

## **Analyzing jumping spider responses to static visual predator objects**

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**Abstract:** Detection of a present predator is critical for prey survival, but prey cannot remain constantly vigilant without suffering fitness costs. To reduce the costs of vigilance, prey species use different cues to determine if another animal is a predator. We wished to determine whether or not *Pelegrina helenae* would respond to digital images of *Phidippus audax* as predators and whether the size of an image played a role in predator recognition response. *P. helenae* were placed in a plastic enclosure facing an iPhone X and shown an image of either *P. audax* or a ladybug and trials were recorded using a GoPro Hero 7. A second experiment was then performed where spiders were shown the same stimuli, but all ladybug stimuli had been increased to match the size of the *P. audax* stimuli. The presence of a *Phidippus audax* stimulus on screen significantly increased the vigilance duration of *Pelegrina helenae* which indicates that there is some specific visual predator cue that *P. helenae* is using to identify *P. audax* as a predator. Size on an image was not significant in the global model, but in the artificial size model, the vigilance duration between *P. audax* and the ladybug stimulus was not significantly different, indicating that size does play some role in predation risk, but not a large enough role to override specific predator cues.

## **Introduction:**

Predation is the primary driver of selection of traits in prey morphology, physiology, and behavior, as prey cannot survive unless they manage to successfully avoid and evade predators (Schmitz 2017, Johnson and Belk 2020). Accurate and rapid detection of a present predator is critical for prey survival, but prey cannot remain vigilant constantly without suffering fitness costs like loss of food, missed mating, decreased parental investment, etc., (Edwards 1983, Magnhagen 1991, Brown 1999, Périquet 2012). To reduce the costs of constant vigilance, prey use different specific cues, visual, chemical, or auditory, etc., to rapidly determine if another animal is a predator (Persons et al. 2001, Lee et al. 2021, Rößler et al. 2022).

Similar to prey, predators must balance maintenance of traits that decrease detection probability by prey and traits that increase hunting success (Ings and Chittka 2009, Menda et al. 2014). For example, a tiger's fur when viewed through the eyes of a chital deer blends into the environment, but langur monkeys, which are associated with chital deer, can see the tiger and alert the deer (Newton 1989). Tigers are reliant on an ambush hunting strategy, so they can only sprint after deer for a short amount of time, so if langur monkeys raise the alert too early, the tiger might end up missing a meal (Sunquist and Sunquist 1989). Jumping spiders are also an excellent example of this balance as they deploy a number of crypsis strategies, including ambush predation, while still retaining a large frontal eye formation which makes them excellent hunters (Jackson 1990, Jackson and Wilcox 1998, Bednarski et al. 2012). However, jumping spiders are both conspecific and heterospecific predators, and this eye formation, specifically their four frontal eyes which are composed of two large anterior median eyes and two posterior median eyes, has been identified as a trait that identifies them as a predator to prey jumping spiders (Rößler et al. 2022).

A myriad of traits, such as body size, number of eyes, eye position, leg position, etc., and the interactions between them may be used by prey to rapidly detect predator presence and therefore assess predation risk. Current methodological approaches, like the use of 3D printed models, may hamper the ability to efficiently test all of these unique combinations of traits, especially as these models are limited to only static predator traits and cannot test how these traits interact with movement (Röbner et al. 2022). A simple tool is required that allows for rapid manipulation and presentation of trait combinations in a variety of different contexts. Digital images and videos are one solution as advances in digital screen resolution and quality have allowed predator-prey recognition and cues to be tested by exposing an animal to digital images or videos of a known predator or prey and observing their reaction (Clark and Uetz 1990).

Using jumping spiders as a study species, we experimentally tested the ability of a common sagebrush-dwelling jumping spider, *Pelegrina helenae*, to detect and attend to digital images of their common jumping spider predator, *Phidippus audax*. The predation in jumping spiders allows predator detection cues to be tested by using larger jumping spiders as a predator species (Menda et al. 2014, Röbner et al. 2022). Given this general trend, we also tested if *Pelegrina helenae* exhibit antipredatory behaviors in response to any nearby, non-threatening object the same size as *Phidippus audax*.

## **Methods:**

### ***Study subjects***

*Pelegrina helenae* were collected from Wheatland Reservoir #3 near Rock River, Wyoming (41°53'16.0"N 105°43'42.2"W) and near Forest Service Road 703A by Laramie, Wyoming (41°15'40.7"N 105°26'20.2"W). Species identification was confirmed using microscopy. Spiders were collected from shrubs using a 20 x 30 inch white cotton pillowcase as a beat sheet. The sampled shrubs consisted of Big Sagebrush (*Artemisia tridentata*) almost exclusively due to them being the most abundant shrub in both locations. In the lab, spiders were kept at 19°C - 22.4°C and fed curled-wing fruit flies, and watered weekly.

### ***Experimental design***

An iPhone X was chosen to display stimuli as it has a high enough resolution, refresh rate, and color quality to allow *P. helenae* to recognize stimuli as real objects. For objects in motion, flicker fusion frequency of the study subject needs to be considered (Miall 1978, Clark and Uetz 1990). Jumping spiders have an estimated flicker fusion frequency of 40 hertz (Clark and Uetz 1990). To avoid animals perceiving flickering in an image, the refresh rate of the screen the stimulus is displayed on needs to be above the animal's flicker fusion frequency. The refresh rate of the iPhone X is 60hz, which is above the critical flicker fusion frequency of *P. helenae*.

For the natural-size experiment, *P. helenae* were shown a randomly assigned image of a life-size *Phidippus audax* or a life-size ladybug (*Coccinella* spp.) and the placement of these images on either the left or right of the iPhone screen was also randomized to prevent spiders from becoming habituated to an image's location. Images of both *P. audax* and the ladybugs were mostly sourced from Flickr and all images had a Creative Commons Attribution-ShareAlike 2.0

Generic license (Appendix 1). The background of each image was removed using GIMP 2.0 (The GIMP Development Team 2019) until only the stimulus object was left. The life-size scale of an image was determined by the average carapace width of each species, which was 5.5 mm for *P. audax* and 6 mm for the ladybug (Edwards 2004). *P. audax* and ladybugs were picked as predator and non-predator objects due to their widespread distribution at the study site leading to a higher likelihood that *P. helena*e would have encountered both in the wild, decreasing the chance that either species would be perceived as novel objects.

For the artificial-size experiment, spiders were shown a randomly assigned *P. audax* or ladybug with a new replacement from the stimulus pool each trial. This process was the exact same as the natural-size experiment, however, the ladybug image size was increased to match *P. audax* by calculating the pixel equivalency of the *P. audax* image. To achieve pixel equivalency, we manually extracted the *Phidippus* or ladybug shape (body and legs) from the original image, calculated the number of non-background pixels in the resulting image, and then scaled up the ladybug image to match the pixel number of the *Phidippus* in its paired trial.

*P. helena*e were placed in a plastic enclosure for each experiment facing an iPhone X. The enclosure was 8.5 inches x 4.75 inches x 4.75 inches. The enclosure was open at the top and the front panel was removed to reduce glare when the iPhone X was placed in front of it. The enclosure was covered in paper to prevent spiders from seeing out and identifying different landmarks that they could then associate with risk or become distracted by.

Eighteen spiders were included in the natural-size experiment. A spider shown *P. audax* in the first trial was shown a ladybug in the second trial and vice versa. Sixteen spiders participated in the artificial size experiment. A GoPro Hero 7 was placed nine inches above the enclosure and oriented 90 degrees down to record the reactions of *P. helena*e. Videos were recorded at 1080p and 60 fps.

Prior to the start of the experiments, spiders were moved into 1-inch x 1-inch plastic containers and placed on a counter near the enclosure for thirty minutes. At the start of the experiment, *P. helena*e were lowered to the ground of the enclosure inside their plastic container and coaxed out using a paintbrush. For both experiments, time began once the spider was placed inside the enclosure and my hand was out of frame. The stimulus was triggered five seconds after the spider was placed in the enclosure (Figure 1). If the spider attempted to climb the walls of the container, it was coaxed back into the enclosure with a paintbrush a maximum of two times per trial. This interruption time was removed from the total trial time.



Figure 1. An example of a stimulus slide from the natural and artificial size experiment. Stimulus audax004 is shown on the right. The red rectangle on the left is representative of where another stimulus object, either ladybug or *Phidippus*, would be shown (depending on the pre-selection random order of the trials). Only a single stimulus—either *Phidippus* or ladybug— was presented during a single trial.

### ***Quantifying vigilance***

Variation in vigilance duration was chosen as our primary metric of behavioral response of *P. helenae* to each stimulus. A vigilance bout was defined as an individual *P. helenae* being physically oriented towards an object with its eyes positioned in a manner where it was looking at the stimulus. Within each trial, time stamps were taken for the beginning and ending points for every instance in a video where the focal *P. helenae* was oriented toward the stimulus.

Individual vigilance bout duration was considered to capture the variation in *P. helenae* behavioral responses to stimulus objects. When spiders are presented with a predator many exhibit a freeze, retreat, or freeze and retreat response (Rößler et al. 2022). The personality of a spider can influence which response they exhibit. A summed vigilance duration would eliminate this variation from the data and could potentially result in the same vigilance duration for a spider that froze for a long period while another alternated between looking and escaping. The first scenario where a spider stays frozen shows recognition of a predator object, while the second scenario could be the result of constant vigilance or random behavior. Therefore...

### ***Statistical analysis***

To preserve variation in the data, each instance of vigilance was considered its own observation. Trials were not independent and spiders were used as subjects across trials and treatments. Individual was included as a random effect in our model to account for any

personalities that may have been present and for the multiple vigilance bouts recorded per trial. Data was analyzed using a generalized linear mixed model using the package glmmTMB (Brooks et al. 2017) in R (version 4.2.1) with a Poisson error structure and trial number nested within individual identity as a nested random effect. The final model used for primary inference retained predator treatment (ladybug versus *Phidippus*), experiment identity (natural versus artificial), and the interaction between predator treatment and experiment identity (to explicitly test if predators were perceived differently when they were paired with a natural versus artificially-sized non-predator. We also conducted a post-hoc analysis on the artificial size data whose model used for primary inference retained predator treatment (ladybug versus *Phidippus*) and experiment identity (artificial) to test if just the size of an image impacted vigilance of *P. helenae*.

### Results:

In the natural size experiment, the average vigilance duration for *P. audax* was 15.20 seconds (95% CI = 8.58 ± 26.92 s). The average vigilance bout for the ladybug stimulus was 6.70 seconds (95% CI = 3.77 ± 11.92 s). The presence of a *P. audax* stimulus onscreen elicited a significantly higher vigilance compared to the ladybug stimulus ( $\beta = 0.819$ ,  $p = 0.018$ ), (Table 1), (Figure 2).

The increased size of the ladybug stimulus was not significant when considered within the global model. When only the data from the artificial size trial was considered, *P. audax* stimulus was not significant ( $p = 0.496$ ), (Figure 3). When considered alone, in the artificial size experiment, the average vigilance bout of *P. audax* was 11.76 seconds (95% CI = 6.42 ± 21.57). The average vigilance bout for the sized-up ladybug was 9.01 seconds (95% CI = 4.93 ± 16.46).

Table 1. The results of the global GLMM model. The *P. audax* significantly altered vigilance bout duration in *P. helenae* ( $p = 0.018$ ). The presence of the ladybug stimulus did not significantly alter vigilance bout duration in *P. helenae* ( $p = 0.413$ ).

model term	$\beta$	SE	z	p
(intercept)	1.902	0.29 4	6.470	<0.000 1
<b>treatment (predator)</b>	<b>0.819</b>	<b>0.34</b> <b>5</b>	<b>2.371</b>	<b>0.018</b>
experiment (equal size)	0.297	0.36 2	0.819	0.413
treatment (predator) x expt. (equal size)	-0.55 3	0.50 3	-1.09 8	0.272

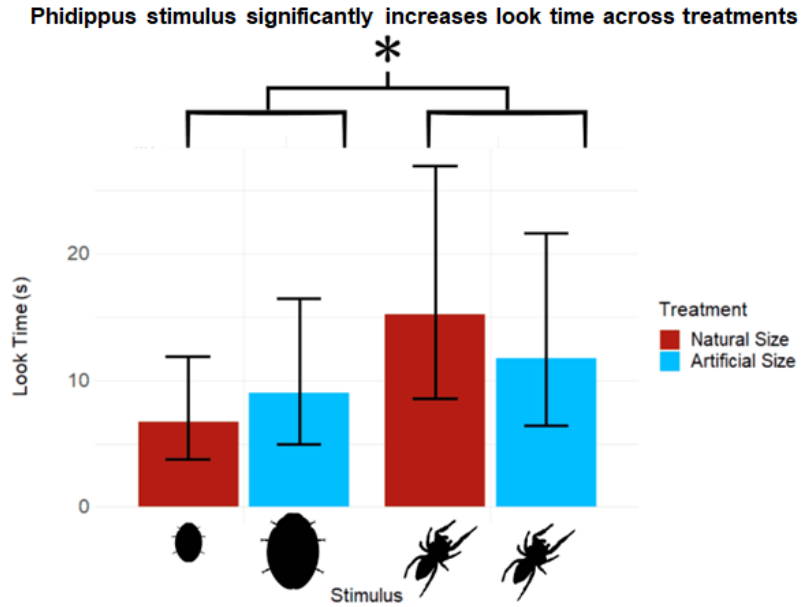


Figure 2. When all variables were considered together, presences of the *P. audax* stimulus was the only significant factor driving *P. helenae* look time ( $p = 0.0177$ ). Images of ladybugs, either natural or artificial size, did not significantly impact look time of *P. helenae*. Error bars are standard errors of 95% confidence intervals.

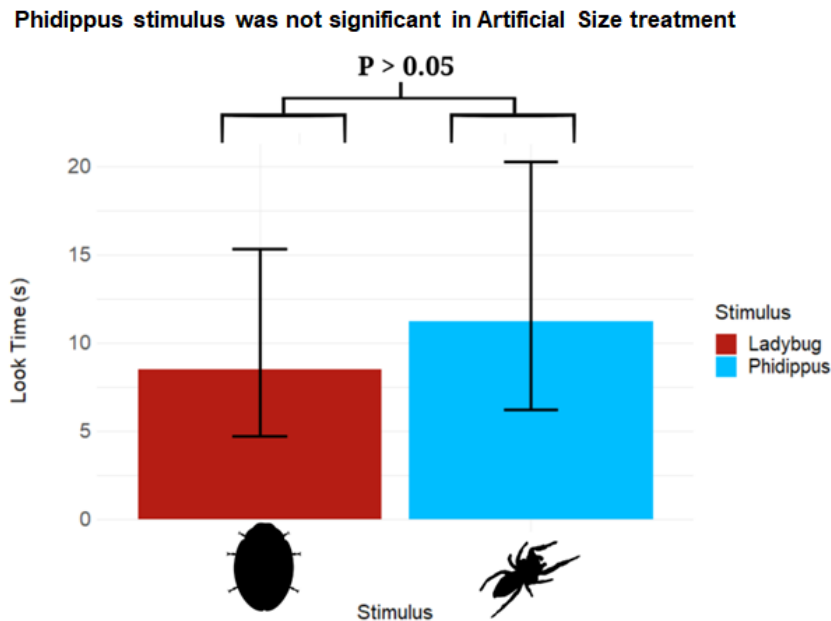


Figure 3. The artificial size trial data ( $n = 16$ ) was modeled separately from the global model. Artificially increased size ladybugs had higher look times than natural-sized ladybugs. This increase in look-time was enough to render *P. audax* not significant ( $p > 0.05$ ). Error bars are standard errors of 95% confidence intervals.

## Discussion:

The presence of a *Phidippus audax* stimulus on screen significantly increased the vigilance duration of *Pelegrina helenae*, which indicates that there is some specific visual predator cue that *P. helenae* is using to identify *P. audax* as a predator. In the global model, size of an image did not significantly impact vigilance duration. When the artificial-size experiment data was considered on its own, there was no significant difference between the vigilance of *P. helenae* pm the *P. audax* stimulus and the ladybug stimulus.

*Pelegrina helenae* were able to identify digital images of *P. audax* as predators. This indicates that digital images and videos are an effective method to test predator detection in prey species and further research can be conducted to determine which specific traits are triggering the recognition response in *P. helenae*. Current methods that test prey responses to static predator objects are often cost-prohibitive and inaccessible due to their use of 3D modeling technology (Röbner et al. 2022). It is possible to use our methodology to test which specific visual cues are triggering this response by modifying images to focus on specific traits such as eye formation, coloration, size, etc. Photo manipulation software is widespread and good quality programs are available for free or low cost, so this method could be easily replicable with other jumping spider species or insects in general.

The exact traits that *P. helenae* are using to identify *P. audax* as predators were not tested in this study. Previous studies have indicated that the eye formation of jumping spiders is a significant cue (Röbner et al. 2022). One possible avenue of experimentation would be presenting just the faces of spiders, or shapes with the jumping spider eye formation on them, and seeing if *P. helenae* respond to those objects as predators.

Other studies have identified movement of an image as the primary factor in predicting jumping spider responses (Bednarski et al. 2012, Bartos and Minias 2016). All stimulus objects in those studies have been prey objects (i.e. crickets). *P. helenae*'s significant response to static predator objects indicates that movement might not be necessary for the identification of predator objects. Future experiments can present both static and in-motion predator objects to *P. helenae* to determine what impact motion has on *P. helenae*'s recognition of predator objects. Flicker fusion frequency of the study species and refresh rate of the display device does continue to need to be accounted for (Miall 1978, Clark and Uetz 1990).

When considered alone, the vigilance duration of *P. helenae* towards *P. audax* and the ladybug stimulus was not significantly different in the artificial size trial, so we can infer that size plays some role in predation risk. However, given that this is a post-hoc analysis further experimentation needs to be done to confirm the true effect of this result. Decreasing the size of the *P. audax* stimulus would be one way to test the role of size in predator recognition and predation risk. By analyzing the impact of size on its own, it's possible that the impact of size on predator detection might be exaggerated as the size of the stimulus was not significant in the global model. While it does play some role, the exact specifics and size threshold that triggers the response is not known at this time. Size is not the single deciding, or primary, factor to *P. helenae* of what is a predator.



In natural settings, prey species, like *P. helenae*, receive and have to sift through large amounts of information to identify both prey and predators. Traits like body size, coloration, and eye formation can all play a role in what is perceived as a predator. By using lab experimentation, we are able to tease out specific traits that *P. helenae* is using to identify predators. Accurate predator detection and recognition is important to prey survival and *Pelegrina helenae* treat digital images of *Phidippus audax* as real predator objects. This indicates that there are strong visual cues that *P. helenae* are selecting for to identify *P. audax* as a predator. This experiment did not consider either auditory or chemical cues in conjunction with visual. The exclusion of auditory, chemical, movement, and other cues in lab experimentation does remove some of the nuance of *P. helenae*'s predator recognition, so more experimentation focusing on the interaction of traits is necessary to truly identify what traits are most important for predator recognition.

### **Acknowledgments**

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## Appendix 1

List of Stimulus Images and Sources. All images were sourced from Flickr and have a Creative Commons Attribution-ShareAlike 2.0 Generic license.

image_id	URL
audax001	<a href="https://flickr.com/photos/brian_tomlinson/49608332178">https://flickr.com/photos/brian_tomlinson/49608332178</a>
audax003	<a href="https://flickr.com/photos/usfws_southwest/32651149615">https://flickr.com/photos/usfws_southwest/32651149615</a>
audax004	<a href="https://flickr.com/photos/briangratwicke/17359930735">https://flickr.com/photos/briangratwicke/17359930735</a>
audax006	<a href="https://www.flickr.com/photos/49580580@N02">https://www.flickr.com/photos/49580580@N02</a>
audax007	<a href="https://www.flickr.com/photos/49580580@N02">https://www.flickr.com/photos/49580580@N02</a>
audax008	<a href="https://www.flickr.com/photos/sankax/4610001371">https://www.flickr.com/photos/sankax/4610001371</a>
audax009	<a href="https://flickr.com/photos/30314434@N06">https://flickr.com/photos/30314434@N06</a>
audax010	<a href="https://www.flickr.com/photos/doundounba/17446641016">https://www.flickr.com/photos/doundounba/17446641016</a>
audax011	<a href="https://www.flickr.com/photos/tnagy/26676264186">https://www.flickr.com/photos/tnagy/26676264186</a>
ladybug001	<a href="https://www.flickr.com/photos/sanmartin/4725416450">https://www.flickr.com/photos/sanmartin/4725416450</a>
ladybug002	<a href="https://flickr.com/photos/patrick_k59/49041959273">https://flickr.com/photos/patrick_k59/49041959273</a>
ladybug003	<a href="https://flickr.com/photos/conall/16871756929">https://flickr.com/photos/conall/16871756929</a>
ladybug004	<a href="https://flickr.com/photos/orangeaurochs/16867414680">https://flickr.com/photos/orangeaurochs/16867414680</a>
ladybug005	<a href="https://flickr.com/photos/dm-set/3481674978">https://flickr.com/photos/dm-set/3481674978</a>
ladybug006	<a href="https://flickr.com/photos/daubiwan/14122675452">https://flickr.com/photos/daubiwan/14122675452</a>
ladybug007	<a href="https://flickr.com/photos/daubiwan/14122343332">https://flickr.com/photos/daubiwan/14122343332</a>
ladybug008	<a href="https://flickr.com/photos/stanzebla/19585722105">https://flickr.com/photos/stanzebla/19585722105</a>
ladybug009	<a href="https://pixnio.com/fauna-animals/insects-and-bugs/ladybug-insects-pictures/nature-wildlife-beetle-ladybug-insect-summer-arthropod-bug">https://pixnio.com/fauna-animals/insects-and-bugs/ladybug-insects-pictures/nature-wildlife-beetle-ladybug-insect-summer-arthropod-bug</a>
ladybug010	<a href="https://commons.wikimedia.org/wiki/File:Coccinella_septempunctata.png">https://commons.wikimedia.org/wiki/File:Coccinella_septempunctata.png</a>
ladybug011	<a href="https://pxhere.com/en/photo/1010495">https://pxhere.com/en/photo/1010495</a>

## Appendix 2

Example images of a *Phidippus audax* (audax001) and a ladybug (ladybug008) unedited. Photo credits in links in Appendix 1.



audax001 and ladybug008 thresholded stimulus objects from the natural size trial

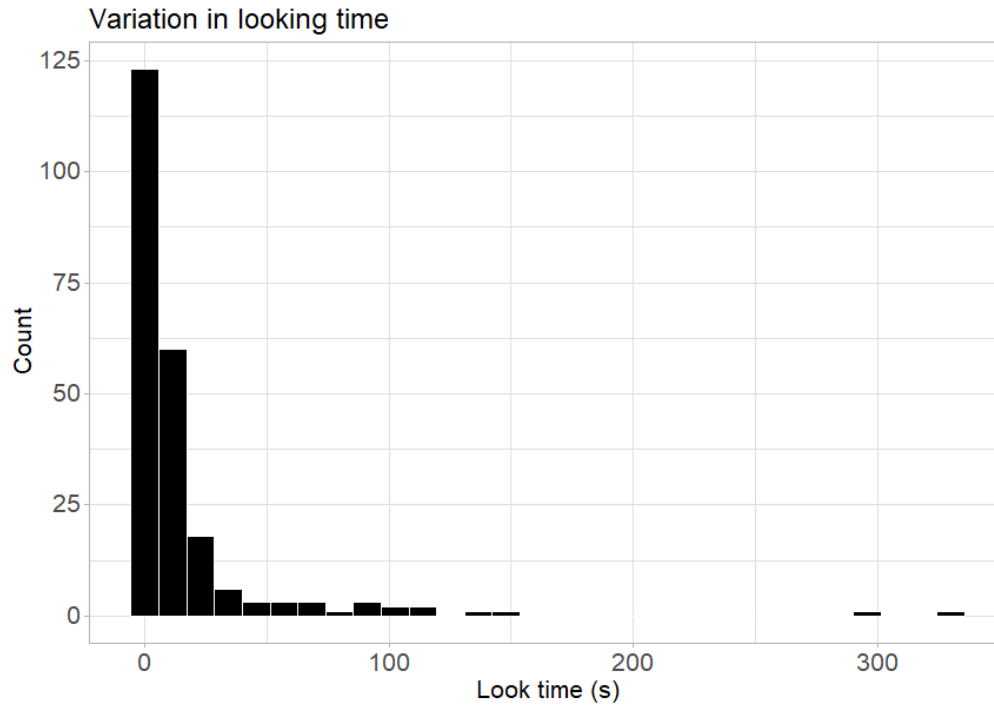


Ladybug008 from the artificial size trial



### Appendix 3

The summed observation time of the majority of *Pelegrina helenae* vigilance duration was 10 seconds. The 290 and 350-second summations were the result of two separate *P. helenae* orienting towards the *P. audax* stimulus and remaining oriented for the rest of the trial.



## References

- Bartos, M. 2022. Visual prey categorization by a generalist jumping spider. *The European Zoological Journal* 89:1312–1324.
- Bartos, M., and P. Minias. 2016. Visual cues used in directing predatory strikes by the jumping spider *Yllenus arenarius* (Araneae, Salticidae). *Animal Behaviour* 120:51–59.
- Bednarski, J. V., P. Taylor, and E. M. Jakob. 2012. Optical cues used in predation by jumping spiders, *Phidippus audax* (Araneae, Salticidae). *Animal Behaviour* 84:1221–1227.
- Brooks M.E., Kristensen, K., van Benthem, K.J., Magnusson, A., Berg, C.W., Nielsen, A., Skaug, H.J., Maechler, M., Bolker, B.M. 2017. glmmTMB Balances Speed and Flexibility Among Packages for Zero-inflated Generalized Linear Mixed Modeling. *The R Journal*, 9:2: 378-400.
- Brown, J.S. 1999. Vigilance, patch use and habitat selection: Foraging under predation risk. *Evolutionary Ecology Research* 1:49-71.
- Clark, D. L., and G. W. Uetz. 1990. Video image recognition by the jumping spider, *Maevia inclemens* (Araneae: Salticidae). *Animal Behaviour* 40:884–890.
- Edwards, G. B. 1990. Anecdotal field notes on the Florida *Phidippus* (Araneae: Salticidae), with notes on Territoriality in *P. regius*. *Peckhamia* 2:96–100.
- Edwards, G.B. 2004. Revision of the jumping spiders of the genus *Phidippus* (Araneae: Salticidae). *Occasional Papers of the Florida State Collection of Arthropods* 11:1-168.
- Edwards, J. 1983. Diet Shifts in Moose Due to Predator Avoidance. *Oecologia* 60:2:185-189.
- Horner, N. V., F. B. Stangl, and G. K. Fuller. 1988. Natural History Observations of *Salticus austinensis* (Araneae, Salticidae) in North-Central Texas. *The Journal of Arachnology* 16:260–262.
- Ings, T. C., and L. Chittka. 2009. Predator crypsis enhances behaviourally mediated indirect effects on plants by altering bumblebee foraging preferences. *Proceedings of the Royal Society B: Biological Sciences* 276:2031–2036.
- Jackson, R. R. 1990. Ambush predatory behaviour of *Phaeacius malayensis* and *Phaeacius* sp. indet., spartaeine jumping spiders (Araneae: Salticidae) from tropical Asia. *New Zealand Journal of Zoology* 17:491–498.
- Jackson, R. R., and R. S. Wilcox. 1998. Spider-Eating Spiders: Despite the small size of their brain, jumping spiders in the genus *Portia* outwit other spiders with hunting techniques that include trial and error. *American Scientist* 86:350–357.
- Johnson, J. B., and M. C. Belk. 2020. Predators as Agents of Selection and Diversification. *Diversity* 12:415.
- Lee, Z. A., A. K. Baranowski, and E. L. Preisser. 2021. Auditory predator cues affect monarch

(*Danaus plexippus*; Lepidoptera: Nymphalidae) development time and pupal weight. *Acta Oecologica* 111:103740.

- Magnhagen, C. 1991. Predation risk as a cost of reproduction. *Trends in Ecology and Evolution* 6:6:183-186.
- Menda, G., P. S. Shamble, E. I. Nitzany, J. R. Golden, and R. R. Hoy. 2014. Visual Perception in the Brain of a Jumping Spider. *Current Biology* 24:2580–2585.
- Miall, R. C. 1978. The flicker fusion frequencies of six laboratory insects, and the response of the compound eye to mains fluorescent 'ripple.' *Physiological Entomology* 3:99–106.
- Newton, P. N. 1989. Associations between Langur Monkeys (*Presbytis entellus*) and Chital Deer (*Axis axis*): Chance Encounters or a Mutualism? *Ethology* 83:89–120.
- Périquet, S., Todd-Jones, L., Valeix, M., Stapelkamp, B., Elliot, N., Wijers, M., Pays, O., Fortin, D., Madzikanda, H., Fritz, H., Macdonald, D. W., Loveridge, A. J. 2012 Influence of immediate predation risk by lions on the vigilance of prey of different body size. *Behavioral Ecology* 23:5:970-976.
- Persons, M. H., S. E. Walker, A. L. Rypstra, and S. D. Marshall. 2001. Wolf spider predator avoidance tactics and survival in the presence of diet-associated predator cues (Araneae: Lycosidae). *Animal Behaviour* 61:43–51.
- Rößler, D. C., M. De Agrò, K. Kim, and P. S. Shamble. 2022. Static visual predator recognition in jumping spiders. *Functional Ecology* 36:561–571.
- Schmitz, O. 2017. Predator and prey functional traits: understanding the adaptive machinery driving predator–prey interactions. *F1000Research* 6:1767.
- Sunquist, M. E., and F. C. Sunquist. 1989. Ecological Constraints on Predation by Large Felids. Pages 283–301 in J. L. Gittleman, editor. *Carnivore Behavior, Ecology, and Evolution*. Springer US, Boston, MA. <[https://doi.org/10.1007/978-1-4757-4716-4\\_11](https://doi.org/10.1007/978-1-4757-4716-4_11)>. Accessed 8 May 2023.
- The GIMP Development Team, 2019. GIMP, Available at: <https://www.gimp.org>.