WONDERS IN "JUMPING SPIDERS' EYES"

- An investigation on Jumping spiders' ability to memorize colours

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Content

Abstract

The investigation focuses on jumping spider's (Salticids) memory on red and blue color respectively. A T-shaped maze was made as the experimental setup, with colored rays (red and blue) projected on two arms of the maze respectively. Red and blue light rays were provided by shining a bench lamp on red and blue cellophanes. The experiment comprises of 2 parts—the training sessions and the trial sessions.

The aim of the training sessions was to let the jumping spiders acclimatize with or even memorize the colored environment with the lure of a prey. *Thiania bhamoensis*, which were collected during field trips, were used as representation of jumping spiders in the experiment. The spiders were grouped and trained under a specific color of light.

In the trial sessions, jumping spiders were put in a T-shaped maze with either red or blue light shone to the two terminals. The reactions of the spiders were observed – the staying of over 1 minute by the spider under a specific colored zone was considered the choice of color made by the spider. The result from the trials was that spiders trained under blue light with prey have a higher average % of staying in blue-colored zone compared to the spiders received no training (control setup). This reveals jumping spiders' ability to memorize blue light ray and hence showing a greater preference to wards blue-coloured zone.

To conclude, Jumping spiders have the ability to differentiate between red and blue colors, and have a stronger ability in memorizing the color blue. Among the whole spider family, jumping spiders' huge, forward facing eyes have always been a distinguishing feature. Apart from having

an extraordinarily clear vision, jumping spiders' intelligence has also been demonstrated in their ability to differentiate between and memorize colors, as shown in this investigation. However, they may not have the ability to memorize and discriminate all colors, and their ability may only be limited to a few colors. Nevertheless, jumping spiders are believed to be the only member of the spider world capable of memorizing different colors, and through this experiment, we hope to explore their extraordinary eyesight for ourselves.

Introduction

A. Objective

To investigate on jumping spiders (Salticids)' ability to memorize the color
(a) Whether jumping spiders exhibit the ability to differentiate between red and blue color
(b) Whether jumping spiders possess a stronger ability to memorize the color red or blue

B. Reason of the investigation

During the 1950s-80s, jumping spiders, generally known as 跳蛛, 金絲貓 or 蠅虎,were common pets of children in Hong Kong. Watching jumping spiders (which were fairly aggressive animals) fight and keeping the miniature jumping spiders inside a matchbox were some of their favorite pastimes. But as time went on, jumping spiders became less well-known by the people due to rapid urban development in Hong Kong and technological progresses. Children nowadays are provided with various kinds of entertainment that are considered "safer", "cleaner" and more "educational" than keeping bugs at home. And as of now, the jumping spiders have already become a past collective memory of HK. Therefore being the post-90s, we would like to reveal the "past glory" of jumping spiders and witness their charisma personally.

Actually, among over 40000 spider species, jumping spiders show many unique characteristics such as well-developed vision, excellent jumping skills and innate ability to fight fiercely. Compared to most spiders, which have poor eyesight, jumping spiders, a kind of hunting spider, have excellent vision with among the highest acuities in invertebrates and hunt by sight (Glenn, 2004). Few species of spiders have such good eyesight—they rely instead on touch, vibration and taste stimuli to navigate and find their prey. Also, most spiders are not sensitive light-dark intensity changes that stimulate nocturnal web building, hunting or wandering activities. However, for jumping spiders, good vision is vital for hunting and capturing prey and for recognizing mates and rivals. They do not spin webs for capturing food like most spiders do, but rely on excellent eyesight and the ability to run and jump quickly to capture prey. Their huge, forward-facing eyes allow them to see things quite well from as much as a foot away, and they have even been observed to leap off an edge to try to capture an insect that was flying past them or that was resting on some other surface nearby. Jumping spiders have eyesight so well developed that they are one of the few spiders that detects objects without the need for movement by that object.

In addition, we have come across several studies regarding jumping spiders' ability to memorize, for example "Jumping spiders associate food with color cues in a T-maze" (Jakob, Elizabeth M. *et al*., 2007) and "Cross-modal effects on learning: a seismic stimulus improves color discrimination learning in a jumping spider" (Nicole and Eileen, 2007).

With the prerequisites of jumping spiders' peculiar eyesight and memory and that jumping spiders represent the story of nature of past-Hong Kong, our group has decided to focus our investigation on jumping its ability to memorize colors.

C. Background of jumping spiders in Hong Kong

Jumping spiders belong to Kingdom Animalia, Phylum Arthropoda, Class Arachnida, Order Araneida, Family Salticidae. At present, 5188 species of jumping spiders have been found in the world (Tsim,2007.) In Hong Kong, up until 2008, 77 species of jumping spiders have been found. However, as there is often the inflow of various species of plants from other regions to HK country parks, there could easily be new species of jumping spiders being seen in our city. There could be potentially 80-100 species of jumping spiders in HK. In terms of their distribution, jumping spiders are most commonly found in places with high species diversity and high ecological value, for example, Hang Hau, Tai Tam and Yuan Lang Country Park.

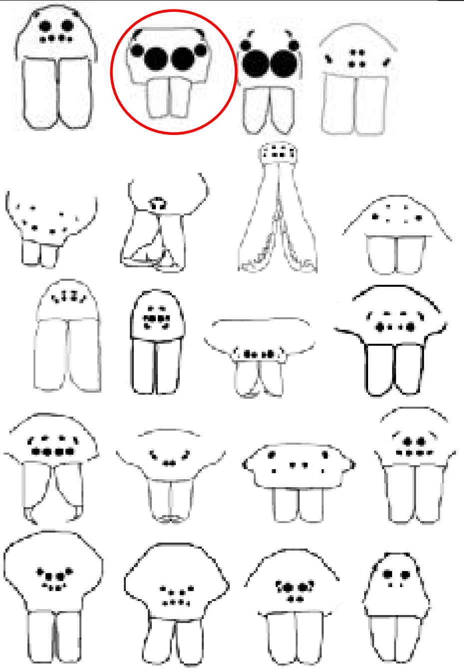


Fig. 1: *Drawing of eye arrangements of some spider families, the circled is Family Salticidae's eye arrangement (source: Spider.us)*

The body length of jumping spiders varies from 2-20 mm. The color of their bodies also varies from red, orange, yellow, green, blue, purple, gold, white and black. Some jumping spiders have long and narrow bodies, while some tend to be more flattened in shape. Jumping spiders have certain distinguishing characteristics. They are generally recognized by their eye pattern. (Fig.1) All jumping spiders have four pairs of eyes—apart from the front row of four eyes, they also have very large anterior median eyes, which are more dramatically prominent than any other spider eyes. Also, the jumping spiders, unlike the other families, have faces that are roughly rectangular surfaces perpendicular to their direction of motion. The legs of jumping spiders are not covered with any very prominent spines, unlike other spiders.

Jumping spiders are generally diurnal, active hunters, which means that they do not as a rule rely on a web to catch their prey. Instead, these spiders usually stalk their prey and use their superior eyesight to locate and capture prey. Then they pounce and give a venomous bite onto the preys' bodies. However, although jumping spiders could physically bite humans, the vast majority cause little or no harm to use as they either choose not to inject venom with the bite, or the venom does not affect people and our metabolism.

Among the species in Hong Kong, we have chosen the following species as experimental spiders because all the jumping spiders we found in the field trips are *Thiania bhamoensis*.

Fig. 2: *A front view of Thiania bhamoensis*

Common name: Fighting Spider, jumping spider
Chinese name: *巴莫方胸蛛*

Classification:
Kingdom Animalia (Animals)
Phylum Arthropoda (Arthropods)
Class Arachnida (Arachnids)
Order Araneae (Spiders)
Family Salticidae (Jumping Spiders)
Genus *Thiania*
Species *bhamoensis*

Body length: around 7-8 mm
Habit: Usually found in plantain trees; has a strong leap, tends to stay in the gaps between leaves to wait for prey

D. Background of jumping spiders' eyes structure

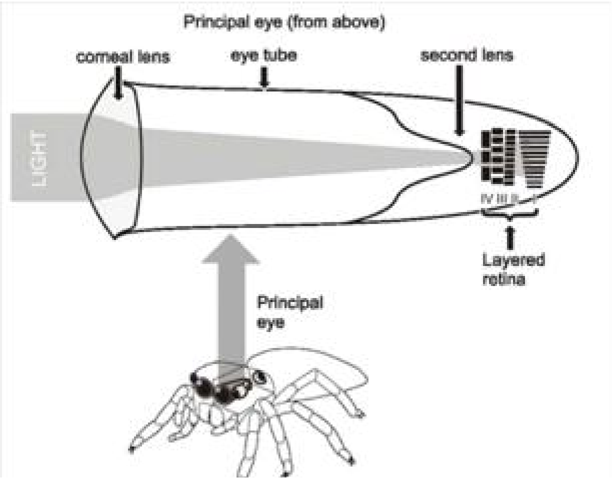


Fig. 3 *Internal structure of one of the principal eyes of jumping spiders*

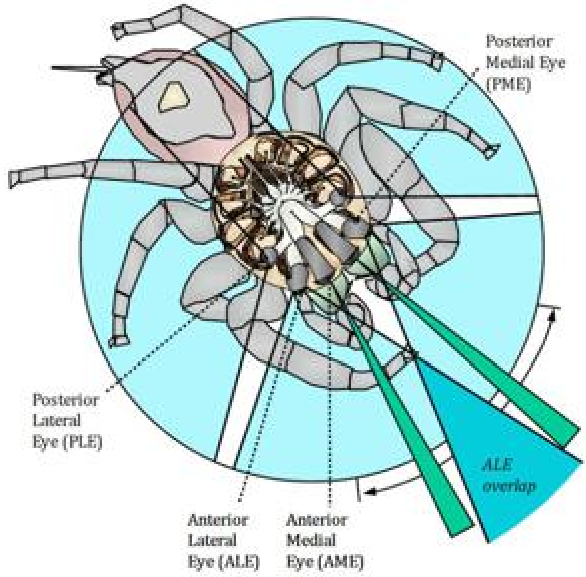


Fig. 4 *Eye structures of jumping spiders*

Jumping spiders are well known for their unique and complex eyes that support spatial resolution. (≈0.04°) which are unparalleled among animals of comparable size. (Matthew and Daiqin, 2006)Spatial acuity refers to an eye's visual angle, which is defined as the minimum separation required before objects in a scene are seen as separated. (Olga *et al* , 2012)

The retinal structure is composed of 4 tiered layers of receptor cells, positioned in the central area of highest acuity(Fig. 2). Each layer of these photo-receptors are sensitive to a specific wavelength of light. The first is at the back of the retina, while the fourth layer is closest to the corneal lens. Layer 4 is suited to UV light, layers 2 and 3 to distinguishing color, and the layer 1 is for spatial resolution. (Wikipedia)

Jumping spiders (Salticids) are generally considered to be the classic example of cursorial hunting spiders with well-developed vision. (Robert, 1986)When jumping spiders hunt, they used three different sets of eyes (Fig 3) for vision.The spider first senses movement of distant prey with the side eyes (PLE), which provide a blurry wide angle image. Once movement is detected, the spider turns in that direction and locks onto the moving prey with the large, middle front eyes (AME). These eyes provide a clear, focussed telephoto image, probably in colour. The spider can track moving prey both by body movements and by using muscles to internally swivel the elongated eye capsules so that the light sensitive retina of each eye remains locked on the prey. While the spider stalks closer, it uses the side front eyes (ALE) judge the distance to the prey. When it judges the prey to be close enough (about 2 cm - 3 cm), the spider leaps. (Australia Museum Website, 2009; Everygreen, 2011)We hope that we can observe their behaviour in the maze. Then, we can compare our observation and learn about the behaviour of jumping spiders.

Materials and Methods

A. Field Trip

Tung Chi at Tai Po, Sai Kung and Ma On Shan are some of the popular places in Hong Kong where traces of jumping spiders could be found. We carried out our first 2 field trips at Tung Chi, Tai Po. Tung Chi is a piece of lowland full of herbaceous and woody plants with damp conditions due to the fact that it is quite near to a stream with a canopy which traps water vapor in air.

Our last field trip was held in West Sai Kung Country Park, which is known for its biodiversity. The country park is of higher altitude than Tung Chi and has a more extensive river courses.

1. Equipment

1 Digital Thermometer	2 Forceps	2 Binoculars
1 Relative Humidity Sensor	35 Plastic zipping bags	2 Writing Pads
1 Light Intensity Meter	2 Scissors	A few Pencils
1 Wind Speed Meter	10 Plastic Boxes	1 Digital Camera

2. Procedures for catching and taking care of Jumping Spiders

1. Any two pieces of leaves sticking together on woody plants were identified.
2. The entire leaf was cut away by the stem using a pair scissors.
3. The 2 overlapping leaves were put into the plastic zipping bag immediately after cut.
4. A few drops of water were added to the plastic zipping bag.
5. Air was blown into the plastic zipping bag to provide oxygen for the spiders.
6. Jumping spiders were kept in the airtight zipper bag or transparent boxes for further experiments and investigations.
7. Few drops of tap water were added to the zipper bag or transparent boxes twice a week.

Fig. 5 *Field trip snapshots*

3. Information of the field trips

Date	5-3-2012	12-3-2012	21-3-2012
Time	11:00 – 14:00	11:00 – 14:00	11:00 – 14:00
Venue	Tung Chi at Tai Po	Tung Chi at Tai Po	Sai Kung, path junction near Cheung Sheung
Aims	● General search for jumping spiders ● Record the abiotic conditions of jumping spiders' habitats ● Catching jumping spiders for later experiments	● Record the abiotic conditions of jumping spiders' habitats ● Observe the general behaviors of jumping spiders	● Record the abiotic conditions of jumping spiders' habitats ● Observe the general behaviors of jumping spiders
Rainfall	Trace	6.6 mm	Trace
Temperature	17.2°C	12.3°C	19.6°C
Relative Humidity	93%	92%	76%
Weather Conditions	Cloudy	Rainy	Fine
Mean UV Index	2	1	4

4. Locations of field trip at Tung Chi

Fig. 6 *Aerial view of Tung Chi*

Fig. 7 *Map View of Tung Chi*

5. Location of field trip at Sai Kung (path junction near Cheung Sheung)

Fig. 8 *Aerial View of Sai Kung field trip location*

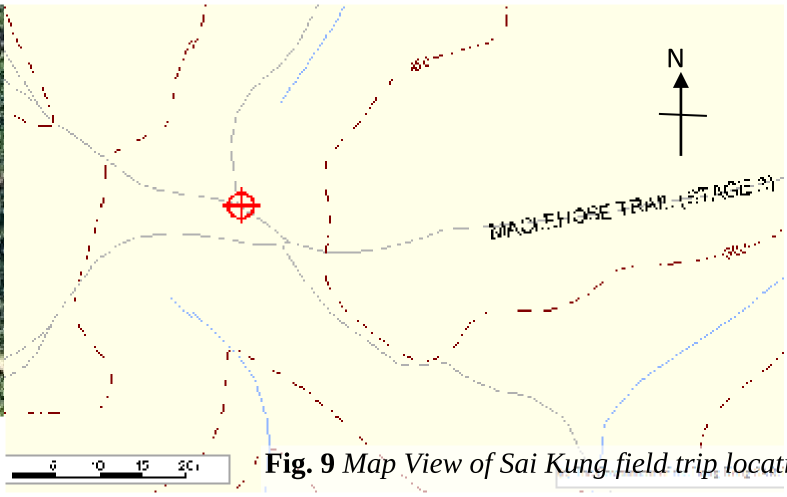


Fig. 9 *Map View of Sai Kung field trip location*

6. Observation in field trips

a. <u>Hiding and Crouching between Leaves</u>

Jumping spiders do not build webs. They make silken retreats between leaves, barks and stones. Their retreats usually have an opening at both ends, as shown in the following diagrams. These retreats act as their shelter. Looking from the outside, it was like two leaves sticking to each other. So it was easy for us to spot the spiders. Salticid retreats are usually tubular and densely woven (Jackson 1979). It is believed that these allow them to shelter from bad weather conditions, build and store eggs.

Fig 10: *Retreats between the leaves (pointed by red arrows)*

b. <u>Spending most of the time inside leaves</u>

It was observed that the jumping spiders were constantly staying inside the compartment between the two leaves stuck together by the retreats. One difficulty during our catching is that it was hard to distinguish whether there were spiders inside the leaves. We could only reveal whether a spider was inside the two leaves by peeling open the two leaves.

c. <u>"Energetic spiders"</u>

Once the leaves were peeled open and that the spider was exposed in the zipper bag, it was observed that the spider started to jump in the zipper bag or move in a very fast pace in all directions. The jumps and movement made by the spiders were agile.

d. <u>Different Color Pattern and Camouflage</u>

It is observed that the cephalus, or the head of the spiders, is of black or dark brown color; the tiny hairs of the spider are iridescent or bronze in color. The sides and the rest of the thorax are brown. The colour and pattern on the abdomen can vary. In the front half of the body of *T. bhamoensis*, in the front half, there appears to be a very broad, brown V-shaped pattern (or a chevron), bounded on both sides by narrower chevrons made up of iridescent, bronze-coloured hairs. (**Fig. 11**)Their first pair of legs is slightly swollen and larger than the others. The first and second pair of legs are brown while the remaining two pairs are yellow in color. Hence, with their bodies appearing to be of similar colors and patterns to the ground, jumping spiders can blend in with the external environment and use their colors as camouflage. This can not only help them catch prey (for example, it waits till a moth, which cannot see it because of its color, comes by, then jumps on it), but also protects them from predators.

Fig.11 Body of *T. bhamoensis*

e. <u>"Silk-producers"</u>

It is observed that after performing a long-distant jump, there was a silk appearing from the spinnerets which is at the end of the abdomen of the spider linking the starting point of the leaping to the end point of leaping. The strand of silk is the draglines which jumping spiders can hang on with tiny leg hairs. To stay safe, jumping spiders use draglines when they jump. If the spider misses its target, they can retreat back to their initial position.

The following photo shown all the jumping spiders we collected from Tung Chi are labeled for further experiment. They are fed with water once a day.

Fig 12 *Labeling of Jumping spiders collected*

B. Experiment

After reviewing some literature articles and similar researches done by scientists, we have decided to make use of a T-shaped maze and light rays of different colors to perform the training and trials of jumping spider so to test their memory on color.

The ability of female jumping spiders to associate color with heat in the presence versus absence of a seismic (vibratory) stimulus was tested . (Nicole and Eileen, 2007)

Heat dish was used to train the jumping spiders up to avoid heading to several colour in a heat- aversion learning experiment, and evidence for a cross-modal effect on color learning of jumping spiders was found.

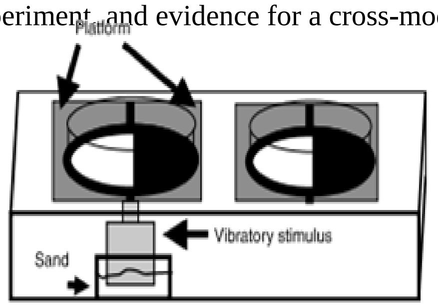


Fig. 13 *Experimental arena*

The experimental arena (see **Fig 13**) was designed according to the following method. Yellow and red papers were placed at the bottom of each arena (yellow paper represented by black; red paper represented by white). The papers were aligned such that one color was completely on the heated side of the aluminum platform and the other color was completely above the non-heated side of the platform. Spiders were dropped into the center of the arena where there was no heat.

Then, the spiders received training trials. Over the series of training trials, individuals exposed to a seismic stimulus jumped onto the heated color less frequently and remained there for less time than did individuals not exposed to a seismic stimulus.

After the training trials, the spiders received a test trial during which no stimulus(heat) was provided. In the final no-heat test trial, individuals from the seismic-present treatment were more likely to avoid the previously heated color than were individuals from the seismic-absent treatment.

The result of the experiment is quite significant as jumping spiders showed active reactions in dangerous environment. However, the long training process and trials, added to the constant exposure to heat, may be harmful to jumping spiders, therefore we hope to modify the experiment using coloured light rays to replace colored plate and using preys instead of seismic stimulus. So, compared to the above experiment, our experiment is relatively simpler and can minimize harms done to the jumping spiders.

Our experiment contains 2 parts, which are the trainings and the trials.

1. Training

The aim of the training sessions was to let the jumping spiders get familiar with colored environment with the lure of a prey. We aim to get the jumping spiders to associate the prey with color under which they were trained, so as to let the jumping spiders memorize their respective colors with the aid of the prey.

Spiders were divided into 3 groups according to the following table.

Codes of spider	Training received
R1-R10	Fed with cricket under red light once 2 days
B1-B10	Fed with cricket under blue light once 2 days
C1-C10	Fed with cricket under light of table lamp once 2 days

Table 1: *Grouping of jumping spiders*

A T-shaped maze was made as the experimental setup, with colored rays (red and blue) projected on two arms of the maze respectively. Red and blue light rays were provided by shining a bench lamp on red and blue cellophanes.

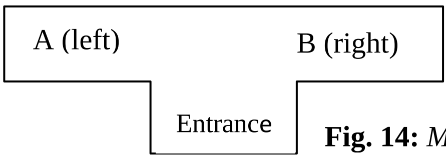


Fig. 14: *Model of maze*

Experimental spiders (R1-R10 and B1-B10) were trained under either red or blue light while control spiders (C1-C10) were trained under the light of the table lamp. In the training sessions, experimental jumping spiders were put in the T-shaped maze with together with the prey at either the red or blue terminals. Whether the spiders interacted with the prey (and hence associate the color of light with the prey and memorize the color) was observed.

Spiders were trained once in every 2 days after consulting an experienced jumping spider keeper. We learnt that jumping spiders could be able to survive without food up to 3 weeks and that feeding once in a week with a small cricket could already help sustain their lives. Therefore, we decided to train jumping spider once 2 days with preys as lure to avoid jumping spiders being too full and lose interest towards the crickets.

As shown in the following table, trainings were held at either side at of the maze at times to avoid jumping spiders from recognizing the side of maze rather than memorizing the colors. The 3 groups of spiders were trained according to the following **table 2**.

Table 2: *Jumping spider's training schedule*

Date	Time	R1-R10	B1-B10	C1-C10
1/3/2012	15:45-17:30	A	A	
5/3/2012	15:45-17:30	B	B	
6/3/2012	13:00-14:00			A
7/3/2012	15:35-17:30	A	A	
8/3/2012	13:00-14:00			B
9/3/2012	15:45-17:30	B	B	
12/3/2012	16:00-17:00			A
13/3/2012	15:45-17:30	A	A	
14/3/2012	15:34-16:30			B

Key: Jumping spiders' places of training

a. Training Procedure

1.) A small cricket was placed under the coloured light ray in the maze.
2.) The Jumping spider was placed near the prey.
3.) The training would be considered successful when the jumping spider interact at least 3 times with the cricket, such as chasing the cricket or killing the cricket
4.) The trainings were held according to the training schedule as shown in table 2.

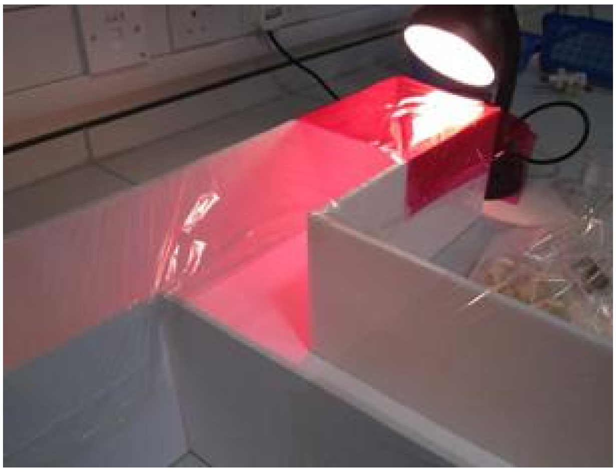


Fig. 15: *Training of R1-R10 group jumping spider at the right side (zone B) of the maze*

Fig. 16: *Crickets as prey*

b. Equipment and Materials

1 maze made by white card boards and food wrapping as covering on top of the maze
2 table lamps
30 Jumping spiders (*Thiania bhamoensis)*
Red and blue cellophanes
2 Forceps
150 Crickets (Fig. 16)
1 Plastic Spoon

2.Trials

Trials were conducted without the presence of prey affecting jumping spiders' decision on the choice of zone. The aim of the trials was to test whether jumping spiders could memorize the respective colors under which they were trained, and whether they could distinguish colors without the lure of a prey. Jumping spiders were placed in the maze in front of the intersection between the 2 colored zones, and their reactions were observed. The spider would be considered to have chosen a color when it stayed in a specific color zone (red or blue) for more than 1 minute. We considered the spider to be able to memorize a color when it stayed in the zone with the color under which they were trained.

2 trials were carried out for each group of jumping spiders in order to increase the accuracy by reducing random errors and to compare each jumping spider's responses in the 2 trials.

a. Trials Procedures

1) The maze is set up for trial 1 as shown in **Fig.***17*

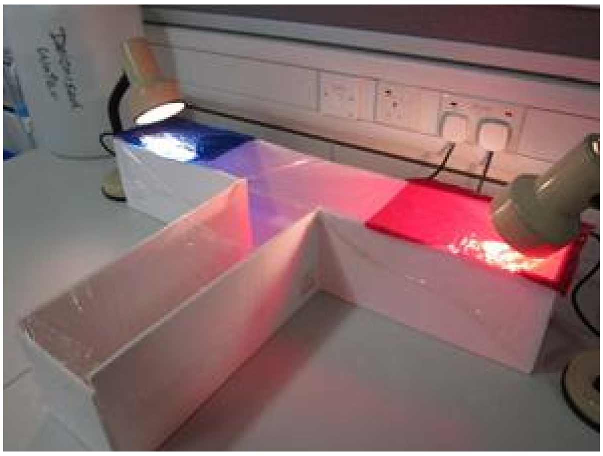


Fig. 17: *Set-up for trial 1 1*

Fig. 18*: Starting position of jumping*

2) R1-R10 jumping spiders were placed at the center of entrance in front of the intersection between the 2 colored zone as shown in **Fig.** 18
3) The jumping spider was considered to have chosen the particular colour of light when it had stayed under either side of the maze for more than 1 minute.
4) A failed trial of spider not responding over 10 minutes will be removed from the maze and tested again after one hour until response was identified.
5) After the trial has been performed to all 10 spiders, the positions of the blue and red cellophanes were swapped.
6) Steps 2-4 were repeated to carry out trial 2.
7) Steps 2-6 were repeated, replacing R1-R10 spiders with B1-B10 spiders and C1-C10 spiders.

Table 3: *Trials Schedules*

Date	Time	R1-R10	B1-B10	C1-C10
14/3/2012	16:00-17:30	Trial 1		
15/3/2012	16:00-17:00		Trial 1	
16/3/2012	15:45-16:45	Trial 2		
	16:45-17:30		Trial 2	
	17:30-18:15			Trial 1
19/3/2012	16:00-17:00			Trial 2

Experiment Result

A. Data Collected

Trials for R1-R10 spiders

Table 4: *1st Trial*

	Date: 14/3/2012 Time: 4:00-5:30									
	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
Right: Red light		N/A			0		0		0	
Left: Blue light	0		0	0		0		0		0
Remarks		dead								

Table 5: *2nd Trial*

	Date: 16/3/2012 Time: 3:45-4:45									
	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
Left: Red light		N/A		0	0	0				0
Right: Blue light	0		0				0	0	0	
Remarks		dead								

Trials for B1-B10 spiders

Table 6: *1st Trial*

	Date: 15/3/2012 Time: 4:00-5:00									
	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
Right: Red light			0						0	
Left: Blue light	0	0		0	0	0	0	0		0
Remarks										

Table 7: *2nd Trial*

	Date: 16/3/2012 Time: 4:45-5:30									
	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
Left: Red light		N/A	0		0		0		0	
Right: Blue light	0			0		0		0		0
Remarks		dead								

Trials for C1-C10 spiders

Table 8: *1st Trial*

	Date: 16/3/2012 Time: 5:30-6:15									
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
Left: Red light	0		0			0	0		N/A	0
Right: Blue light		0		0	0			0		
Remarks									dead	

Table 9: *2nd Trial*

	Date: 19/3/2012 Time: 4:00-5:00									
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
Left: Red light	0	0		0				0	N/A	0
Right: Blue light			0		0	0	0			
Remarks										

Key: 0-Jumping spider choosing to stay in the red light zone for more than 1 minute

0-Jumping spider choosing to stay in the blue light zone for more than 1 minute

B. Observation

1. Jumping spider can lift their heads. As shown in **Fig 19**, it can lift up its head so that it can better see objects above itself. Therefore, jumping spiders' eyesight is not limited to the horizontal level of their eyes. Jumping spiders performed this posture when forceps were placed 2-3 cm above their heads. After researching literature reviews, we found out that this head movement is called "Stalking". Stalking was defined as a steady head-on movement towards a lure. Three categories were recognized: cryptic stalking (consistent adoption of the retracted-palps posture and freezing when a lure is no more than 50 mm away); ordinary stalking (consistent adoption of the posture used during ordinary locomotion, including holding the palps loosely in front of the chelicerae, and failure to freeze when faced by a lure that was 50 mm or closer); ambivalent stalking (test spiders sometimes adopted the retracted-palps posture or sometimes froze when faced by the lure when no more than 50 mm away, but failed to do so consistently). (Duane and Robert, 2000)

Fig 19: *jumping spider lifting up its head*

2. Jumping spiders often stayed on the plastic wrap on the top of the maze.(**Fig.20**)We observed that more than one third of jumping spiders eventually climbed up to the top of the maze with inverted body posture and stayed intact. We predicted that the jumping spiders were attracted to the warmth of table lamp transmitted to the plastic wrapping, as the temperature at the top of the maze was higher than in the maze atmosphere. Jumping spiders might favor a warmer area in the maze than of a cooler one since web builders and jumping spiders are very abundant in damp and warm habitats (Jackson, 1982) and the warmer environment might resemble jumping spiders' habitat.

Fig 20: *jumping spider staying on top of maze*

Discussion

A. Description of result

The statistics corresponding to the 2 trials for spiders R1-R10 (spiders trained under red light) are shown below.

Table 10: Result of trials for R1-R10 spiders		
	T1	T2
No. of spiders choosing red light	3	4
No. of spiders choosing blue light	6	5
No. of spiders in total	9	9
% of spiders choosing red light	33.34%	44.45%
% of spiders choosing blue light	66.67%	55.56%
Average % of spiders choosing red light in the 2 trials	38.90%	
Average % of spiders choosing blue light in the 2 trials	61.10%	
No. of spiders choosing red color consecutively for 2 trials	1 (R5)	

In trial 1, % of spiders choosing red light was 33.34% while % of spiders choosing blue light was 66.67%. In trial 2, % of spiders choosing red light increased by around 10% (44.45%) while % of spiders choosing blue light decreased by around 10% (55.56%). In average, the % of spiders choosing red light and blue light in the 2 trials were 38.9% and 61.1% respectively. There was only 1 spider (R5) which was able to choose the red colored zone consecutively for the 2 trials.

The statistics corresponding to the 2 trials for spiders B1-B10 (spiders trained under red light) are shown below.

Table 11: Result of trials for B1-10 spiders		
	T1	T2
No. of spiders choosing red light	2	4
No. of spiders choosing blue light	8	5
No. of spiders in total	10	9
% of spiders choosing red light	20.00%	44.45%
% of spiders choosing blue light	80.00%	55.56%
Average % of spiders choosing red light in the 2 trials	32.22%	
Average % of spiders choosing blue light in the 2 trials	67.78%	
No. of spiders choosing blue color consecutively for 2 trials	5 (B1, B4, B6, B8, B10)	

In trial 1, % of spiders choosing red light was 20% while % of spiders choosing blue light was 80%. In trial 2, % of spiders choosing red light increased by around 25% (44.45%) while % of spiders choosing blue light decreased by around 25% (55.56%). In average, the % of spiders choosing red light and blue light in the 2 trials were 32.22% and 67.78% respectively. Five out of 10 spiders (50%) were able to choose blue color correctly for the two trials.

The statistics corresponding to the 2 trials for spiders C1-10 are shown below.

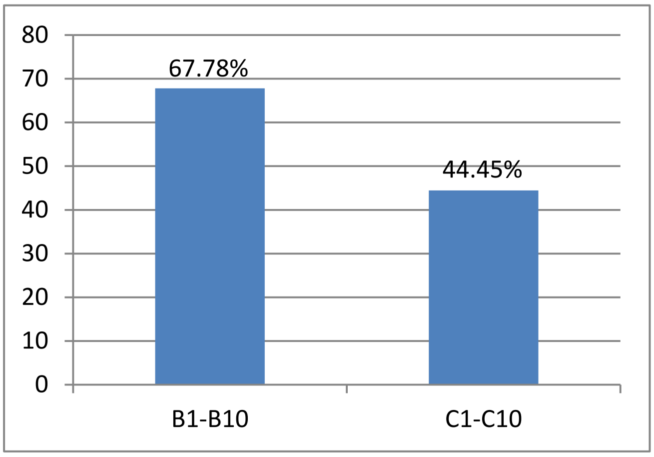
Table 12: Result of trials for C1-10 spiders		
	T1	T2
No. of spiders choosing red light	5	5
No. of spiders choosing blue light	4	4
No. of spiders in total	9	9
% of spiders choosing red light	55.56%	55.56%
% of spiders choosing blue light	44.45%	44.45%
Average % of spiders choosing red light in the 2 trials	55.56%	
Average % of spiders choosing blue light in the 2 trials	44.45%	
No. of spiders choosing red color consecutively for 2 trials	2 (C1, C10)	
No. of spiders choosing blue color consecutively for 2 trials	1 (C5)	

In both trials, the % of spiders choosing red light or blue light were the same, with 55.56% of spiders choosing red light while 44.45% of spiders choosing blue light. 2 spiders out of 9 (22.22%) had chosen red light in the 2 trials while 1 out of 9 (11.11%) had chosen blue light. Spiders showed similar response to the two colors of lights shown. Therefore, it shows that jumping spiders do not show preference to either red or blue color.

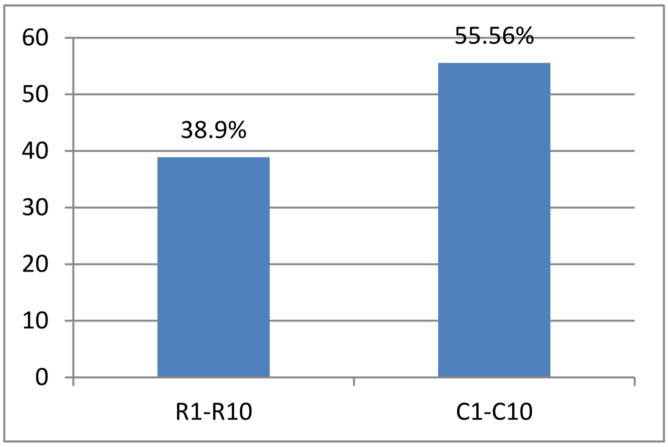
B. Analysis of Results

1.Comparison between trained spiders (R1-R10, B1-B10)and untrained spiders(C1-C10)

Graph 1: Comparison between B1-B10 and C1-C10(control set-up) on the average % of spiders choosing the colour of light they are trained with in trials



Graph 2: Comparison between R1-R10 and C1-C10(control set-up) on the average % of spiders choosing the colour of light they are trained with in trials

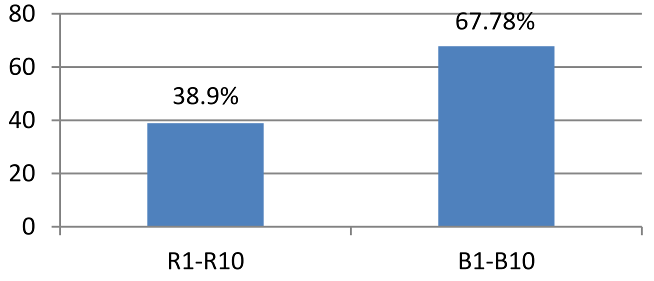


Refering to Graph1, when compared to spiders without training(44.45%), a higher average % of spiders which is trainned under blue light(67.78%) chose the blue light zone. This shows that the training can casue some effect on altering their preference in choosing between the two colors. As mentioned above, jumping spiders show no preference towards red or blue. So, the result can show that spiders can memorize blue light ray after training.

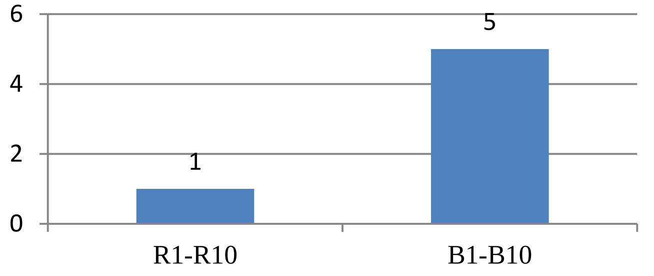
Referring to Graph 2, when compared to spiders without training(55.56%), a lower average % of spiders which is trainned under red light(38.9%) chose the red light zone. This is an unexpected result. One of the possible reasons may be due to difference in sensitivity between red and blue photoreceptors. This causes jumping spiders' photoreceptors to be decidedly inefficient at detecting long wavelength light (i.e. red) and being unable to discriminate wavelengths in the red region from green (Blest et al., 1981). However, we are aware that there may be other factors contributing to the situation, one of which is random error.

2. Comparison between jumping spiders' ability to memorize red and blue colours

Graph 3: Average % of spiders choosing the colour of light they are trained with in trials



Graph 4: Number of spiders choosing the correct color zone they were trained consecutively for 2 trials



Referring to graph 3, the result shows that jumping spiders had higher % of choosing the correct color zone if they are trained under blue light (67.78%) than red light (38.9%). It can be seen that the average % of B1-B10 spider choosing blue light in the 2 trials was nearly 2 times than that of the average % of R1-R10 spiders choosing red light. By comparing the results, it is very likely that jumping spiders have better ability to memorize blue colour than red colour.

Another supporting evidence is by looking at the number of spiders that consecutively chose the correct colour zone they were trained at in both trials:

Referring to **Graph 4**, for spiders which have been trained under red light conditions, only 1 spider out of 9(11.11%) was able to choose red light in the 2 trials despite the fact that they have been trained under red light. For spiders which have been trained under blue light conditions, however, it was seen that 5 out of 10(50%) spiders being able to choose blue color for the 2 trials. The number of spiders being able to choose blue color for the 2 trials was significantly larger than those being able to choose red color for the 2 trials.

By comparing the results, it is very likely that spiders have better ability to memorize blue color than red color.

Fig 21: *Thiania bhamoensis in the maze with the cricket*

C. Significance of result

Jumping spiders have always been called one of the smartest animals or bugs in the world for its intelligence in memorizing colors and its ability to differentiate among four primary colors visible to their eyesight, namely red, green, blue and UV light. Jumping spiders are believed to be the only member of the spider world (*Araneae*) capable of memorizing different colors and this experiment has shown jumping spiders' intelligence.

D. Errors

There are some errors incurred in the experiment and are discussed below.

1. The unknown in appetite of spiders made training sessions rather difficult. As we don't know the exact appetite of the spiders, it was very difficult to judge whether the spiders were attracted to the prey during training sessions that were held every two days. The situation of spiders not interested in preys may occur during training sessions may hinder spiders' actual memorization of the specific color, and hence may affect our result findings.

2. Besides using preys to attract spiders during training sessions, preys were also fed to spiders at irregular times. That means the frequency of feeding of spiders had not been kept constant. As a result, the varied appetite of spiders during trial session may affect spiders' will to choose the correct colored zone; if it had been fed and not attracted by the prey, even if it recognizes the correct color, it might not have the motivation to enter the correct zone.

3. Each spider had varied starting positions during trials. During the experiment, it was very hard to put each spider to exactly the same starting point as the spiders were moving around once they entered the maze, and it would be very chaotic to place the spiders to exactly the right starting spot. Hence the variation of starting positions may affect the experimental result as length of route travelled by the spiders might be a factor affecting spiders' decision in choosing the colored zone.

4. Due to time limits, only 2 trials had been done for each set of spiders. The number of trials was very small and huge random error existed. The spiders may have approached the right colored zone just merely by coincidence rather than by memory.

Fig 22 *Placing the prey*

5. There was a difference in duration of spiders staying in the colored zone. Some spiders stayed in the zone for minutes while some only stayed for less than a minute. Therefore, although the standard of staying over one minute was used in the experiment, it was very hard to judge whether the spider really showed response towards the lights, as some spiders who has shown response to the correct colored light might only stay in the zone for not enough a minute and jumped away.

E.Limitation

1. The species of jumping spiders that we investigated on is *Thiania bhamoensis*. Different jumping spider species may have different behavior and learning abilities. In this experiment, we are not able to collect data to represent the learning abilities of all jumping spiders responding to color cues.
2. The time between the final training and trials was quite long, so the fact certain jumping spiders could not move toward the "correct" color during trials may be because their memory of colors during the trainings were lost, and not because they were totally unable to memorize the colors.
3. Only two colors can be tested in our results, and thus it cannot represent jumping spiders' memory on the whole range of colors.

F. Improvements

1. Time each training trials accurately and try to remove the spider from the T-maze as soon as possible. If not, switch off the bench lamp and remove the prey immediately after experiment time to ensure the spider would not be confused that there will be prey without the color cues or no prey with color cues.
2. Prolong the training offered to the jumping spiders.
3. Feed the jumping spiders regularly once 2 days, including during weekends.
4. Use more types of preys during training sections, for examples, flies with wings removed, ants etc.

G. Further studies to be done

1. Investigate the relationships between number of trials provided and its learning ability
2. Investigate the jumping spiders' memory on other colours, e.g. green, yellow
3. Investigate the effect of light intensity on jumping spiders' memory
4. Investigate the effect of wave of light wave on jumping spiders' memory
5. Compare jumping spiders' ability to memorize dangers by colours and lures by colour
6. Investigate the contribution of each pairs of jumping spiders' eyes to memorizing colours

Conclusion

Jumping spiders exhibit the ability to differentiate between red and blue color.
Jumping spiders(*Thiania bhamoensis*) exhibits better ability in memorizing blue color than red color. The reason behind is that jumping spiders' photoreceptors are decidedly inefficient at detecting long wavelength light (i.e. red), being unable to discriminate wavelengths in the red region from green (Blest et al., 1981).

Reflection

Through this investigation, we were able to explore the delicate eye structures and the incredible ability to memorize of the jumping spiders, which were the collective memory of the pastime. We came to understand more of the different structures of jumping spiders for example the eye, and how these structures might come in handy for survival or adaptation of jumping spiders to the external environment.

The field trips have given us a valuable opportunity to understand the habitats of jumping spiders. It is a particularly arduous process for us to design the experimental processes, yet, we have gained a lot throughout the whole process of investigation, for example to learn to design fair experiments. Moreover, this project helps us gain a better understanding of each members and provides us with the opportunity to perform team work whenever facing obstacles.

We admired how fine the body parts of the jumping spiders were designed to allow them to coordinate effectively and survive in extreme conditions. This precious experience also allows us to appreciate the greatness of nature. The nature has immense biodiversity and organisms were designed uniquely and of a purpose. The complexity of structures of small organisms makes us wonder how amazing the ecological system is. No matter how technology develops, mankind can never create an artificial system of organisms, or even understand fully how the system functions. Scientists, strived very hard over years, have not been able to produce the silk retreat jumping spiders build every day. Most importantly, we should protect the environment and the ecosystem. So mankind can interact with organisms harmoniously and continue to explore the wonders in nature.

Fig 23 *Colourful jumping spiders*

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