

Temperature at which peak frog jumping performance is reached does not vary with latitude

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Abstract

Frog jumping performance variables including, but not limited to, jump distance and take-off velocity, follow thermal performance curves, with performance increasing with temperature until some peak performance value is reached, then decreasing. Thermal performance curves are generally broader for species from higher latitudes, and ectotherms from tropical regions are generally more sensitive to temperature changes than ectotherms from temperate regions. Because of these sensitivity differences and the fact that frogs are ectotherms, I examined whether frog populations from temperate regions reach their peak jump distances and take-off velocities at higher temperatures than those from tropical regions using data compiled from previous studies. I found that for both jumping distance and velocity, there is no significant difference between the temperature at which peak performance is reached for temperate and tropical frog species. Additionally, phylogenetic analyses showed no evolutionary impact on peak performance temperatures based on latitude. This could mean that frogs are unlike other ectotherms in that frog species from higher latitudes are not less sensitive to temperature changes than those from lower latitudes, or that with the broadening of the thermal performance curve,

the peak remains unchanged. However, the results could also indicate an overgeneralization of latitudinal categories or that the peak performance values assessed were not true peaks.

Ultimately, these findings and the curation of a database for use in this study emphasized that future studies should focus on data collection for a greater number of frog species at a wider temperature range and for more jump performance variables.

Introduction

It is well understood that temperature affects physiological functions, including performance. Beginning with a lethal minimum temperature, physiological performance increases with temperature to an extent, reaching some peak performance value before subsequently decreasing with temperature until a lethal maximum is reached (Wilson, 2001). In frogs, an ectothermic species, various aspects of jumping performance have been found to follow this trend, which can be represented by a thermal performance curve (Fig. 1) (Moen et al., 2022). Moen et al. found that a few treefrog species increase their jump take-off velocities with increasing temperatures, and Wilson found a similar trend with both horizontal jump distance and take-off velocity while studying five populations of *Limnodynastes peronii* (Moen et al., 2022; Wilson, 2001). Other aspects of frog jumping performance, including force, acceleration, power, take-off angle, and contact time have also been assessed, showing similar trends (Wilson, 2001; Mitchell and Bergmann, 2015; Marsh and John-Adler, 1994; Hirano and Rome, 1984). As frogs utilize jumping as a means of predator avoidance and a way to capture prey, it is important to understand how temperature affects different aspects of this essential life function (Wilson and Franklin, 2000).

Additionally, environmental temperatures vary with latitude, with higher latitudinal regions experiencing greater variation (Sunday et al., 2011). Thus, organisms from these regions tend to have performance abilities at a wider range of temperatures (Navas et al., 2008). Similarly, it has been found that terrestrial ectotherms in the tropics are more sensitive to small temperature changes than those living at higher latitudes. This is because they experience less frequent exposure to change (Deutsch et al., 2008). Because the previous study assessed insects, but frogs are ectotherms too, I was curious to see if the same trend occurred in frogs. Are frog species from temperate regions less sensitive to temperature changes than those from tropical regions? Unfortunately, current data availability on frog jumping performance does not fully capture variation across temperature. Though this opens up an area for future data collection and comparative analyses, I decided to focus my study on whether latitudinal regions interact with temperature to impact peak jumping performance values rather than focusing on the full temperature range at which frogs have performance capabilities. Specifically, since frog species from temperate regions should be able to perform within a greater temperature range, I wondered if this would change the temperature at which peak performance was reached and designed my study to address the question, do frog populations from temperate latitudes reach peak performance values at higher temperatures than those from tropical regions?

To study this question, I examined the temperature at which peak frog jumping performance was reached in comparison to the latitudinal region in which the study populations were obtained. For 14 frog species, I looked at the temperature at which peak jump take-off velocity was reached. For 7 species, I looked at the temperature at which peak jump distance was reached. I then included a phylogenetic analysis to assess evolutionary impacts on peak performance temperatures. I predicted that frog populations from temperate regions will reach

their optimal performance values for both distance and velocity at higher temperatures, on average, than frog species from tropical regions.

Methods

Database Curation

I compiled data on frog jumping performance from ten previous studies conducted between 1984 and 2021 to create a frog jumping performance database. The database, metadata, further information about included and excluded studies, and the R code used for the analyses featured in this paper are all stored on Github under user: hehess19 (see Data Availability). The database features data on multiple parameters of jumping performance, acclimation method, latitudinal region, and mass from 22 ecologically diverse species within 13 genera (*Acris*, *Ascaphus*, *Charadrahyla*, *Exerodonta*, *Hyla*, *Limnodynastes*, *Osteopilus*, *Pseudacris*, *Ptychohyla*, *Rana*, *Smilisca*, *Spea*, and *Tlalocohyla*). Multiple existing databases, journals, and data repositories including PubMed, Google Scholar, Duke Libraries, Journal of Experimental Biology, Data Dryad, and Networked Digital Library of Theses and Dissertations were searched for literature on frog jumping performance over a range of temperatures. Search terms included “frog jumping performance,” “frog locomotor performance,” “temperature and frog jumping performance,” “frog thermal physiology,” etc.

In the curation of this database, one prioritization was accessibility. It is important for previously collected data to be easily reusable without having to contact the author so that experiments can be replicated and data can be corrected (Mulligan et al., 2022). However, much of the data collected on frog jumping performance in earlier studies was difficult to obtain

because raw data was either lost or reaching out to the authors resulted in no response. In these cases, I used GetData Graph Digitizer to extract data points from the figures in the original publication. Data obtained using GetData Graph Digitizer is clearly noted in the database. Digitization of data from publications resulted in some data points being raw data and other data points being averages. Sample size for provided data points therefore ranges from $n = 1$ to $n = 24$, where n represents the number of jumps, not the number of frogs. In considering data availability and accessibility, preference during the literature search was given to articles in the following order: those which had accessible and downloadable raw data, those which included raw data in a table in the article, those which included data averages in a table in the article, then those which included data averages in the form of a figure in which GetData Graph Digitizer could be used to extract the data. All included articles contained data on expected body temperature and jumping distance (measured as the horizontal distance between one jump) or resultant take-off velocity. Articles were excluded on the basis of not including a frog as the species of study, not having jumping performance data, or having jump distance data collection methodology or data presentation that drastically differed from included articles.

A second prioritization during database curation was version control. The database, metadata, and R codes used for analyses are stored on GitHub (<https://github.com/hehess19>), where other researchers can access the data and run their own analyses, replicate my study, or note issues and send edit suggestions. In the database specifically, data was included even if it was only provided for one or two parameters of performance rather than all variables in the database. This shows researchers where data is lacking, prompts future studies, and ultimately promotes advancement in this field of study (Schwanz et al., 2021).

Finally, the inclusion of reference information within the metadata including full

citations, DOIs, rationale for data categories, assumptions made, strategy for searching the dataset, inclusion and exclusion criteria, and extra information on excluded articles was also prioritized. I wanted to be as clear as possible regarding how I created the dataset and what each variable means so as to minimize any confusion. This reference information can act as a starting point for future research or for expanding the database and limits any ambiguities associated with the data (Schwanz et al., 2021). Including reference information such as methodology, clearly defined variables, and acknowledgment of researchers whose data was used but who were not listed as authors of the publication has already proven to be a successful strategy for top researchers in the field of biology (Pontzer et al., 2021).

Sampling and Latitude

Within the 22 frog species included in the database, 17 species contain data for take-off velocity while 10 species contain data for jump distance, 16 frog species are from tropical latitudes while 7 frog species are from temperate latitudes, and one species (*Limnodynastes peronii*) contains populations in both latitudes (Table 1). Tropical latitudes were defined as the region between 23°27'N and 23°27'S and temperate latitudes were defined as any latitude outside of this region (Sheldon, 2019). Three frog species (*Acris gryllus*, *Hyla squirella*, and *Osteopilus septentrionalis*) were included in the database but excluded from the analyses in this paper as their jumping performance was only assessed at 20°C. As such, the temperature at which peak performance was reached could not be accurately assessed in these species. This resulted in analyses being done on 14 species with velocity data and 7 species with distance data.

Jumping Performance and Thermal Performance Curves

Jumping performance parameters included in the database are jump distance, take-off velocity, force, angle, power, acceleration, and contact time. All of these parameters are defined in the metadata for the database. For this study, however, only jump distance and take-off velocity data were used. Jump distance was defined as the horizontal distance (m) of one jump (Mitchell and Bergmann, 2015). Take-off velocity was the resultant velocity (m/s) at the beginning of the jump (Mitchell and Bergmann, 2015). For each frog species, I plotted distance and/or velocity against expected body temperature, then fitted a trend line to the data using the `geom_smooth()` function in R to visualize trends in the thermal performance curve.

Phylogeny

I extracted my trees of the 14 species with velocity data and the 7 species with distance data using the phylogeny of amphibians created by Jetz and Pyron (2018). Branch lengths are given in units of time (Jetz and Pyron, 2018). A Bayesian posterior distribution of trees calibrated by time is provided by Jetz and Pyron (2018) and found on VertLife (www.vertlife.org/phylosubsets). I used VertLife to download two sets of 100 trees from the posterior distribution. I pruned one set to include only the 14 taxa with velocity data and one to include only the 7 taxa with distance data. Following Moen et al. (2022), I obtained two maximum clade credibility trees using TreeAnnotator (Bouckaert et al., 2019). I set the posterior probability limit equal to 1.0 and estimated branch lengths as means (Moen et al., 2022). I used the default settings in TreeAnnotator of a burn in percentage equal to 10. I then used FigTree to visualize the resulting trees (Figs. 2-3).

Analysis

I conducted a one-way analysis of variance test (ANOVA) to test whether or not there were any significant differences between the mean temperature at which peak performance was reached in temperate species and the mean temperature at which peak performance was reached in tropical species. In this analysis, my categorical independent variable was latitudinal region (temperate or tropical) and my quantitative dependent variable was the temperature at which peak performance (maximum take-off velocity or maximum jump distance) was reached. The temperature at which peak performance was reached was represented by the expected body temperature of the jumping individual (or individuals, if the data point was a mean) where the individual or individuals reached their maximum jump distance or take-off velocity. Expected body temperature was used due to lack of data for observed body temperature for all species.

I then conducted a phylogenetic generalized analysis of covariance (ANCOVA) to test whether the evolution of the included frog species correlated with the latitudinal impact on peak performance temperatures. In doing so, a phylogenetic least squares (PGLS) estimation was conducted using the corBrownian correlation structure of residual error as done by Revell and Harmon (2019). This correlation structure sets the expected correlation between species as directly proportional to their proportion of common ancestry since the root (Revell and Harmon, 2019). For *Limnodynastes peronii*, the data from the two tropical populations were averaged and used as a single data point for the species in the ANCOVAs. I avoided averaging all five populations to avoid averaging data across latitudes. I chose to use the tropical populations since there is less data on tropical species in the database than there is for temperate species.

Results

Thermal Performance Curves

The performance curves generated showed a variety of trends. For 6 species, curves with velocity as the performance parameter showed the expected trend of performance increasing with temperature to a point, then decreasing (Fig. 4). For 5 species, curves with distance as the performance parameter also showed this expected trend (Fig. 5). Curves with velocity as the performance parameter for 5 other species showed the expected increase of performance with temperature but did not show the expected decrease after a point (Fig. 6). This also occurred with one species, *Ascaphus truei*, with distance as the performance parameter (Fig. 7). Four species showed unclear performance trends with increasing temperature when velocity was the performance parameter (Fig. 8). One species, *Rana pipiens*, showed unclear performance trends with increasing temperature when distance was the performance parameter (Fig. 9). When trying to figure out the temperature associated with maximum jumping performance for each species, the temperature where peak performance was reached could not be extrapolated from all of the thermal performance curves as not all curves followed the expected trends or had a clear peak. Thus, for consistency in analysis, raw data points in the database were assessed to determine the peak jump distance values for each species, peak take-off velocity values for each species, and the expected body temperatures associated with the peak performance values for each species.

Latitudinal Variation in Peak Performance Temperatures

For the 14 species with velocity data, a one-way ANOVA was performed to compare the effect of latitude on the temperature at which peak jump take-off velocity was reached. The one-

way ANOVA revealed that there was no statistically significant difference between the average temperature at which peak jump take-off velocity was reached between temperate and tropical species ($F(1,16) = [0.024]$, $p = 0.879$) (Fig. 10). The average temperature at which peak take-off velocity was reached for temperate species was 29.3°C and the average temperature at which peak take-off velocity was reached for tropical species was 28.9°C. For the 7 species with distance data, another one-way ANOVA was performed to compare the effect of latitude on the temperature at which peak jump distance was reached. This one-way ANOVA revealed that there was no statistically significant difference between the average temperature at which peak jump distance was reached between temperate and tropical species ($F(1,10) = [0.49]$, $p = 0.5$) (Fig. 11). The average temperature at which peak jump distance was achieved for temperate species was 25.5°C and the average temperature at which peak jump distance was achieved for tropical species was 28°C.

Phylogenetic analysis showed no evolutionary impact on the temperature at which peak performance was reached in temperate versus tropical species for neither velocity nor distance. The phylogenetic generalized ANCOVA conducted on species with velocity data showed that there was no significant effect of latitude on temperature at which peak velocity was reached ($F(1)=[1.55675]$, $p=0.2359$) (Table 2). The phylogenetic generalized ANCOVA conducted on species with distance data also showed that there was no significant effect of latitude on temperature at which peak distance was reached ($F(1)=[1.3383]$, $p=0.2996$) (Table 3).

Discussion

Thermal Performance Curves

The thermal performance curves show where data in the database is lacking. Though some curves followed the expected trend of an overall increase in performance with increasing temperatures to a certain point before subsequently decreasing (Fig. 4-5), some curves showed only an increase in performance with increasing temperatures (Fig. 6-7), and others showed unclear trends (Fig. 8-9). This variation in the performance curves informed my decision to focus on the peak performance values and associated temperatures, since the curves could not accurately capture variation across temperatures for all species. The curves ultimately highlight where future research and data collection efforts should be focused in order to expand the database and possibilities for comparative analyses.

Because not all of the curves took the expected shape with a clear peak, I could not extrapolate the peak point from all curves to find the expected temperature at which peak performance was reached. I instead used raw data from the database for analyses. Specifically, I used the expected body temperature at which the peak performance value in the database was reached in order to maintain consistency rather than pulling some points from the expected peaks generated by the curves and some points directly from the database. I used expected body temperature over observed body temperature because not all species had data available for observed body temperature. As such, future studies should focus on more thorough data collection in regard to observed body temperature so that comparative analyses on body temperature can be more exact.

Data from species in which the performance curves showed only an increase in performance with increasing temperatures pose the problem of not knowing if the peak value for performance is the true peak or not (Fig. 6-7). If temperature were to be increased further, it is possible that performance would improve further or it is possible that performance would begin

to decline. Thus, future studies should focus on pushing species to higher temperatures to assess where they truly achieve optimal performance. Additionally, some curves were generated from only two or three points (Figs. 5A, 5E, 6D, 7). These curves therefore do not accurately represent a species' variation in performance across a range of temperatures and as such, future studies should focus on broadening the range of temperatures at which performance data is collected.

Lastly, for species with unclear trends, it is possible that these species are unlike other species and that their thermal performance curves do not take the expected shape, or it is possible that there were errors in data collection (Fig. 8-9). Perhaps expected body temperature did not accurately reflect observed body temperature so the data point was incorrectly assigned to a temperature, or perhaps data was otherwise recorded incorrectly during the experiment or during my digitization process. Regardless, future research should focus on collecting more data on species with unclear trends to determine if they are truly anomalies or if they do, in fact, create thermal performance curves that take the expected shape.

Ultimately, researchers can use the generated thermal performance curves as visualizations to see what studies may need replicated and what data may be corrected (Mulligan et al. 2022). Despite the lack of data presently available, they provide unique opportunities for future comparative analyses on frog jumping performance (Schwanz et al., 2021).

Latitudinal Variation in Peak Performance Temperatures

I found that for both jump take-off velocity and jump distance, the temperature at which peak jumping performance was achieved did not differ significantly between temperate and tropical species (Fig. 10-11). Though this addressed my hypothesis that temperate species would

reach peak performance at higher temperatures than tropical species, the results did not agree with my hypothesis for either jump performance variable.

Global surface temperature is expected to increase by 1.2-1.9°C by 2040, 1.2-3.0°C by 2060, and 1.0-5.7°C by 2100 (Allan et al., 2022). Frog species from tropical regions would be expected to be less tolerant of these changes than frog species from temperate regions due to less frequent exposure to temperature change (Deutsch et al., 2008). However, thermal tolerance does not necessarily equate to thermal performance (Moen et al., 2022), so based on my results which show that temperate and tropical species reach peak performance values at roughly the same temperature, it is possible that no frog species is equipped to better achieve peak jumping performance during future climate change on the basis of the latitudinal region that they occupy. Additionally, though frogs from temperate regions are expected to have performance abilities over a broader range of temperatures than tropical species (Navas et al., 2008), my results imply that with this broadening of temperature range, the peak of the thermal performance curve does not change. It is possible, however, that this assumption is biased due to lack of true peak data. For species in which performance never declined (Fig. 6-7), if the true peak performance value occurs at a higher temperature, this may cause the temperature at which peak performance is reached to differ significantly between temperate and tropical species. Thus, the need for future data collection at higher temperatures for these species is further justified.

It is also possible that the lack of significant differences in peak performance temperature between frog species is due to an overgeneralization of latitude categories. I based variation in performance solely on latitude, but previous studies have shown that jumping performance in frogs can vary based on microhabitat (Mendoza et al., 2020) and elevation in conjunction with latitude (Wilson, 2001). Additionally, some researchers choose to separate latitudinal categories

into temperate, subtropical, and tropical regions rather than just temperate and tropical (Wilson, 2001). Had I taken any of these factors into account, it is possible that there would have been greater variation in the temperatures at which peak performance was reached between species. However, those analyses would then be looking at more local scale observations, and I wanted to focus on large scale variation. By grouping species into their occupation of temperate versus tropical latitudes, I could better understand sensitivity to temperature variation shared by multiple species in a region regardless of smaller scale differences like elevation or microhabitat.

A major weakness in this study is that I did not account for body mass as a covariate of performance. Mendoza et al. found that jumping power decreased with an increase in body mass, suggesting that body mass could affect other parameters of jumping performance as well such as take-off velocity and distance (2020). In studying velocity, Mendoza et al. found a positive relationship between body mass and take-off velocity within species but found that it accounted for little of the variation between smaller and larger species (2020). However, they did not assess jump distance. I did not include body mass as a covariate due to lack of available data for all species. Thus, future research should focus on collecting more body mass data, analyzing it as a covariate to both take-off velocity and jump distance, and analyzing it as a covariate in comparative analyses on temperature at which peak performance is reached.

Phylogenetic generalized ANCOVAs showed no evolutionary correlation between latitude and the temperature at which peak performance was achieved for neither jump distance nor take-off velocity (Tables 2-3). Thus, it appears that phylogeny does not play a role in frog jumping performance at high temperatures. These results are not completely unexpected as it has been already been found that phylogeny does not affect jumping performance at low temperatures for 12 species of treefrogs that occupy regions between the Neotropics and

temperate North America (Moen et al., 2022). The fact that phylogeny does not influence frog jumping performance at high temperatures implies that improving jumping performance was not necessary for frogs to colonize temperate versus tropical latitudes (Moen et al., 2022). Phylogeny does, however, affect thermal tolerance of the 12 treefrog species studied by Moen et al. at low temperatures (2022). Specifically, as species evolved to occupy temperate regions, thermal tolerance to low temperatures increased (Moen et al., 2022). Thus, future research efforts should assess whether or not phylogeny also impacts thermal tolerance at high temperatures.

Acknowledgements

I thank Sheila Patek for her mentoring and feedback on this project and the jumping performance database. I also thank my classmates: Glory Agun, Sophie Hanson, Rebecca He, and Jonathan Pertile. I thank Robbie Wilson for his suggestion to use a graph digitizer to extract data from publications in which data was no longer accessible beyond the published literature. Lastly, I thank all of the professors and researchers who spoke to our class about database design, data digitization, and the overall research process.

Data Availability

The frog jumping performance database along with its metadata and the R code used for analyses and figure productions in this publication can be found on GitHub under user: hehess19 (<https://github.com/hehess19/frog-jumping-performance>).

Figures

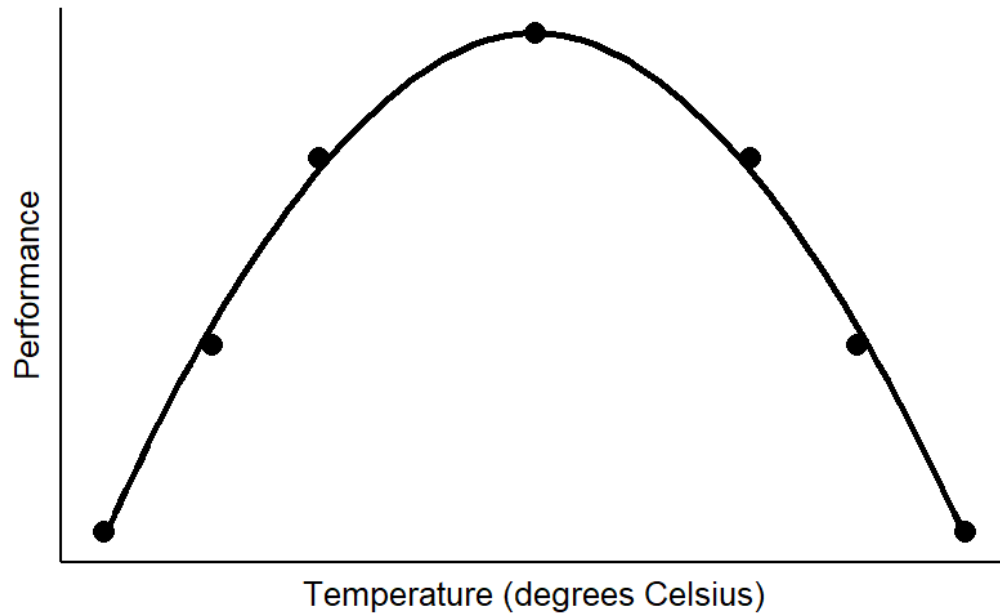


Figure 1. In a hypothetical thermal performance curve for any ectothermic frog species, performance improves with increasing temperature until reaching a peak, after which it decreases with increasing temperature.

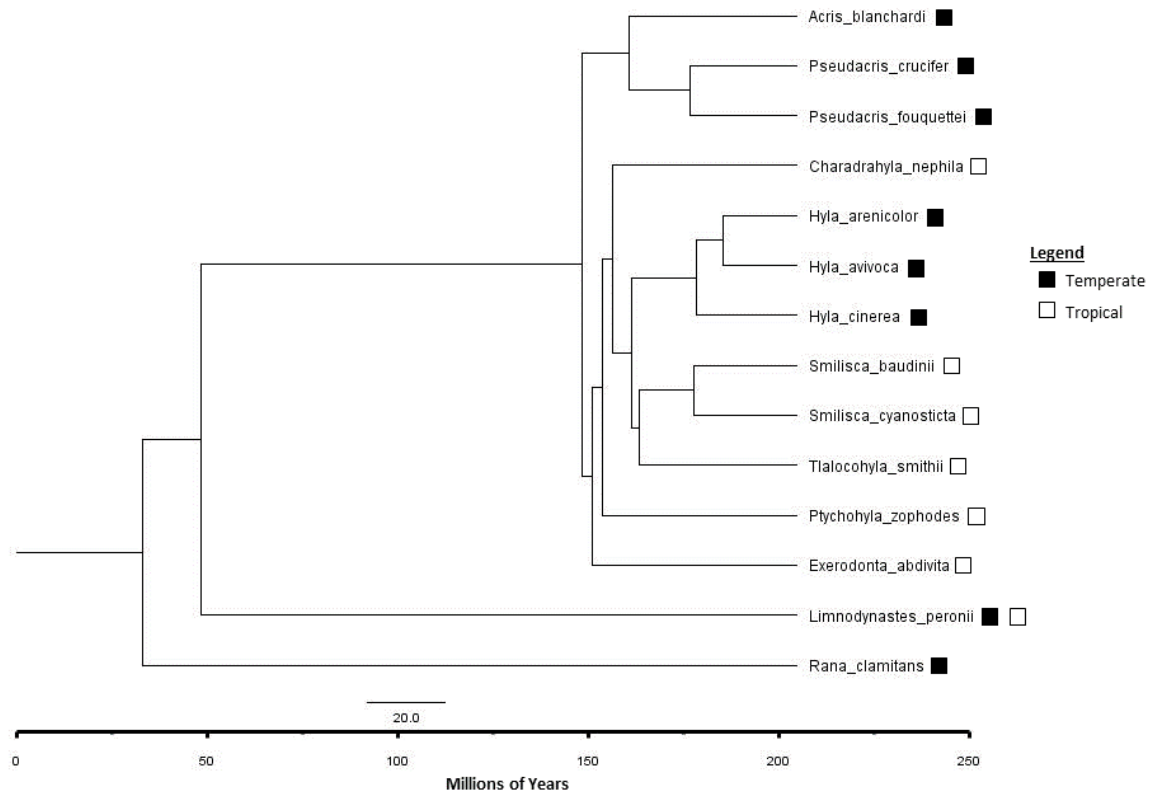


Figure 2. Phylogeny of frogs used in take-off velocity analyses. Taxa were pruned from Jetz and Pyron (2018). Symbols indicate the latitudinal region the study populations of each species were obtained from. There were some populations of *Limnodynastes peronii* obtained from both temperate and tropical regions.

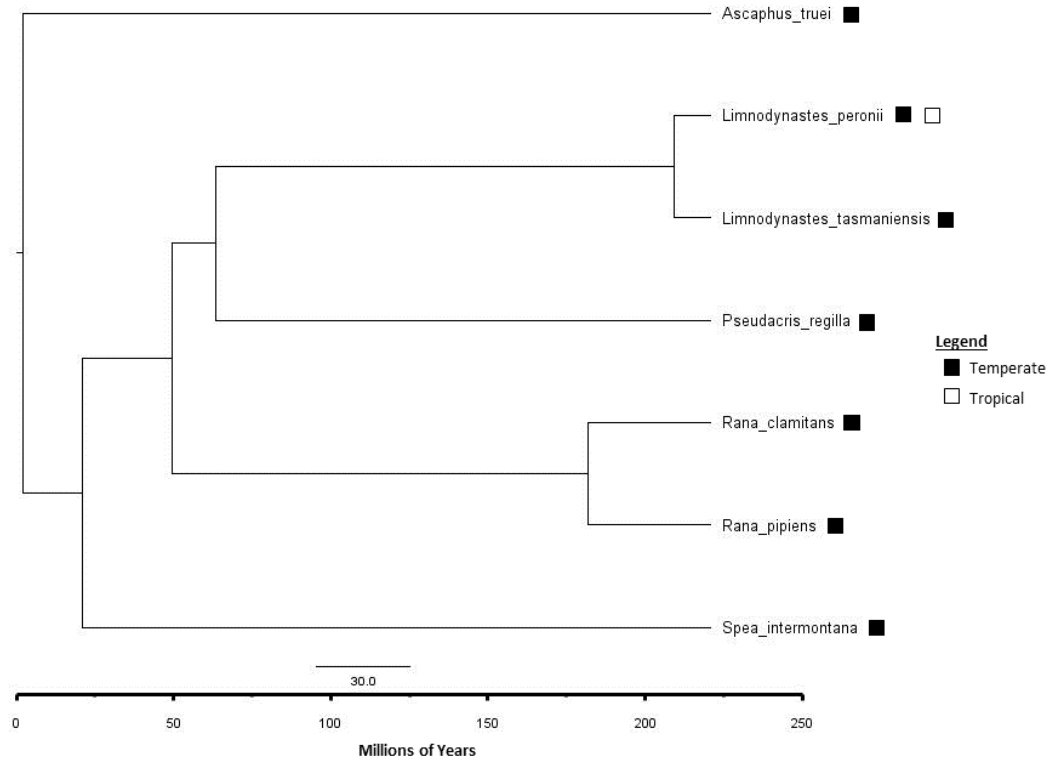


Figure 3. Phylogeny of frogs used in jump distance analyses. Taxa were pruned from Jetz and Pyron (2018). Symbols indicate the latitudinal region the study populations of each species were obtained from. There were some populations of *Limnodynastes peronni* obtained from both temperate and tropical regions.

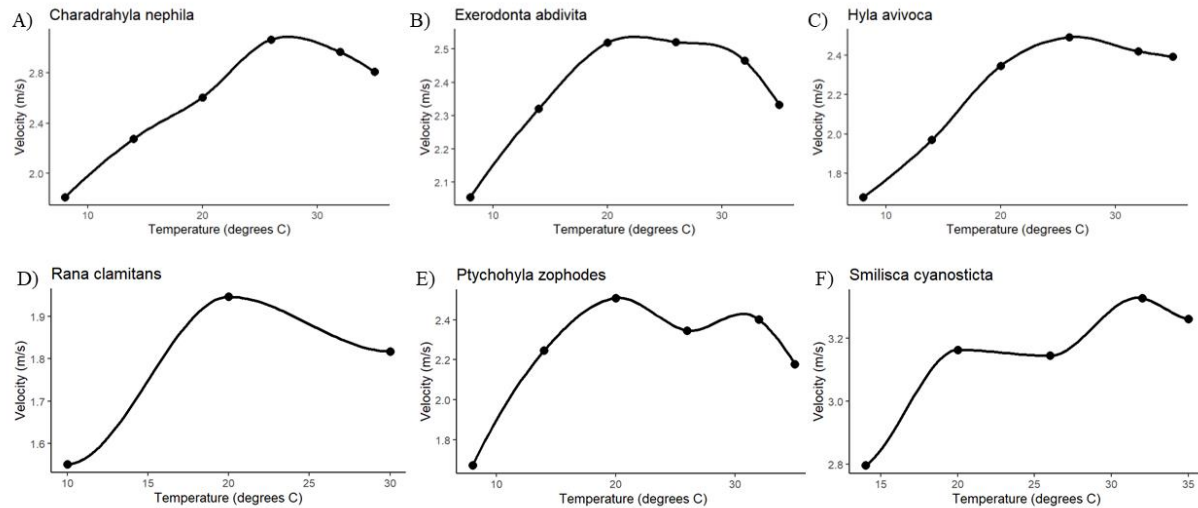


Figure 4. Thermal performance curves with jump take-off velocity (m/s) as the performance parameter showed the overall expected trend for 6 species, with velocity increasing with temperature to a point and subsequently decreasing. Velocity is plotted against expected body temperature (°C). A) Thermal performance curve for velocity for *Charadrahyla nephila*. B) Thermal performance curve for velocity for *Exerodonta abdivita*. C) Thermal performance curve for velocity for *Hyla avivoca*. D) Thermal performance curve for velocity for *Rana clamitans*. E) Thermal performance curve for velocity for *Ptychohyla zophodes*. F) Thermal performance curve for velocity for *Smilisca cyanosticta*.

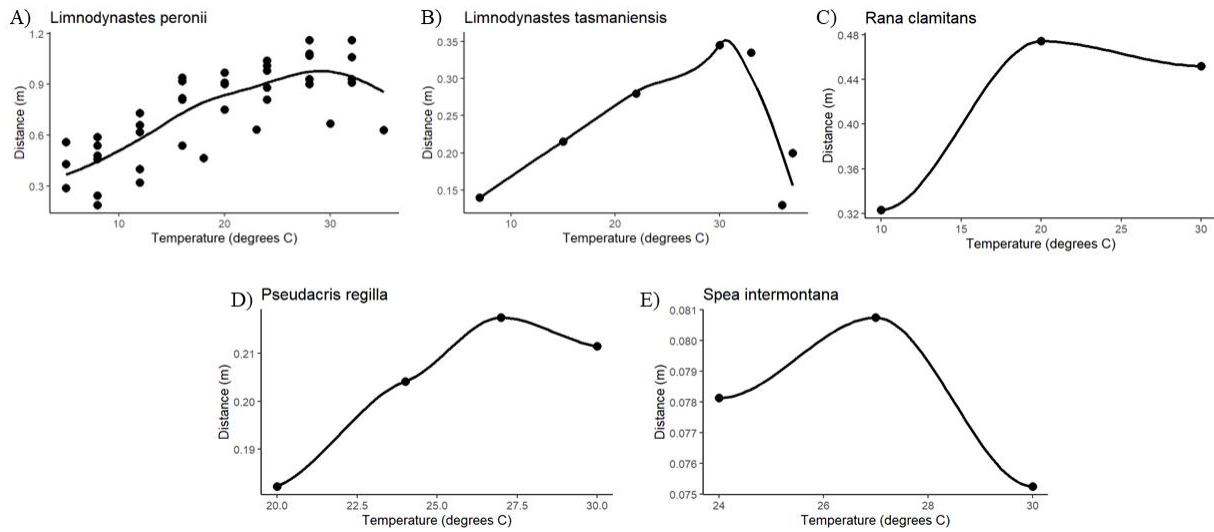


Figure 5. Thermal performance curves with jump distance (m) as the performance parameter showed the overall expected trend for 5 species, with the distance of one horizontal jump increasing with temperature to a point and subsequently decreasing. Jump distance is plotted against expected body temperature ($^{\circ}\text{C}$). A) Thermal performance curve for jump distance for 5 populations of *Limnodynastes peronii*. B) Thermal performance curve for jump distance for *Limnodynastes tasmaniensis*. C) Thermal performance curve for jump distance for *Rana clamitans*. D) Thermal performance curve for jump distance for *Pseudacris regilla*. E) Thermal performance curve for jump distance for *Spea intermontana*.

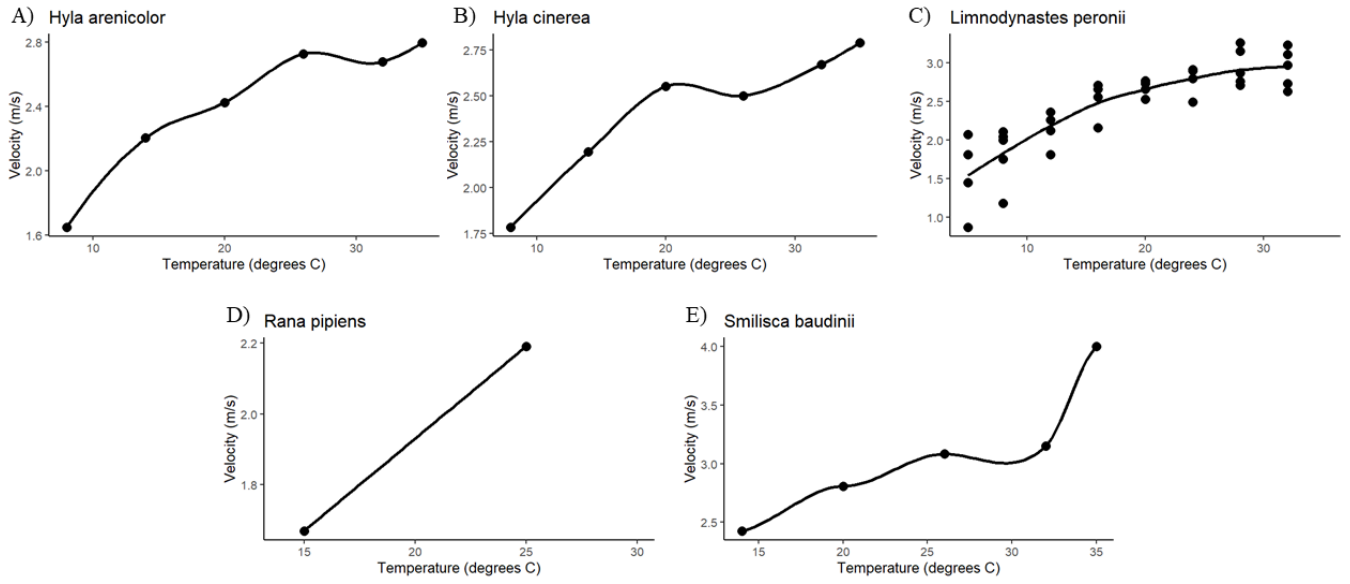


Figure 6. Thermal performance curves with jump take-off velocity (m/s) as the performance parameter showed the expected increase of velocity with temperature but did not show the expected decrease after a certain point for 5 species. Velocity is plotted against expected body temperature (°C). A) Thermal performance curve for velocity for *Hyla arenicolor*. B) Thermal performance curve for velocity for *Hyla cinerea*. C) Thermal performance curve for velocity for 5 populations of *Limnodynastes peronii*. D) Thermal performance curve for velocity for *Rana pipiens*. E) Thermal performance curve for velocity for *Smilisca baudinii*.

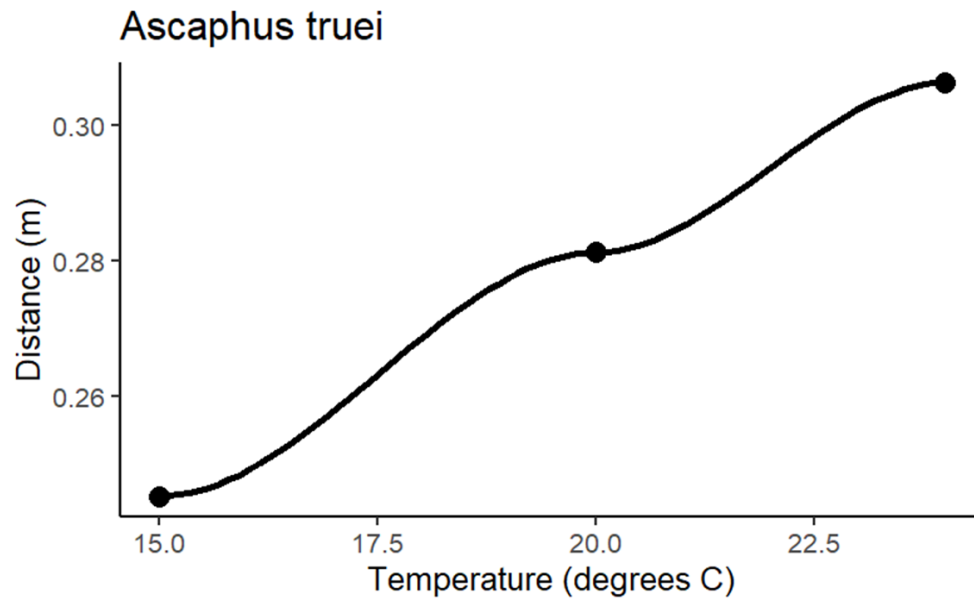


Figure 7. The thermal performance curve for *Ascaphus truei* with jump distance (m) as the performance parameter showed the expected increase of jump distance with temperature but did not show the expected decrease after a certain point. Jump distance is plotted against expected body temperature (°C).

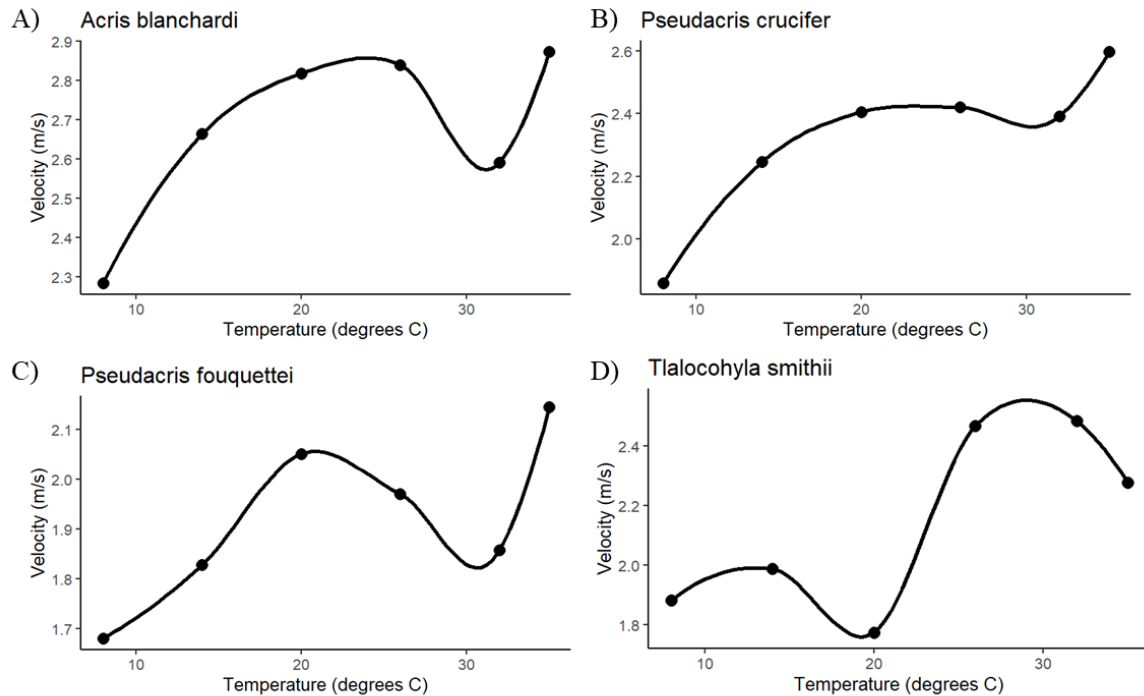


Figure 8. For 4 species, thermal performance curves with jump take-off velocity (m/s) as the performance parameter showed unclear trends, with both increases and decreases in velocity as temperature ($^{\circ}\text{C}$) increased. A) Thermal performance curve for velocity for *Acris blanchardi*. This curve followed the expected trend until about 32°C , where there was a sharp decrease in velocity before subsequently increasing again. B) Thermal performance curve for velocity for *Pseudacris crucifer*. This curve followed the expected trend until about 32°C , where there was a slight decrease in velocity before subsequently increasing again. C) Thermal performance curve for *Pseudacris fouquettei*. This curve followed the expected trend until about 35°C where there was a sharp increase in velocity after previous points had shown a decrease in velocity with increasing temperature. D) Thermal performance curve for velocity for *Tlalocohyla smithii*. This curve shows an increase, then decrease, then increase, then decrease in velocity as temperature increases.

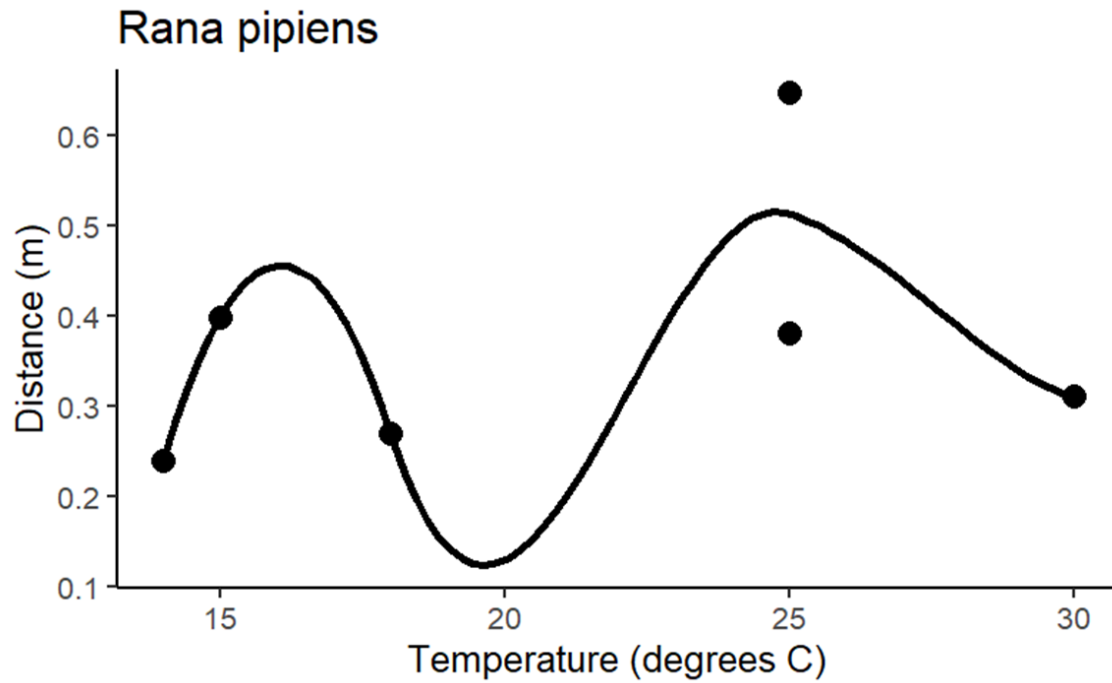


Figure 9. The thermal performance curve for *Rana pipiens* with jump distance (m) as the performance parameter showed an increase, then decrease, then increase, then decrease in jump distance as expected body temperature (°C) increased.

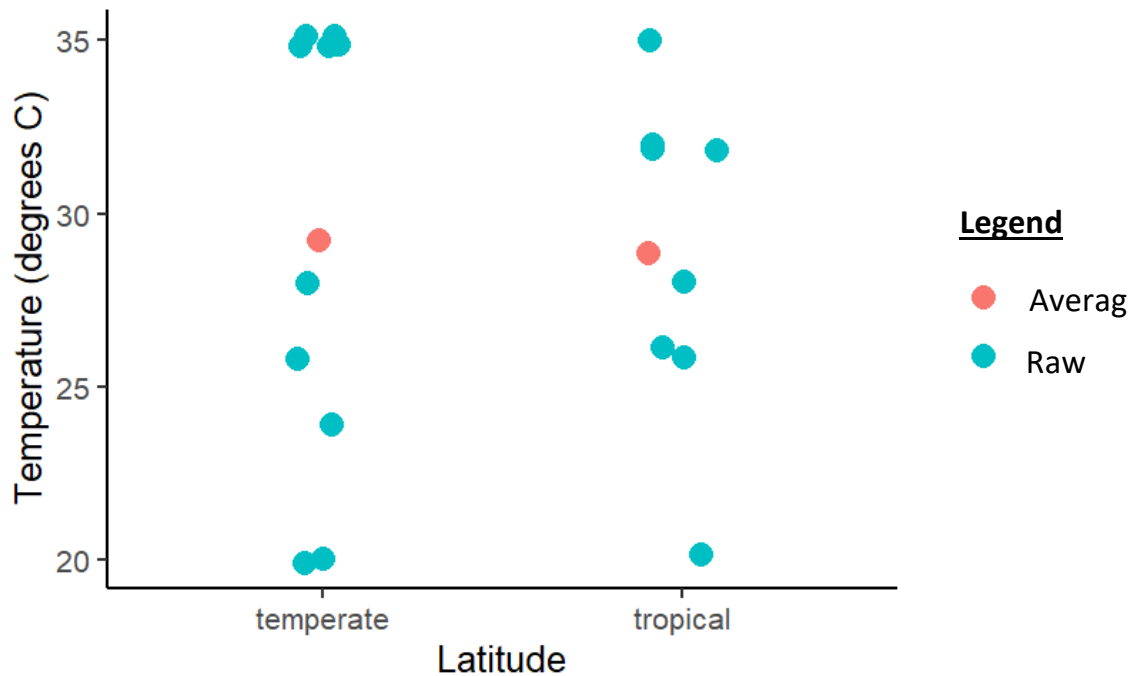


Figure 10. The one-way ANOVA for the 14 species with jump take-off velocity data revealed that there was no statistically significant difference between the average temperature at which peak jump take-off velocity was reached between temperate and tropical species ($F(1,16) = [0.024]$, $p = 0.879$). Raw data points are shown in blue. The mean temperatures at which peak velocity was reached are shown in red. Mean temperature for temperate species was 29.3°C and mean temperature for tropical species was 28.9°C. All points are jittered.

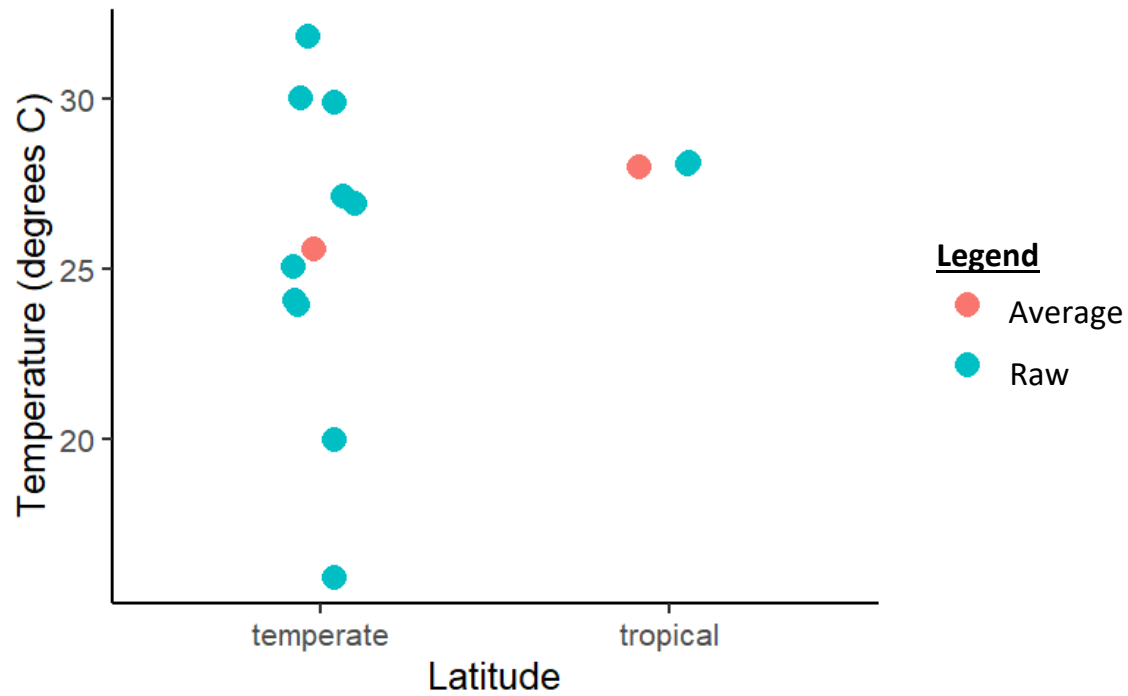


Figure 11. The one-way ANOVA for the 7 species with distance data revealed that there was no statistically significant difference between the average temperature at which peak jump distance was reached between temperate and tropical species ($F(1,10) = [0.49]$, $p = 0.5$). Raw data points are shown in blue. The mean temperatures at which peak distance was achieved are shown in red. Mean temperature for temperate species was 25.5°C and mean temperature for tropical species was 28°C. All points are jittered.

Species	Collection Location	Latitude	Data Type
<i>Acris blanchardi</i>	Stillwater, OK, USA	temperate	velocity
<i>Acris gryllus</i> *	Central Florida, USA	temperate	distance, velocity
<i>Ascaphus truei</i>	British Columbia, Canada	temperate	distance
<i>Charadrahyla nephila</i>	La Sierra Juarez, Oaxaca, Mexico	tropical	velocity
<i>Exerodonta abdivita</i>	La Sierra Juarez, Oaxaca, Mexico	tropical	velocity
<i>Hyla arenicolor</i>	Fort Davis, TX, USA	temperate	velocity
<i>Hyla avivoca</i>	Idabel, OK, USA	temperate	velocity
<i>Hyla cinerea</i>	Idabel, OK, USA	temperate	velocity
<i>Hyla squirella</i> *	Central Florida, USA	temperate	distance, velocity
<i>Limnodynastes peronii</i>	Prosperine, Queensland, Australia Eungella, Queensland, Australia Brisbane, Queensland, Australia Melbourne, Victoria, Australia Gippsland, Victoria, Australia	tropical tropical temperate temperate temperate	distance, velocity
<i>Limnodynastes tasmaniensis</i>	St. Peters, South Australia, Australia	temperate	distance
<i>Osteopilus septentrionalis</i> *	Southern Florida, USA	temperate	distance, velocity
<i>Pseudacris crucifer</i>	Farmington, AR, USA Fayetteville, AR, USA	temperate temperate	velocity
<i>Pseudacris fouqueti</i>	Farmington, AR, USA Paris, AR, USA	temperate temperate	velocity
<i>Pseudacris regilla</i>	British Columbia, Canada	temperate	distance
<i>Ptychohyla zophodes</i>	La Sierra Juarez, Oaxaca, Mexico	tropical	velocity
<i>Rana clamitans</i>	Westborough Wildlife Management Area, MA, USA	temperate	distance, velocity
<i>Rana pipiens</i>	Alburg, VT, USA	temperate	distance
<i>Smilisca baudinii</i>	La Sierra Sur, Oaxaca, Mexico	tropical	velocity
<i>Smilisca cyanosticta</i>	La Sierra Juarez, Oaxaca, Mexico	tropical	velocity
<i>Spea intermontana</i>	British Columbia, Canada	temperate	distance
<i>Tlalocohyla smithii</i>	La Sierra Sur, Oaxaca, Mexico	tropical	velocity

* Species excluded from analyses in this paper on the basis of only having data at 20°C

Table 1. Summary of collection location, latitudinal region, and performance data type for the 22 species included in the database. *Acris gryllus*, *Hyla squirella*, and *Osteopilus septentrionalis* data were excluded from analyses as performance was only assessed at one temperature (20°C) and an accurate assessment of peak performance temperature could not be determined.

	numDF	F-value	p-value
(Intercept)	1	26.03204	0.0003
Latitude	1	1.55675	0.2359

Table 2. Summary statistics from the phylogenetic generalized ANCOVA conducted on the 14 species with velocity data. Data from the two tropical *Limnodynastes peronii* populations were averaged and this new value was used as the only *Limnodynastes peronii* data for phylogenetic analysis.

	numDF	F-value	p-value
(Intercept)	1	109.2541	0.0001
Latitude	1	1.3383	0.29963

Table 3. Summary statistics from the phylogenetic generalized ANCOVA conducted on the 7 species with distance data. Data from the two tropical *Limnodynastes peronii* populations were averaged and this new value was used as the only *Limnodynastes peronii* data for phylogenetic analysis.

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