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Using Thermography to Determine Mechanisms of Heat Loss in the Southern Flying Squirrel (Glaucomys Volans)

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USING THERMOGRAPHY TO DETERMINE MECHANISMS OF HEAT LOSS IN

THE SOUTHERN FLYING SQUIRREL (*GLAUCOMYS VOLANS*)

by

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DEDICATION

My thesis is dedicated to my mother Deanna Marchiselli-Flynn. You have enriched my life with books and introduced me to the medical field from a very young age. You have taught me to remain strong and level headed when facing obstacles outside of my will. Thank you for fueling my passion for animals and ambition to become a veterinarian.

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ABSTRACT

Climate change is one of the biggest factors currently affecting the health and energetics of animals. Species evolve to operate optimally under certain environmental conditions and changes in those conditions can be detrimental to the species. Previous studies have shown increased evaporative cooling in flying squirrels at higher temperatures but not much is known about their ability to use other avenues of heat loss such as thermal windows; areas of the body that exchange heat with the environment via convection. For example, the patagium of southern flying squirrels may also serve as a thermal window to aid in heat dissipation. To determine the heat loss mechanisms that southern flying squirrels use to cope high environmental temperatures, I caught wild southern flying squirrels at the University of Maine's Demeritt Forest in Old Town, Maine, USA, exposed individuals to ambient temperatures near or above the upper limits of their thermoneutral zone, and photographed them using a FLIR thermal camera. Thermal imaging was used to identify areas of body areas used to dissipate heat. Subcutaneous body temperatures were simultaneously logged using a thermally-sensitive Passive Integrated Transponders (PIT tag). Contrary to my predictions, there was little to no evidence of the patagium being a thermal window as observed in the thermal images. Other body regions such as the tail and paws provided evidence of thermal conductance with physical behaviors such as self-urination and sprawling being observed as well. Further studies should aim at how the vasculature in the observed areas works to dissipate heat. Thermometric measurements and a larger sample size may aid in supporting my initial hypothesis.

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INTRODUCTION

Animals can control their body temperature within a restricted range using a range of thermoregulatory mechanisms (Tattersall 2012). As animals who produce heat internally using elevated rates of metabolism, all mammals are classified as endotherms (Grigg et al. 2021). Endotherms can further be classified as homeotherms, endotherms that maintain a relatively constant body temperature, or heterotherms, endotherms that can lower their metabolic rate below basal and abandon their stable body temperature (Grigg et al. 2021). Thermoregulatory processes include biochemical, physiological, and behavioral ways to control body heat both internally and at body surface level (Tattersall 2012).

Since endotherms metabolically produce heat, at high temperatures, they must couple this with mechanisms to dissipate heat to maintain homeostasis. Endotherm thermoregulation is characterized by the thermoneutral zone which is the range of ambient temperatures where an organism can maintain its body temperature while minimizing its metabolic activity (Withers 2016). The thermoneutral zone is delimited by upper and lower critical temperature; below the thermoneutral zone, an organism must increase heat production and above the thermoneutral zone, an organism must use mechanisms of heat loss to lower its body temperature (Scholander 1950). Once the ambient temperature exceeds an organism's thermoneutral zone, the organism can cool itself through evaporative heat loss via both the respiratory and integumentary systems (Huheey et al. 1967). Evaporative water loss is extremely useful when it comes to cooling due to water's innate ability to retain heat (Dejours 1987). Fick's Law is used to describe the relationship between relative humidity and evaporative water loss. The common

theory was that evaporative water loss should be inversely proportional to ambient relative humidity (Withers et al. 2014). However, a study on evaporative water loss in the little kaluta (*Dasykaluta rosamondae*), found that there was little correlation between evaporative water loss and relative humidity with no significant effect on body temperature as well (Withers et al. 2014). Some small mammal endotherms followed this pattern while others did not (Withers et al. 2014). It was postulated that some endotherms possess physiological adaptations to compensate for an increase in ambient humidity (Withers et al. 2014).

In addition to evaporative heat loss, at high ambient temperatures below body temperature dry heat loss can be used. Thermal windows are areas where heat exchange predominantly occurs (Weissenböck 2010). These areas experience either an increase or decrease in blood flow based on the direction in which the organism's body temperature must shift (Weissenböck 2010). Heat can dissipate through thermal windows in many different ways such as convection, radiation and conduction to the environment (Erdsack 2012). Infrared thermography is a useful tool in order to visualize these thermal windows. Infrared thermography is a non-invasive technique that measures mid to long-wave infrared radiation emanating from all objects and converts this to temperature (Tattersall 2016). As a hands-off approach, infrared thermography allows for data collection without the effects of handling on the subject's body temperature. Thermal imaging cameras translate the infrared radiation within the sensor's range of sensitivity into a temperature-based image, or thermogram (Tattersall 2016). Using thermal software, body surface temperature values can be obtained at each pixel of the image. Thermal windows are

visible when imaged due to dilation of a vascular network and the subsequent heat dissipation.

Studying a species' physiological processes can allow researchers to predict when and how a species will be affected by climate change. Identifying a species response to environmental changes, whether it is cold or warm, is crucial in order to protect and preserve species populations. Rodents are good model species for such studies because they are small, common, and widespread. Flying squirrels are an interesting species of focus when looking at climate change and its implications on thermoregulatory processes. Here in Maine, southern flying squirrels are experiencing a range shift at their northern margin into Canada (Wood et al. 2016). This northern range shift has been to the detriment of northern flying squirrels. Populations of the northern flying squirrels have been in recent decline due to disease, interspecies competition, and an increasing climate (Wood et al. 2016). Effects of heat tolerance on northern flying squirrels is yet to be determined but a warmer climate has allowed for a nematode parasite to thrive and decimate the northern flying squirrel populations (Myers et al. 2009).

Flying squirrels' responses to low temperatures are well known, but in terms of their physiology and their social habits. Southern flying squirrels are more susceptible to low ambient temperatures than their northern counterparts, likely due to their small size (Olsen et al. 2017). However, organisms may respond to thermal variance by inhabiting microclimates of their environment (Tattersall et al. 2012). Microclimates provide shelter for a species from many environmental conditions. Flying squirrels have been observed aggregating during the winter in nesting sites mainly in tree holes. Over a four year study of 97 nesting sites, during the winter months the average number of flying squirrels per

nest was 5.7 while in the summer the density was much lower at an average of 1.3 individuals per nest (Muul 1968). This is thought to be a mechanism to keep warm while minimizing energetic costs (Thorington et al. 2010). The squirrels found aggregated showed a degree of relatedness (Thorington et al. 2010). Southern flying squirrels also express a degree of non-kin social foraging and communal thermoregulation (Murrant et al. 2014). The extent of this relationship is still unknown but seems feasible when it is energetically advantageous to work as a group for the benefit of the individual (Murrant et al. 2014). Flying squirrels employ a thermoregulatory strategy called nonshivering thermogenesis (NST). Their average NST is lower in the summer and peaks during the winter months, indicating an inverse relationship with ambient temperature (Merrit et al. 2001). Squirrels also experience a higher NST when nesting alone rather than when nesting as a community (Merrit et al. 2001).

Responses to heat are less well-known in flying squirrels partly due to minimal studies in this area. The thermoneutral zone of southern flying squirrels throughout summer was measured to be 30 to 36°C and while in this zone the average body temperature was 39.1°C (Neumann et al. 1967). Body temperature began to increase once the ambient temperature was near 37°C (Neumann et al. 1967). At this point, the flying squirrels were observed to salivate and roll over on their backs with their limbs extended and gliding membranes stretched out (Neumann et al. 1967). The blood vessels of the gliding membrane became enlarged and filled with blood. It was hypothesized that the blood was being shunted from their core to that of the gliding membranes as a mechanism to dissipate some of the heat load through the greater surface area (Neumann et al. 1967). In a more recent study, an upper-critical limit (UCL) could not be

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determined on metabolic rate alone when faced with temperatures up to 40 °C (Hensley 2019). However, evaporative water loss (EWL) increased at 36.2 °C (Hensley 2019) and other heat-loss behaviors (licking, urination, postural changes) were observed at these temperatures. There is a lack of data on northern flying squirrels when it comes to heat tolerance which is a particular importance because they are the ones who may be more susceptible to climate change. Being their closest relatives and easier to catch, southern flying squirrels can aid in understanding how heat loss occurs in northern flying squirrels as well.

To help better understand how small endotherms cope with climate change, my project aims to characterize the mechanisms of heat dissipation in flying squirrels when exposed to temperatures near their upper critical limit. Using thermal imaging, I will determine the anatomical areas of optimal heat dissipation in flying squirrels. My objective is to draw conclusions on how these physical features aid in thermoregulatory mechanisms. With a higher surface area being indicative of heat dissipation, the patagium of the southern flying squirrel is an optimal area of interest. I hypothesize that when faced with high ambient temperatures, the southern flying squirrel will use its patagium as a thermal window.

MATERIALS AND METHODS

<u>Animal Handling</u>

Southern Flying Squirrels were caught in the Dwight D. Demeritt Forest in Old Town, Maine from June-October 2021. The Dwight D. Demeritt Forest is a temperate deciduous forest containing pines, oaks, shrubbery, and a substantial amount of mushrooms. In order to capture the flying squirrels, 30-40 Folding Sherman Sheet Metal Traps (LFA 9 x 3 x 3.5 Folding, Aluminum Trap, Tomahawk Live Trap, Hazelhurst, WI) were placed in a grid along the forest floor. Traps were placed about five meters apart and at the base of larger trees. Traps contained cotton balls for nesting and a mixture of peanut butter, oats, and seeds were used for bait. Traps were opened around sunset (18h00-19h00 pm) and closed around sunrise (06h00-07h00).

Captured individuals were transferred to a handling bag for morphometric measurements. Flying squirrels were sexed and reproductive status was logged. Physical measurements consisted of ear length, hindfoot length (with and without toes), and tail length and forearm length was measured when able. Measurements were taken using an electronic caliper in millimeters and weight was measured using a digital scale (UNIWEIGH Digital Pocket Scale, Cochin, India) to the nearest tenth of a gram. Flying squirrels were tagged on their ears using ear tags (Mouse Ear Tags, National Band and Tag Company, Newport, KY) and passive integrated transponder (PIT) tags (BioThermo13, Biomark, Boise, ID) were placed subcutaneously for identification purposes as well as to track subcutaneous body temperature during the experiment. Small soft tissue biopsy samples (3mm) were taken from ears for species identification and for testing for diseases. Flying squirrels included in the study were either adult males or non-

reproductive females. Flying squirrels were stored in ventilated critter carriers (Lee's Kritter Keeper, Medium Rectangle, Lee's Aquarium and Pet Products, San Marcos, CA) at room temperature (~27°C) during transfer from the forest to the Levesque Lab at the University of Maine and while not in the experimental set-up. Individuals were housed in the lab for under 12 hours and returned to the forest upon completion of the experiment. They were given access to apple slices for hydration and sustenance throughout the entire experiment. All capture and handling procedures were approved by the University of Maine's Institutional Animal Care and Use Committee Protocol #A2020-05-01 and followed the Wildlife Scientific Collection Permit #2020-516 issued by the State of Maine Department of Inland Fisheries and Wildlife issued to D. Levesque.

Thermography Set Up

The thermographic chamber consisted of a 32-gallon plastic garbage bin (Rubbermaid, Atlanta, Georgia) that had been wrapped in insulation with two openings on the lid. One opening was for the thermal camera (FLIR T450sc) to sit (~1 m above) and have a full dorsal view of the subject inside. The other opening was equipped with a thermoelectric cooling system (TE Technology, Traverse City, Michigan) connected to a TC-720 temperature controller (TE Technology, Traverse City, Michigan) to manipulate the temperature and monitor airflow within the chamber. The cooling system was linked to a computer and the thermometric units accompanying software (TC-720) was used to operate. A custom built antennae (Kleinhause 2019) was coiled around the outside of the chamber and subcutaneous temperature was monitored via pit-tag and recorded using a Biomark HPR Plus Reader (Biomark Inc., Boise, ID). The thermal camera remained filming throughout the entire experiment.

Thermography Experiment

Each squirrel was exposed to temperatures in four temperature increments spending between 30-60 minutes at each increment. Squirrels were placed in the chamber at a temperature of either 25 or 28°C. Temperatures were increased at an increment of 2-3°C. Experiments lasted a maximum of 3 hours. Area of interest was the patagium, but other areas of the body were considered thermal windows if their surface temperature exceeded that of the rest of the body's surface by 4±1°C.

Data Analysis

The subcutaneous temperature data from the Biomark HPR Plus Reader (Biomark Inc., Boise, ID) was plotted as a line graph using Microsoft Excel (2020). Due to incorrect settings of the thermal camera (FLIR T450sc), the videos did not include thermometric data. To compensate for this, image analysis was performed using the Color Histogram and 3D Surface Plot packages in FIJI ImageJ (Tattersall 2021). Images were colorized as a thermal gradient and plotted based on each pixel's pigment. Videos were manually skimmed through and screenshots were taken if the test subject exhibited certain behaviors related to thermoregulation (salivating, urinating, sprawling etc.). Screenshots were also taken at each experimental temperature increment. Any frame that had clear visuals of thermal windows or vasculature were saved as well.

RESULTS

Two experiments were conducted in total. Temperatures within the chamber

ranged from 25-40°C (Table 1). When the animal was in some areas of the chamber, the

receiver was unable to get subcutaneous temperature measurements (Figure 1A). Any

false readings (34°C or lower) were also scrubbed from the dataset before analysis. There

was stabilization in subcutaneous temperature when it reached around 37°C (Figure 1A).

Subcutaneous temperature in the second experiment had an initial elevated temperature

most likely due to handling with ensuing fluctuations between 35.5-36.5°C (Figure 1B).

Subcutaneous temperature was later maintained a little above 37°C (Figure 1B).

Table 1: Information on the southern flying squirrels used for thermography experiments. The ID, date, sex, mass, and experimental temperatures are shown.

Squirrel ID	Date	Location	Sex	Mass (g)	Temperatures (°C)
UM111	8/19/2021	Demeritt Forest, Onoro, ME	M	62.3	28, 30, 33, 36
UM246	10/4/2021	Demeritt Forest, Onoro, ME	M	50	28,30,33,35,38,40
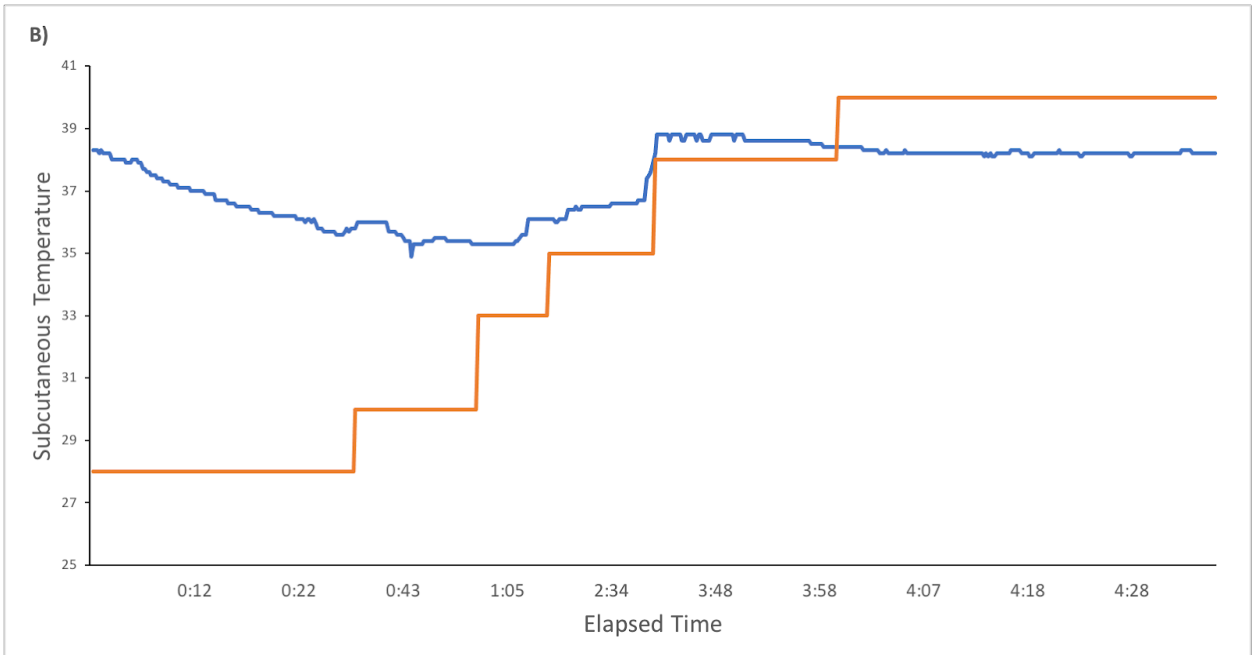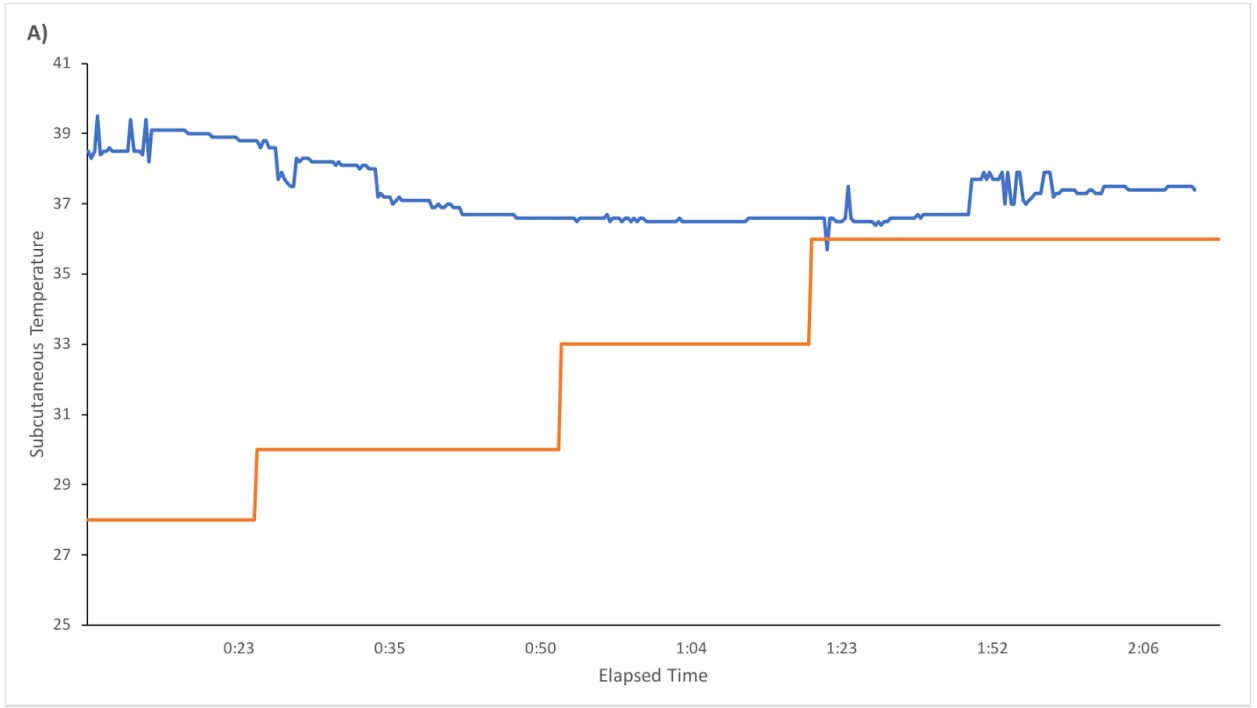
Figure 1: The subcutaneous body temperature (blue) in relation to time and ambient temperature (orange) in the first (A) and second (B) experiments.
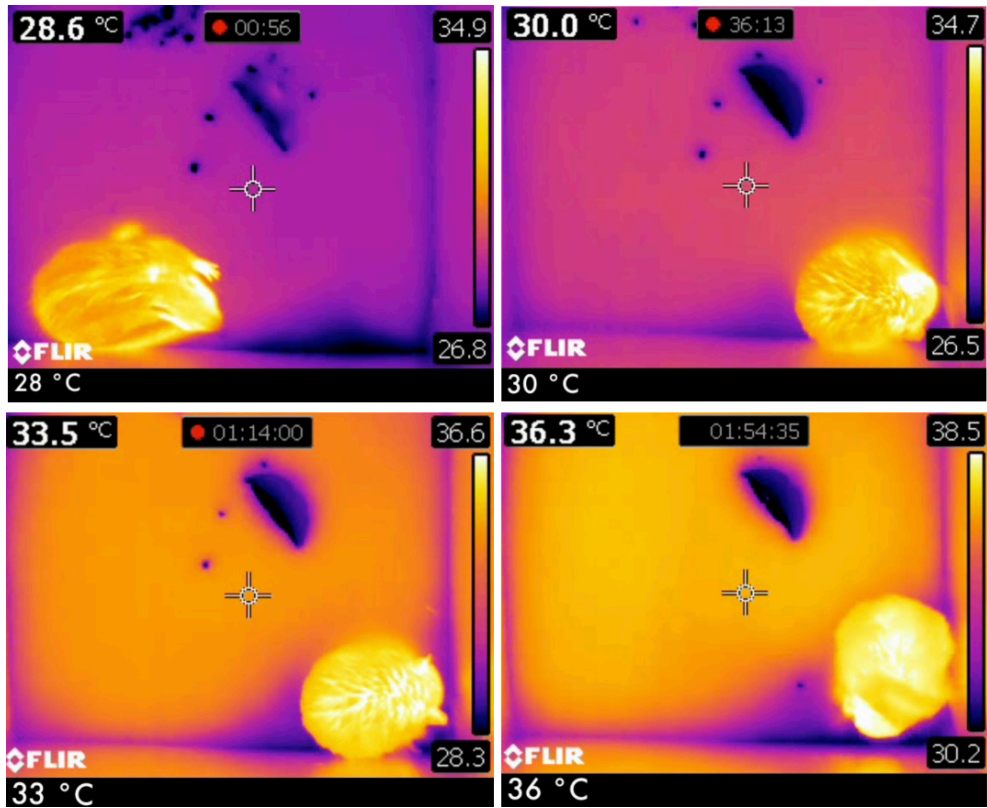
Figure 2: Thermal images of a southern flying squirrel at each experimental temperature increment (28°C, 30°C, 33°C, 36°C) in the first experiment.
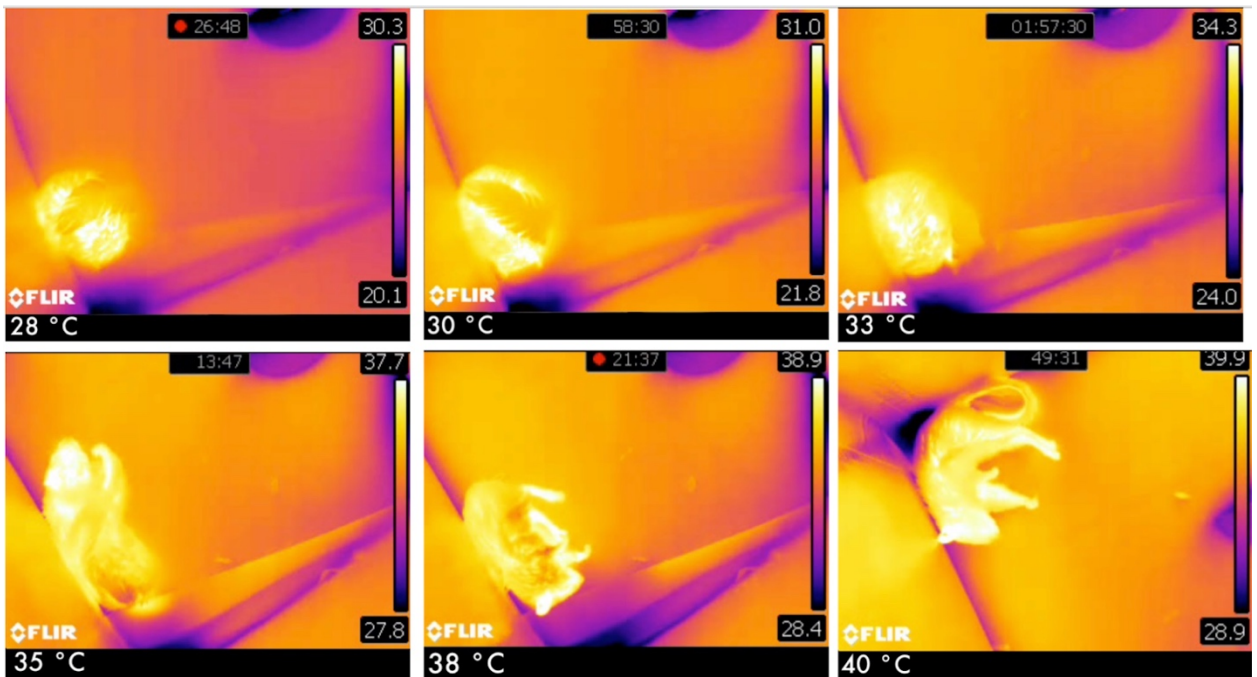

Figure 3: Thermal images of the southern flying squirrel at each experimental temperature increment (28°C, 30°C, 33°C, 35°C, 38°C, 40°C) in the second experiment.

At high temperatures neither squirrel showed clear use of the patagium as a thermal window. In both experiments the squirrels used other anatomical areas of heat dissipation like the paws and ears. By the end of the first experiment (max ambient temperature of 36°C), the highest record surface temperatures increased by 3.6°C (Figure 2). The first flying squirrel had a gradual increase in surface temperature but remained relatively relaxed and curled up throughout the experiment (Figure 2). The second flying squirrel showed more signs of heat stress with many postural changes and spreading out the limbs (Figure 3). The second animal also had a large increase in the highest measured surface temperature with an 9.6°C increase (Figure 3).

Although there was no thermometric data embedded in the videos color analysis indicated a slight increase of heat in the patagium at ambient temperatures greater than 38°C, however it was indistinguishable from the rest of the body and could not be classified as a thermal window (Figure 4). Conversely, surface area temperatures of the ears and paw exceeded that of the rest of the body (Figure 4). Similarly, at higher temperatures, the vasculature of the tail became clear both dorsally and ventrally, indicating its use as a thermal window (Figure 5). Above ambient temperatures of 35°C other thermoregulatory behaviors were observed including self urination and hypersalivation on the extremities, stretching and visible agitation, covering the body via the tail, and extending of the limbs (Figure 6).
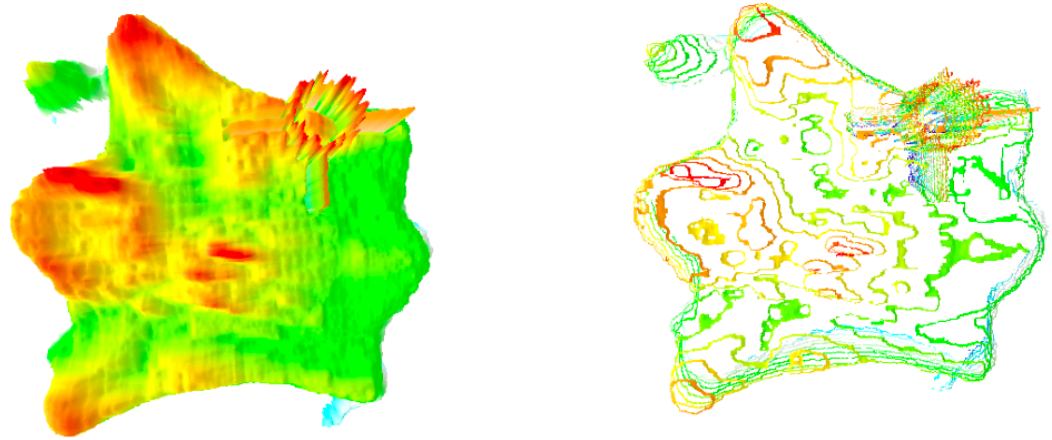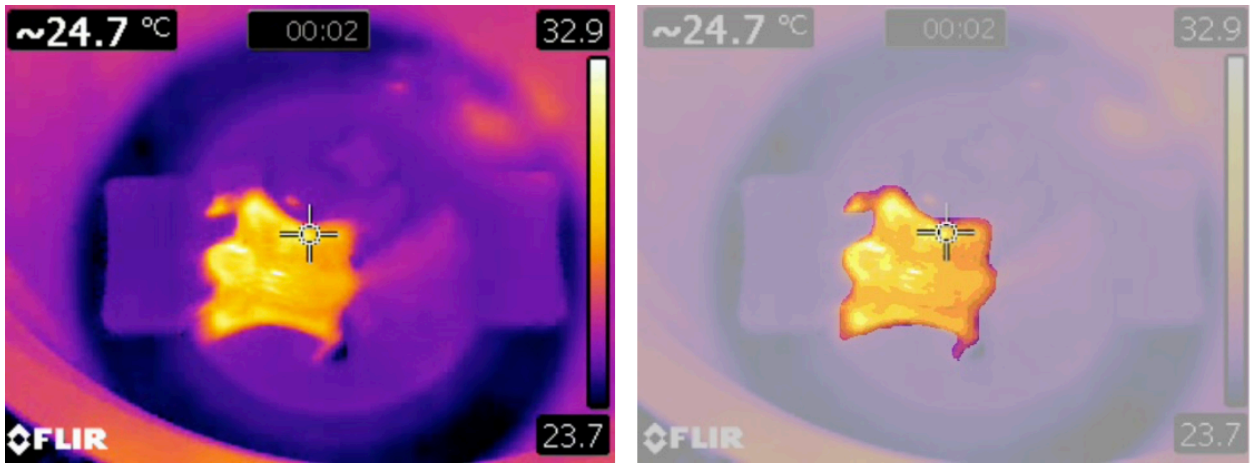
Figure 4: Full exposure of patagium from a manipulated scenario. Original image (top left), Area of analysis (top right), Thermal surface plot (bottom left), and Thermal area gradient plot (bottom right).
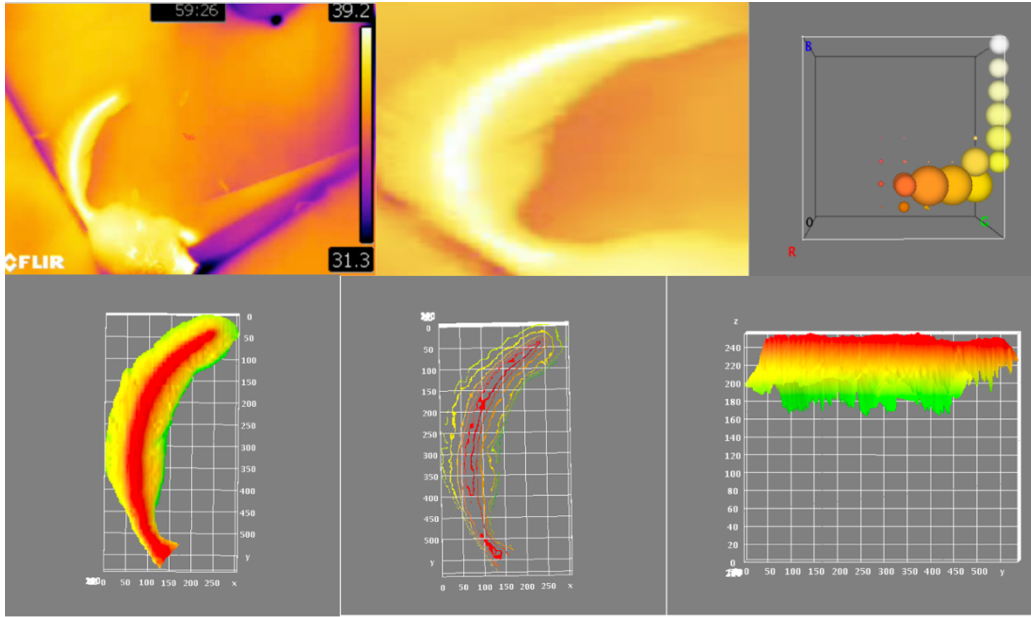
Figure 5: Tail vasculature from the second experiment. Original image (top left), Area of analysis (top middle), Color histogram (top right), Thermal surface plot dorsal view (bottom left), Thermal area gradient plot (bottom middle), and Thermal surface plot lateral view (bottom right).
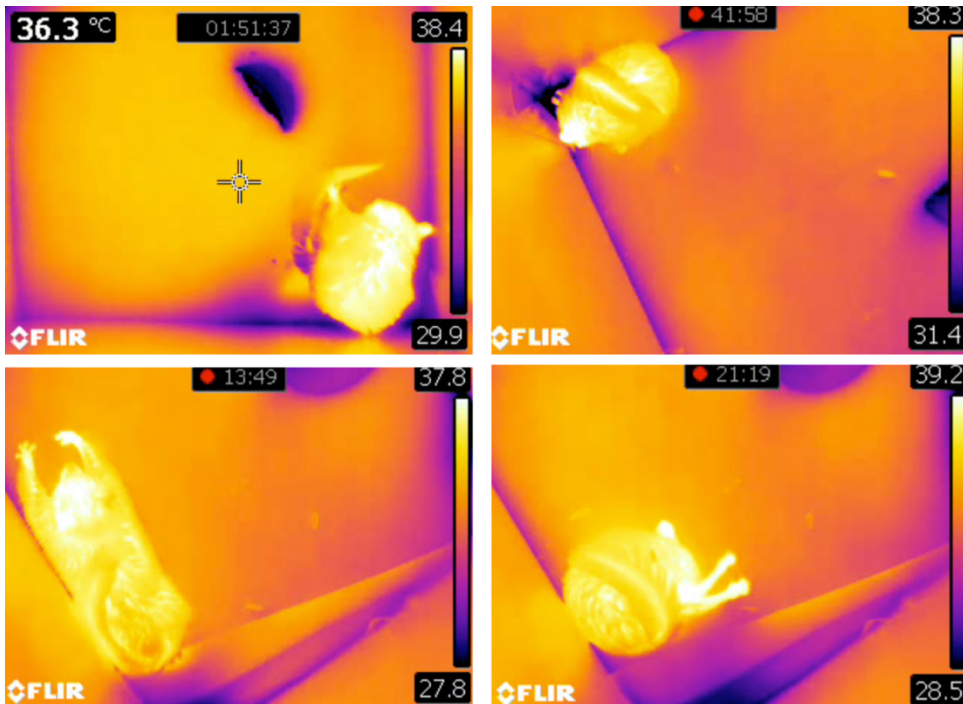
Figure 6: Observed thermoregulatory behaviors. Self urination and salivation (top left), using tail vein for thermal conductance (top right), stretching and visible agitation (bottom left), and sprawling of limbs to increase convective heat loss (bottom right).

DISCUSSION

Southern flying squirrels proved to be relatively tolerant to heat at higher temperatures. My hypothesis of the patagium serving as a thermal window was not supported by the results. There were no visible indications or use of the patagium in convective heat loss, although having a small sample size puts a constraint on my ability to draw broader conclusions. When ambient temperature exceeds that of body temperature, the only way to stay cool is via evaporation of water (Tattersall et al. 2012). However, if body temperature still exceeds that of ambient temperature, then heat can be dissipated via dry thermal conductance (Tattersall et al. 2012). In the second experiment, the flying squirrels' subcutaneous temperature exceeded the ambient temperature throughout most of the experiment indicating that it could have been relying on dry heat loss. The subcutaneous temperature of the flying squirrel was lower than the ambient temperature when it reached 40°C towards the end of the experiment. During this timeframe, the flying squirrel could most likely switch from dry convective heat loss to evaporative cooling.

Water has a high heat conductivity and a heat transfer 24-times greater than that of air (Dejours 1987). The rate of evaporative heat dissipation is directly proportional to the difference in water vapor density of the evaporating surface of the animal and the environment (Gerson et al. 2014). In flying squirrels, evaporative cooling becomes impaired as humidity increases at moderate temperatures up to 37°C (Webster et. al 1987). At this point evaporative water loss showed an increase, indicating that flying squirrels prioritize other methods of heat loss prior to this temperature point (Hensley 2019). Even when faced with temperatures up to 40°C, an upper critical temperature in

metabolic rate couldn't be determined (Hensley 2019). On the other end of the spectrum, an individual needs to maintain its metabolic water load. Losing too much water during thermoregulatory mechanisms can lead to hyperthermia and dehydration. Bats had a higher evaporative water loss in arid conditions than in humid (Willis 2011). However, employing evaporative water loss in arid conditions becomes costly over long periods of time with no source to maintain metabolic water capacity with survivability decreasing as evaporative water loss use increases (Willis 2011). Since dry heat loss does not rely on metabolic water capacity, it can be a useful tool for species to employ in dry condition. My study focused on the mechanisms of dry heat loss and how these are shaped by the flying squirrel's anatomy.

The ratio of body size to surface area plays an important role in determining an endotherm's degree of heat loss and use of thermal windows. Increased heat loss in areas of large extremities is thought to be linked to endotherms that have a large core body size (Speakman et al. 2010). Flying squirrels are an exception to this and, the patagium and tail, have larger surface area to volume ratio. The tail is approximately 78% of total head and body length with this thought to increase with body size (Thorington et al. 1981). Non-volant sciurids of similar size tend to be lower than that (Thorington et al. 1981). Gliding surface area in an individual weighing 70 g was estimated to be 150 cm^2 (Thorington et al. 1981). This gliding surface area would be the same as the potential thermal window surface area. Surface area also generally increases to compensate for an increased mass (Thorington et al. 1981). An extensive vascular system coupled within these areas would make perfect thermal windows (Weissenbock et al. 2010). Thermal windows must be highly vascularized with reduced insulation in order to facilitate heat

transfer with the environment (Reichard et al. 2010). Vasculature can react to temperature

conditions in two ways: reducing blood flow via vasoconstriction in response to colder

temperatures and increasing blood flow via vasodilation in response to warmer

temperatures (Reichard et al. 2010).

A parallel to the patagium of flying squirrels can be found in bats. In a study on

the Brazilian free tailed bat (*Tadarida brasiliensis*), thermal imaging of the patagium

expanded during flight revealed symmetrical thermal windows along the ventral

antebrachial region of the individual (Reichard et al. 2010). Photographing this region in

particular revealed a vast network of veins thought to only be exposed during flight as a

mechanism of heat transfer since the majority of energy used during flight is lost in the

form of heat (Reichard et al. 2010). As blood flows through these arterioles it is cooled

via convective transfer with the environment. Bats also use their patagium in a fan like

manner to dissipate heat during roosting (Reichard et al. 2010). While flying squirrels do

not sustain flight, they have been observed to glide up at a relatively constant height for

an average of 50 m from an 18 m height (Bahlman et al. 2012). Like bats, being

nocturnal allows for southern flying squirrels to avoid peak solar heat load (Tattersall et

al. 2012).

Flying squirrels extend their patagium via a styliform cartilage (Thorington et al.

1998). In using their flexor carpi ulnaris muscle, the styliform cartilage fully extends the

patagium distally from the body through a tibiocarpalis muscle that runs along the lateral

edge of the patagium (Thorington et al. 1998). Flying squirrels experience higher wing

patagial loading than bats (Thorington et al. 1981). Bats also have their digits throughout

their patagium allowing for direct muscular attachment. Flying squirrels would need an

adept vascular network to provide oxygen to their free hanging tibiocarpalis muscle. Having a small core body size with a lot of cutaneous extremity would make it difficult to thermoregulate if that said extremity does aid in any thermoregulatory processes. Supplying blood to these extremities would require intricate vasculature. When mapping the vasculature of Brazilian free tailed bat (*Tadarida brasiliensis*), the radial artery provides blood to the upper region of the patagium while superficial circumflex iliac vein provides blood to the lower region of the patagium (Reichard et al. 20120. Flying squirrels may have a similar vasculature system throughout their patagium. Whether or not this serves as just a source of providing oxygen to the extremities or a thermal window is yet to be determined.

There are many other anatomical regions that can serve as thermal windows. Thermal images of the southern flying squirrel indicated a surface area increase in regions such as the ears, feet, and tails. Although difficult to visualize in small Sciuridae, thermal images of the pinna in elephants provided excellent imaging of an adept vascular network (Weissenbock 2010). After spending a period of time outdoors, the pinna had distinct regional temperature differences and the veins became visible (Weissenbock 2010). Measurements from larger species allows for better visualization since vasculature should remain relatively consistent across mammalian taxa. However, in a more closely related species, rats showed little vasodilation in their ears after being exposed to an increase in ambient temperatures (Grant 1962). Prior to an experiment with rats looking at their tail vasculature, there were three main veins visible to the naked eye (Grant 1962). Microscopic examination revealed that there was no dilation even though they

appeared hotter (Grant 1962). This may account for the lack of visible vasculature in the southern flying squirrel.

Rodents rely immensely on the vasculature of their tails during thermoregulation. As observed in rats, the tail temperature rises rapidly when body temperature reaches 39°C (Grant 1962). There is a strong dilation of the tail vein after being heated (Grant 1962). Southern flying squirrels appear to be similar with the tail vein becoming visible around 38°C. Temperatures of the fore and hind feet behave similarly with the veins on the dorsum of the foot becoming dilated (Grant 1962). The tail and hind foot temperatures increase at the same degree as seen through bilateral abdominal sympathectomy, a procedure to cut the sympathetic nerves involved in excessive sweating (Grant 1962). This link between the tail and paws showing the same degree of heat dissipation explains other behaviors observed in the southern flying squirrel such as sprawling out the hind legs and tail at higher temperatures. Rodents have been observed to curl up into balls at colder temperatures to reduce surface area (Stryjek 2021). The southern flying squirrels of this experiment started out with this posture and slowly abandoned it to their more sprawled positions as ambient temperatures increased. These visual aspects of thermal regulation can be backed by metabolic data.

The behaviors and heat loss observed in the thermal videos mirrors the metabolic data on flying squirrels. At around 36°C, both evaporative water loss and the ratio of evaporative heat loss to metabolic heat production increased (Hensley 2019). At the same temperature, the squirrels in my study began to show visible signs of heat stress and abandoned their ball-like posture. At around 40°C, the squirrels of my experiment were sprawled out with the tails extended. Thermal windows were very clear at this point.

Evaporative water loss, subcutaneous temperature, and the ratio of evaporative heat loss to metabolic heat production also had a large spike at this ambient temperature (Hensley 2019).

Temperate deciduous forests in the northern hemisphere, flying squirrels' natural habitat, have had an overall average increase in temperature with this expected to increase in the near future (Di Fillipo et al. 2015). In the past few decades, the southern flying squirrels' range has shifted dramatically north (Wood et al. 2016) as increasing temperatures have enabled the southern flying squirrel to cross ranges with the northern flying squirrel. Climate change can have some irreversible effects on a species. Changes in the environment can push natural selection to cause a change in a species allele frequency (Helmuth et al. 2005.). On the individual level phenotypic plasticity can occur (Helmuth et al. 2005). Given the southern flying squirrels' adaptability and establishment north of its traditional range, there has been observed species competition between the northern and southern species. Northern flying squirrels have been pushed out of the southern margins of their range in recent years (Weigl 2007). Southern flying squirrels have been observed to be more active and aggressive around nesting sites and food Weigl 2007). As southern flying squirrels move northbound to deal with the changing environment, a ladder of ecological effects is activated. Climate change does not only affect a single species but the entire ecosystem.

CONCLUSIONS

Although my study lacked conclusive evidence to support my initial hypothesis, this study points towards new ways to look at thermal windows in southern flying squirrels. There was insufficient imaging of the patagium to draw conclusions as to the degree of its contribution to overall thermal conductance; however, imaging provided substantial evidence of the paws, ears, and tail being used as vectors of heat loss. Future research should focus on the vasculature and biological features of the aforementioned anatomical areas. An increase in sample size would provide more sufficient data and possibly more imaging of the patagium. Thermodynamics of gliding mammals is a little-studied field and my work on the more common southern flying squirrel can be translated along the taxon to more rare and endangered species. Knowing both behavioral and biological mechanisms of heat loss in a species allows researchers to draw conclusions on how to maximize conservation efforts and predict impacts of climate change on a species.

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Colin Patrick Flynn was born on June 3rd, 2000, in Danbury, Connecticut. He spent his whole childhood there and graduated from Danbury High School in 2018. During his time as an undergraduate at the University of Maine, Colin enjoyed his many biology courses and showed a particular interest in his animal focused laboratories. He plans to continue his education with a Doctor of Veterinary Medicine with a focus on wildlife. While home from university, Colin works at an emergency and specialty animal hospital in New York. In his spare time, Colin enjoys hanging with his friends, going on adventures, or just staying in and watching a movie.