Using Marker-Based Motion Capture to Develop a Head Bobbing Robotic Lizard

Anna Frohnwieser[1(✉)], Alexander P. Willmott[2], John C. Murray[3], Thomas W. Pike[1], and Anna Wilkinson[1(✉)]

[1] School of Life Sciences, University of Lincoln, Lincoln, UK
{afrohnwieser,awilkinson}@lincoln.ac.uk
[2] School of Sport and Exercise Science, University of Lincoln, Lincoln, UK
[3] School of Computer Science, University of Lincoln, Lincoln, UK

Abstract. Robotic animals are regularly used in behavioral experiments, typically in experimental interactions with individuals of the species they were modelled on. In order to do so successfully, these robots need to be designed carefully, taking into consideration the specific perceptual system of the model species. We used marker-based motion capture to measure head bobbing in a widely popular lizard species, bearded dragons, and found that head bobbing is highly stereotypic yet differs subtly when displayed towards males and females. These results were then used for the construction of a robotic lizard, with the aim to use it in behavioral and cognitive studies, focusing on social cognition. This is the first study to use motion capture of head bobbing in lizards to inform the design of a robotic animal.

Keywords: Motion capture · Robotic lizard · Bearded dragon · Head bobbing

1 Introduction

Recreating realistic animals is a difficult task. Particularly in studies involving the interaction between a robot and real animals, care has to be taken as to how the robot is perceived by the animals. This includes, among other factors the robot's size, coloration, odor and motion characteristics. It is important to consider that each species has a different perceptual system, and therefore human perception alone is not a sufficient indicator of the realism of a robotic animal (see [1]). For example, color perception often differs substantially between different species, and so colors recreated for the human eye may not elicit realistic perceptual responses in the animal species being studied [2]. Careful, well-designed studies should be undertaken to examine the animals' perception of the robot to ensure that it appears as realistic as possible. When developing a robotic animal to mimic the species it is modelled after, even small aberrations in speed, angle or combination of movements may make it seem unrealistic. Depending on the task the robot is being created for, this can be detrimental. Even when the anatomy,

E. Tuci et al. (Eds.): SAB 2016, LNAI 9825, pp. 12–21, 2016.
DOI: 10.1007/978-3-319-43488-9_2

including bone structures, joints and muscles, is understood, it remains challenging to know how specific movements take place. In this paper we explain how we used motion capture to create a robotic bearded dragon (*Pogona vitticeps*) that moves in a realistic manner, which will be used in experiments focusing on social cognition (i.e., the study of how animals interact, acquire information and learn from each other). We chose bearded dragons as our model species because their behavioral repertoire is relatively simple and therefore comparatively easy to replicate and interpret [3]. The aim is to create a robot that is able to mimic some of the species' most characteristic behaviors. This will allow us to investigate these behaviors, and specifically other animals' response to them, in more detail, and ultimately to use robotic "demonstrators" in social learning experiments. Animal social cognition is a field that can vastly profit from using robotic animals, as they allow for greater reliability and control over the many factors outside the experimenter's power when using live animals (see [1]). Using robots for this type of work enables us to study social cognition in animals in much greater depth, providing full control over the presented stimuli and making it possible to vary them precisely, while excluding "noise" in the information provided, influenced for example by motivation and reliability of the demonstrator animal and interactions between demonstrators and subject animals [1]. Bearded dragons are responsive to social cues and show sophisticated social learning abilities [4]; these experiments will therefore provide valuable insights into reptile social behaviors and the perceptual mechanisms that underlie them.

1.1 Motion Capture of Animals

The most common use of marker-based motion capture in animals is with horses. They are mainly recorded for the film and games industry to recreate realistic models. Abson and Palmer [5] showed how biomechanical knowledge, including painting of the internal anatomy onto the skin of the horse, combined with well thought out marker and camera placement can lead to efficient recordings that require minimal post-processing. Other groups have used motion capture to improve the locomotion of quadruped robots. For example, Moro and colleagues [6] used motion capture of a horse walking on a treadmill to improve types of locomotion typical for horses in a small robot. Few other species have been used in motion capture studies. To understand the characteristic hopping motion and body posture of kangaroos, markers were placed on a kangaroo's joints [7]. Motion capture has also been used to record lizards, including bearded dragons [8–10], with the aim of informing war robots. These studies focus on walking behavior to generate data that is used for building walking robots capable of navigating difficult terrain, however none of them consider other behaviors of the lizards.

1.2 Head Bobbing in Lizards

One of bearded dragons' most characteristic behaviors is head bobbing—rapidly moving the head up and down, which can be supported by expansion of the skin on the neck and changes in coloration. This behavior is thought to be produced as an aggressive signal, showing dominance over a conspecific or during their mating ritual, and will often be responded to with arm waving, which is a submissive signal [3]. Because it is a very common behavior, carries a lot of communicative value and is relatively easy to replicate in a robot we chose head bobbing as our main focus for this study.

Behavioral studies investigating head bobbing have been conducted in several lizard species, some of which have used robotic lizards. Jenssen [11] investigated the influence of different behavioral modifiers on head bobbing in the Jamaican lizard (*Anolis opalinus*), while Lovern and Jenssen [12] showed that different types of head bobs emerge at different ontogenetic stages in green anoles (*Anolis carolinensis*). Martins and colleagues [13] used a robotic sagebrush lizard (*Sceloporus graciosus*) to investi-gate the influence of different types of head bobs on male and female conspecifics, showing that males attend more to the overall posture while for females the number of head bobs is important in evaluating other lizards. Macedonia and colleagues [14,15] showed how different anoles species can recognize members of their own species via their head bobs and how altering the dewlap color or head bob motion of a robotic anoles lizard influences species recognition. Other studies looked at inter species variation in head bobs (*Sceloporus graciosus* and *Anolis sagrei*), using robotic lizards to elicit head bobbing in live animals [16,17]. Ord and Stamps [18] investigated which factors of displays in Anolis lizards (*Anolis gundlachi*) influence perception in noisy environments by using robotic lizards that showed these displays in different combinations. To our knowledge, these robots were built to match a lizard perceived by the human sensory system, and no specific studies were carried out into how they were perceived by the animals they were modelling. While this seems sufficient in most cases, subtle differences in coloration, motion or odor, that might not be detectable by humans, can potentially influence the responses of other animals and thus the results of these experiments (see [1]). Head bobbing in lizards has previously been measured from video recordings [19]. Depending on the quality of the videos data recorded this way usually lacks detail, as movements that are too small and too fast to be visible to the human eye are missed. Furthermore, three dimensional data cannot be recorded if only one camera is used, and the animals have to be perfectly aligned with the camera, as any rotation of the head or body will lead to inaccurate results. To our knowledge, no studies have been conducted on head bobbing in bearded dragons. Therefore, the present experiment was designed to gain insight into the specific motion of head bobbing in bearded dragons to inform the design of a robotic lizard that will be used in behavioral and cognitive studies with these animals.

2 Methods

2.1 Motion Capture

Animals. Three male and two female bearded dragons (*Pogona vitticeps*) were used for motion capture. All animals were habituated to being handled by humans on a daily basis. They were housed at the cold-blooded cognition laboratory at the University of Lincoln in groups of two to three animals per vivarium, with males being held separately to avoid aggression. The room temperature was kept at 28°C (±3) with additional heat lamps provided in each vivarium. All animals received water ad libitum, vegetables and fruit once per day and live food three times per week. None of the animals had previously been housed together and they were of different ages, with two males and one female being at least four years old and one male and one female being two years old.

System. Kinematic data were collected at 150 Hz using the Cortex software package (v. 5.3, Motion Analysis Corporation (MAC), Santa Rosa, CA) running on a PC coupled to twelve MAC Raptor motion capture cameras. The cameras were placed around a platform (120 cm x 60 cm) that was partitioned into two equal halves by a glass plate (Fig. 1a) in such a way that both sides could be recorded individually. This gave us the opportunity to record two interacting animals individually and simultaneously. Each animal was equipped with

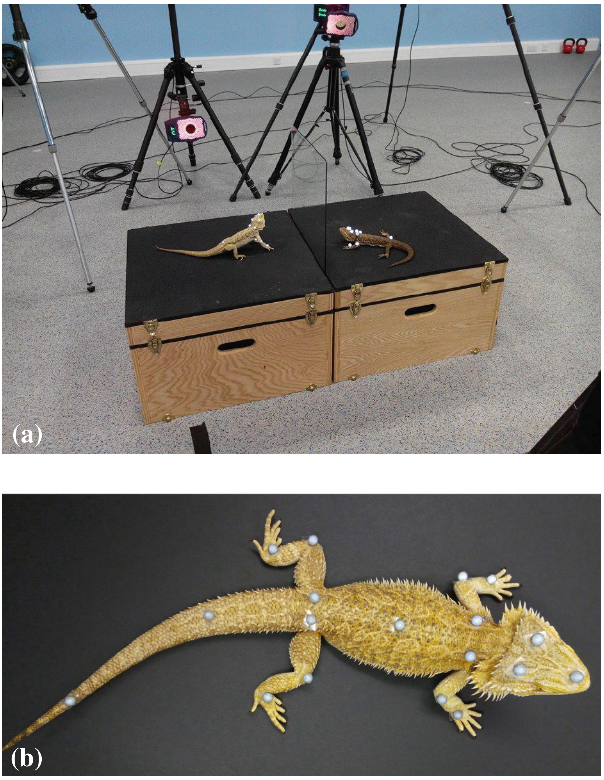

Fig. 1. (a) Set up of the experiment, showing the platform, divided by a glass plate, the digital cameras and two bearded dragons with markers (b) Bearded dragon with 18 retroreflective markers attached to its skin

18 6.4 mm diameter retroreflective markers: three on its head, two on each leg, two on the shoulders, two on the hips, one at the center of the back and two on the tail (Fig. 1b). Marker locations were chosen to correspond with joints and anatomical points important for modelling the movements we were interested in, while taking into account the small size of the animals. The markers were applied using toupée tape, which is commonly used in human studies and proved to work well with bearded dragon skin, attaching securely while being easy to remove. The animals were habituated to the markers and did not attempt to remove them or pay any attention to them. Therefore, we believe they did not influence their behavior.

Procedure and Trials. An animal was placed on either side of the platform, with a cloth covering the glass partition. The animals were left to habituate for a few minutes, during which food was used to elicit movement. Animals were considered habituated when they moved freely on the platform to explore it. The cloth was then lifted and the recording started. During recordings animals were allowed to move freely on the platform. Each recording lasted 5 min, and 21 recordings were taken in total. The animals were recorded in several different pairings depending on their motivation and behavior in previous trials (Table 1).

Table 1. List of combinations of animals recorded, number of 5 minute trials each combination was recorded for and number of head bobs recorded for each combination.

Animal 1	Animal 2	Number of trials	Number of head bobs
Male 1	Male 2	3	1
Male 1	Female 1	3	12
Male 2	Female 1	3	0
Male 2	Female 2	2	0
Male 1	Female 2	2	6
Male 3	Female 2	4	0
Male 1	Male 3	4	8

Post-Processing. Data was post-processed using Cortex software. Post-processing consisted of assigning marker IDs and manual clean-up of switched markers, which was necessary due to the small size of the animals and relative closeness of the markers.

2.2 Construction of the Robot

To construct the robot, 3D scans of bearded dragons were taken using an iSense scanner attached to an iPad with a Z-resolution of 0.5 mm. These scans were then imported into Google Sketchup and modified to allow for articulation of

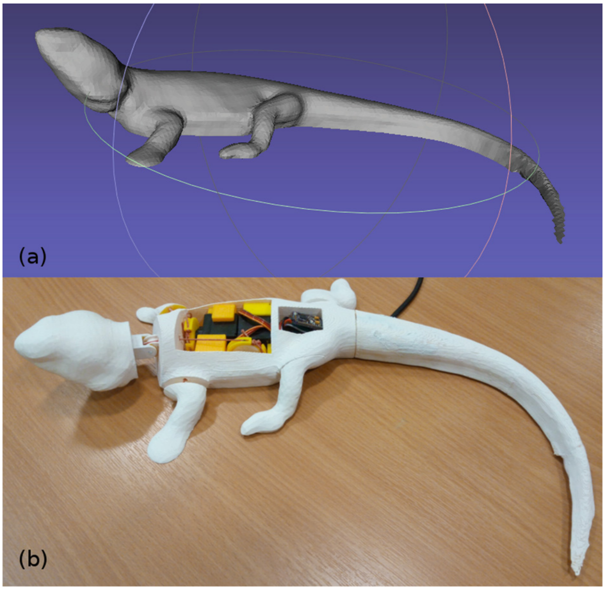

Fig. 2. (a) 3D scan of a bearded dragon that was used for the construction of the robot; (b) first prototype of the robot.

the head and front legs. This modified model was then 3D printed and two servo motors placed inside it. A Femtoduino Arduino clone board was used to control the servos to provide the movement of the head and arms (Fig. 2).

Several additional studies were undertaken to ensure the robot was realistic. 3D print-ed models of bearded dragons were used to investigate the importance of color, shape and eyes (Frohnwieser, Pike, Murray &Wilkinson in prep). Bearded dragons were presented with a white model lit in different colors for one minute each, the same model with or without eyes attached to it and several white objects with or without eyes. We found that bearded dragons responded more to a model if it was presented in bearded dragon skin color than grey, more to the model than objects of different shapes, and more to the model and the objects when they had eyes attached to them.

3 Results

In this study, three male and two female bearded dragons were recorded interacting with each other (see Table 1). Out of these, one male (Male 1) showed the desired head bobbing behavior. He was therefore paired with all other animals, to allow for a comparison between head bobbing towards males and females. In total, 27 instances of head bobbing were recorded, 18 towards females and 9 towards males. Two of them had to be excluded due to missing markers and artefacts. We focused our analysis on the marker at the tip of the head (Fig. 1b) and recorded its movement on the vertical axis. This allowed us to look at the sequence and speed of head bobbing. The results showed that head bobbing is highly stereotypic. All head bobs showed the same sequence of five dips and five raises of the head, with oscillations of decreasing amplitude. Each head bob sequence lasted for about 4.3 s, with the first dip being the longest (Fig. 3a). This was remarkably consistent across all head bobs that were recorded.

There was a difference in head bobs towards male and female lizards (Fig. 3b). When head bobbing at a male, the focus animal's head stayed significantly higher than when head bobbing at a female (autoregressive integrated moving average [ARIMA] models, incorporating both moving average and seasonal components, were fitted to the averaged male and female data, and differences between them compared using a Cox test: $z = -13.85$, $p < 0.001$). This difference was evident for all five bobs within a sequence, and was most prominent for the first head bob, with the head being 11.2 mm higher at the lowest point of the bob and 10 mm higher at the highest.

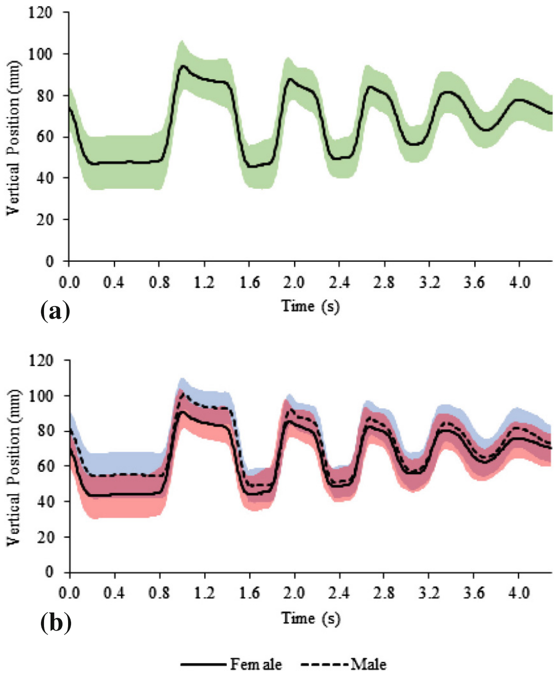

Fig. 3. (a) Mean ± standard deviation (shaded area) vertical head position over all 25 recorded head bobs. (b) Comparison of head bobs towards male and female lizards, showing mean vertical head position (lines) ± standard deviation (shaded areas).

4 Conclusion and Future Work

Our results show that head bobbing in bearded dragons is highly stereotyped with each sequence containing five characteristic head bobs. Furthermore, these sequences differ in the height of the head when displayed towards male or female lizards. Motion capture provides an easy and efficient way to measure this type of data, ensuring that all behaviors are recorded and that no data is missed. Furthermore, it reduces the occurrence of artefacts that manual coding of video data might cause. Marker-less approaches of capturing motion from synchronized video cameras are being developed, which can be useful for animals that cannot be recorded in a laboratory setting or that do not tolerate the attachment of markers [20]. However, this technique relies on textural differences within the animal and is not as efficient or detailed as marker-based approaches. As we did not find any aversive effects of the markers to the bearded dragons and they can easily be moved to a laboratory, we think marker-based motion capture is an excellent tool to record their behaviors.

The data recorded in this experiment was translated onto the robot using individual data points, i.e., the number of head bobs per sequence, the maximum and minimum vertical position of each head bob and the time span the head remained in each position. Therefore, the motion of our robot is highly realistic and recreates the head bobs with a very high level of detail. Since we found differences in head bobbing towards males and females we can use the robotic bearded dragon to investigate these behaviors in more detail, asking questions such as "Are the two types of head bobs perceived differently by the animal watching the robot?", "Do the two types of head bobs elicit different reactions, such as aggressive or mating behaviors?" or "Does exaggerating the differences between the two types of head bobs elicit greater responses than the original ones?".

We propose that more detailed studies should be undertaken into the exact motion of animals before creating robots to represent them. This is especially important when designing a robot to be used in interaction studies with live animals, as these might perceive and attend to factors invisible to the human eye. While for robots interacting with humans it may be sufficient to use human perception alone as a measure of how realistic they are, this is surely not the case for robots interacting with animals, as perception differs greatly between species. It is therefore instrumental to use subjective measures of features such as color, odor or motion in the creation of these robots. When planning and constructing our robotic lizard we have undertaken such studies, specifically to investigate the importance of color, shape and eyes, to make it possible to create a robotic lizard that is able to interact with real animals.

The data presented in this article shows how motion capture can improve the construction of robotic animals by measuring detailed movements and translating them onto a robot, which can be invaluable information for improving the study of robotics, animal behavior and animal cognition. We showed that with this method subtle differences that might otherwise be missed, such as the height difference in displays towards males or females, can be measured easily and in great detail.

Acknowledgements. The authors would like to thank Franky Mulloy, Joe Moore, Anthony Gorman and Sophie Moszuti for their help with data recording; Suzie Li Wan Po, Meredith Tise, Annali Beese, Matthew Walker and Manuel Jara for their involvement with creating the models and robot; and Dawn Simpson, Emma Huntbach and Hannah Thompson for animal care; and three anonymous reviewers for valuable input.

References

1. Frohnwieser, A., Murray, J., Pike, T., Wilkinson, A.: Using robots to understand animal cognition. J. Exp. Anal. Behav. **105**, 14–22 (2016)
2. Fleishman, L.J., Endler, J.A.: Some comments on visual perception and the use of video playback in animal behavior studies. Acta Ethol. **3**, 15–27 (2000)
3. Brattstrom, B.H.: Social and thermoregulatory behavior of the bearded dragon Amphibolurus barbatus. Copeia **1971**(3), 484–497 (1971)
4. Kis, A., Huber, L., Wilkinson, A.: Social learning by imitation in a reptile (Pogona vitticeps). Anim. Cogn. **8**(1), 325–331 (2014)
5. Abson, K., Palmer, I.: Motion capture: capturing interaction between human and animal. Vis. Comput. **31**, 341–353 (2014)
6. Moro, F.L., Spröwitz, A., Tuleu, A., Vespignani, M., Tsagarakis, N.G., Ijspeert, A.J., Caldwell, D.G.: Horse-like walking, trotting, and galloping derived from kinematic motion primitives (kMPs) and their application to walk/trot transitions in a compliant quadruped robot. Biol. Cybern. **107**, 309–320 (2013)
7. Hutchinson, J.: Outdoor Motion capture helps analyse kangaroo posture and hopping mechanisms (2010). http://www.vicon.com. Accessed 1 Mar 2016
8. Kim, C., Shin, H., Lee, H.: Trotting gait analysis of a lizard using motion capture. In: 2013 13th International Conference on Control, Automation and Systems (ICCAS 2013), pp. 1247–1251 (2013)
9. Kim, C., Shin, H., Jeong, T.: Motion analysis of lizard locomotion using motion capture. In: 2012 12th International Conference on Control, Automation and Systems, pp. 2143–2147 (2012)
10. Kim, H., Shin, H., Lee, H.: Trotting gait generation based on the lizard biometric data. Trans. Korean Inst. Electr. Eng. **62**(10), 1436–1443 (2013)
11. Jenssen, T.A.: Display modifiers of Anolis Opalinus (Lacertilia: Iguanidae). Herpetologica **35**(1), 21–30 (1979)
12. Lovern, M.B., Jenssen, T.A.: Form emergence and fixation of head bobbing displays in the green anole lizard (Anolis carolinensis): a reptilian model of signal ontogeny. J. Comp. Psychol. **117**(2), 133–141 (2003)
13. Martins, E.P., Ord, T.J., Davenport, S.W.: Combining motions into complex displays: playbacks with a robotic lizard. Behav. Ecol. Sociobiol. **58**, 351–360 (2005)
14. Macedonia, J.M., Stamps, J.A.: Species recognition in Anolis grahami (Sauria: Iguanidae): evidence from responses to video playbacks of conspecific and heterospecific displays. Ethology **98**, 246–264 (1994)
15. Macedonia, J.M., Clark, D.L., Riley, R.G., Kemp, D.J.: Species recognition of color and motion signals in Anolis grahami: evidence from responses to lizard robots. Behav. Ecol. **24**, 846–852 (2013)
16. Partan, S.R., Otovic, P., Price, V.L., Brown, S.E.: Assessing display variability in wild brown Anoles Anolis sagrei using a mechanical lizard model. Curr. Zool. **57**, 140–152 (2011)

17. Smith, C.B., Martins, E.P.: Display plasticity in response to a robotic lizard: signal matching or song sharing in lizards? Ethology **112**, 955–962 (2006)
18. Ord, T.J., Stamps, J.A.: Alert signals enhance animal communication in "noisy" environments. Proc. Natl. Acad. Sci. USA **105**(48), 18830–18835 (2008)
19. Bels, V.L.: Analysis of the display-action-pattern of Anolis clorocyanus (Sauria: Iguanidae). Copeia **1986**(4), 963–970 (1986)
20. Sellers, W.I., Hirasaki, E.: Markerless 3D motion capture for animal locomotion studies. Biol. Open. **3**, 656–668 (2014)

http://www.springer.com/978-3-319-43487-2

From Animals to Animats 14
14th International Conference on Simulation of Adaptive Behavior, SAB 2016, Aberystwyth, UK, August 23-26, 2016, Proceedings
Tuci, E.; Giagkos, A.; Wilson, M.; Hallam, J. (Eds.)
2016, XI, 366 p. 175 illus., Softcover
ISBN: 978-3-319-43487-2