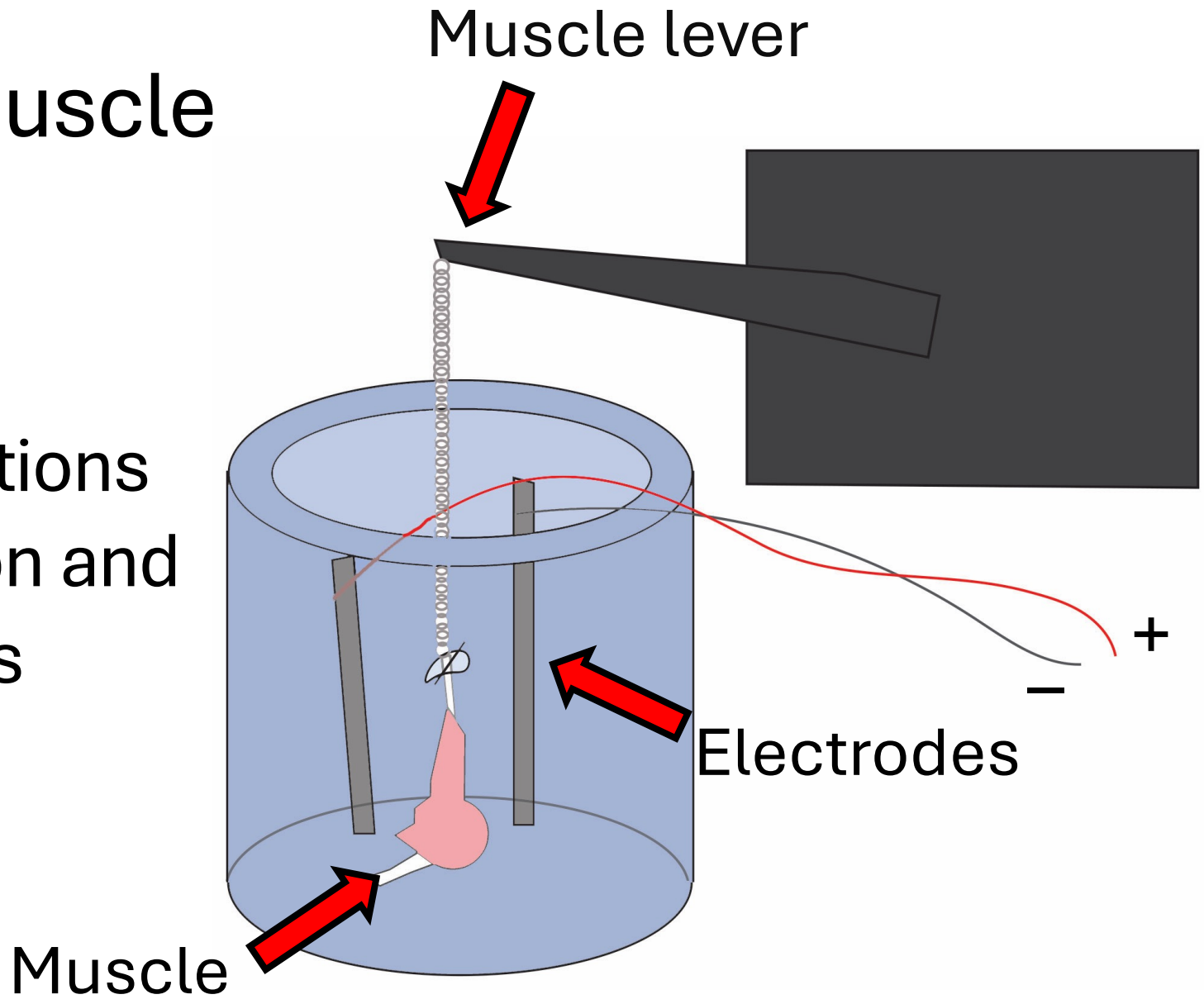
Anderson and Deban 2010

Many animals compensate for muscle temperature effects via biomechanics, morphology, or behavior

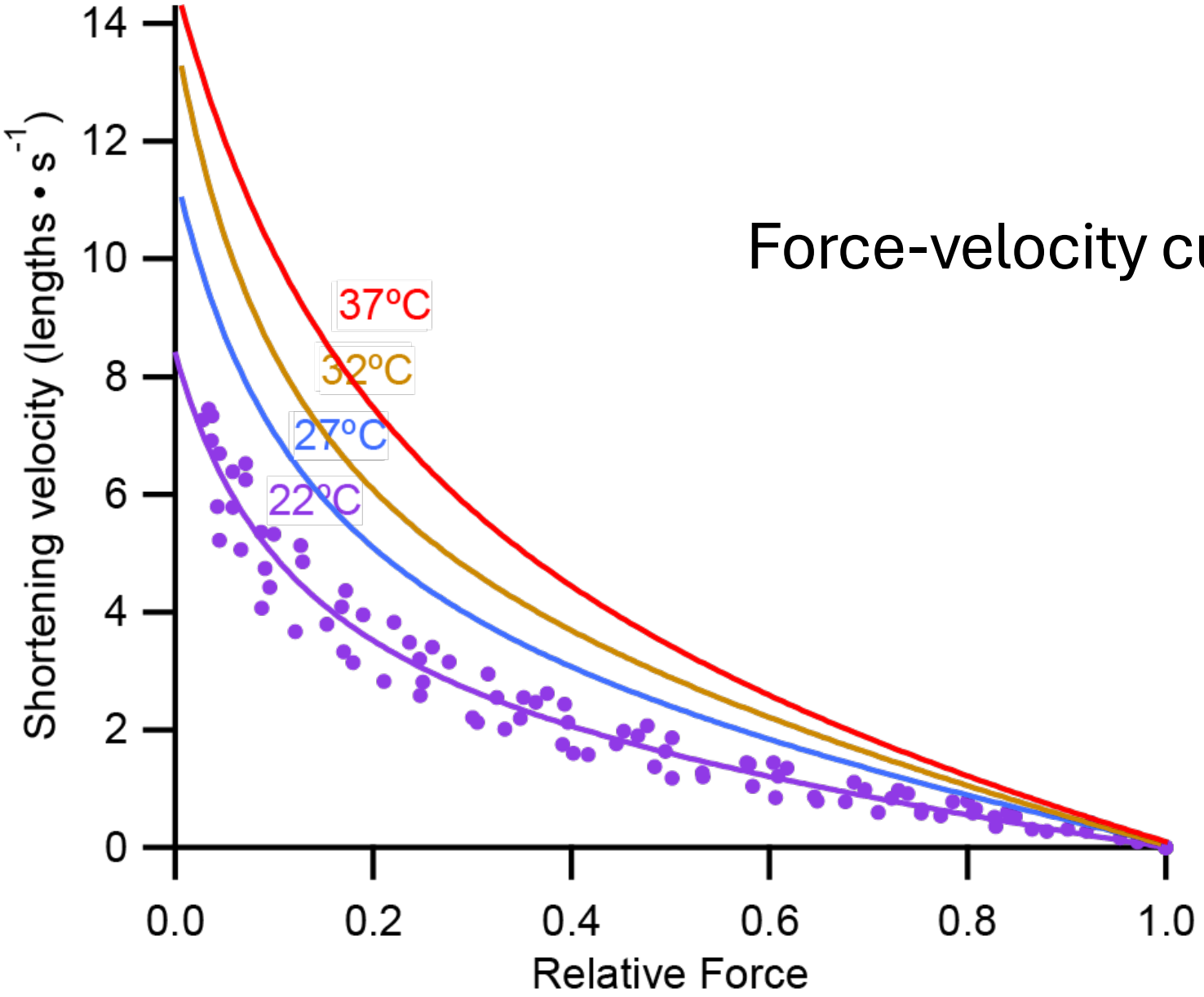
Adaptation in muscle temperature sensitivity is less common…

How do we study muscle properties?

Isolated muscle preparations measure force production and velocity in small muscles



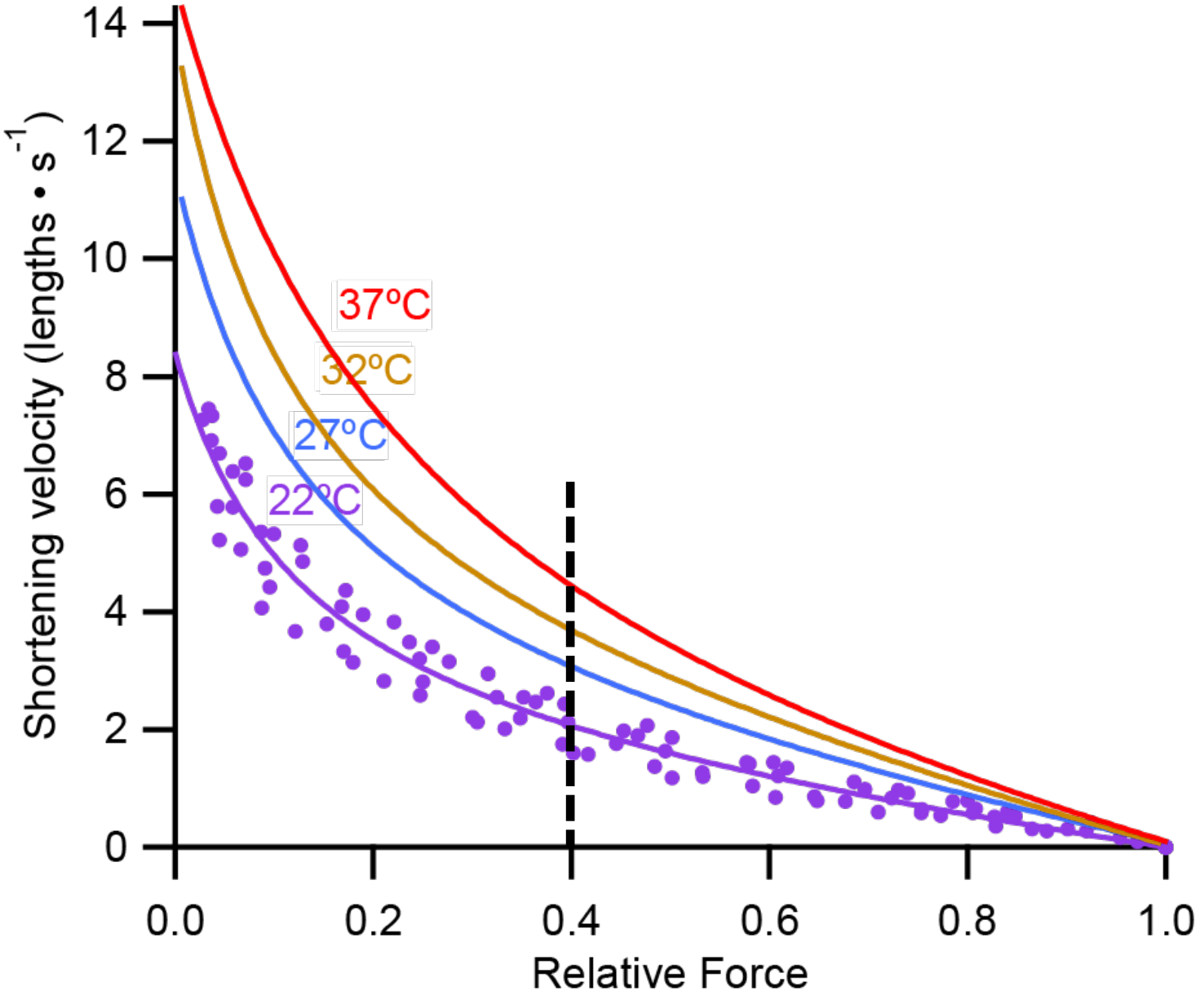
Muscle function changes with temperature



Force-velocity curve

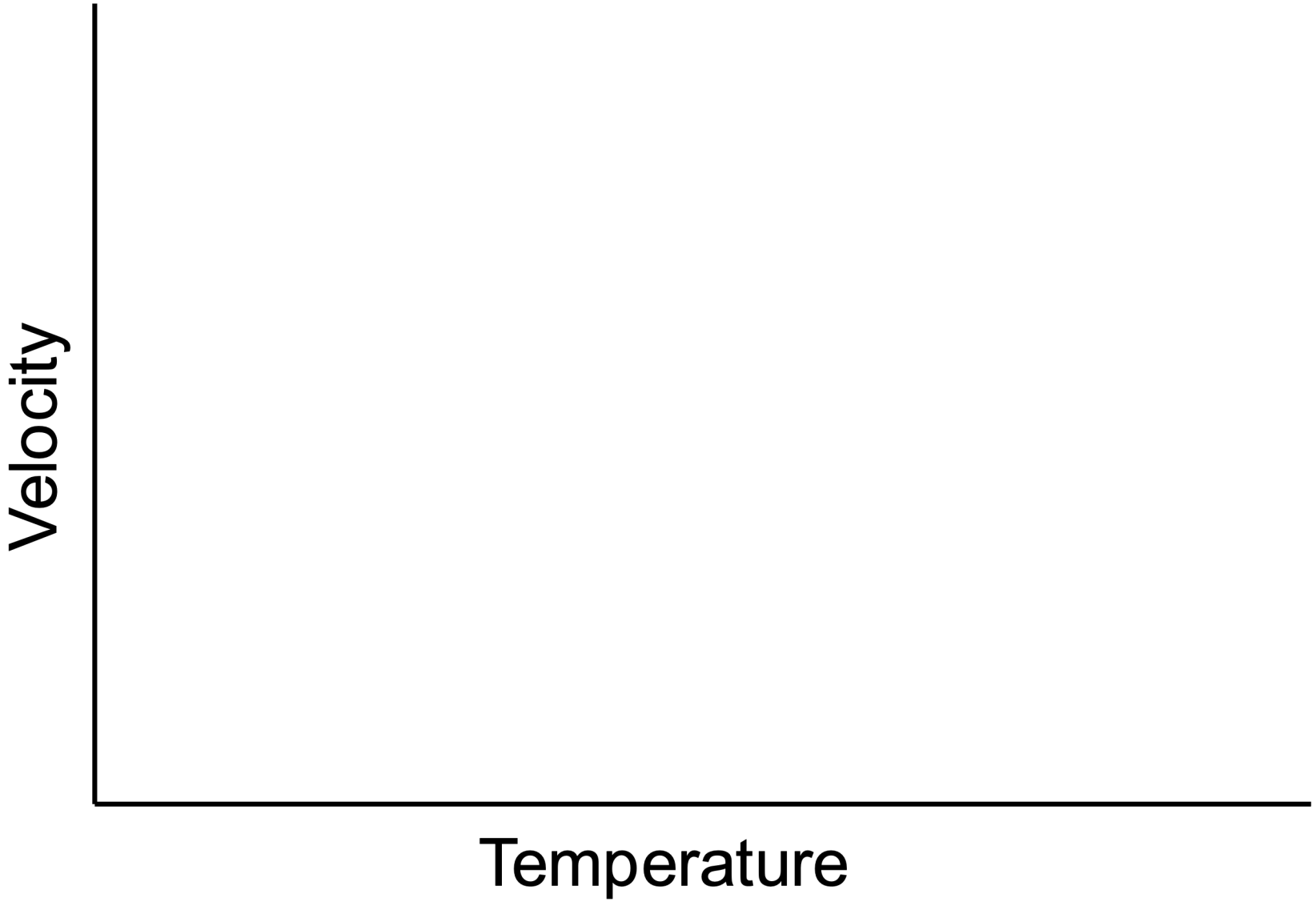
Rummel, et al. *JEB* 2018

Establishing a thermal performance curve



Rummel, et al. *JEB* 2018

Establishing a thermal performance curve



Rummel, et al. *JEB* 2018

How do we quantify the effect of temperature?

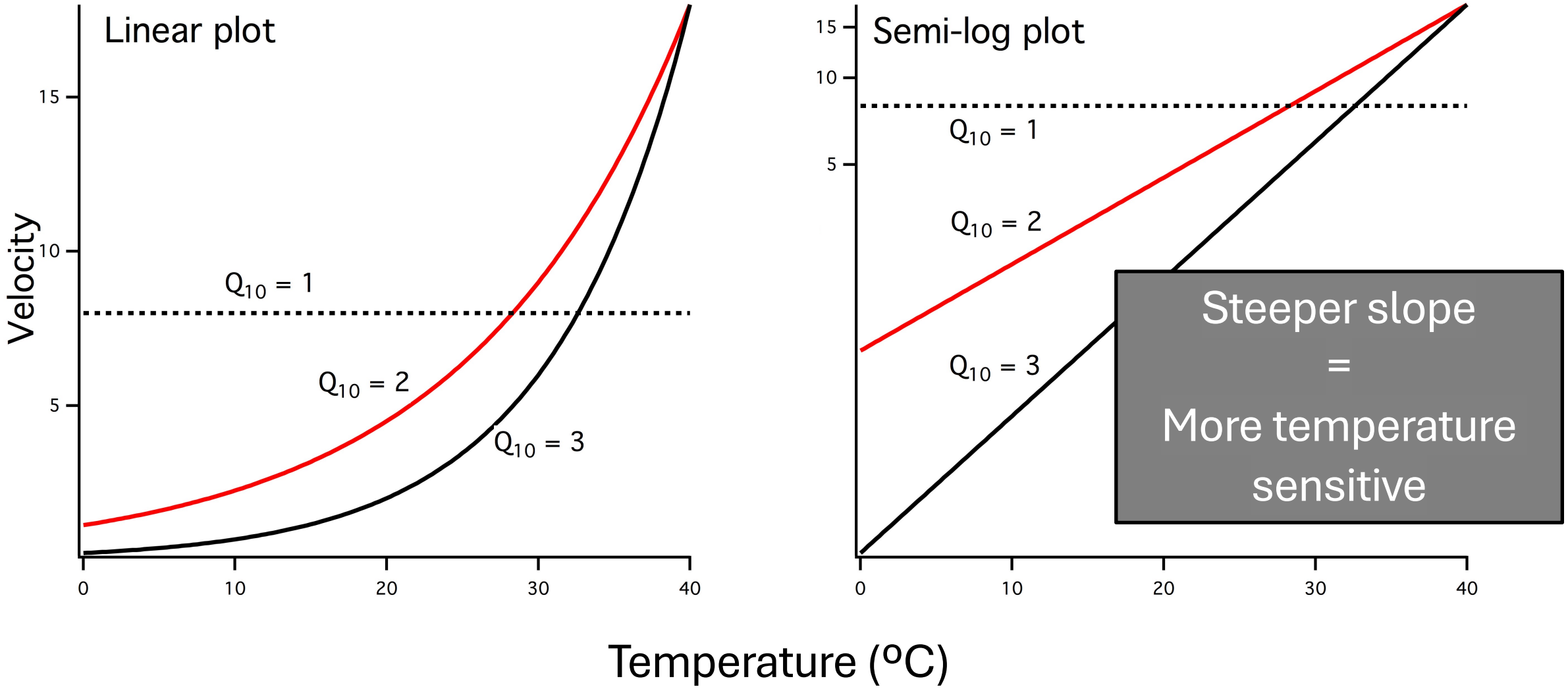
$$Q_{10} = \left(\frac{R_2}{R_1} \right)^{\left(\frac{10}{T_2 - T_1} \right)}$$

If $R_1 = R_2$, $Q_{10} = 1$

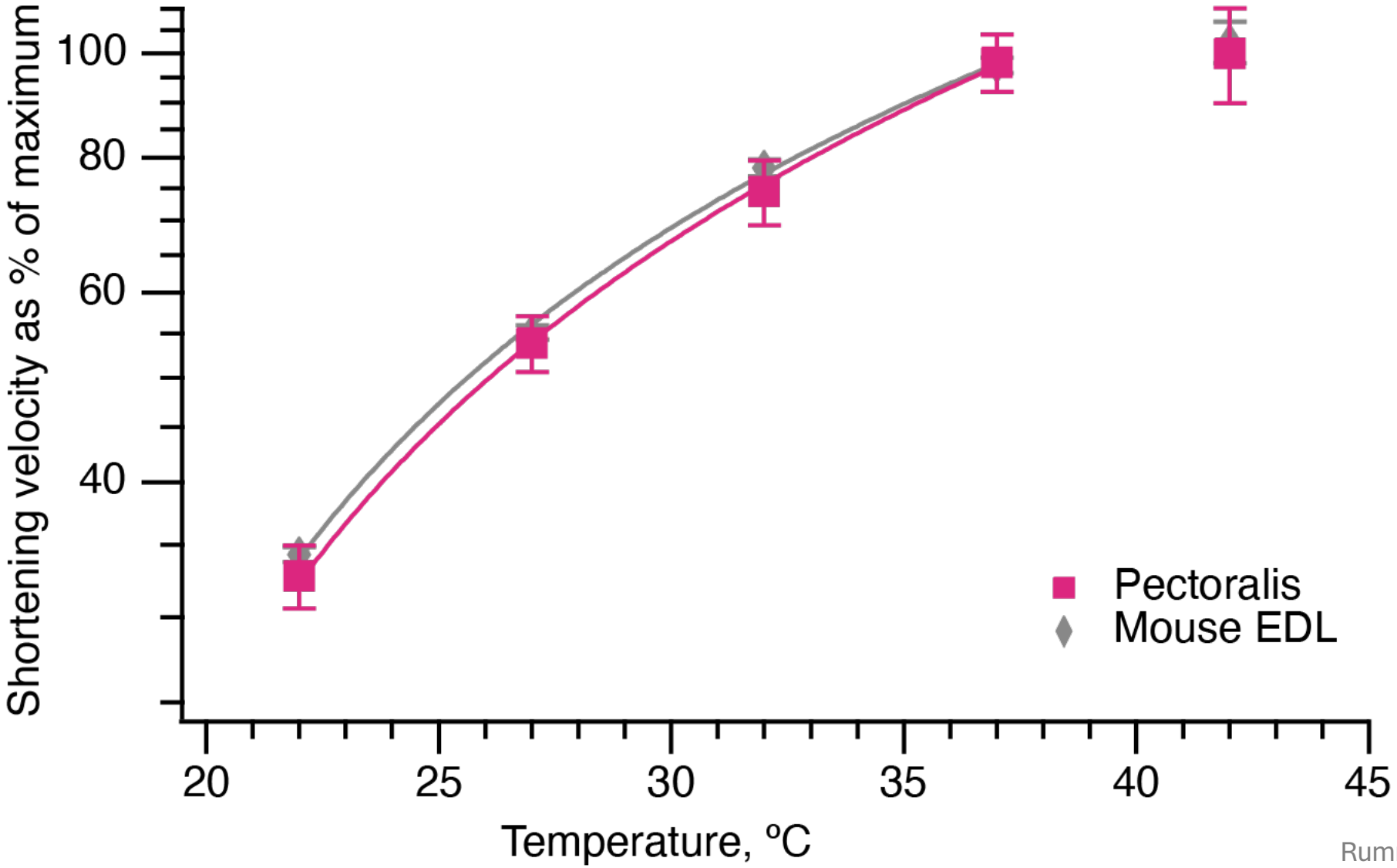
$Q_{10} = 1$ means temperature independence

Typical Q_{10}'s for biological processes are between 2 and 3

How do we quantify the effect of temperature?

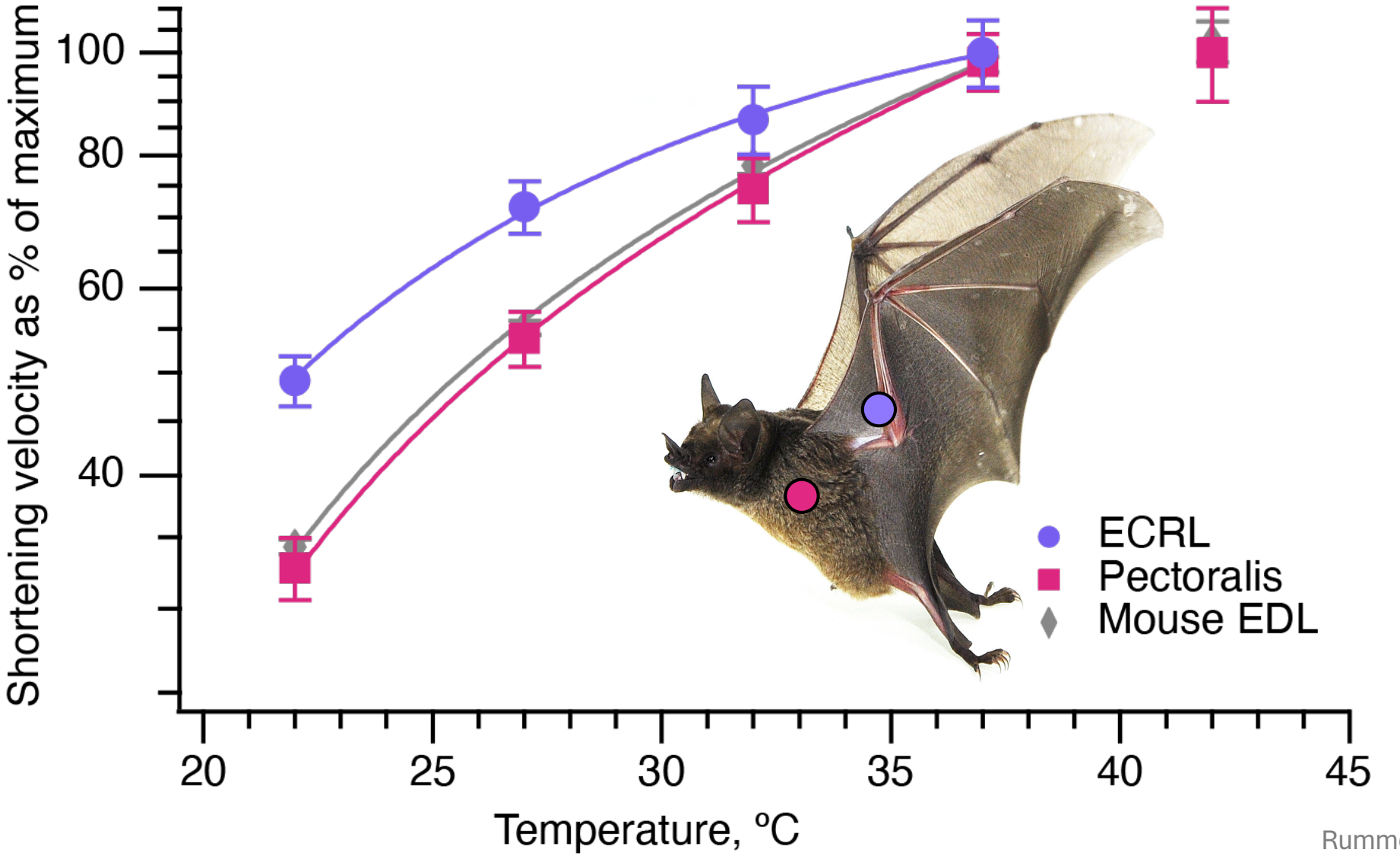


Bat muscle temperature sensitivity



Rummel, et al. *Proc. B.* 2021

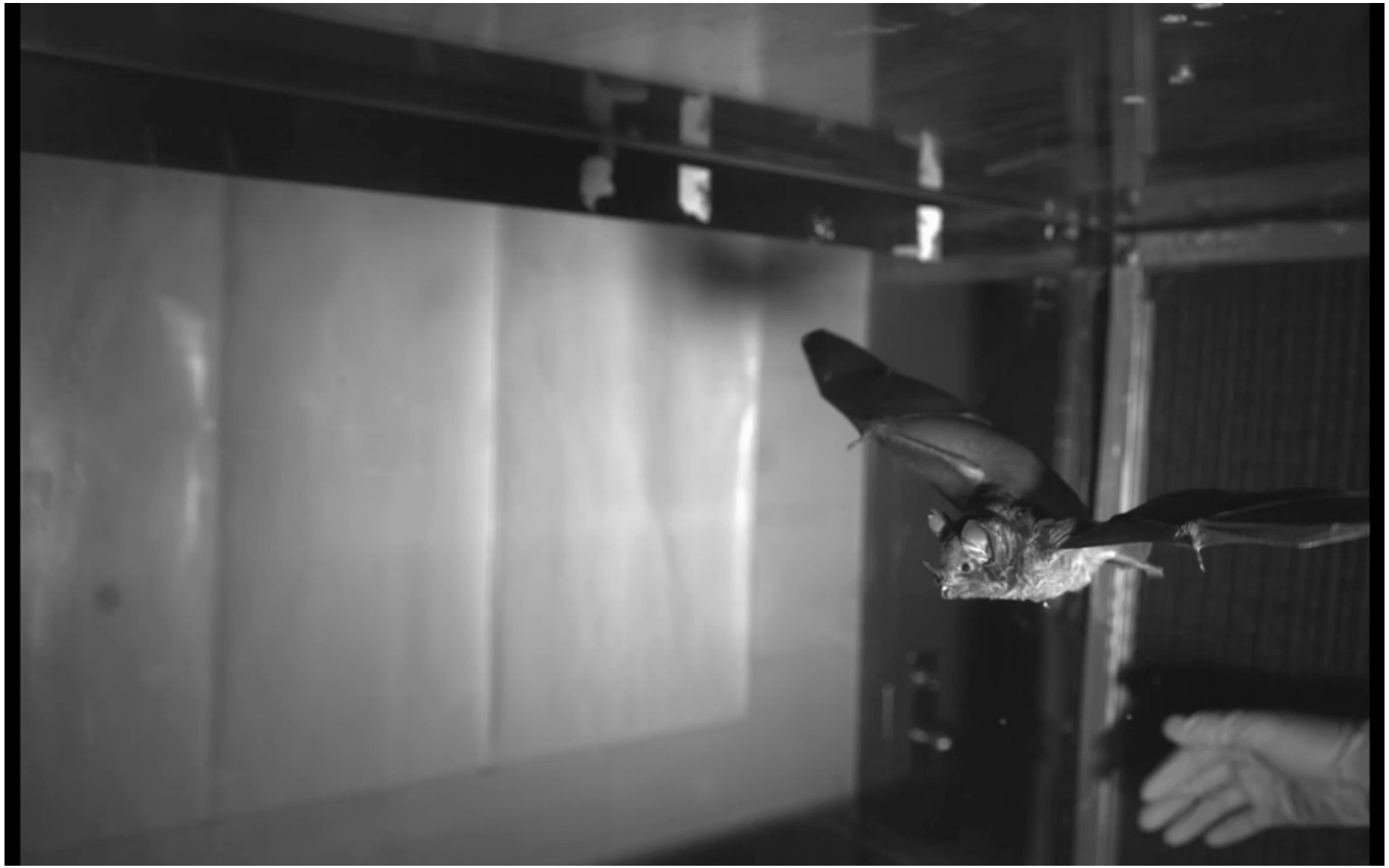
Bat forearm muscles are less temperature sensitive than typical mammalian muscles

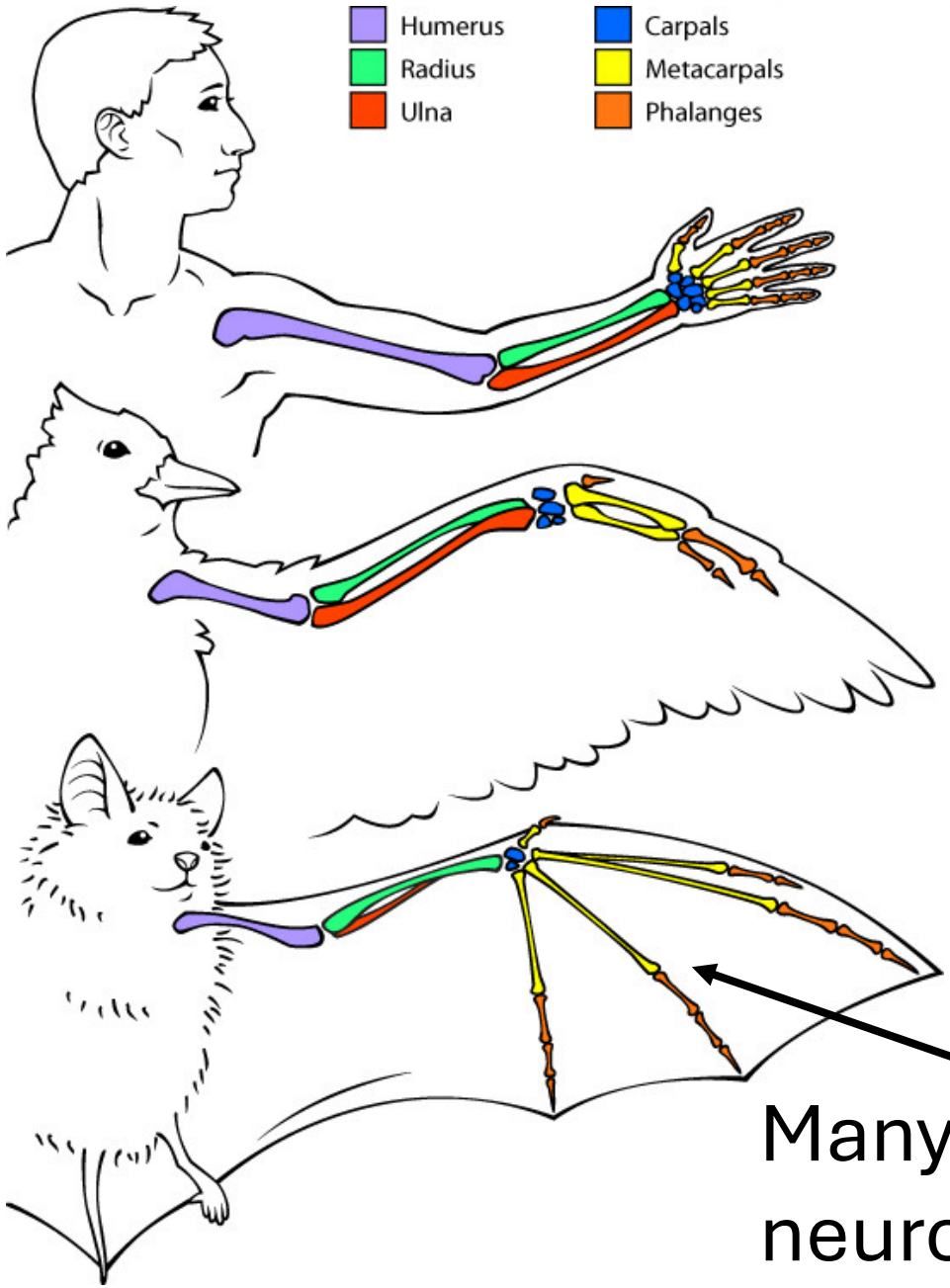


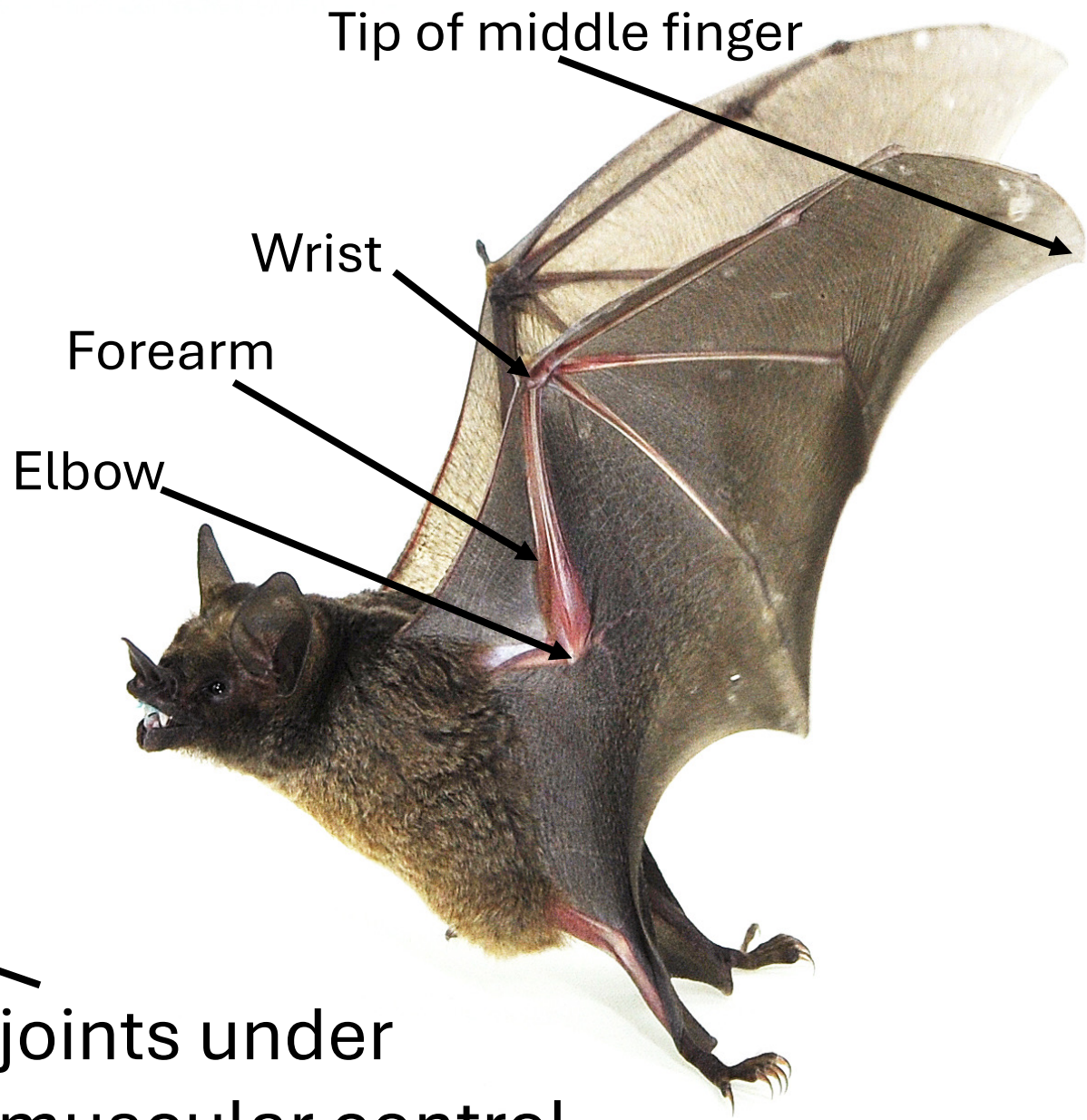
Rummel, et al. *Proc. B.* 2021

Integrating these principles with biomechanics in the study of bat flight

Bats are high performance locomotors

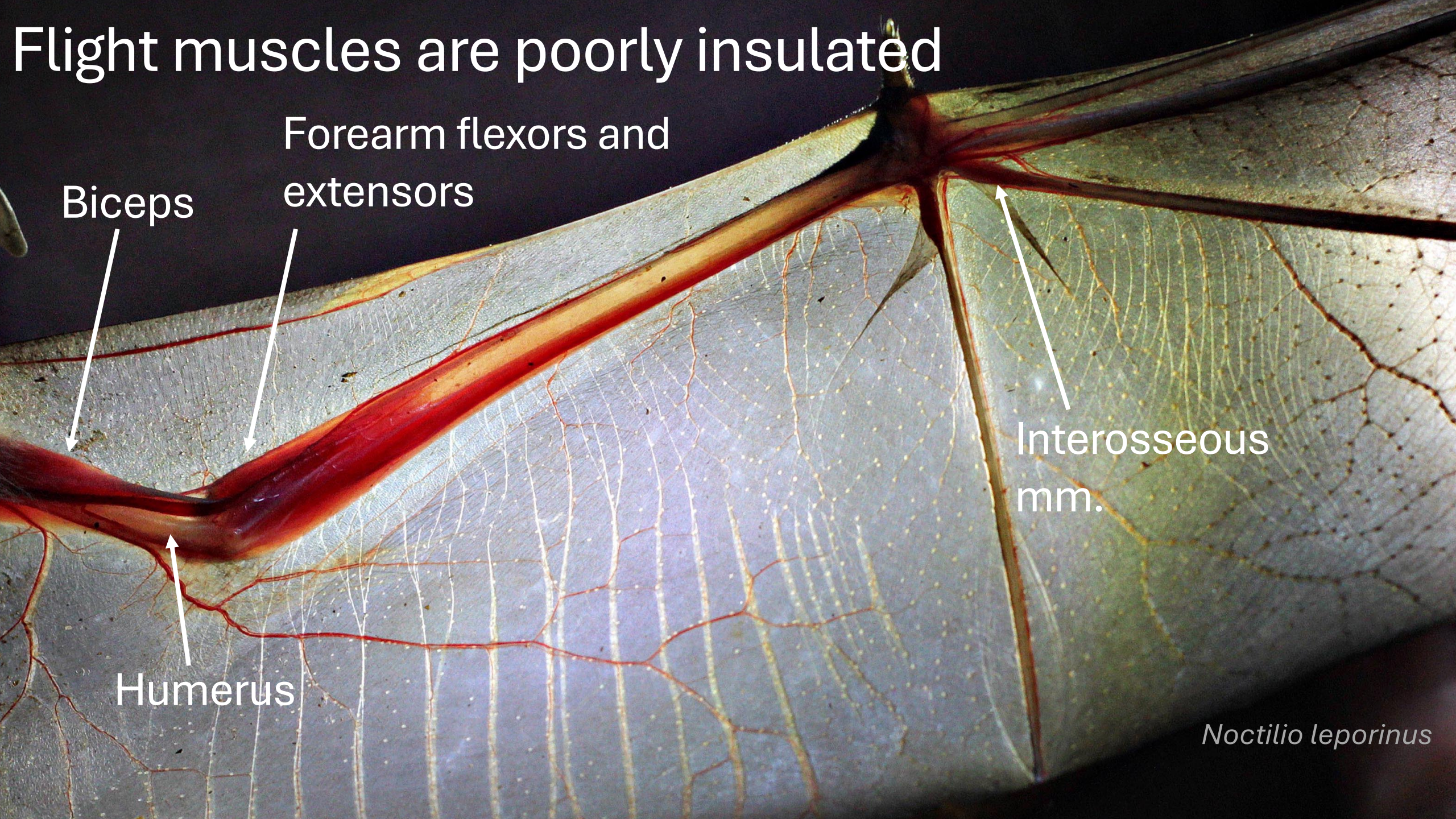






Many joints under neuromuscular control

Flight muscles are poorly insulated



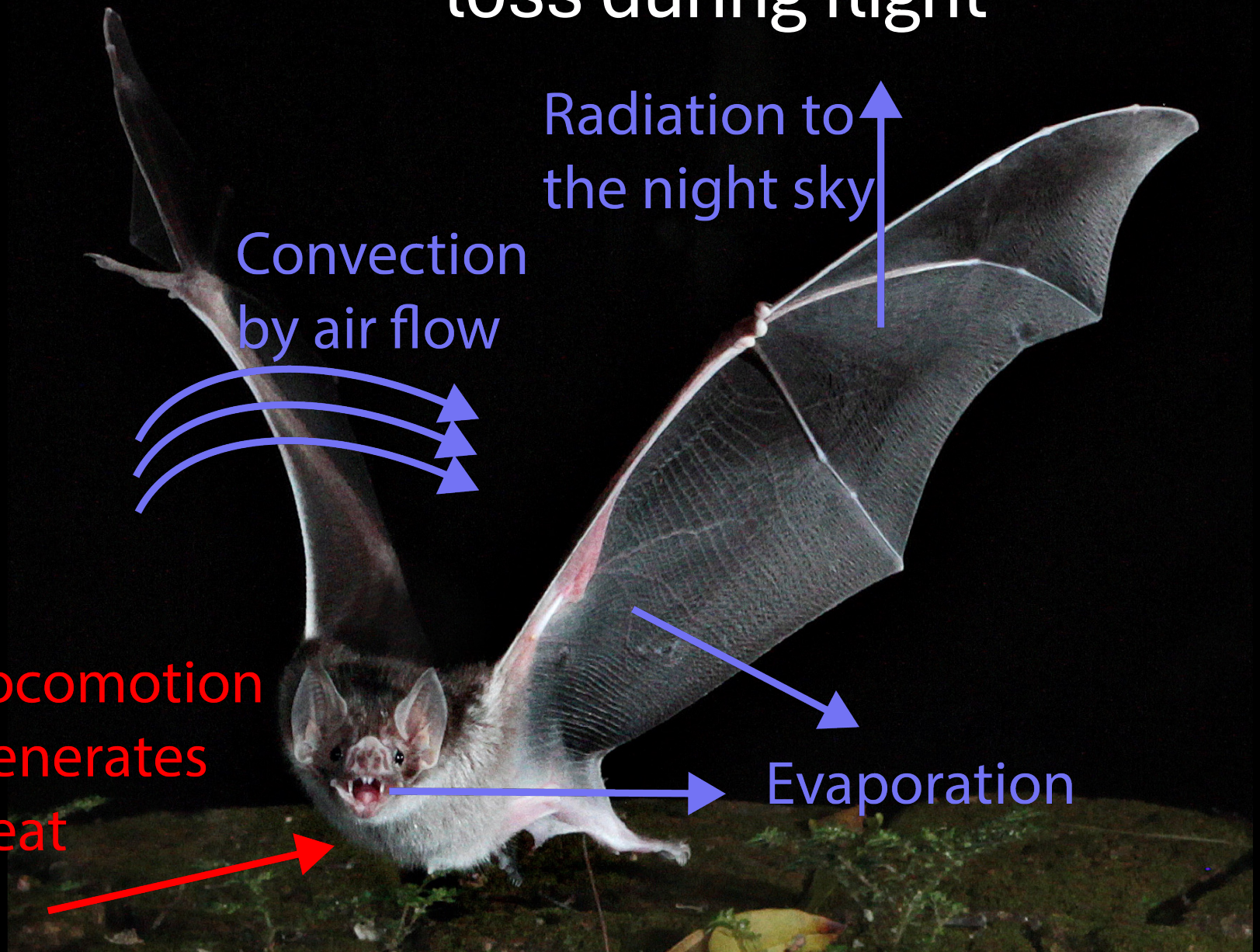
Flight muscles are poorly insulated

Carollia perspicillata

Elbow

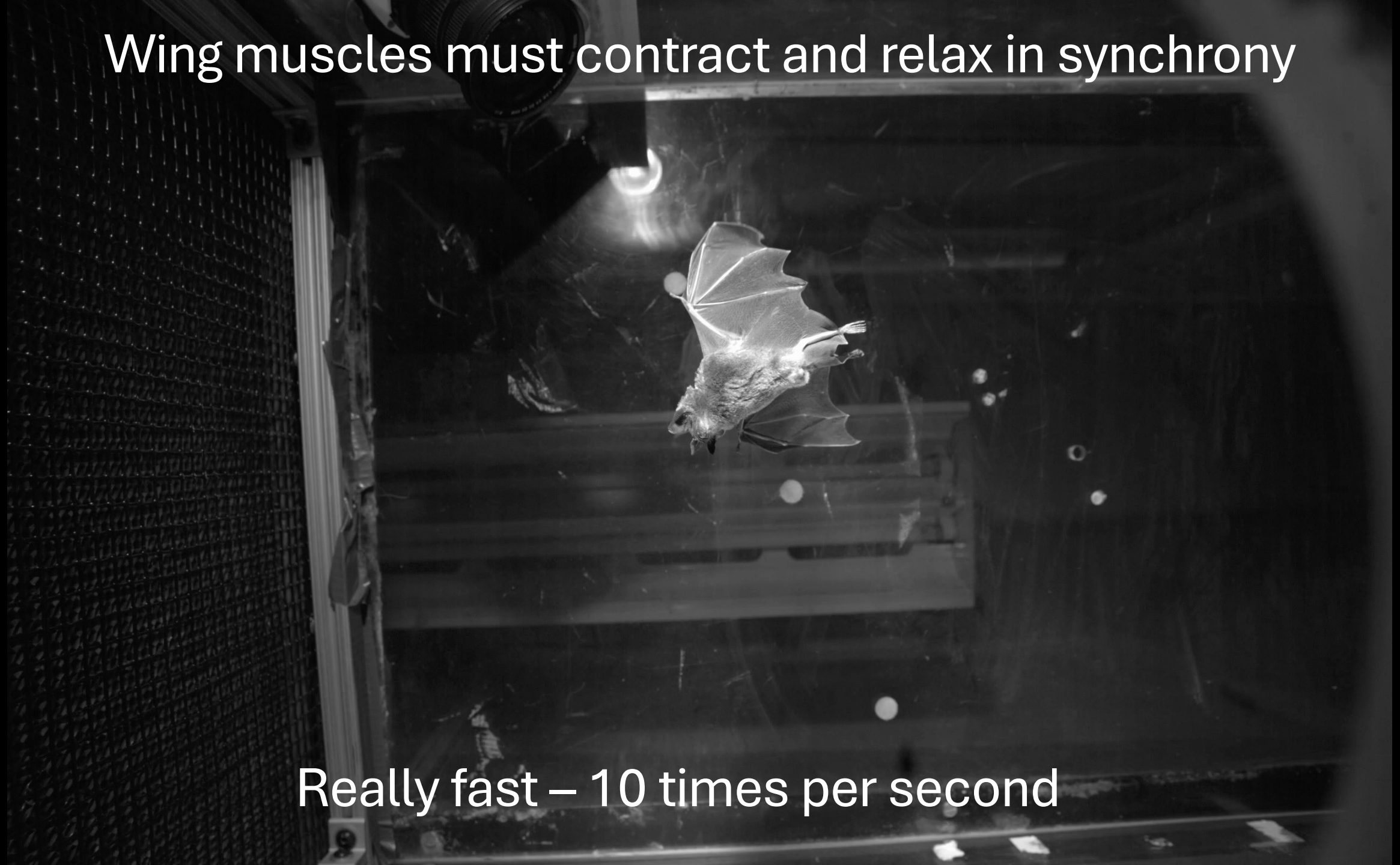
Golden-mantled ground squirrel

Flight muscles cool via multiple avenues of heat loss during flight



Desmodus rotundus

Wing muscles must contract and relax in synchrony



Really fast – 10 times per second

How do we integrate kinematics, physiology, and environment?

Wind tunnel

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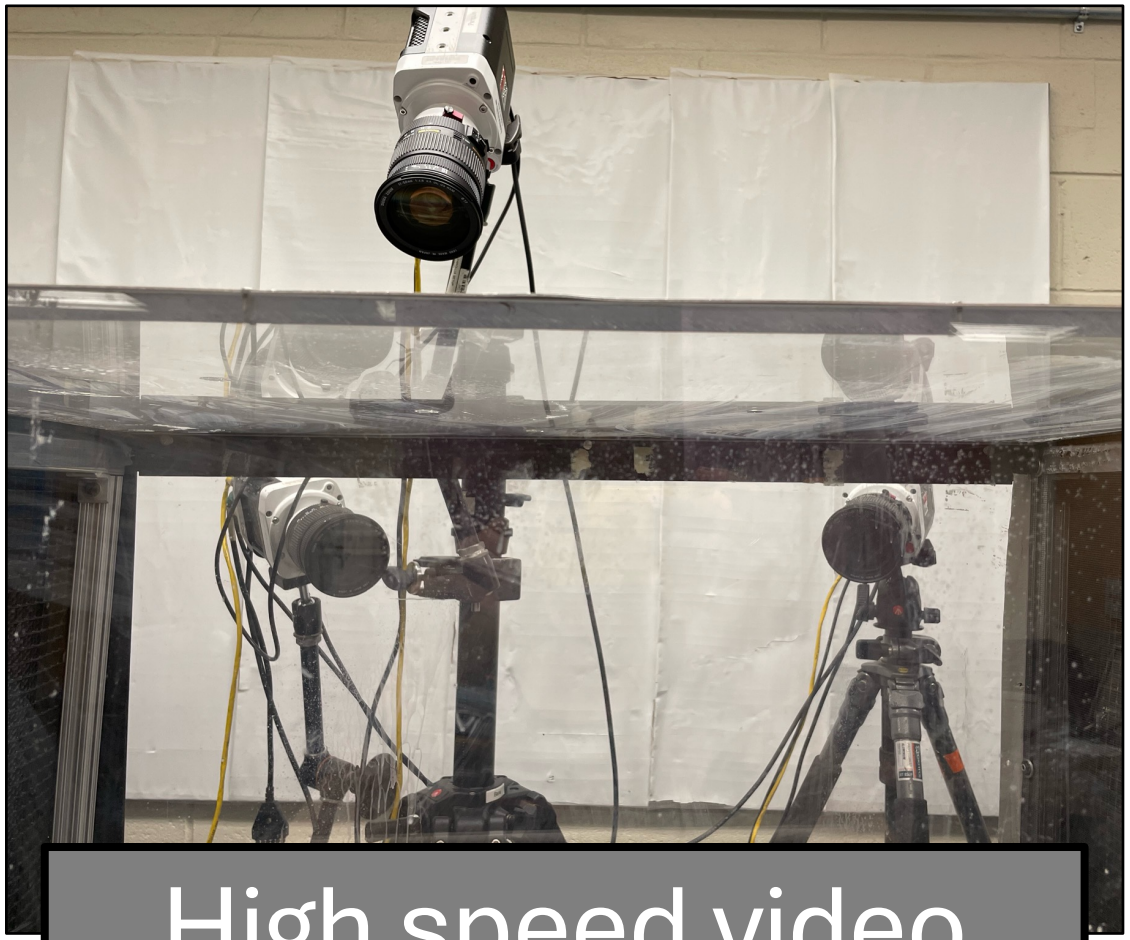
controlled lab environment:

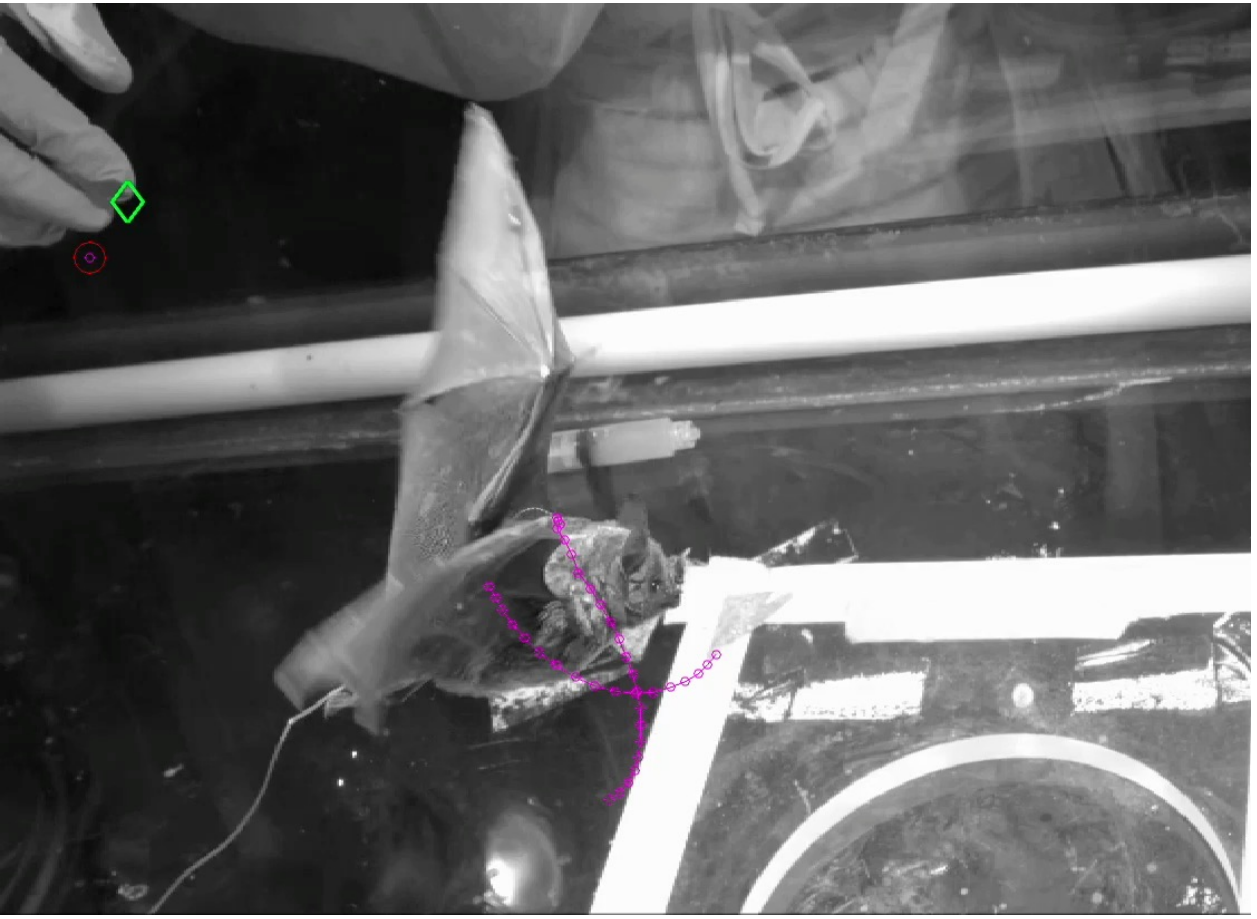
Fine scale measurements of movement and physiology

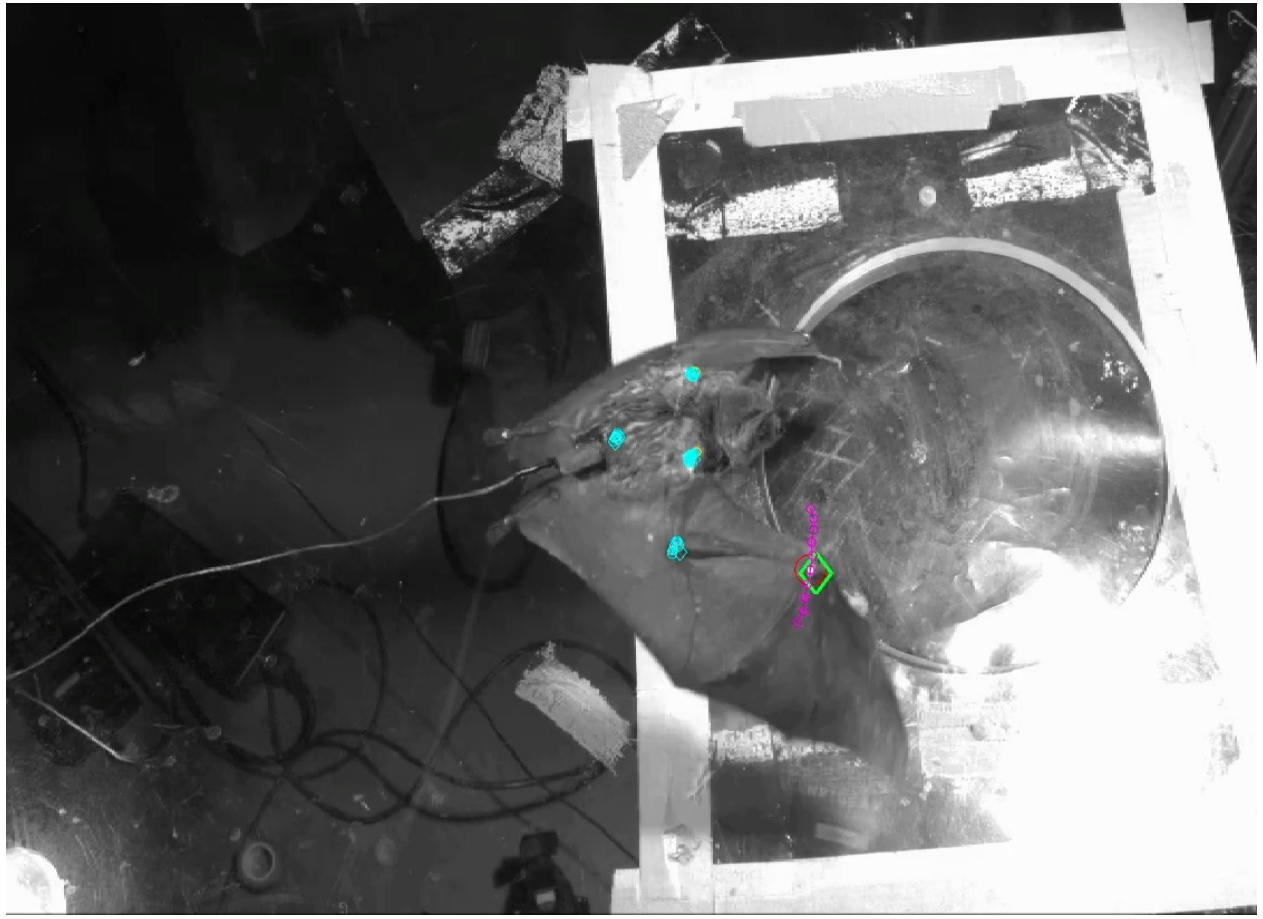
How do we integrate kinematics, physiology, and environment?



High speed video

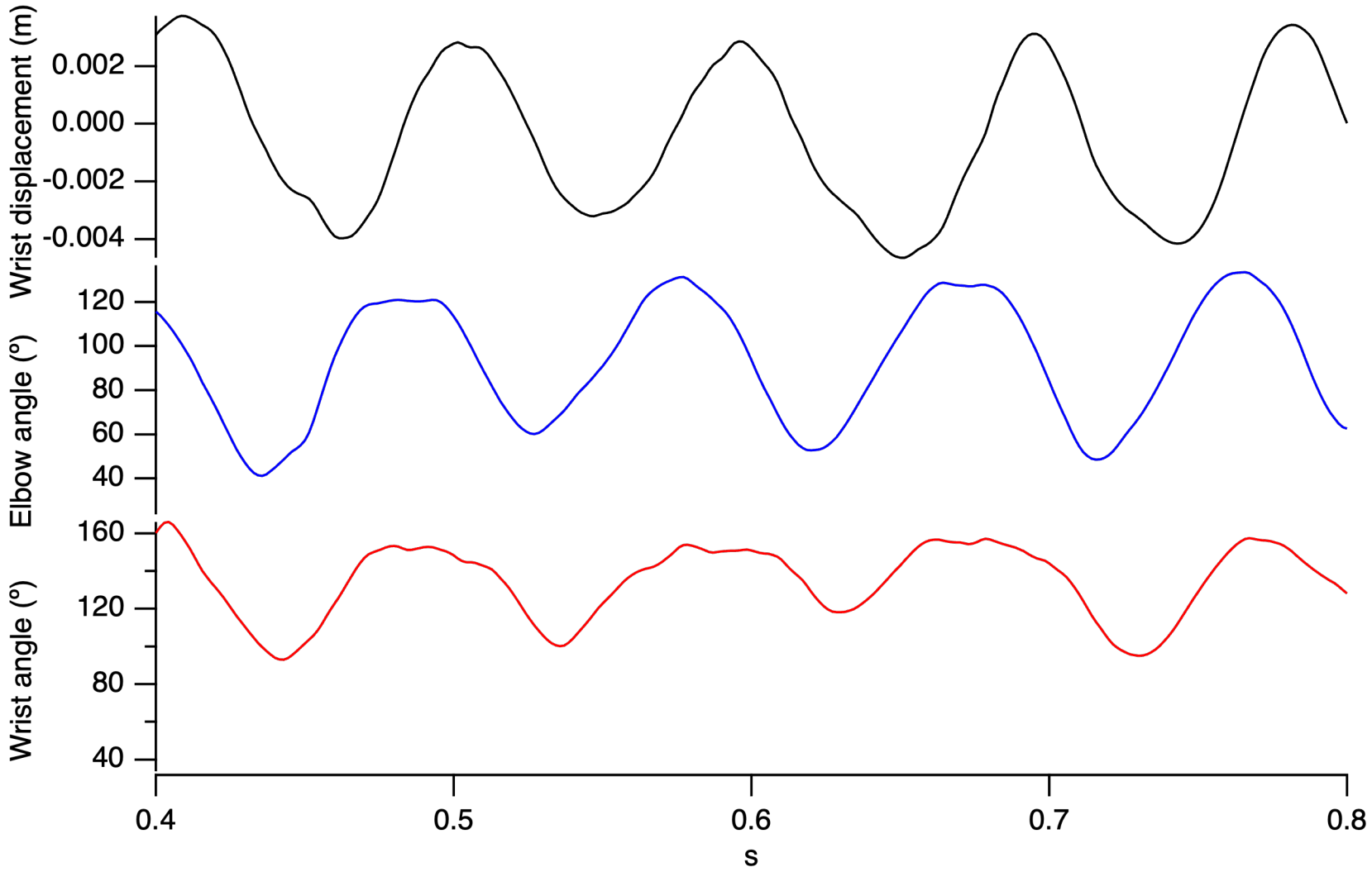
Measuring wing movements using DLTdv8





Hedrick Lab: https://biomech.web.unc.edu/dltdv/

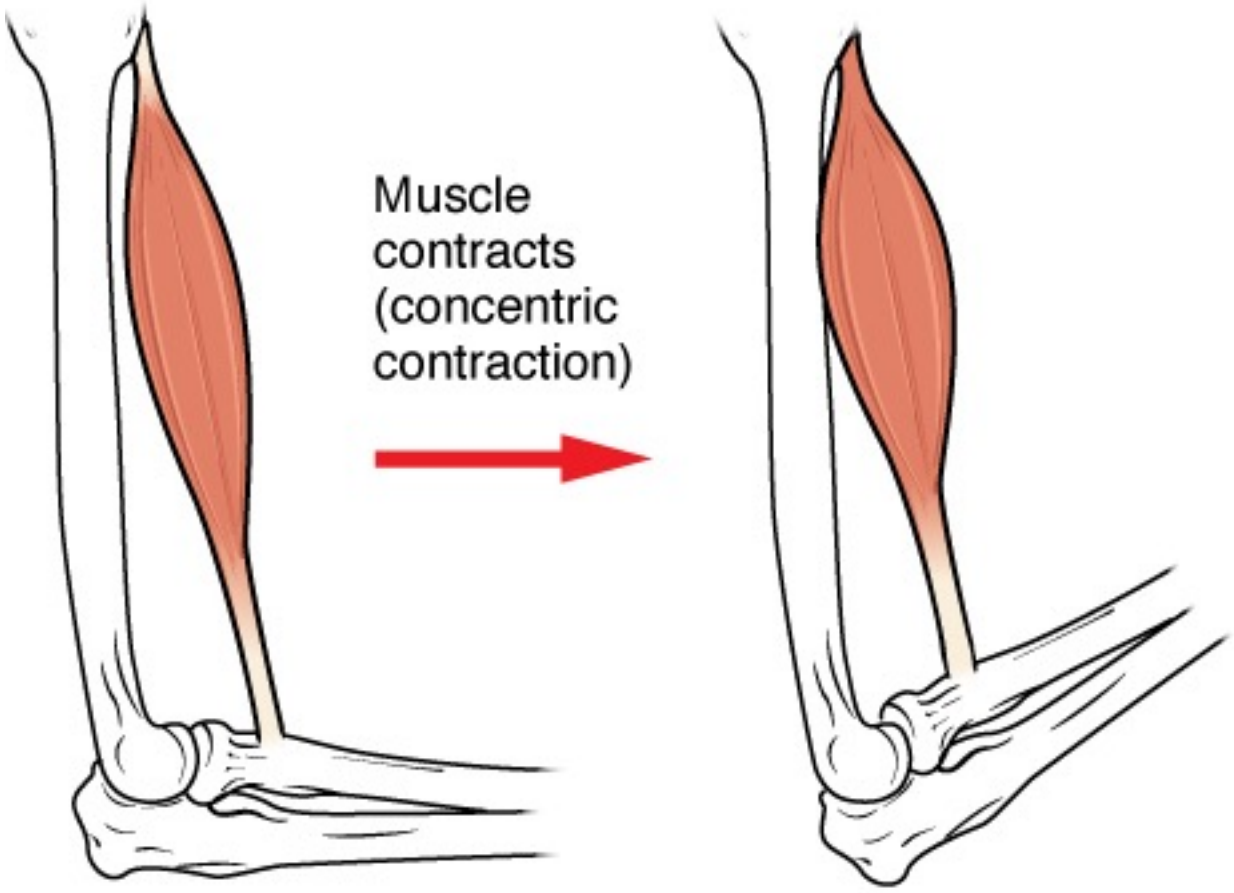
Extracting information about the wingbeat



Combining kinematics with other measurements

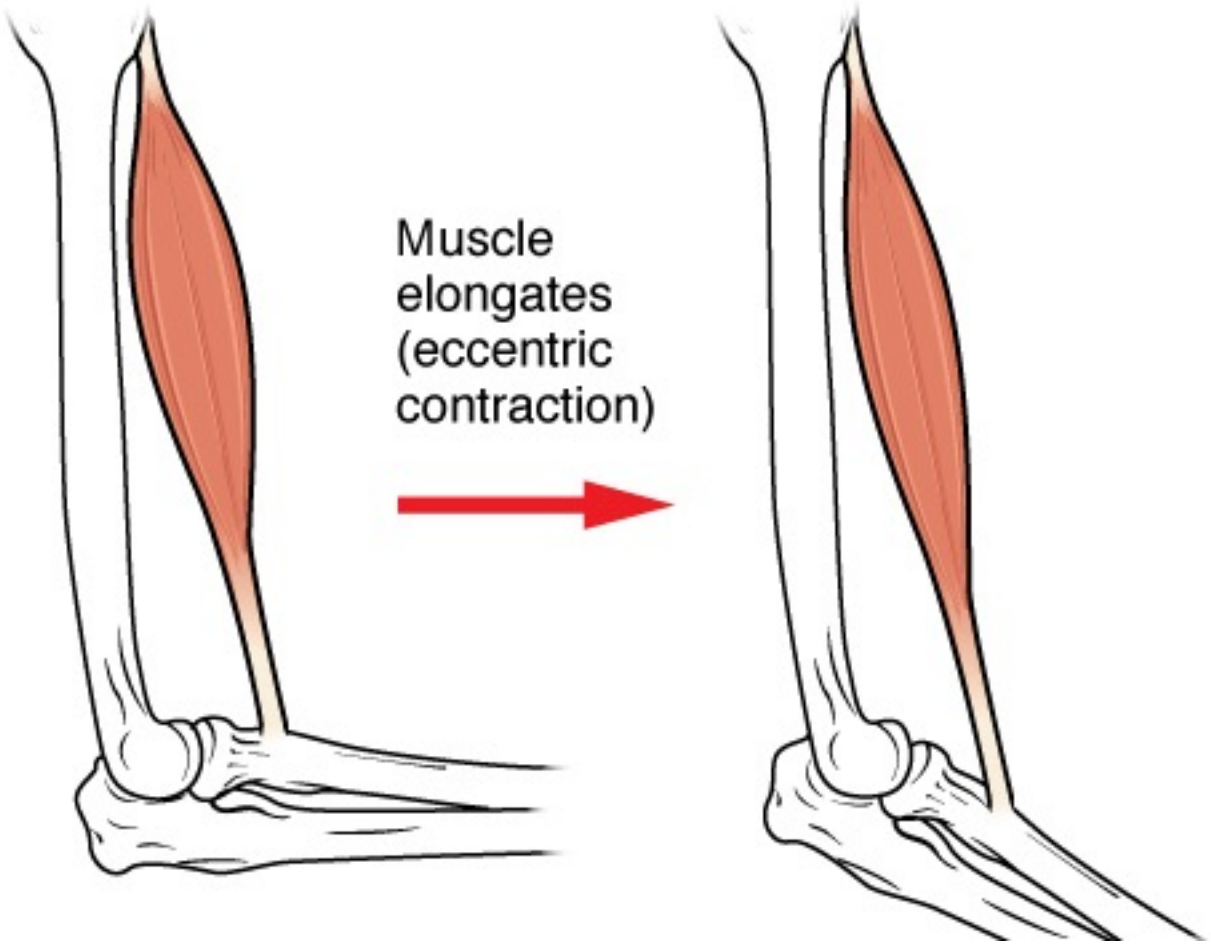
1. The relationship between wing/joint movements and muscle activity (electromyography)

Muscle contraction – three types



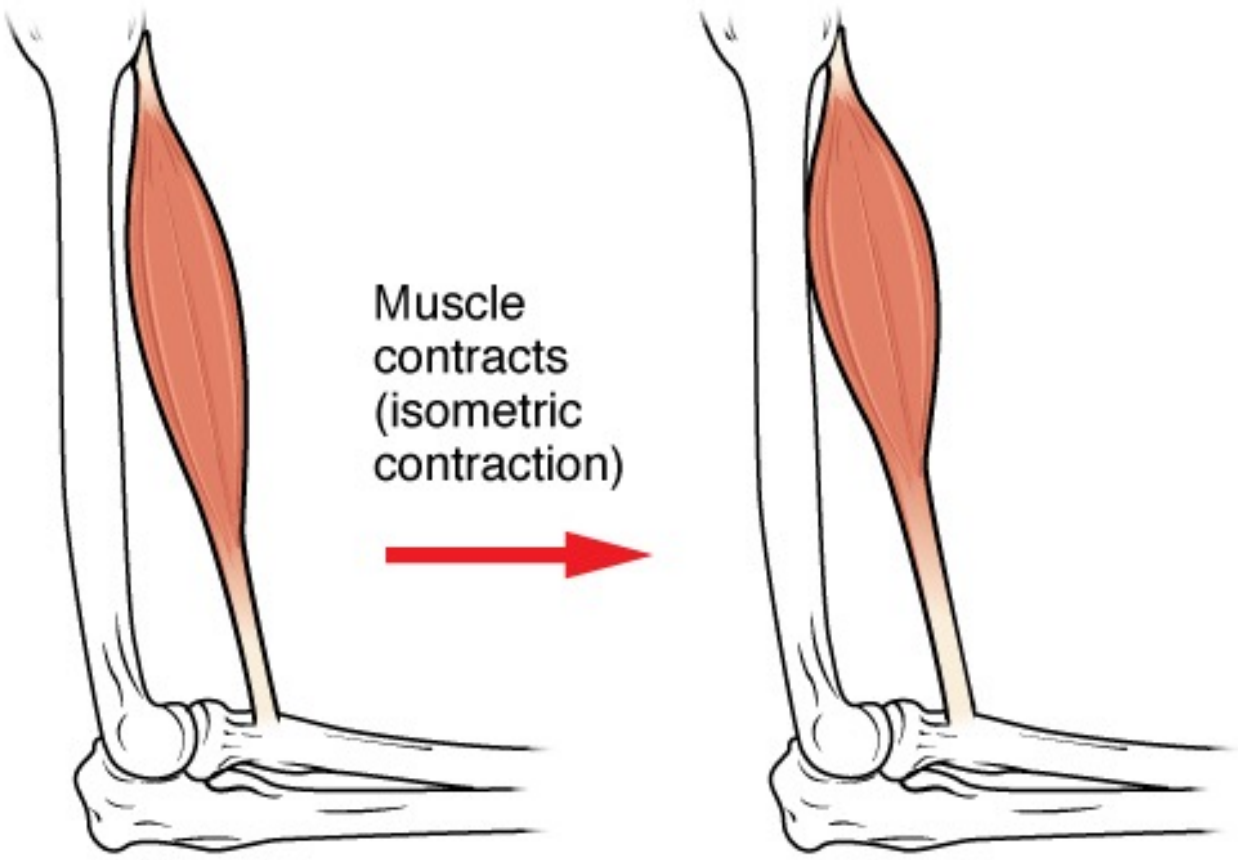
Shortening contraction went joint angle **decreases** when muscle is active

Muscle contraction – three types

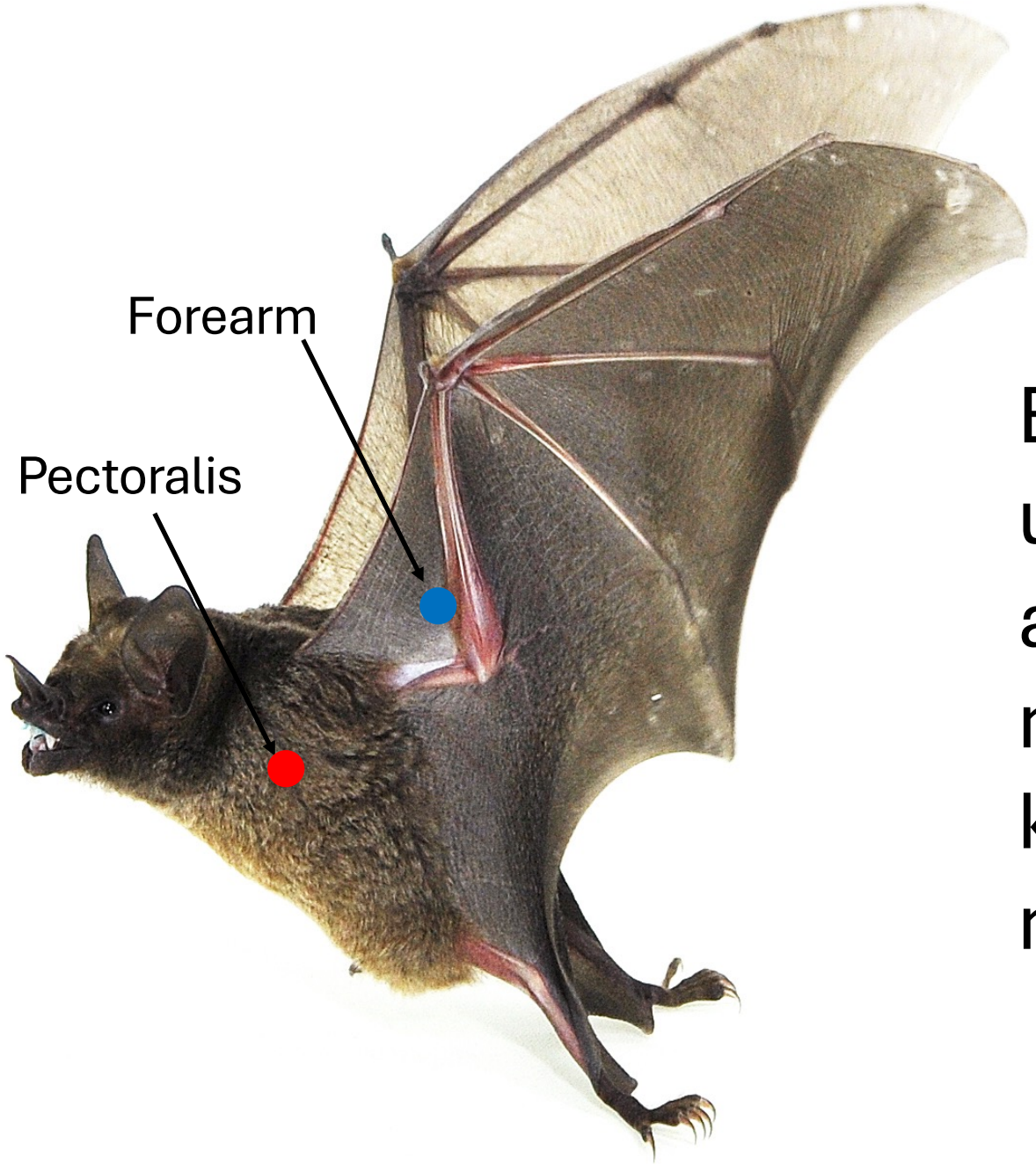


Lengthening contraction when joint angle **increases** when muscle is active

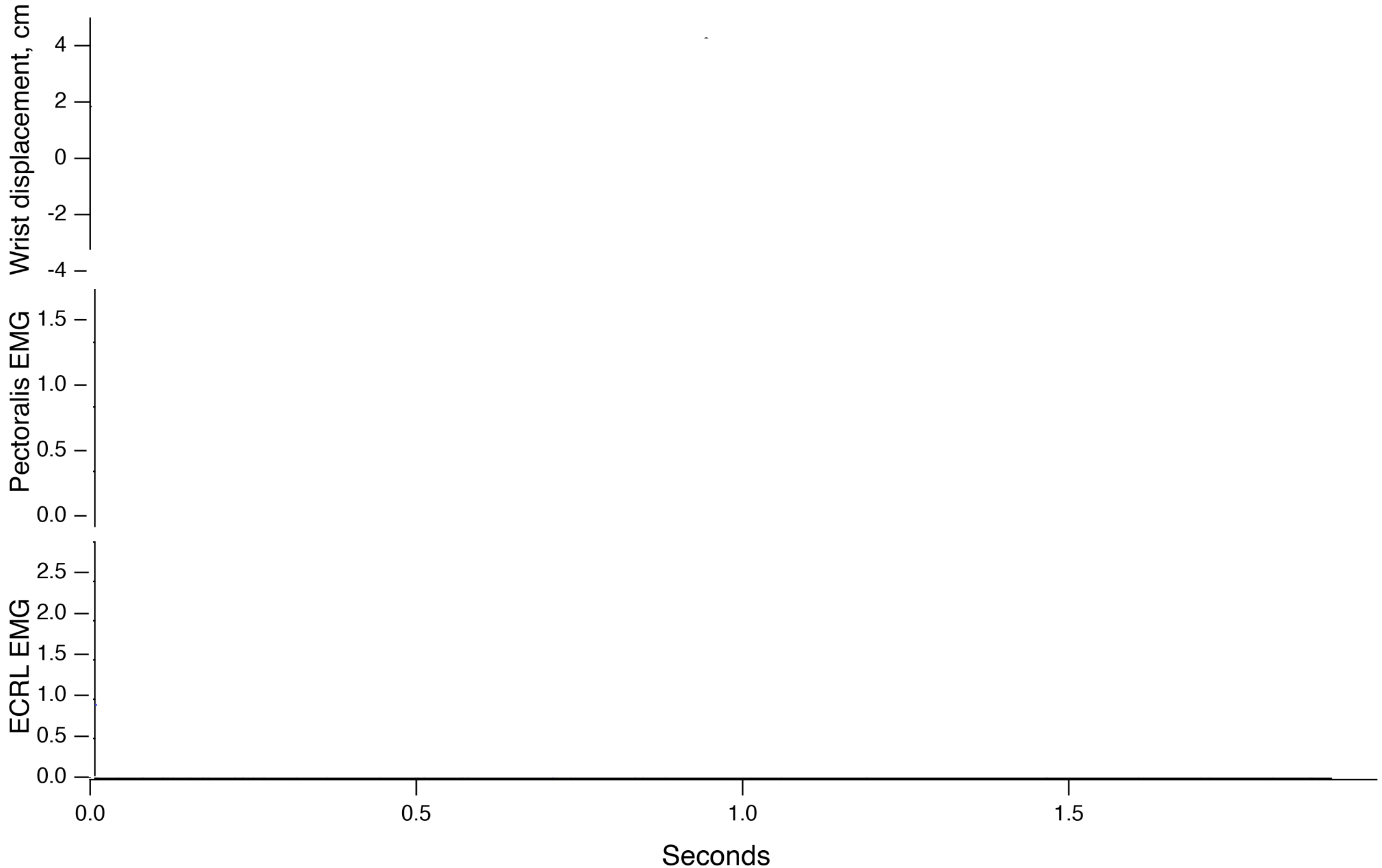
Muscle contraction – three types



Isometric contraction – no length change



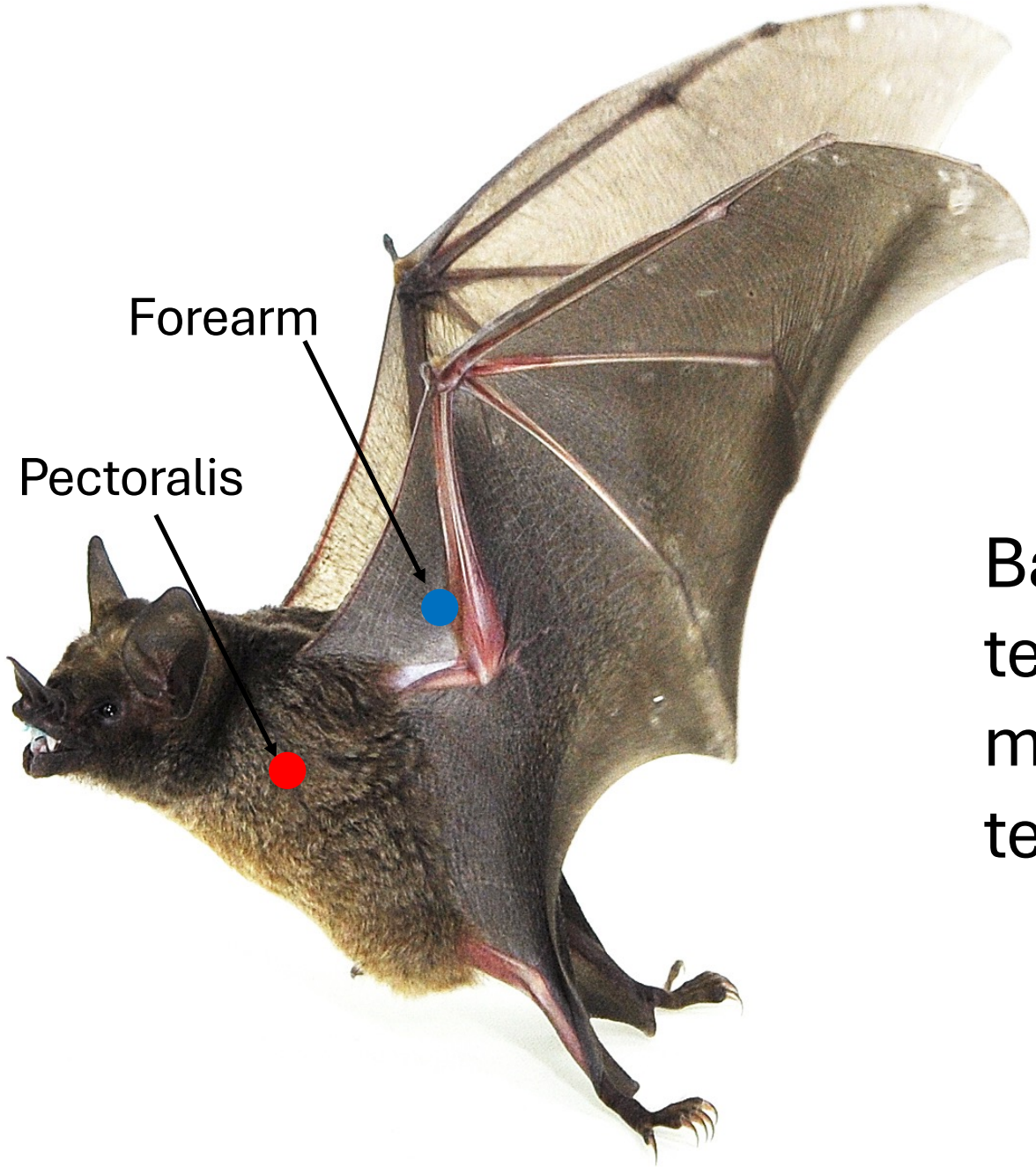
Electromyography tells us when muscles are active: we can correlate muscle activity with kinematics to understand muscle function


Wrist displacement, cm
4
2
0
-2
-4
Pectoralis EMG
1.5
1.0
0.5
0.0
ECRL EMG
2.5
2.0
1.5
1.0
0.5
0.0
0.0
0.5
1.0
1.5
Seconds

Combining wind tunnel kinematics with other measurements

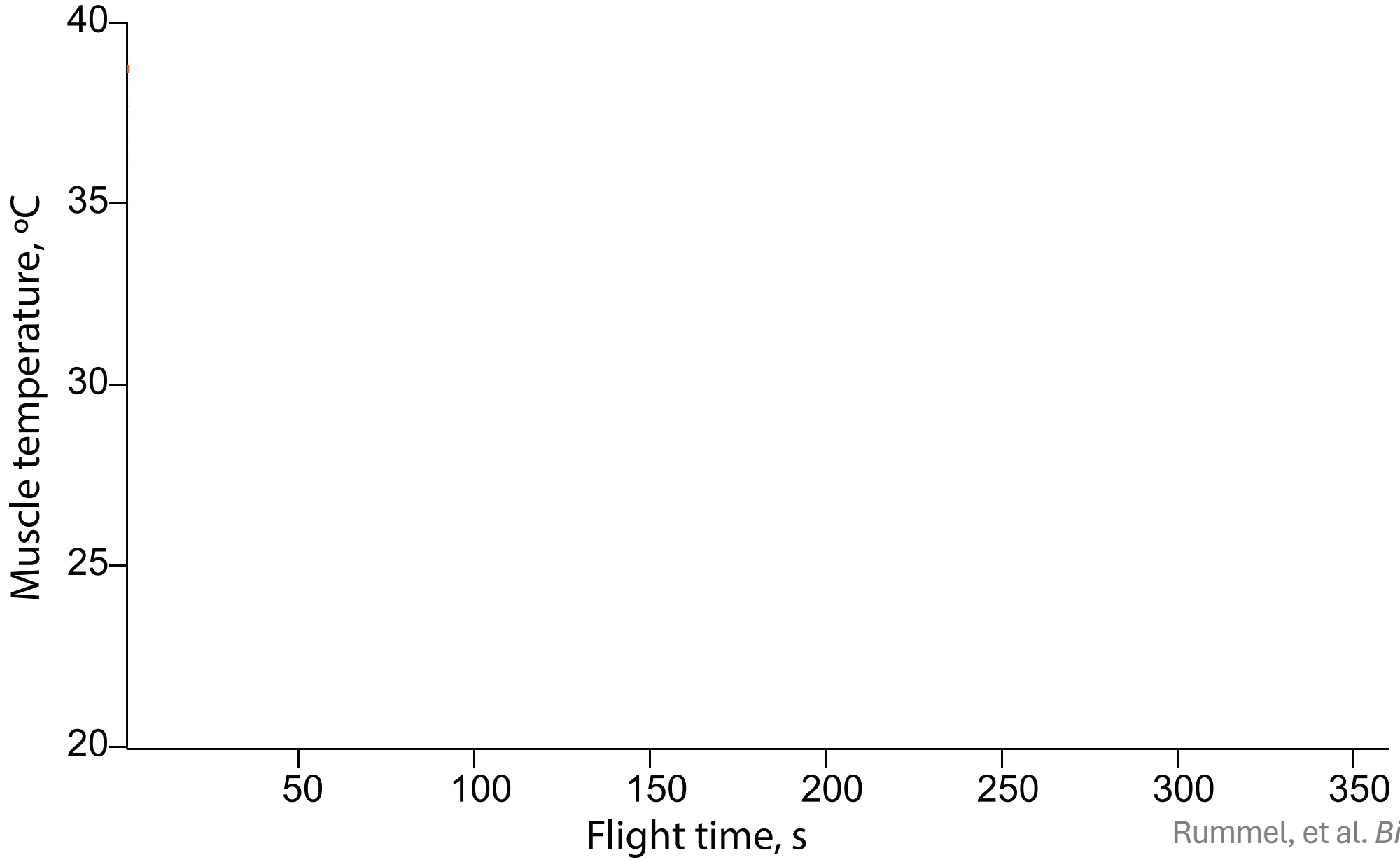
1. The relationship between joint movements and muscle activity (electromyography)

2. The relationship between flight activity and muscle temperature, i.e. quantify regional heterothermy



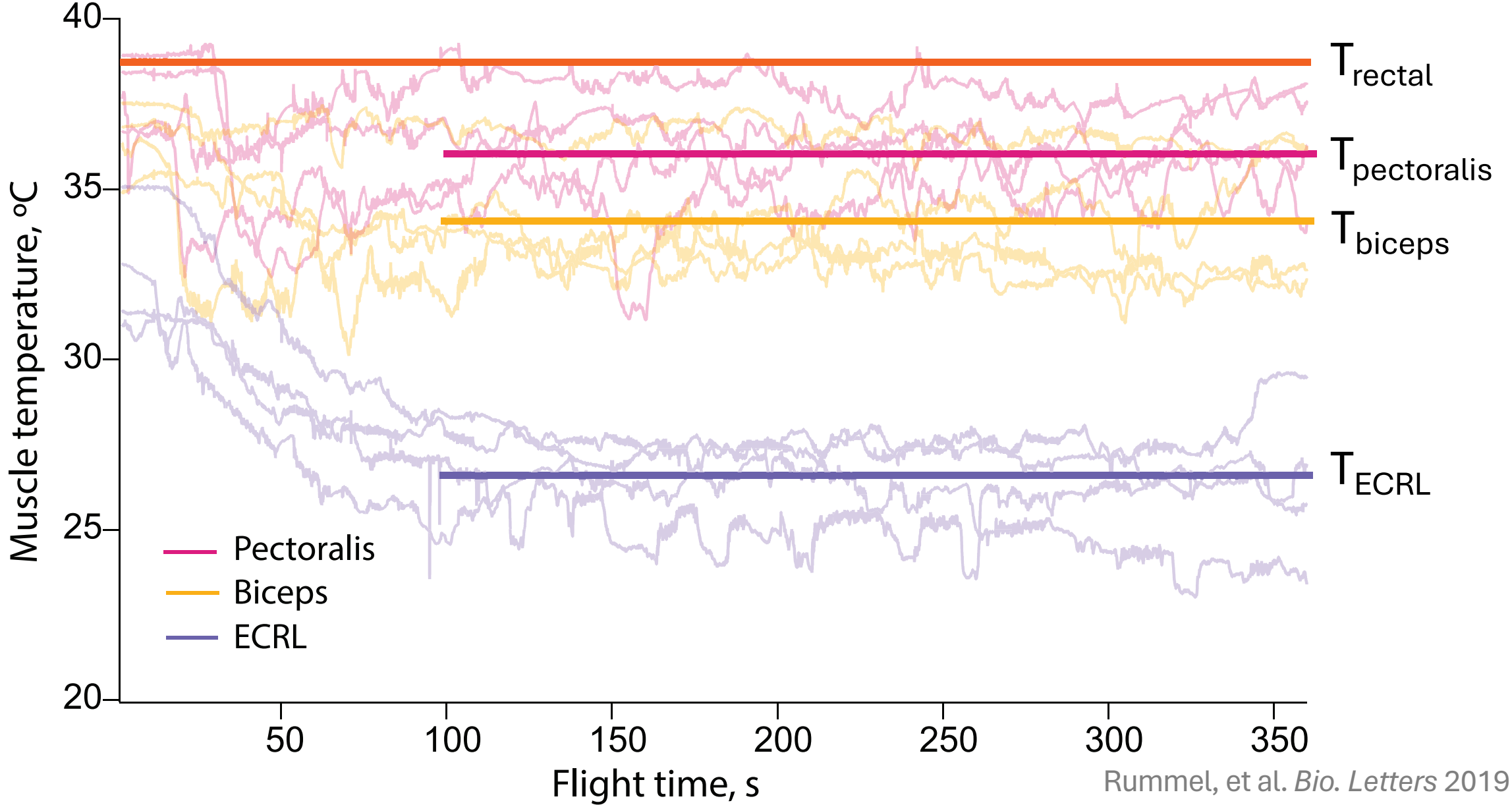
Bats instrumented with temperature sensors that measure muscle temperature

Measuring regional heterothermy in the lab



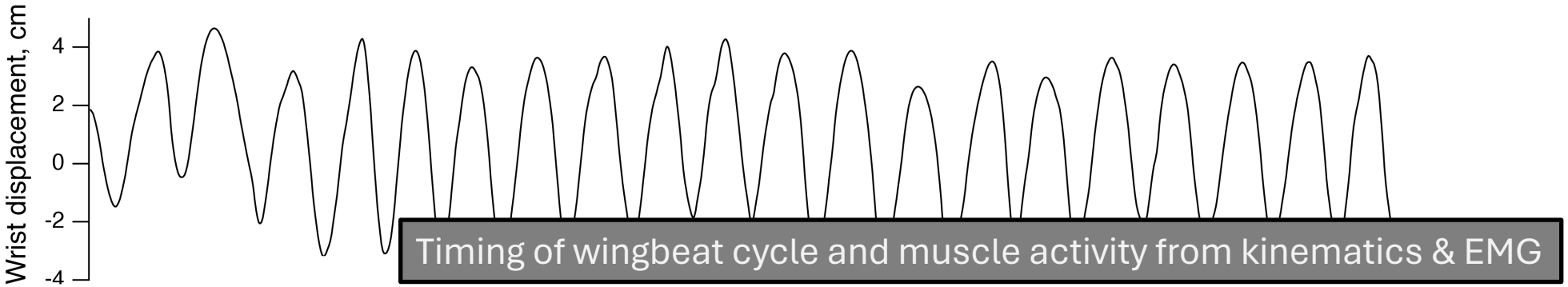
Rummel, et al. *Bio. Letters* 2019

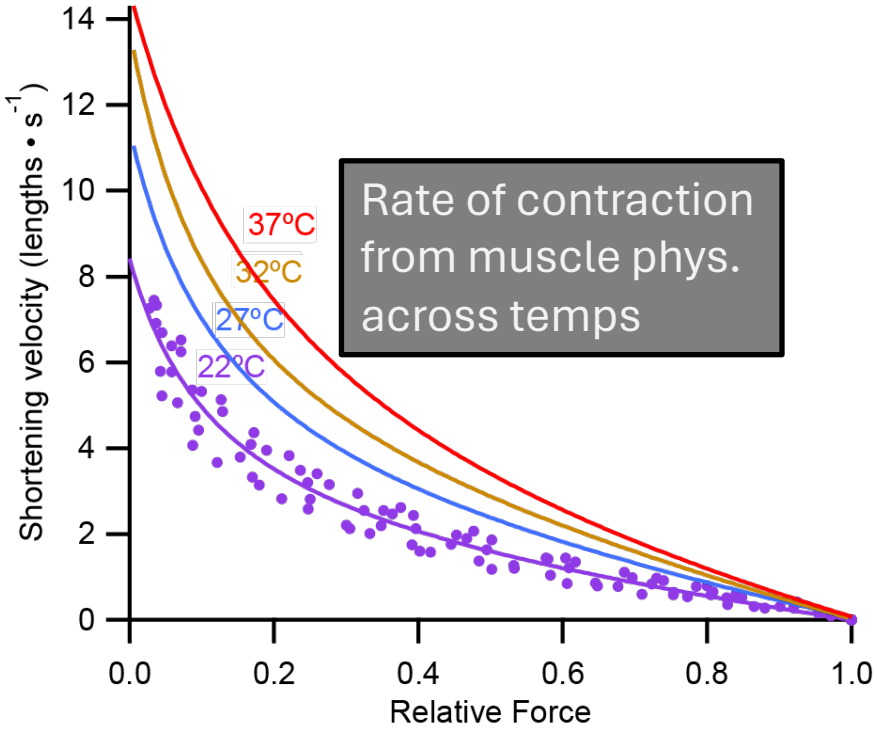
During flight, wing muscle temperature falls

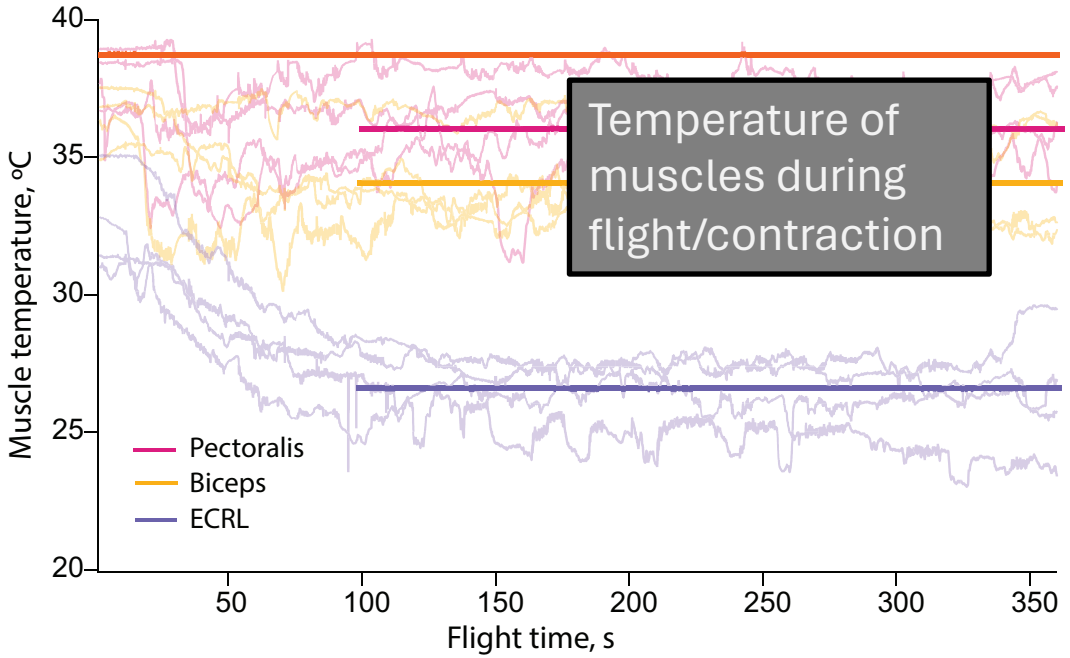


Rummel, et al. *Bio. Letters* 2019

Combining kinematics with muscle activity, physiology, and temperature measurements is a powerful approach







Take-home messages

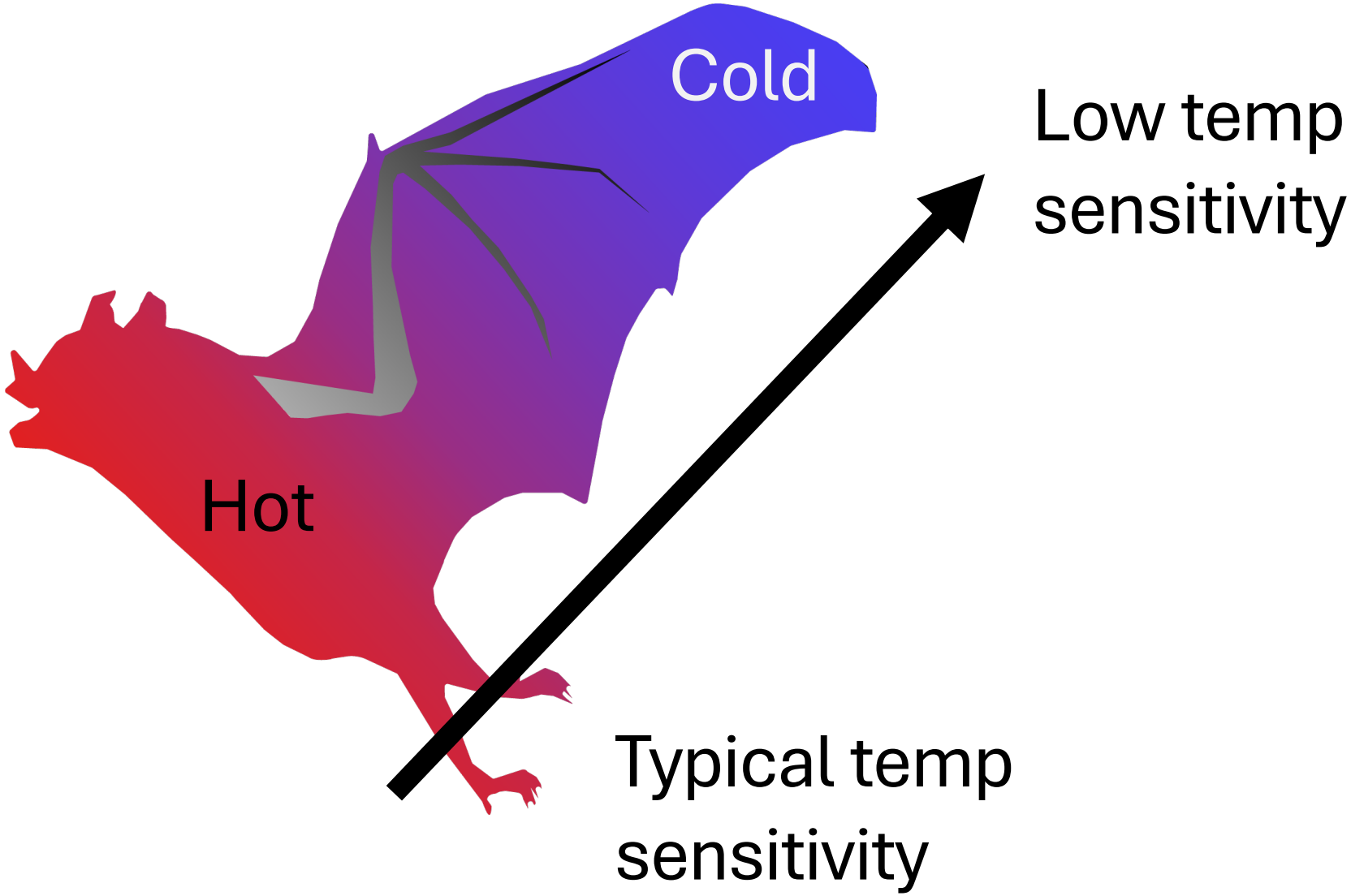
Regulating temperature across time and body region is critically important for most animals

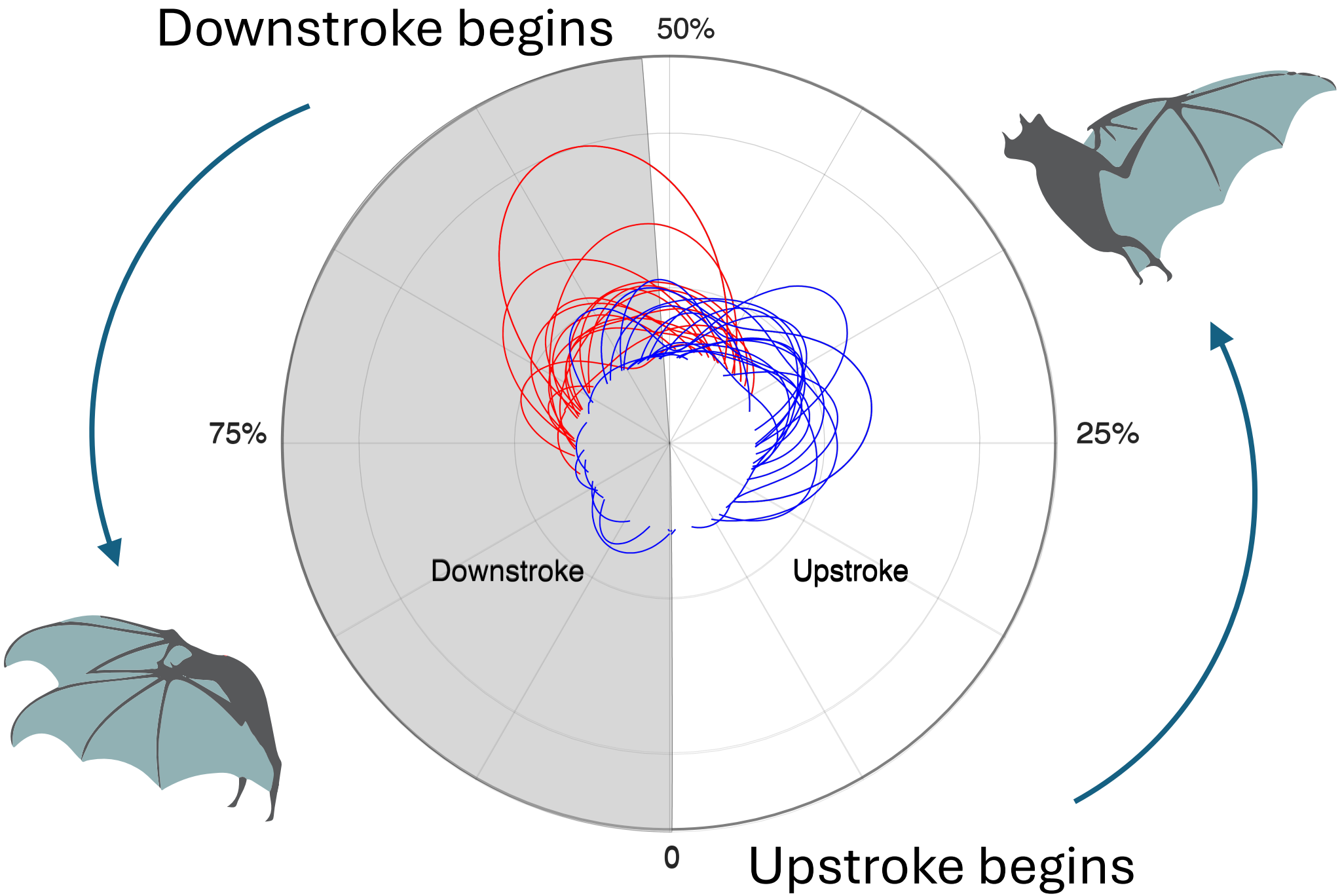
The locomotor system is extremely temperature sensitive

Integrating measurements of body temperature, muscle physiology, and biomechanics can help us understand the capacity for performance

Thank you for listening!

Combining kinematics with muscle activity, physiology, and temperature measurements




Downstroke begins
50%
75%
25%
Downstroke
Upstroke
0
Upstroke begins

Measuring regional heterothermy in the field

Field experiments

Fly bats in an enclosed space like a tent or corridor

Mark Thiessen