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Intelligence of Bearded Dragons

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Abstract

The purpose of this thesis is to study and explain the intelligence of bearded dragons. Bearded dragons (*Pogona spp*.) are a species of reptile that have been popular in recent years as pets. Until recently, not much was known about their intelligence levels due to lack of appropriate research and studies on the species. Scientists have been studying the physical and social characteristics of bearded dragons to determine if they possess a higher intelligence than previously thought. One adaptation that makes bearded dragons unique is how they respond to heat. Bearded dragons optimize their metabolic functions through a narrow range of body temperatures that are maintained through thermoregulation. Many of their behaviors are temperature dependent, such as their speed when moving and their food response. When they are cold, these behaviors decrease due to their lower body temperature. A second unique feature of bearded dragons is the ability to see color. The ability to see color would give the animal an adaptive advantage to discriminate between objects in their habitats. An organism must have different classes of photo receptors in the retina and the appropriate neuroreceptors to analyze outputs from them in order to possess color vision. Early studies have shown that bearded dragons likely possess these mechanisms. A third feature that bearded dragons possess is the ability to social learn. In a study conducted where they watched a demonstration, they were able to repeat the same action. These results show evidence that bearded dragons are capable of using social information to learn through imitation. A fourth unique feature is how they perceive visual illusions. Through a study conducted on how they perceive the Delboeuf illusion, it was found that they perceive illusions in a very human-like way. They chose the smaller portion which indicates that they may view this illusion similarly to humans, primates, and birds. Bearded dragons are also capable of entering REM and short-wave sleep cycles. While this feature is less complex than a human cycle, it has been shown to be present through monitoring their brain waves. Even though reptiles have been previously studied, most of the behavioral and physiological reasons for their intelligence levels are still unknown due to lack of research on various reptilian species. As more studies continue to be conducted, more information will become available to understand their intelligence and the reasons behind it.

Table of contents

Introduction

Bearded dragons (*Pogona spp.*) are a species of reptile that have emerged in recent years as popular exotic pets due to their docile nature, manageable size, and hardiness. This species of reptile is native to Australia and are found worldwide as pets. Due to the creation of The Environment Protection and Biodiversity Conservation Act of 1999, bearded dragons can no longer be imported or exported from the country, so they are typically bred within the United States and other countries where they are kept as pets (Department of Agriculture, 2020). Many color varieties and sizes are being bred in the pet trade industry along with breeds that have reduced scale counts, such as the silkback (scaleless) and leatherback (reduced scale count). There are currently six species of bearded dragons recognized: *Pogona barbata, Pogona henrylawsoni, Pogona microlepidota, Pogona minor, Pogona nullarbor, and Pogona vitticeps* (Raiti, 2012, p. 117). Of these different species, the central bearded dragon (*Pogona vitticeps*) is most commonly kept in captivity in the United States.

Bearded dragons belong to the family Agamidae. This is the fourth largest family of lizards that includes over 300 species that live in Africa, Asia, and Australia (Raiti, 2012, p. 117). This group is characterized by a lack of tail loss, round pupils, presence of tubercules and spines on juxtaposed scaled skin, and a broad fleshy tongue (Doneley, 2006, p. 1607). Other species within this family include water dragons, frilled lizards, and many other species. The species within this family are terrestrial or semi-arboreal and are oviparous, laying their eggs within a small, shallow burrow during the warmer months. Many of these species, including the bearded dragon, are omnivorous, consuming arthropods, worms, small rodents, fruits, leafy green vegetables, and flowers (Raiti, 2012, p. 117).

Bearded dragons are relatively large lizards, typically ranging from eighteen to twenty-two inches in length. They possess a broad triangular shaped head, flat bodies, and a long tail. They have a gular pouch on the underside of the neck that can be expanded (Doneley, 2006, p. 1607). This pouch is also referred to as a "beard", which led to the name bearded dragon. Bearded dragons have large spikes that protrude from the sides of their bodies and heads. These spikes are also present on leatherbacks but are absent in silkbacks due to being scaleless. When they are threatened, they will flare out their beard and open their mouths to appear larger and thwart off predators. Males will also flare out their beards if females are present to indicate signs of wanting to mate.

Husbandry

Bearded dragons are commonly kept in large terrarium enclosures with rocks, branches, and basking spots to imitate their natural environment. In Australia, their natural habitats are light forests, scrubs, grasslands, and occasionally rocky or sandy areas (Doneley, 2006, p. 1607). They require UVB and heat lights to provide basking spots for them to bask in during the day. They are diurnal, so they are usually awake during the day and sleep during the night. This is unique among lizards as many are nocturnal. Due to this, they require heat and synthetic sunlight for about twelve hours each day to maintain an appropriate body temperature and metabolize calcium to keep their bones strong. They also need weekly baths to help hydrate them because they will not typically drink out of a water bowl. Soaks also function to help stimulate defecation and can help prevent impaction from improper substrates or diets.

As babies, bearded dragons will shed frequently, but this decreases in frequency as they reach maturity. They shed their entire body in pieces, unlike other species like chameleons or geckos that shed in one piece. Many bearded dragons are missing toes and the tips of their tails due to difficulty shedding that leads to necrosis of the tissue. Their life expectancy in captivity is between seven to twelve years, depending on the level of appropriate care provided (Raiti, 2012, p. 118). As babies, they consume mostly live insects due to needing a higher protein content. As they reach maturity, their diet shifts to mostly greens and vegetables with less live food. Their live food has to be “gut-loaded” with vitamins and minerals prior to consumption by the animal. This ensures that the reptile is getting the appropriate level of nutrition from their food source. In the wild, they are opportunistic feeders and will only hunt when prey is near them (Doneley, 2006, p. 1607). The amount of food they eat varies on the time of year. During the winter they typically consume less due to going into a semi-hibernation state called brumation.

Males are very territorial and will fight for dominance with other males, so they should be housed separately. Females will also stake out territory, but they are not as aggressive as the males. Bearded dragons reach sexual maturity between six and fifteen months of age (Doneley, 2006, p. 1608). At this time, females are capable of becoming gravid when mated to a male. Their mating season typically occurs during the warmer months, with a female capable of producing multiple large clutches of fertile eggs after being mated. Even if they are not bred, females will commonly produce infertile eggs every few weeks to months during the spring and summer.

Common Problems

Even though bearded dragon care is relatively simple, there are many skin and internal diseases and conditions that may require veterinary care. External and internal parasites are common, especially in younger juveniles. Pinworms, coccidia, and flagellated protozoa are some of the gastrointestinal parasites that can be found by doing a fecal float test (Doneley, 2006, p. 1610). These parasites are not always harmful and small amounts are not considered necessary to treat. If treatment is needed, anthelmintics can be given orally to kill the parasites. Metabolic bone disease is a disease which is seen among bearded dragons who are not given proper lighting. They must have UVB, and their food dusted with calcium in order to keep their bones healthy and strong. MBD causes malformed bones and joints, especially in juveniles who are growing. This disease cannot be cured but changing the husbandry can stop the condition from worsening.

Bearded dragons are prone to getting respiratory infections. During their baths, they may aspirate water into their lungs that may cause a respiratory infection to occur. They can also get stomatitis, which causes an infection in their mouths that must be treated with antibiotics. Any time there is stress or injury to the animal, food refusal is common. This is usually a secondary condition that is caused by a primary disease. In some cases it is due to two males being housed together and the larger one steals all of the food or it could be more serious and require veterinary intervention.

Skin infections are also commonly seen among bearded dragons. Difficulty shedding can commonly cause bacterial infections on the skin if it comes off before it is ready. These are also common in bearded dragons who are not kept in the proper conditions. These skin infections can lead to a condition called yellow fungus, which causes patchy discolored yellow skin that may become necrotic over time (Doneley, 2006, p. 1610). Eventually, the skin infection can go so deep into the tissue that it causes necrosis of internal organs. If caught early enough, it can be treated with a long course of antifungals. Many of these skin infections are commonly treated by veterinarians with topical and systemic medications and antibiotics. Injectable antibiotics are also used in more advanced cases.

Thermoregulatory Behavior

Over the past decade, scientists have been studying the physical and social characteristics of bearded dragons to determine if they possess a higher intelligence than previously thought. Due to the limited number of studies that have been done, no definitive reason for their behavior has been discovered, but the studies completed have shown that they are more complex than researchers realized.

One adaptation that makes bearded dragons unique is how they respond to heat. Bearded dragons optimize their metabolic functions through a narrow range of body temperatures that are maintained through thermoregulation, which keeps them alive (Cadena & Tattersall, 2009, p. 203). Many of their behaviors are temperature dependent, such as their speed when moving and their food response. When they are cold, these behaviors decrease due to their lower body temperature. Bearded dragons must be able to respond to a thermal gradient and maintain their body temperatures to survive and add to their overall fitness (Cadena & Tattersall, 2009, p. 203). Even though bearded dragons are ectotherms, they have been shown to have these abilities within lab studies. This requires them to use physiologic responses to modify their behavior to maintain their body temperature.

The degree to which they can thermoregulate depends on the thermal quality of the environment they are in (Cadena & Tattersall, 2009, p. 203). Poorer thermal environments have been shown to cause more energy and time invested in locomotion associated with thermoregulatory behavior (Cadena & Tattersall, 2009, p. 203). These principles led to Huey and Slatkin developing a mathematical cost-benefit model for thermoregulation in lizards in 1976 (Cadena & Tattersall, 2009, p. 203). Their model predicted that lizards will only thermoregulate if the costs associated with the behavior do not outweigh the physiological benefits (Cadena &

Tattersall, 2009, p. 203). This then means that if the costs are higher, then less thermoregulation is expected. This allows lizards to handle changing environmental conditions better and allows them to minimize the energy required when the benefits are minimal or harmful to the lizard.

Studying thermoregulation of lizards within a laboratory setting allows the costs to be controlled and manipulated and the animal would thermoregulate accordingly. This allows more precise thermoregulation in experimental settings that require less thermoregulatory effort (Cadena & Tattersall, 2009, p. 204). The study that was completed evaluated the cost-benefit prediction model by Huey and Slatkin. They used three experimental scenarios that had three different cost-benefit situations. The first scenario was an extreme temperature shuttle box where the temperature in the first compartment was maintained at 122°F and the second compartment was 59°F. This scenario represented the highest cost for the lizard. The second scenario used a ramping temperature shuttle box that decreased or increased depending on the location of the lizard at a constant rate. Temperature changes of 33.26°F, 32.72°F, and 32.18°F min^{-1} were used, and this scenario posed an intermediate cost for the lizard. The third scenario used a temperature gradient that posed a low cost to the lizard due to the low amount of movement required to obtain its preferred temperature.

Eight male and four female (12 total) bearded dragons were used for this experiment. They were raised from hatchlings to one year of age and ranged from 219 grams to 417 grams in weight (Cadena & Tattersall, 2009, p. 204). They were housed in glass terrariums that had a 100-watt heat light at one end of the tank. They were given shade and shelter and had a twelve-hour photo period daily (Cadena & Tattersall, 2009, p. 203). Daily the lizards were given vegetables and once a week were given live insects. They used two types of apparatuses to evaluate thermoregulation: a shuttle box and a thermal gradient. The shuttle box was composed of a wooden chamber that was separated into two compartments with plexiglass. There was a hole in the bottom of the plexiglass to allow for movement between the chambers by the bearded dragon (Cadena & Tattersall, 2009, p. 204). The enclosure was lit by two symmetrically placed fluorescent bulbs and there were infrared cameras installed to allow for constant monitoring of the lizards. They could regulate their own temperature by stepping on a switch located on the floor between the two compartments. This switch indicated where they were inside the box and activated the heating or cooling system depending on which compartment the bearded dragon was in (Cadena & Tattersall, 2009, p. 204). A 50°F temperature difference was maintained between the compartments that allowed the bearded dragon to go to the warmer or cooler side. When the lizard was placed in the heated compartment, the air was heated at a fixed rate that continued climbing until they moved to the cooler side, where the air was cooled at the same rate as the heated side (Cadena & Tattersall, 2009, p. 204).

The thermal gradient consisted of a wooden box that had incandescent bulbs suspended along the gradient. Copper tubes were covered by a copper sheet with hot water (122°F) flowing in from one end and cold water (59°F) flowing in from the other end, creating a gradient. The air was also heated at the same temperature as the copper tubes. Data was obtained at thirty second intervals through small telemeters that were implanted in the lizard’s abdominal cavity. They were allowed three weeks to recover before experimentation occurred and all of them recovered and resumed normal behavior (Cadena & Tattersall, 2009, p. 205).

The bearded dragons were fasted for twelve hours before the experiment and each was given four and a half hours to acclimate to their new environment, with the remaining seven and a half hours being recorded from 8:00 a.m. to 8:00 p.m. Series I consisted of exploratory shuttling where the lizards were randomly placed on either the left or right side (Cadena &

Tattersall, 2009, p. 205). In series II, the lizards were placed on the warm side (Cadena & Tattersall, 2009, p. 205). If they were placed on the cool side after being already cool from the night, then they would have been lethargic and not wanting to move. This would have ended with unreliable data being obtained. The purpose of the experimental shuttling was to determine if they preferred either side of the box without thermal stimuli and to determine the amount of movement that would occur without concern for temperature regulation. The data could then be compared between series I and II to determine if the thermal stimuli were causing a different behavior than the shuttling box (Cadena & Tattersall, 2009, p. 206). The box was heated to 94°F on both sides, which is a normal range for bearded dragons who are active and moving around and data was recorded for each lizard at thirty-minute intervals. This data was then averaged and turned into a percent to eliminate possible biases from lizards that had higher or lower levels of movement than the others (Cadena & Tattersall, 2009, p. 206).

For series II, ten lizards were exposed to different environmental thermal qualities, which was done by varying the rate of temperature change in the shuttle box. The higher the range, the more thermally challenging the environment is due to increasing the amount of shuttling necessary to maintain their proper temperature (Cadena & Tattersall, 2009, p. 206). Some of the lizards would move to thermoregulate for only one to three hours of the twelve-hour experiment duration then move to the cool side for the remainder, while others would sit in between the two compartments. Nine lizards were also evaluated using the thermal gradient, which allows them to position themselves at an optimal spot within the gradient to thermoregulate (Cadena & Tattersall, 2009, p. 206).

Within the first half our of being placed inside the shuttle box, all lizards showed some exploratory movement. The variability within the twelve-hour period was high, with the lowest being 2 shuttles and the highest being 405 shuttles (Cadena & Tattersall, 2009, p. 209). Over 90% of the shuttling behavior occurred within the first four hours of the experiment (Cadena & Tattersall, 2009, p. 209). They compared a possible bias of different sides of the shuttle box, which revealed that there was no statistical difference between the time spent in the left or the right compartment. The series II experiment showed much more shuttling behavior due to the thermal stimulus that was present. In this experiment, the lizards engaged in frequent shuttling behavior after they were placed in the box (Cadena & Tattersall, 2009, p. 209). Like the series I, the most movement occurred during the first four hours, with shuttling becoming more periodic and sporadic after this point. By moving back and forth between the compartments, the lizards were able to successfully regulate their temperatures at a constant rate. Two of the bearded dragons were found to be poor regulators, requiring three to four exposures to the experiment to be successful in thermoregulating (Cadena & Tattersall, 2009, p. 210). During the temperature conditions that were more extreme, over 50% of the lizards were seen once or more in between the two compartments with their head in one compartment and their tail in the other (Cadena & Tattersall, 2009, p. 210).

These experiments led experimenters to believe that bearded dragons are precise thermoregulators that are capable of maintaining a body temperature between 94.5°F and 95.4°F with a range of 36.5°F to 37.4°F in all situations but the lowest thermal quality condition used in this study (Cadena & Tattersall, 2009, p. 211). The weight of the lizard did not seem to have any impact on the ability to thermoregulate. The difference in the number of shuttles in series I and series II indicated that the movement of the lizards was thermoregulatory and was temperature based. The thermoregulatory behavior of the lizards based on environmental thermal quality was consistent with the cost-benefit model proposed by Huey and Slatkin in 1976 (Cadena &

Tattersall, 2009, p. 211). Low-cost behavioral (changing posture and mouth gaping) and physiological (adjusting heart rate, cardiac shunts, and changing peripheral blood flow) changes play an important role in the thermoregulation of many reptiles, including bearded dragons (Cadena & Tattersall, 2009, p. 211). Many of their behaviors including feeding, ability to avoid predators, and embryonic development have shown temperature dependency and would be negatively affected if the lizard could not precisely thermoregulate (Cadena & Tattersall, 2009, p. 211). Field studies of other reptiles have indicated that they prefer to select high thermal-quality habitats where they have a variety of temperature ranges available to choose from to control their body temperature (Cadena & Tattersall, 2009, p. 211). There are many negative costs that play a role in thermoregulatory behavior including predation risk, territorial fighting, food and water availability, and metabolic costs of locomotion.

In conclusion, the findings indicate that the thermoregulatory effects of bearded dragons vary depending on the costs associated with it. When the cost is low, lizards will thermoregulate using more energetically expensive behavioral strategies, such as shuttling. As the costs continue to increase, they will use more energetically saving behaviors, such as mouth gaping and changes in heart rate. This allows them to minimize energy expenditure and maximize the physiological benefits. Due to the fact that their thermoregulatory abilities in higher thermal qualities are better at regulating temperature than in lower thermal qualities, it indicates that they sacrifice thermoregulatory precision in lower quality environments. This is indicated by the cost-benefit analysis presented. The ability of bearded dragons to thermoregulate shows that they are a much more evolved species than originally thought by researchers and scientists.

Color Discrimination

The ability of an animal to see color is not a common feature they possess. Due to this, the presence of the ability to see color would give the animal an adaptive advantage to discriminate between objects in their habitats. An organism must have different classes of photo receptors in the retina and the appropriate neuroreceptors to analyze outputs from them in order to possess color vision (Hereha, 2012, p. 29). Achromatic mechanisms allow an organism to perceive an object’s brightness by using a summation of photoreceptor outputs, while chromatic mechanisms compare the outputs to give the perception of color to an object (Hereha, 2012, p. 29). Achromatic contrast would be more useful for an organism to have to be able to detect motion. Chromatic contrast would be useful to help an organism recognize a food source.

In 1914, Karl von Frisch first showed that bees have color vision using his grey card experiment (Hereha, 2012, p. 29). He trained honeybees to associate a reward of sugar water with a color (blue). He then put thirty different colored chips in front of the bees to see if they could pick out the color card that they associated with their reward. If bees possessed an achromatic mechanism, then they would commonly mix up the blue colored chip with one of the grey chips because the intensity matched. His demonstration later inspired more studies to be tried on different species and organisms (Hereha, 2012, p. 29). In 2001, Fleishman and Persons displayed different color flag stimuli against varying color backgrounds to study the visual fixation of anole lizards (Hereha, 2012, p. 30). Their study found that the brightness contrast between the background and the flag was the major factor that influenced stimulus detection, which was mediated by achromatic mechanisms. Chromatic contrast also played a role in increasing levels of detection across all contrasts of brightness and when no brightness contrast was present (Hereha, 2012, p. 30). Anoles possess an elaborate visual communication system that relies on the extension of their dewlap, which is a fan structure attached to their throats (Hereha, 2012, p. 30). They appear to rely on this mechanism to recognize others of their kind to avoid fights or for mating purposes. Due to this, chromatic mechanisms have been identified as the likely method that they use since brightness levels change with lighting (Hereha, 2012, p. 30).

To further study the use of chromatic mechanisms by lizards, a study was done on bearded dragons that tested their ability to associate a color (green) with a food reward and be able to discriminate between several colors regardless of color intensity differences (Hereha, 2012, p. 30). Before this experiment, little research had been done on this species related to their visual system and the significance of color vision for bearded dragons. A study completed on eastern bearded dragons showed that dermal color changes occurred during fights between males. It showed that during the peak of the fight the males lightened in color, while they darkened towards the end, especially in the male who was defeated (Hereha, 2012, p. 31). In 2008, a study by Velasco and Tettershall showed that central bearded dragons (*Pogona vitticeps*) also had the ability to modify skin coloration, which showed darkening in lower temperature and lighting situations (Hereha, 2012, p. 31). Both of these studies show a change in the brightness of the bearded dragon subject, which could be interpreted theoretically using achromatic neural mechanisms.

In addition to the behavioral experiment that was done with associating color with a reward, the photoreceptors were also analyzed. One of the few studies to analyze photoreceptors on lizards was done in 2000 by LeBas and Marshall on a relative of the bearded dragon, the ornate dragon. It revealed the presence of yellow oil droplets at wavelengths shorter than 520 nm and colorless oil droplets at wavelengths between 350 and 700 nm, which indicated no absorption occurred (Hereha, 2012, p. 32). There were three photoreceptors identified, which showed peak absorption at 440, 493, and 571 nm (Hereha, 2012, p. 32). They proposed that ornate dragons may possibly use spectral reflectance (within the UV range 370 to 400 nm) located on the female's throat for mate choice, which would require a UV cone (Hereha, 2012, p. 32). Due to this, researchers wanted to test if bearded dragons possessed a UV-sensitive cone based on the results of their distant relatives.

For this experiment, four captive bred bearded dragons were used. One of the bearded dragons was acquired earlier than the rest and successfully learned the color discrimination behavior, which led to this study being conducted (Hereha, 2012, p. 32). The lizards were kept in a 12 x 12 x 12-inch cage with plexiglass front, screen top, and white plastic walls. There was a natural daylight halogen bulb as a light source that was mounted six inches above the cages. They were kept on a consistent schedule of twelve hours of daylight and twelve hours of nightlight, with the daylight temperature being kept at 80°F. They were fed daily during the week and had a diet of phoenix worms and chopped lettuce dusted with calcium. The phoenix worms were later used as the reward for the behavioral experiment. A 1-inch green paper chip glued to a hollow plastic hemisphere was used as the stimulus for the bearded dragons (Hereha, 2012, p. 33). The 1-inch chips were used with the first bearded dragon and were replaced with 1.5-inch chips as he became larger in size. The color of the chips was obtained from the Munsell color standard chart that is based on human perception of brightness (Hereha, 2012, p. 33). This chart was used based on the expectation that bearded dragons would react similarly to humans in relation to spatial sensitivity. Chips of different brightnesses were chosen randomly for each bearded dragon for each training trial.

The bearded dragons were fed out of a grey block with round holes on opposite sides. The reward was located on either side of the block, which was chosen with a coin flip. The first training phase consisted of placing a live worm in the hole with the green stimulus attached to the wall behind the hole. They were then given eight minutes to find the worm successfully. Once this phase was completed six times consecutively within the given time, they moved onto the next phase (Hereha, 2012, p. 35). This phase consisted of placing a dead worm in the hole with the green chip attached behind it. They were given eight minutes to successfully find the worm and could proceed to the next phase after six consecutive trial passes. The third phase consisted of placing a dead worm in the hole and partially covering it (less than 50%) with the green chip. The fourth phase consisted of covering the hole with the dead worm more than 50%. The last phase consisted of the hole being fully covered with the lizard needing to somehow uncover the hole to reach the dead worm (Hereha, 2012, p. 35). Once they successfully passed all of these phases, the chip color was changed. The test stimuli had shorter or longer wavelengths than the green chip previously used. Colors that were contrasting to the green (such as red and blue) were placed on the hole on the opposite side of the block and the lizard had to discriminate between the colors and move the green chip for the reward (Hereha, 2012, p. 35). After they could successfully complete these phases, the actual experiment could begin with more like colors to green.

For the first experiment, lizards were given a choice between a green trained stimulus of varying brightness (1A, 1B, or 1C) and a test stimulus of another color that had a longer wavelength than green (Hereha, 2012, p. 36). The brightness of the test stimuli was the same as 1B of the trained stimuli. The combinations used and the side of the block they were placed on were randomized using a spread sheet. A control test was also done by placing a worm under the test stimulus instead of the trained green stimulus. This was done to examine if bearded dragons actually respond to color or qualities of the worm after being killed and if they could complete the task in eight minutes or less (Hereha, 2012, p. 36).

The second experiment used the same test and trained stimuli, but the light levels inside two bearded dragon’s cages were lowered using a filter and a diffuser. They were given ten minutes to acclimate before the experiment began. The first bearded dragon lost the ability to find the reward and had to be retrained prior to the start of the third experiment, which tested normal to short wavelength test stimuli (Hereha, 2012, p. 37). The test stimuli were switched to a blue color with the same intensity as the trained green color.

Three juvenile bearded dragons were used to analyze their photoreceptors. This was tested using microspectrophotometry (MSP) and mRNA analysis for the expression of visual pigments and oil droplets (Hereha, 2012, p. 37). This portion of the experiment was completed by Dr. Ellis Loew at Cornel University on the bearded dragon’s retina.

The results of the normal light and long wavelength test stimuli experiment showed that bearded dragon 1 was above average for discriminating between the green trained stimuli and the test stimuli (colors 4, 5, and 6). This bearded dragon was not above random in selecting the trained stimulus and deciding between 1’s versus 2B (Hereha, 2012, p. 38). The bearded dragon showed an 80% pass rate when the test stimulus was colors 4, 5, and 6. Bearded dragon 2 was significantly above random for discriminating between the test stimuli (4, 5, and 6) and the green trained stimuli (1A, 1C, and 1B), but was not above random for 1’s versus 2A (Hereha, 2012, p. 38). This bearded dragon also showed an 80% success rate when the test stimulus was 4, 5, and 6 regardless of brightness. They also analyzed the results based on the different brightness of green. Bearded dragon 1 showed discrimination at above random for 1C versus 2B and chose the

1C trained stimulus in ten out of twelve trials (Hereha, 2012, p. 38). The bearded dragon was not above random for discriminating between 1B versus 2C and 1C versus 2B and favored test stimulus 2B over trained stimulus 1C in nine out of twelve trials (Hereha, 2012, p. 38). Bearded dragon 2 was above random when discriminating between 1A versus 2B but was at chance level when discriminating between 1B versus 2B and 1C versus 2B.

For the low light and long wavelength test stimuli experiment, bearded dragon 2 showed above average results for choosing between the green trained stimuli (1A, 1B, and 1C) and test stimuli 4, 5, and 6 (Hereha, 2012, p. 44). The bearded dragon was not above random for choosing between 1's versus 2B. The choice of trained stimulus 1A was above random when discriminating between 1A versus test stimuli 4, 5, and 6, but was not significant when discriminating between 1A versus 2B. The choice between 1B and test stimuli 4, 5, and 6 was significantly more probable than random with a 29:40 ratio (Hereha, 2012, p. 44). The discrimination between 1C and test stimulus 5 was above average but was not above random for 1C versus test stimuli 4 and 6 and 1C versus 2B with a 28:40 ratio.

For the normal light and short wavelength test stimuli experiment, bearded dragon 1 was above average when discriminating between trained stimuli (1A, 1B, and 1C) and test stimuli 9, 10, and 11, but was not above average when discriminating between 1's versus test stimulus 8 (Hereha, 2012, p. 47). Bearded dragon 2 was significantly above random when choosing between the trained stimuli and test stimuli 7, 8, 9, and 10 (Hereha, 2012, p. 47). Out of thirty trials, bearded dragon 2 only made four mistakes with test stimulus 8 and had a perfect score for the test stimuli 9, 10, and 11. Bearded dragon 1 was above random when choosing between trained stimulus 1A versus test stimulus 11 but was not above random when choosing between 1A and test stimuli 8, 9, and 10. The bearded dragon was above average for picking between test stimuli 1B and 1C versus test stimuli 9, 10, and 11 and was below average when picking between them and test stimulus 8 (Hereha, 2012, p. 48). Bearded dragon 2 was significantly above average when choosing between 1A, 1B, and 1C and the test stimuli 8, 9, 10, 11 except when choosing between 1B and test stimulus 8.

Based on the results from the trials, researchers concluded that bearded dragons demonstrated the use of color vision. The results that were achieved could only occur if the bearded dragons had the ability to use chromatic neural mechanisms (Hereha, 2012, p. 48). Based on the way the experiment was designed, the lizard would get close to half of the trials wrong if they were making a choice based on the brightness of the stimuli used (Hereha, 2012, p. 48). The brightness of the test stimuli was matched to the brightness of trained stimuli 1B, which would cause brightness irregularities to be seen in the data due to the use of achromatic pathways even if the contrast between the stimuli was high. The data indicated that bearded dragon 1 seemed to develop a preference for choosing the brighter stimuli when the chromatic contrast was small (Hereha, 2012, p. 48). This can be seen when the lizard made more mistakes when using the 1A trained stimulus, but when the chromatic contrast was higher, the bearded dragon was completely successful. Bearded dragon 2 appeared to have developed a preference for the darker stimuli used in the experiment. Bearded dragon 2 also had more errors at low light levels than other parts of the experiment but was still above random for choosing against test stimuli 4, 5, and 6 (Hereha, 2012, p. 48). The decreased light levels reduced success of the lizard, which indicated that a small decrease in light would not impact the visual system much but did impact the success of the trials. The low light also caused more errors with the experiment. Bearded dragon 1 lost the trained behavior and had to go through the training trials again. The lizards would also often hide or sleep when the filter was placed over their cages (Hereha, 2012, p. 53).

It also caused them difficulty when finding the reward and they would often miss the holes or not see them entirely. It can be inferred that due to their desert dwelling nature, bearded dragons require a specific level of light intensity to stay active and have optimal vision.

The trained stimulus that had the closest chromatic contrast to the test stimulus provided a challenge for both bearded dragons. The normal light with short wavelength test stimuli experiment was the only one where the bearded dragons were able to discriminate between 1’s versus 8. Bearded dragon one had more difficulty and was only successful in a 13:30 ratio, while bearded dragon 2 was much more proficient (Hereha, 2012, p. 54). This could be related to bearded dragon 1 having to be retrained or bearded dragon 2 became more proficient at the behavior after the low light experiment. The data still provided enough evidence to say that bearded dragons have the ability to reliably discriminate objects based on color, depending on the brightness threshold (Hereha, 2012, p. 54). Due to the way the experiment was setup, it was difficult to be able to quantify the threshold at which two colors are chromatically distinguishable for the bearded dragons (Hereha, 2012, p. 54). Scientists would argue that an energetically expensive trait that an animal possesses, which is not necessary for survival, would be lost over time. This is leading researchers to believe that this trait in bearded dragons is low in energy cost or is essential for their survival, even if that reason is not yet known. Many theories researchers have about reptiles and color vision are still waiting for more studies to be completed to learn more about this unique trait they possess.

Social Learning

The ability to learn through imitation of others has always been perceived as a trait that only humans possess due to their higher intelligence. Through research and studies, it has been discovered that both mammals and birds are capable of this as well as humans, but the ability in reptiles was relatively unknown until recent studies. Imitation is considered to be cognitively complex due to the imitator having to acquire the information, draw inferences about the behavior, the constraints of the situation, and the intentions and goals of the action (Kis et al., 2014, p. 325). Reptiles and mammals evolved from a similar amniotic ancestor and being able to understand the similarities and differences in their cognitive behavior is essential for understanding their evolution (Kis et al., 2014, p. 325). Recent studies within the reptile field have yielded promising results that indicate they possess sophisticated abilities. They have discovered that the red-footed tortoise is capable of gaze following and can learn to solve a task that appears unsolvable by observing the actions of another tortoise (Kis et al., 2014, p. 326). The Florida redbelly turtle is able to learn to approach a visual object cue by watching other turtles complete this task (Kis et al., 2014, p. 325). Young male skinks have also demonstrated the ability to learn the instrumental task of displacing a lid quicker by watching others than without (Kis et al., 2014, p. 325). The findings of these studies indicate that reptiles do possess the ability to use social information, but the way they do this and the mechanisms that control their behavior is still unclear to researchers.

The University of Lincoln did a research study that used a bidirectional control procedure to test if bearded dragons were capable of imitating another of the same species. The model involves comparing the performance of two groups of observers (bearded dragons) watching demonstrations by another bearded dragon that differ in their body movements, but create the same environmental changes (Kis et al., 2014, p. 326). Imitation occurs when the demonstrated action occurs more often than an alternative action and can be measured by considering what the outcome of the action will be or the details of the specific behavior performed (Kis et al., 2014,

p. 326). For this study, they considered a successful imitation a combination of producing the same outcome and performing the same behavior as the demonstrator.

The bearded dragons belonged to either the university or private owners but were kept at the university during the entirety of the study. The study pool consisted of five male and seven female bearded dragons with an age range of one to three years old. A three-year-old female was chosen to be the demonstrator due to the possibility that the males would respond aggressively to the video demonstration if a male was used (Kis et al., 2014, p. 326). None of the lizards had been previously used for cognitive testing and they were handled daily by caregivers. The twelve subjects were divided into two experimental groups and one control group (Kis et al., 2014, p. 326). The experimental arena (100x40x50 cm) was divided into a test area where the subjects were kept and the demonstration area where a computer screen was set up. The testing apparatus was a 40x40 cm board with a 12x12 cm hole that was covered by a wire door that could be moved by sliding rails in front of the board left or right (Kis et al., 2014, p. 326). This could be achieved by using either their feet or their heads to move the rails.

The demonstrator lizard was trained to open the wire door by using shaping and trial and error techniques for a three-week period (Kis et al., 2014, p. 326). She was given a habituation period to allow her to explore the enclosure and eat mealworms from a dish before the test apparatus was placed inside the arena. First, she was trained to go through the hole with the wire door completely open to get a worm placed on the other side. Gradually the door was closed until she could successfully complete the test. She was given access to the apparatus for one hour for each session until she could solve each step of the experiment (Kis et al., 2014, p. 326).

For the experimental procedure, the bearded dragons were given habituation time in the arena before the onset and were considered habituated once they ate and explored their area readily. Once the habituation phase was finished, they were shown an eleven second video for the demonstration phase. The video showed the female approaching the test apparatus, opening the door with a sliding head movement, and going through the now opened door. To ensure they learned about the behavior and not just simply moving the door towards or away from the hole, the demonstrator was trained to open it from one direction and the subjects were shown a mirror image of the demonstration (Kis et al., 2014, p. 326). In the control group, the demonstration video showed the bearded dragon standing in front of the door and the door opening by itself to the right side. Neither video showed the demonstrator being rewarded with a mealworm.

After the demonstration, the subjects were moved to the experimental section of the arena and the test apparatus was placed in front of them (Kis et al., 2014, p. 327). They were given free access to the test apparatus for five minutes while their behavior was being recorded. They were returned to their cages after they successfully opened the door, or the five minutes was up. If the lizards were not able to get the mealworm behind the door, then they were not rewarded, even if they were able to open the door (Kis et al., 2014, p. 327).

The results showed that all experimental subjects were able to successfully open the door, while none of the control subjects were successful (Kis et al., 2014, p. 327). On their first successful trial, all eight of the bearded dragons opened the sliding door the same way the demonstrator did in the video they were shown. This preference for opening from the demonstrated side was present throughout the entire experiment with 67-100% (Kis et al., 2014, p. 327). There was considerable individual variation present with the number of successful openings ranging from 2/10 to 10/10 and the first successful opening varied from trials one to five (Kis et al., 2014, p. 327). Also, the number of successful lizards in a trial was not related to the number of trials previously administered. There was no change in the number of successful experimental subjects in the first or second trial conducted during the day. All subjects in the control group and all but one subject in the experimental group had trials where there was no contact with the wire door and the three groups did not differ in the average number of contacts with the test apparatus (Kis et al., 2014, p. 329). In the trials when they did touch the wire door, the lizards appeared to make more contact in their successful trials compared to their unsuccessful trials, but the number was not significant. The three groups did not seem to have a bias towards how often they contacted the left or right side of the apparatus. They also showed no individual difference in the side bias in successful or unsuccessful trials (Kis et al., 2014, p. 329). The main difference between the control group and the experimental group was that no subjects in the control group showed the sliding head movement like everyone in the experimental groups did (Kis et al., 2014, p. 330). Since this was the movement the demonstrator did to open the wire door, it can be inferred that the experimental group were mimicking her behavior. There was also more sliding door movement in the successful trials than the unsuccessful trials (Kis et al., 2014, p. 330).

These results show evidence that bearded dragons are capable of using social information to learn through imitation. This is further supported by the specific direction that they used to open the wire door and the observation of the opening behavior being present in the experimental group but not the control group. There was some consideration to the fact that the lizards were exposed to multiple experimental trials, which raised the possibility of individual learning contributing to the performance. However, no association could be found that linked the performance to the number of trials completed, which suggests that this is unlikely (Kis et al., 2014, p. 330).

In previous literature, imitation has been defined as the learning of an action by watching it be performed and copying the action. The behavioral analysis of the experimental group has shown that they were capable of watching a demonstration and reproducing the action observed. This action was not observed in the control group who did not view the demonstration. The findings observed in this study suggest that bearded dragons exhibit complex cognitive behavior that has been previously shown in humans and birds.

Another study about social learning in bearded dragons focused on how their incubation temperatures influenced phenotypical and behavioral traits. They used two groups of bearded dragons that were incubated at different temperatures (within the normal range for the species) and were scored on their ability to complete a social learning task.

The less complex forms of social learning are social and local enhancement where information is learned from another animal (Arndt & Wilkinson, 2017, p. 3). Stimulus enhancement involves drawing an observer's attention to a demonstrator and to a stimulus to provoke an interaction with it. An example of this behavior was seen in the 1920s in England when blue tits opened milk bottle tops to get to the inside contents by using foraging behaviors like tearing and pecking (Arndt & Wilkinson, 2017, p. 3). Others of the same species saw this behavior and it spread through the population, although it was not considered imitation since no specific action was learned. It was instead considered a form of stimulus enhancement due to the birds being attracted to the lids and learning which object to interact with (Arndt & Wilkinson, 2017, p. 3). Local enhancement is where the observer's attention is drawn to a specific location. An example of this is that rats have been found to have a preference to search for food in locations where rat excrement is found due to it meaning that the food is safe to consume (Arndt & Wilkinson, 2017, p. 3). For local and stimulus behavior, a demonstrator is not necessary since no specific action is being learned. The most complex form of social learning is imitation (intentional or true imitation), due to the level of control required to reproduce an action. This behavior has been difficult to test due to the number of factors that can influence the results. When interpreting the behavior it is hard to tell if the animal is copying the demonstrator or is intentionally imitating them. The subject could also come to rely on trial and error instead of actually learning the behavior.

Reptiles have been a focus group for cognitive and behavioral studies in recent years and there is evidence that shows several cognitive behaviors including spatial, visual, and social cognition (Arndt & Wilkinson, 2017, p. 4). The most studied cognition in reptiles is spatial. It has been shown that turtle and tortoise species are capable of using spatial cognition to navigate through a maze (Arndt & Wilkinson, 2017, p. 4). Studies done on reptiles have shown that even solitary species, like the bearded dragon, are still capable of social learning. Other species of reptiles have been shown to be capable of behavioral flexibility that allows them to adapt their behavior to respond to unfamiliar or familiar stimuli, which was a trait believed to only be present in birds and mammals until recent studies like the one mentioned earlier. Earlier researchers thought that only birds and mammals needed to be capable of adapting their behavior to food source changes, but a study conducted on anole lizards showed they were capable of adapting to food source changes and were also able to solve motor tasks as well as associative and reversal learning (Arndt & Wilkinson, 2017, p. 4). Monitor lizards were shown to be successful at opening a feeding tube they were presented with during three experimental trials. After receiving their first prey, they showed significant improvement and fewer unnecessary tries to open the tube correctly after the first trial (Arndt & Wilkinson, 2017, p. 4). This showed that reptiles are capable of social learning and opened the gateway for future cognitive studies on other species of reptiles, including bearded dragons.

The earliest stages of an animal's phenotypic development are mostly shaped by its environment, especially in species who develop outside of the mother's body (Arndt & Wilkinson, 2017, p. 5). The previous studies on reptile eggs were focused on morphological differences, which have been shown to occur in laboratory and natural settings suggesting there is a need for phenotypic plasticity in both environments. More recently there has also been research conducted on the cognitive development of reptiles and how incubation temperatures can play a role. Studies conducted on the keelback snake found that many of the examined traits were affected by their incubation temperature, with faster, longer swimmers, and larger offspring coming from the group that was cold incubated (Arndt & Wilkinson, 2017, p. 5). A paper that recently came out focused on the brain size of the scincid lizard. They found that lower incubation temperatures produced lizards with larger telencephalons and larger neurons in the medial cortices, but neural density was higher in the hot incubation group (Arndt & Wilkinson, 2017, p. 5). A higher neural density can lead to more potential synaptic connections, which is thought to correlate to higher intelligence levels.

An aspect of cognitive behavior that may be influenced by incubation temperatures is social learning. Incubation temperatures have been shown to influence morphological traits, including personality and physical capabilities, so it is not far fetched to think that it would also affect their social learning behavior (Arndt & Wilkinson, 2017, p. 5). A study by Amiel et al. in 2016 showed how environmental factors influence brain development and the impact it could have on cognitive skills. Based on this research, a study was conducted on bearded dragons to compare the incubation temperature with social learning and cognitive abilities.

The test subjects for this study were the same thirteen bearded dragons used in the study previously mentioned at the University of Lincoln. Each vivarium had a shelter, water bath, branches, heat light, and UVB light. The lizards were randomly assigned either the hot (86° F) or cold (80°F) incubation temperature with six bearded dragons being used for the cold and seven for the hot (Arndt & Wilkinson, 2017, p. 8). The cold incubated lizards were hatched between May 30th and June 1st and the hot incubated lizards were hatched between July 1st and July 8th. All bearded dragons received daily handling and the same demonstration video was used as in the previous study mentioned with the female bearded dragon.

The experimental arena (120 cm x 41.5 cm x 51 cm) was divided in two by the test apparatus into the test area and the demonstration area (Arndt & Wilkinson, 2017, p. 8). The test apparatus was a wooden board placed in the middle of the arena that had a horizontally sliding door with vertical bars in front of the hole, which could be opened to the left or right side. The demonstration area had a computer monitor to show the demonstration video and the test area had a camera to observe their behavior. All of the lizards were habituated to the environment before the experiment began. They were considered habituated when they readily explored and ate mealworms from a petri dish (Arndt & Wilkinson, 2017, p. 8). They were also given two ten-minute trials for two days to explore the arena.

Each lizard completed a total of ten trials for this study. They were given time to habituate for thirty seconds and then they were shown the demonstration video of a bearded dragon opening the horizontal sliding door to the right or left using a specific head movement (Arndt & Wilkinson, 2017, p. 9). They were assigned to watch either the left or right opening demonstration depending on which incubation group they were in. Once the video was done, they were moved to the test area and the apparatus was put into place. The subjects had five minutes to open the door and access the mealworm reward and the trial was terminated when they either completed the task or the time limit was over (Arndt & Wilkinson, 2017, p. 9).

In the successful trials where the door was opened and the lizard ate the mealworm, the time it took for the door to be opened was significantly lower for the cold incubated group than the hot incubated group (Arndt & Wilkinson, 2017, p. 10). The average for the hot incubated group was 225 seconds (3.75 minutes) and was 140 seconds (2.33 minutes) for the cold incubated group. There was no significance between the cold and hot incubated groups in terms of opening the test door, but the cold incubated group appeared to open the door and find the reward more often within the trial time (Arndt & Wilkinson, 2017, p. 10). There was also individual variation in the number of successful trials, with some having none and some having all successes. Most of the lizards completed their first success within trials one to three, except for the ones who did not have any successful ones. The hot incubated group had an average of three partially completed trials while the cold incubated group had an average of seven partially completed trials. The average number of completed trials for the hot incubated group was two and the average for the cold incubated group was five (Arndt & Wilkinson, 2017, p. 12). The interactions the lizards had with the door using their head or claws were also calculated but showed no real difference between the hot and cold incubated groups. The hot incubated group showed an average of seventy interactions per trial and the cold incubated group showed an average of ninety interactions per trial.

This study observed the difference in social and cognitive behavior between two groups of bearded dragons who were incubated at a hot or cold temperature. This was tested by showing them a demonstration video and testing if they could complete the same door opening action the demonstrator completed. The results showed a definite difference between the social learning behavior of the bearded dragon subjects. The cold incubated group was significantly faster in completing the task than the hot incubated group. The cold incubated group was also more successful in opening and going through the door to get the mealworm reward than the hot incubated group. There was not a difference in motivation between the different groups, as shown with the minimal difference between the number of head or claw interactions with the door. This indicates that the reason for solving the task was cognitive and not due to a difference in motivation. Previous research showed that bearded dragons incubated at warmer temperatures were faster runners and showed better foraging behavior, while this study indicated the cold incubated lizards showed better social learning behavior (Arndt & Wilkinson, 2017, p. 14). This could indicate that colder incubated bearded dragons invest more time into observing and learning to be more effective at foraging, but no conclusive studies can be drawn from this information alone. Another study on scincid lizards showed better performance in spatial learning tasks when incubated at hot temperatures. It is likely that different lizard species experience different effects from incubation temperatures. Even though the cold group was more successful, both groups of bearded dragons had success in this trial with opening the door and getting the reward. Due to the results, it can be inferred that colder incubated bearded dragons may be more intelligent than others, but more testing would need to be done before any more conclusions about the species can be made.

Perception of Visual Illusions

Optical illusions have been commonly used to test the visual perceptions of vertebrates because they can reveal how the system is able to adapt to visual input (Agrillo et al., 2019, p. 419). Optical illusions are suggestive interpretations that differ from physical stimulation and are being used to investigate animal visual perception. These tests allow researchers to see if different animal species interpret visual inputs as humans do and whether they detect visual inputs with any variability (Agrillo et al., 2019, p. 419). The investigation of different species can also help researchers to determine the environmental and evolutionary impact on visual perception. The majority of testing so far has focused on mammals and primates. Some of the species tested, such as pigeons and bantams, showed a human-like perception of visual illusions, while others experienced a reverse illusion that was the opposite of human observations. Some species, such as rhesus monkeys and bamboo sharks, did not perceive the illusion at all. A study on the Ebbinghaus illusion (relative size perception) on bantam chickens showed that 4-day-old chicks perceived the illusion in a human-like direction, while a study done on 6-month-old chickens concluded the opposite (Agrillo et al., 2019, p. 420). This shows evidence that different methods of investigating illusion sensitivity can lead to different results in the same species of animal.

Unlike mammals, reptiles have yet to be studied extensively on how they perceive visual illusions, including the bearded dragon. Previously, they were thought to be unintelligent and sluggish, but previous studies on their cognitive abilities have proven this way of thinking to be false. Recent studies have also shown that bearded dragons and red-footed tortoise are able to perceive similarities between pictures and the objects they represent, respond to video stimuli, and discriminate between different quantities of a food reward (Agrillo et al., 2019, p. 420).

A joint study conducted by the University of Padova and the University of Lincoln tested how the red-footed tortoise and bearded dragons perceive one of the most famous geometrical illusions, the Delboeuf illusion. The simplest version of this illusion consists of two identical circles near each other, with one encircled by a circle with a smaller circumference and the other with a circle with a large circumference. Humans will perceive the former as larger than the latter even though they are both the same size (Agrillo et al., 2019, p. 420). Chimpanzees were shown to overestimate the size of the circle when surrounded by a circle with a smaller circumference. Another version of this illusion used with chimpanzees replaced the target circles with food portions. They often overestimated the dimension of the food portion in the smaller array and underestimated the dimension of the food portion in the larger array (Agrillo et al., 2019, p. 420).

Even human perception of food size has been influenced by this illusion. They tend to overestimate food portions when it is presented on a smaller plate (Agrillo et al., 2019, p. 420). The food portion presented on the smaller plate appears to assimilate to its contours, which leads it to be perceived as larger than it actually is, while the larger plate is often perceived as smaller than it actually is. In order to conduct this test on reptiles, they used the same spontaneous choice procedure followed with the chimpanzees (Agrillo et al., 2019, p. 420). Animals are believed to exhibit their natural behavior that reflects their cognitive and perceptual functions when faced with a spontaneous choice test. However, extensive training procedures could lead to performances beyond the norm for the species through experience and recruitment of other neural networks to accommodate the requirements of the specific cognitive task (Agrillo et al., 2019, p. 420). If reptiles (bearded dragons and red-footed tortoise) perceived this illusion in the human-like way, then they would choose the reward on the smaller array.

This experiment was conducted on eight red-footed tortoises (five females and three males) and twelve bearded dragons (eight females and four males) that were housed at the University of Lincoln (Agrillo et al., 2019, p. 421). The tortoises were housed in a room kept at 68°F and the bearded dragons were housed in glass terrariums. All of the animals had a constant supply of water, food, shelter, UV lights, and heat lights during the experiment. None of them were withheld food, but it was also used as a reward for the trials. They were handled on a daily basis and none of them had previously been used for cognitive studies. The stimuli used in the trials was mango jelly for the tortoises and vegetable extract jelly for the bearded dragons. They were cut with a circular round cutter to maintain a consistent size and shape. Each jelly was placed in the middle of a 7.5 x 8.5 cm black plastic card. The card had a central white circle that represented the plate (Agrillo et al., 2019, p. 421). The larger plate used had a diameter of 4.92 cm while the smaller plate had a diameter of 1.83 cm. The reptiles were also presented with two different size food portions that were 1.5 cm and 1.23 cm in diameter (Agrillo et al., 2019, p. 421). The card was presented on an L-shaped steel bracket to improve the subject's viewpoint. The experiments were conducted in a 100 x 100 cm arena that had an inclined ramp with the food and cards placed at the bottom so they could view them easier.

Before the test phase started, each animal received a familiarization phase with a single card containing some of the jelly in the center of the arena (Agrillo et al., 2019, p. 421). This allowed them to habituate to their environment and ensure they would eat in the arena before the trials were conducted. The test phase began after they were all habituated. This phase consisted of twelve sessions with four trials each and 48 trials total. Each reptile received two sessions daily and were given at least one hour between sessions. Control trials were performed to test their motivation to choose the larger food portion. Control A was given two different sized portions of jelly on small plates and control B was given the same but on two large plates.

In the test trials, the subjects were given two of the same size jelly portions with one on the small plate and one on the large plate (Agrillo et al., 2019, p. 421). The ratio between the area with the jelly and the smaller plate was 0.67, which is a commonly used ratio in human illusion experiments (Agrillo et al., 2019, p. 421). The positions of the larger and smaller plates were switched for each trial and each was recorded and analyzed. They defined the reptile's choice as the jelly that they first touched. A concern was that the bearded dragons had learned to avoid as much of the white border on the cards as possible. In order to assess if they had learned to choose the configuration with less white, they arranged an additional control test group. The lizards were presented with two different sized food portions on the card, but the white circles were absent (Agrillo et al., 2019, p. 422).

The results of the test control group showed that nine out of twelve bearded dragons in control group A selected the larger food portion and five in group B also selected the larger portion (Agrillo et al., 2019, p. 423). In control group C, six out of nine bearded dragons chose the larger food portion as well. This group was also tested to see if they learned to avoid the white on the cards. When they were presented with a larger and smaller food portion without the white plates, eight of the lizards still chose the larger portion (Agrillo et al., 2019, p. 423). This showed that they were not motivated to avoid as much white as possible but were instead focused on the stimuli (food reward) presented on the cards. (Agrillo et al., 2019, p. 421). Control group A and B of the tortoises showed only two and one subject selecting the larger plate. The group analysis showed a lack of significant preference for either portion size in both control trials (Agrillo et al., 2019, p. 424). This lack of preference continued into the experimental trials for the tortoises. This revealed that bearded dragons were susceptible to the visual illusion while tortoises were not.

The experimental trials in this experiment showed that bearded dragons perceive visual illusions, likely in a similar way to humans based on the Delboeuf illusion used in this study. This indicates that some reptiles can interpret and alter visual input related to an object's size as previously found in chimpanzees, dogs, birds, fish, and humans. This suggests the existence of assimilation and contrast phenomena in reptiles, which could mean that these perceptive mechanisms are more widely present in the animal world than previously thought (Agrillo et al., 2019, p. 425). This study also found that red-footed tortoises did not perceive the visual illusion and did not maximize their food intake. Due to these results, no conclusions could be made about their perception of the Delboeuf illusion from this study alone. As more studies are done in the future, hopefully more will be learned and discovered about how reptiles perceive visual illusions, but this study does show intriguing possibilities for reptile perception and intelligence.

REM Sleep

Researchers have concluded that animals ranging from invertebrates to humans sleep. The electrophysical characteristics of sleep, such as slow-wave (SW) and rapid eye movement (REM) activities have been thought to only be present in mammals and birds. The principal characteristic of sleep, which is called behavioral sleep, is shared by many invertebrates and vertebrates (Shein-Idelson et al., 2016, p. 590). Some of the first electrophysiological studies of sleep were conducted on humans and revealed electroencephalographic (EEG) correlates of brain states during sleep, including slow-wave and rapid eye movement sleep (Shein-Idelson et al., 2016, p. 590). It is thought that these sleep activities may be ancestral to mammals and birds, which has led researchers to believe they may then be present in non-avian reptiles.

A study was conducted in 2016 on bearded dragons due to their ancestry being the most distant from avian species. They surgically implanted five bearded dragons with either tetrode arrays or linear silicon probes in the dorsal forebrain (DVR) and allowed them to recover (Shein-Idelson et al., 2016, p. 590). They recorded extracellular electrical activity (local field potential) continuously for eighteen to twenty hours during the night and combined behavioral monitoring with electrophysiology. These recordings were repeated for each animal for several days to weeks.

The local field potential recordings from the dorsal forebrain during the behavioral sleep showed a slow oscillation and negative deflections of various amplitudes (Shein-Idelson et al., 2016, p. 590). The local field potentials were broken down into clustered segments of low frequency activity and clustered segments of broadband activity, which were closer to activity in the awake state of the lizard. During a six-to-ten-hour duration, beginning after being exposed to darkness and ending one to several hours before daylight, the low frequency to broadband activity ratio oscillated regularly and continuously with an average of an eighty second period (Shein-Idelson et al., 2016, p. 590). They called this period E-sleep (electrophysiological sleep) and it began shortly after the onset of behavioral sleep and ended thirty minutes to several hours before behavioral sleep ended. In all of the lizards, E-sleep represented a majority of their behavioral sleep time (Shein-Idelson et al., 2016, p. 590). Also, the period of low frequency to broadband activity oscillation was temperature dependent. Bearded dragon 1 had a beginning temperature of 77°F and greater than 100 second intervals. The temperature was then brought up to 80.6°F and the interval dropped to 60 seconds. During a single night at a constant temperature, the oscillation interval increased slowly by two seconds per hour on average (Shein-Idelson et al., 2016, p. 590). The amplitude of the oscillation tended to increase at the beginning and decreased towards the end of the night but had wide variations in between those times.

The low frequency power reflected the repeated occurrence of large negative reflections of low frequency potential at a rate of less than one per second (Shein-Idelson et al., 2016, p. 590). Filtering of these low frequency potentials revealed that they almost always had bursts of greater than 70 Hz multi-unit activity, which were locked during the descending phase (Shein-

Idelson et al., 2016, p. 590). In comparison to the low frequency and broadband activity studied on rats, the bearded dragons were slower, which is likely due to the temperature difference between the species.

Short-wave sleep in mammals is often accompanied by eye movements, which was also tested on the sleeping lizards. They monitored the eye contralateral to the local field potential recording site using infrared cameras to quantify eye movement using computerized video analysis (Shein-Idelson et al., 2016, p. 590). The results revealed that they did show eye twitching intervals interposed with immobility or slow drift. They measured the phase of the eye movements in relation to the low frequency to broadband activity ratio, which confirmed that they alternated between REM and SWS sleep and that their eye movements are preferentially occur in the quarter cycle before the ratio reaches its minimum (Shein-Idelson et al., 2016, p. 591). The two E-sleep states that bearded dragons experience (low and high low wave to broadband ratios) phenotypically fit with SWS and REM sleep classically defined in mammals and birds. Each of the states continuously alternate in a clock-like fashion, with up to 350 consecutive cycles per night (Shein-Idelson et al., 2016, p. 591). Short wave sleep occupies 50% or under of each cycle on average with the rest of the time being occupied by REM sleep.

The spiking activity that occurred during these states was also examined. DVR frequencies during sharp waves (local field potential) were high but the average SWS rate was zero (Shein-Idelson et al., 2016, p. 591). During REM sleep, the spiking activity was high and reached values similar to values recorded in the awake state. The DVR ripples were concluded to be high-frequency bursts that correspond to sharp waves (high pass) during SWS that occasionally interrupted a silent background (Shein-Idelson et al., 2016, p. 591). Due to the similarity between the sharp-wave ripples found in the rat hippocampus and in bearded dragons, it was originally assumed that the recordings would be centered in the same spot in lizards. Using CT scans and electrolytic lesions followed by histology, it was found that all of the SWS and REM sleep activity originated from the anterior dorsal ventricular ridge (DVR) and not from the hippocampus in the cortex of the brain (Shein-Idelson et al., 2016, p. 591). Even though the activity did not originate in the cortex, they found that right before the onset of a sharp wave the firing probability of neurons in both the DVR and cortex decreased. Activity in the cortex also changed around the individual sharp waves that occurred. The neurons in the cortex decreased before a sharp wave and then increased (Shein-Idelson et al., 2016, p. 593).

They compared the modulation of the firing rates of neurons in the DVR and cortex over both sleep cycles. It was found that both oscillated within the eighty second time frame and were phase-locked with each other (Shein-Idelson et al., 2016, p. 593). The short-wave ripple related firing activities in the DVR and cortex occurred near the low point of the sleep-cycle modulation and the mean firing rates were always higher in the cortex than in the DVR (Shein-Idelson et al., 2016, p. 593).

This study concluded that sleep-related brain dynamics that are similar to REM and SWS in mammals do exist in bearded dragons. This does decrease the probability of their earlier theory that these sleep cycles resulted from convergent evolution among humans and birds. It does suggest that the circuits underlying the electrophysiological signatures of sleep evolved from a common ancestor in amniote evolution before the synapsid- sauropsid bifurcation at least 300 million years ago (Shein-Idelson et al., 2016, p. 593). Even though bearded dragons experience REM and SWS similarly to humans, it is a less complex version, especially in relation to sleep in large mammals. In bearded dragons, SWS and REM alternate throughout the night that can generate up to 350 cycles while sleeping that are eighty seconds each. Humans typically experience four to five ninety-minute cycles while sleeping with more REM cycles than SWS (Shein-Idelson et al., 2016, p. 593). Due to the ancient origin of the areas of the brain associated with sleep in mammals, it is likely that the reptilian brain sleep pattern was an ancestral control system for sleep related brain dynamics. The short-wave ripples in lizards were similar to ones identified in the rat hippocampus. These were also present in the dorsal ventricular ridge in the bearded dragon, which was unexpected due to the medial cortex being assumed previously to be the reptilian equivalent to the mammalian hippocampus. Also, the firing patterns during cortical short waves in the rat hippocampus resembled the cortical firing of DVR sharp waves in the bearded dragon (Shein-Idelson et al., 2016, p. 593). In order for more information to be discovered, more research needs to be conducted on the DVR in reptiles, which is a dominant part of the forebrain, and how it relates to a mammalian equivalent. The existence of sleep-related dynamics in the bearded dragon brain can help illuminate how this species is capable of information processing during sleep in future research and studies. As of now, the only conclusion that can be made is the presence of SWS and REM sleep that was discovered to be present in the bearded dragon, a non-avian reptilian species.

Personal Experience

Over the past ten years, the author has owned two bearded dragons as pets. The author's first bearded dragon was a male who lived to be seven years old and died of unknown causes. The second bearded dragon is a female who is currently three years of age. When the author first got their lizard, they had no idea how much personality they possess and how much they seem to enjoy social interaction. They love to be around people and interact with their environment outside of their enclosures. Their male bearded dragon had many health issues during his life. He was purchased from a pet store and was infested with two types of parasites and had tail rot.

After nursing him back to health, he continued to grow and mature, but he never acted like a regular bearded dragon. He had neurological problems that likely came from an adenovirus that he contracted as a baby from another bearded dragon. His symptoms included balance and instability problems, aspirating when drinking water, lack of depth perception, difficulty catching insects, and immunosuppression. While these issues never impeded on his quality of life due to the care he was given, it definitely made him neurologically impaired. Due to the neurological impairment, he would not have been able to complete the studies mentioned above. Unlike other healthy beardies, his intelligence was not the same and was decreased by his condition.

The author's second bearded dragon was purchased at a reptile convention two years ago when she was nine months old. She has also had numerous health issues that have required two surgical procedures (skin biopsy and ovariohysterectomy), but she is not neurologically impaired. She has never exhibited the symptoms of the adenovirus that their previous bearded dragon likely had and shows increased cognitive awareness and abilities. She is always very aware of her surroundings and is able to see items in front of her and move around them. When it is time to feed her, she is able to easily aim for and grab her prey without missing it (more often than not). She has even shown a preference for a blue colored bowl and will not eat out of any other container. The male bearded dragon showed color preferences also and was always attracted to the color blue as well. He once tried to eat a shag rug that had a blue section on it. Since bearded dragons are very social lizards, she is often let out of her cage to run around. When doing this, she can clearly be seen trying to decide which way to move in the room she is in.

Their female bearded dragon also enjoys walking up to the screen door to our front porch and flattening out her back to bask in the sunlight. The male would do this as well. They both learned this behavior after watching their cat and dog sunbathing at the door. The male would head bob at the cats and even inanimate objects occasionally, which is a dominant behavior they often show in captivity as pets. When he was little, he would arm wave. This is a submissive behavior that younger bearded dragons often display to other animals or more dominant bearded dragons. The female bearded dragon does not use these dominant or submissive motions since she is less defensive and territorial than the male was. Both bearded dragons also showed the ability to recognize a routine and became accustomed to being woken up, fed, let out of their cages, and put to bed at specific times. If this schedule changed, then it took them time to adjust to it.

Even though bearded dragons are a very complicated pet to own with many specific care needs, they have really helped to open the author's eyes to look into the research done on their intelligence. Over the past ten years these are some of the cognitive behavioral activities and instincts that they have noticed their two bearded dragons displaying. These behaviors definitely show that there is more intelligence that bearded dragons possess than what was previously believed by researchers.

Conclusion

Over the past few decades, more and more research has been conducted on reptiles to determine how their intelligence and behaviors compare to humans and primates. The first study discussed focused on the thermoregulatory behavior of bearded dragons. This study concluded that bearded dragons are precise thermoregulators and are capable of maintaining a precise body temperature of 94.5°F and 95.4°F (Cadena & Tattersall, 2009, p. 211). Many of their behaviors including feeding, ability to avoid predators, and embryonic development have shown to be dependent on temperature and would be negatively affected if the lizard could not precisely thermoregulate (Cadena & Tattersall, 2009, p. 211). The second study discussed focused on the ability of bearded dragons to see color and discriminate between two different colors. An apparatus was set up with holes on either side with a food reward being covered by a colored paper circle. The bearded dragon was trained to respond to the test color and was given the choice to choose between the test color and a second color that was different on the other side of the apparatus to get a food reward. Based on the results from the trials, the researchers concluded that bearded dragons demonstrated the use of color vision. The results that were achieved could only occur if the bearded dragons had the ability to use chromatic neural mechanisms (Hereha, 2012, p. 48).

A third study discussed social learning in the bearded dragon through watching an observer bearded dragon open a door to get a food reward and then repeating the action themselves. The results showed evidence that bearded dragons are capable of using social information to learn through imitation. This is further supported by the specific direction that the lizards used to open the wire door (left or right side) and the observation of the opening behavior being present in the experimental group but not the control group. All members of the experimental group were able to successfully open the door after watching the demonstrator, but none of the control group (who were not shown the demonstration) could complete the task. The second study about social imitation focused on how incubation temperatures affected their ability to social learn. Incubation temperatures influence other morphological traits, including personality and physical capabilities, so researchers believed that it would also affect their social learning behavior (Arndt & Wilkinson, 2017, p. 5). The experiment involved incubating bearded dragons at a high and low temperature within the normal range for the species. They were then shown the same demonstration video of the bearded dragon opening the door and were supposed to repeat the action to get a food reward. The results showed a definite difference between the social learning behavior of the bearded dragon subjects. The cold incubated group was much faster in completing the task than the hot incubated group. The cold incubated group was also more successful in opening and going through the door to get the mealworm reward than the hot incubated group. This means there is a correlation between the intelligence of bearded dragons and the incubation temperatures used.

A fourth study focused on how bearded dragons and tortoises perceive visual illusions. A black card contained two white circles. One had a smaller diameter circle around it, and one had a larger diameter circle around it. Food portions were placed on these circles and the subjects chose which plate they wanted the food portion from. The bearded dragons consistently chose the smaller food portion, while the tortoises showed no preference for either size plate. The experimental trials showed that bearded dragons perceive visual illusions, likely in a similar way to humans based on the Delboeuf illusion used in this study. This indicates that some reptiles can interpret and alter visual input related to an object’s size as previously found in chimpanzees, dogs, birds, fish, and humans.

The last study discussed focused on the ability of bearded dragons to enter short wave and rapid eye movement sleep cycles (REM and SWS). This study focused on their brain wave patterns and eye movements during a normal sleep cycle using electrodes placed within their dorsal ventricular ridge. Researchers concluded that sleep-related brain dynamics that are similar to REM and SWS in mammals does exist in bearded dragons, but it is a less complex version than what humans experience. In bearded dragons, SWS and REM alternate throughout the night that can generate up to 350 cycles while sleeping that are eighty seconds each. Humans typically experience four to five ninety-minute cycles while sleeping with more REM cycles than SWS (Shein-Idelson et al., 2016, p. 593).

All of these studies focused on aspects of bearded dragon intelligence that has not been actively studied previously. They all show that bearded dragons possess a higher intelligence level and brain development than previously thought. Without the features mentioned in the studies, they would not have been able to give researchers the results they achieved. While much has been found in recent years, many more studies need to be conducted and analyzed before more definitive results can be made regarding the reason bearded dragons and other reptile species react to stimuli and different experimental situations the way they did in the studies discussed earlier.

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