

# Diurnal body temperatures in semi-captive Tokay Geckos (*Gekko gekko*); evidence for thermoregulation?

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DIURNAL reptiles have long been known to thermoregulate but relatively little is known about thermoregulation in nocturnal forms (Avery, 1982; Huey, 1982). The observation that some nocturnal geckos may bask during the day, led to a series of investigations into their diurnal thermal biology (e.g. Werner, 1965, 1966; Bustard, 1967, 1968a, b; Dial, 1978; Kearney & Predavec, 2000). The results indicated that diurnal thermoregulation is a fundamental dynamic and integral aspect of their ecology (Huey, 1982). The present paper gives details of the thermal ecology of four male Tokay Geckos (*Gekko gekko*) living freely in a reptile housing complex consisting of both tropical and desert enclosures. The Tokay Gecko is a large (up to 35cm) species from south east Asia (Rogner, 1997) commonly seen in the pet trade and well known for its unfriendly disposition. Although it is primarily inactive during the hours of daylight we measured body temperatures and environmental temperatures to test for evidence of diurnal thermoregulation and also for any differences in body temperatures between individuals. The results are based on a second year Higher National Diploma research project at Huddersfield Technical College carried out by D.S. and supervised by R.M.

## METHODS AND MATERIALS

The body temperatures of 4 adult *G. gekko*, all males, were recorded between 11:30 - 16:00 hrs from September 2001 to April 2002 under both sunny ( $n = 222$ ) and overcast weather ( $n = 460$ ). Skin surface temperature was measured at a distance of 6-7 cm from the animals dorsal region.

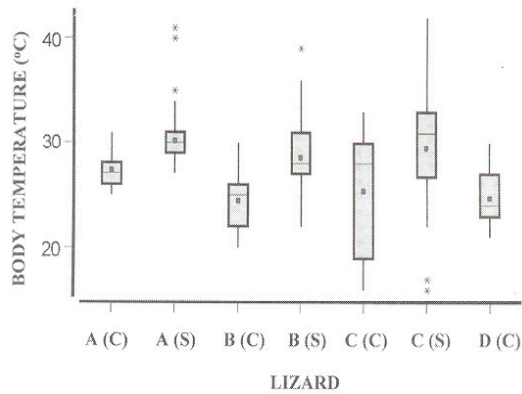
This non-invasive method of measurement has the benefit of minimising behaviour disturbance. The core body temperature of lizards is in good agreement with skin surface temperature (Alberts & Grant, 1997) with the differences becoming greater with increasing body mass (Meek, 1999) suggesting little differences in the relatively small lizards used in this study. The lizards were free ranging in a large glasshouse unit (12 by 31 metres and 5 m in height) used to house a variety of species of reptile. Glasshouse temperatures varied with weather conditions due to being exposed to natural light and ranged from extremely hot during sunny weather in summer to more moderate temperatures on winter days. Humidity also varied from 30% during summer in the dry units to above 90% in the tropical enclosures, although these were not systematically recorded during the study.

All animals were initially liberated in a tropical house, the central animal unit within the complex, but with the exception of lizard D dispersed throughout the building. Two lizards took up residence in each of the dry habitats (housing desert reptiles and monitor lizards) and two in each of the tropical units (housing iguanas, water dragons, boa constrictors, terrapins etc). The lizards in the dry units are here defined as A and B with lizards C and D living in the tropical units. Each individual was relatively easy to identify visually either from head size, body markings or broken and regenerated tails. Heating pipes around the periphery of each unit gave the animals the opportunity to bask by positioning in their close proximity and this included access to the heating units in the walk-through enclosures.

Sunny					
	Mean	Std. Dev.	$s^2$	Range	$n$
Lizard A	30.0	1.9	3.6	27-41	74
Lizard B	28.5	3.2	10.2	22-39	74
Lizard C	29.1	5.1	26.0	16-41	74
Model 1	35.6	6.2	37.9	22-46	74
Model 2	28.4	2.7	7.6	24-40	74
Model 3	21.7	2.8	8.1	16-31	74
Model 4	24.9	3.3	11.1	17-36	74
Overcast					
Lizard A	27.3	1.2	1.4	25-31	131
Lizard B	24.6	2.1	4.4	20-30	102
Lizard C	26.1	4.6	21.2	16-33	126
Lizard D	25.0	2.6	6.7	21-30	101
Model 1	25.6	2.5	6.1	22-32	131
Model 2	26.3	1.9	3.8	23-30	131
Model 3	18.2	1.7	3.1	15-25	131
Model 4	21.1	1.9	3.7	17-36	131

**Table 1.** Body temperatures of semi captive Tokay geckos under overcast and sunny weather with corresponding model temperatures. Mean temperatures are given with one standard deviation, variances ( $s^2$ ), ranges and sample sizes ( $n$ ). Sample sizes are based on the data collected from each lizard or model during the study period.

Four water filled cylinders constructed from sheets of copper Imm thick 16.5cm in length and 5.5cm in diameter were placed in various locations in the building where the maximum and minimum temperatures were expected to occur. Model I was placed in an open situation so that if the sun was shining it would receive maximum heat, with Model 2 about 10 cm from a heat pipe in the desert unit. Model 3 was located in a fully shaded position in a cool area of one of the dry units and Model 4 in a shaded area in a tropical unit. Models I and 2 therefore represented potentially the hottest areas, and Models 3 and 4 the coolest areas available to the lizards. These cylinders were slightly larger than the lizards but were painted black to enhance their heating rates and were measured simultaneously with lizard body temperatures using the infrared detector. Comparison of inanimate models (indicators of



**Figure 1.** Box plots of body temperatures for individual lizards during different weather conditions. Overcast weather is shown as C and sunny weather S alongside lizard identifications A to D. The rectangular boxes indicate the interquartile ranges with the means shown as solid circles and medians as horizontal bars. The lines either side of the interquartile ranges represent the general ranges of the data but during sunny weather asterisks indicate outliers - data that are between 1.5 to 3 times from the interquartile ranges. There was insufficient data available for lizard D during sunny weather for inclusion.

operative temperatures) and lizard body temperatures can be used as a test for thermoregulation with the assumption of no thennoregulation in the models (Bakken & Gates, 1975). The type of model used is less critical than originally thought (Vitt & Sartorius, 1999; Shine & Keamey, 2001). The low heat capacity of hollow-walled copper tubes respond readily to changes in radiation levels and have value in predicting the amounts of time operative temperatures exceed given thennal thresholds. Generally speaking, at the temperatures recorded in this study, the differences in model size, colour, amount of contact with the substrate and orientation have little influence on model temperature, but heating and cooling rates may differ because of differences in thennal time constants (Shine & Keamey, 2001).

**RESULTS**

Table I gives a statistical summary of the body and model temperature results including sample sizes; Figure 1 a graphical summary of the body

	Overcast			
	Model 1 (open location)	Model 2 (10cm from heat pipe)	Model 3 (shaded/desert)	Model 4 (shaded/tropical)
Lizard A	48.9 *	26.2*	2369.9*	725.7*
Lizard B	34.8**	52.7**	405.9*	103.5*
Lizard C	n.s.	8.3**	177.9*	57.66*
Lizard D	30.2**	38.4**	359.2*	99.45*
	Sunny			
Lizard A	50.1**	17.22*	372.6*	118.4*
Lizard B	78.5**	n.s.	184.6*	43.9*
Lizard C	40.7**	n.s.	111.9*	35.7*

**Table 2.** Matrix of F-values comparing lizard body temperatures to corresponding model temperatures under overcast and sunny weather obtained using analysis of variance. When lizard body temperatures were significantly higher than model temperatures a single asterisk is attached to the F statistic; when body temperatures were significantly lower than model temperature two asterisks are attached with no significant difference between lizard and model temperatures shown as n.s. See text for an interpretation of these results.

temperatures. There were significant differences between the means of body temperatures whatever the weather conditions (sunny,  $F(2,219) = 3.36, p = 0.036$ ; overcast  $F(3, 456) = 20.96, p < 0.0001$ ). The details of the differences are as follows: - when the weather was overcast lizard A was significantly higher than lizards B and D ( $p = 0.01$ ) which were not significantly different from each other ( $p = 0.66$ ) with lizard A also higher than lizard C ( $p = 0.005$ ). Lizard C body temperatures were also significantly higher than lizards B and D ( $p = 0.003$ ). When the weather was sunny the only significant difference was between the body temperatures of lizard A and lizard B with A higher ( $p < 0.0001$ ). Body temperatures were significantly lower during overcast weather than in sunny weather in the three lizards that data were available for under both sets of weather conditions; lizard A,  $F(1, 203) = 154.0$ ; lizard B,  $F(1,174) = 93.54$ ; lizard C,  $F(1,198) = 17.9$ , all  $p < 0.0001$ .

Table 1 shows standard deviations and variances of body temperatures around the means. A test of variance ratios (Martin & Firth, 1983) between lizards indicated that the variance in body temperature of lizard C was significantly greater than the other lizards; sunny weather lizard C versus lizard B,  $F = 2.54, p < 0.001$ , lizard C versus lizard A,  $F = 7.2, P < 0.0001$  both at  $d.f = 73$  for  $v_1$  and  $v_2$ . Lizard B also had a significantly greater variance than lizard A,  $F = 2.83, p < 0.0001$  ( $v_1$  and  $v_2$  again at  $d.f. = 73$ ).

The pattern of differences in body temperatures was similar during overcast weather. Again lizard C had a significantly greater variance than the other lizards (F-tests from 3.13 - 14.69, all  $p < 0.0001$ ). The between weather conditions variance of lizard C was not significantly different ( $F = 1.03, p > 0.05$  at  $v_1 = 125, v_2 = 73$ ) but lizards A and B (there was no useful data during sunny weather for lizard D) had greater variances during sunny weather; lizard A,  $F = 3.4, v_1 = 130, v_2 = 73$ ; lizard B,  $F = 2.28, v_1 = 101, v_2 = 73$ , both  $p < 0.0001$ .

In summary the body temperature results indicate that irrespective of weather conditions Lizard A had the highest mean and the lowest variance and Lizard C the greatest variance in body temperature. Means and variances in body temperatures were in general higher in sunny weather.

Table 2 shows a matrix of F-values based on analysis of variance of lizard and model temperatures. The results show that, in the main, the differences were between lizard A and the other lizards in respect to models 1 and 2. Lizard A was significantly higher than this model (the model close to a heat pipe) whilst the other lizards were either significantly lower or not different. Model 1, the model exposed to open situations, had significantly higher temperatures than all lizard body temperatures during sunny weather but

was significantly lower than lizard A during overcast weather. Under either sunny or overcast weather all lizards had significantly higher body temperatures than the shade models 3 and 4.

## DISCUSSION

Given that research into the thermoregulatory behaviour of geckos has received less attention than most other groups of lizards, it is nevertheless the case that when evidence for diurnal thermoregulation has been sought it has been found. The difficulty with geckos lies in determining overt thermoregulatory behaviour when they are inactive, since it is often inconspicuous. However the general departures of *G. gekko* body temperatures from model temperatures, particularly the models that reflected operative temperatures at the extreme ends of the ranges, provide good evidence for thermoregulation. For example, had body temperatures been in agreement with the hottest model during sunny weather, the animals would have died from overheating - thermoregulation must also involve avoiding critically high temperatures as well as heating to optimum physiological temperatures. During overcast weather, the lizards generally had body temperatures that were above most model temperatures suggesting active thermoregulation to achieve target body temperatures. In the absence of any pronounced basking or posturing in respect to heat sources, the conclusion must be that thermoregulation is achieved through microhabitat selection. Other geckos may thermoregulate diurnally but in different ways, for instance *Heteronotia binoei* and *Gehyra variagatus* thermoregulate during the day through movement beneath the bark of dead trees after nocturnally foraging for food (Bustard, 1967, 1968a,b) and apparently consists of the animals attaching themselves to the part of the bark being heated by the sun and moving onto the bole of the tree when they begin to overheat (R. Bustard, pers. comm.).

The high mean and low variance in body temperature of lizard A irrespective of weather conditions appears to have been achieved through the occupation of a diurnal home site that had favourable thermal characteristic since model temperatures in this animals territory were close to optimal for Tokay Geckos, in the sense that they were close to the mean body temperatures of

between 26.8 to 27.8°C recorded in a laboratory thermal gradients by Sievert & Hutchison (1988). The greater precision in body temperature of lizard A was probably due to its occupation of a narrow space (just wide enough to insert the 6cm wide infra red detector) between two wooden vertical surfaces, one end of which was only 12 cm from heating pipes. This facilitated a ready access to a heat source without moving any distance from cover (defined as 'protected basking' by Werner & Whitaker, 1978). Additionally the area was subject to only limited sunshine and remained thermally stable, at least on a day-to-day basis. The other lizards occupied similar types of home sites but with larger gaps between the occupied spaces (at least 12 cm) and greater distances from the heating pipes (at least 60 cm). In theory, had the other males been able to occupy the home site of lizard A, they would have had a similar thermal profile. Current theory predicts that the precision with which a reptile thermoregulates, estimated from variance in body temperature (Sievert & Hutchison, 1988), reflects the potential costs that the environment imposes on its behaviour; an ability to thermoregulate to optimum physiological temperatures produces the benefits of increased growth, greater locomotory ability, avoidance of predators and rate of egg production among others (Huey, 1982).

The less precise body temperatures observed in lizard C could in part reflect higher levels of activity in a heterogeneous environment, which in theory should increase variance in body temperature. For instance, casual observations (simple daily checks) of the presence of each lizard at their normal location showed that lizard A was the most likely to be present and lizard C (the largest in the study) the most likely to be absent. Lizard C additionally often showed injuries that were apparently sustained through inter-male conflict, probably in disputes over thermal resources since heat has been identified as an environmental resource (Magnuson et al., 1979) and may be defended in lizards (Huey, 1982). In this respect it is of interest that 2 female *G. gekko* introduced in May 2002 after the present study was completed, took up residence with lizard A and where repeated successful reproduction has since taken place - there was no human interference with reproduction, and the young could still be

found in association with the adults over 1 year later. This has already been observed in other geckos, for example in *G. variagatus* where offspring remained with the parents until they were sexually mature after which they were driven away by the adults - females by the dominant female and males by the dominant male (R. Bustard, 1967 and pers. comm.). It is well known that the thermal properties of an environment may influence the development of certain reptilian embryos, including those of geckos, and thus selection of home sites with thermally favourable characteristics may be crucial in gecko reproduction.

Although the present results provide evidence for diurnal thermoregulation we have no information concerning nocturnal thermoregulation in *G. gekko*. Sievert & Hutchison's (1988) laboratory study of 10 individual *G. gekko* in a thermal gradient showed selection of higher and greater precision of body temperatures at night and a distinct influence of light on thermoregulatory behaviour. They went on to suggest that *G. gekko* may be pre-adapted for utilising human habitations and exploits differences in microhabitat temperatures to maintain preferred body temperatures, a view supported by this study.

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