

SELECTED BODY TEMPERATURE, THERMAL TOLERANCE AND INFLUENCE OF TEMPERATURE ON FOOD ASSIMILATION IN JUVENILE CHINESE SKINKS, *EUMECES CHINENSIS* (SCINCIDAE)

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ABSTRACT. - We studied, in the laboratory, several aspects of thermal biology of juvenile Chinese skinks, *Eumeces chinensis*. We did not find between-sex differences in all tested traits. The selected body temperature, the critical thermal minimum and the critical thermal maximum averaged 28.2, 6.2 and 41.1 °C, respectively. Within the range of 22 to 36 °C, temperature significantly affected food intake, food passage time and mass change. Food intake generally increased between 22 and 30 °C, and decreased at temperatures higher than 30 °C. Food passage time remained almost unchanged between 22 and 24 °C, sharply decreased from 24 to 26 °C, and leveled at higher temperatures. The juveniles gained mass within the range of 22 to 32 °C, and lost mass at higher temperatures. Influence of temperature on apparent digestive coefficient and assimilation efficiency, although statistically significant, was slight, suggesting the two traits are relatively less sensitive to variation in temperatures.

KEY WORDS. - Reptilia, Scincidae, *Eumeces chinensis*, selected body temperature, thermal tolerance, food passage time, food assimilation.

INTRODUCTION

Behavioral and physiological performances of reptiles have been known to vary with their body temperatures. However, the optimal temperature and the thermal sensitivity of different performances may differ considerably within and among species (Bustard, 1967; Lang, 1979; Pough, 1980; Huey, 1982; van Damme et al., 1991; Ji et al., 1995, 1996, 1997). In the field, reptiles tend to regulate and maintain body temperatures within their voluntary range so that various performances could be at or near their optimal temperatures (Huey, 1982; Stevenson et al., 1985; Huey & Kingsolver, 1989; Peterson et al., 1993). The set points of thermoregulation in the field can be estimated in the laboratory by measuring body temperatures selected by animals in a thermal gradient. For a given species or a given age

or sex group of reptiles, the selected body temperature may largely reflect a compromise for different performances. Because a net gain of energy through feeding means tissue growth and/or offspring production, testing influence of temperature on food assimilation in reptiles could be ecologically very important.

Eumeces chinensis studied here is a ground-dwelling oviparous skink, and is widely distributed in southern provinces (including Taiwan and Hainan) of China (Zhao & Adler, 1993). In Zhejiang, *E. chinensis* is one of the most conspicuous lizard species because of its larger size and higher population density in many counties and cities in the province (Gu, 1990). In a previous study, we examined selected body temperature, thermal tolerance and the effects of temperature on running performance and digestive physiology in adult *E. chinensis* (Ji et al., 1995). Here, we present data on juveniles. Our aim is (1) to contribute further data to thermal biology of the species and (2) to compare our data with those collected in other parallel studies.

MATERIALS AND METHODS

The majority of data presented here was collected in May and June 1997. Additional data were collected in the same months 1998. All skinks were collected from an intensively studied population in Lishui, Zhejiang, East China. Captured skinks were transported to our laboratory at Hangzhou Normal College, where they were measured, weighed and sexed. The minimum snout-vent length (SVL) of our juveniles was 49.2 mm, and the maximum SVL was 67.9 mm, which is smaller than the SVL of the smallest adult (reproductive) in this population (88 mm; Lin & Ji, in press). Prior to and during intervals of experiments, skinks were housed 4-5 to each glass terrarium (50 x 30 x 30 cm), which was filled with soil, blocks of wood, stones and grasses. Mealworms (larvae of *Tenebrio molitor*) and water were provided ad libitum. Skinks in the laboratory were exposed to a natural light cycle and could receive some direct sunlight.

Selected body temperature and thermal tolerance. - To prevent possible interactions between experiments, we conducted each experiment at intervals of a week. The sequence was selected body temperature (T_{sel}), thermal critical minimum (CT_{min}) and thermal critical maximum (CT_{max}) determinations. Prior to each experiment, skinks were maintained in a constant-temperature room at 28 °C for 48 h to allow habituation to the starting temperature. The lights were automatically switched on at 07:30 (Beijing time) and on a 12L: 12D cycle. Because no formal acclimation period was employed, skinks were considered acclimatized to natural conditions at the start of trials.

Selected body temperature was determined in a 100 x 50 x 50 cm glass terrarium. Two light bulbs (total 1000 W) suspended above one end created a thermal gradient ranging from 18 to 70 °C (2 cm above the terrarium floor). Skinks were moved into the terrarium at 0730 when the lights were switched on. To avoid the possibility of diurnal variations in T_{sel} , we began all our measurements at 1500 and ended within 2 h. The time period was chosen so that data from this study could be more comparable to those collected by us in other lizard species. Body temperatures (cloacal, T_b) of active skinks in the thermal gradient were taken using a WMZ-3 electronic thermometer (Shanghai Medical Instruments). To address the reliability of our measurements, we measured each skink twice on two consecutive days. We considered the mean of the two readings as a skink's body temperature in the thermal gradient. Efforts were made to make the two measurements fall within the same period (no

more than 1 h) of the two days. We used the mean of all readings of body temperature as the selected body temperature.

Critical thermal minimum and critical maximum were determined in a LRH-250A incubator (Guangdong Medical Instruments). Experiments were conducted between 10:00 and 15:00. Skinks were cooled or heated from 28 °C at the rate of 0.25 °C per min. During the experiment, we observed the behavior of the skinks. The body temperatures associated with a transient loss of righting response at lower and upper thermal limits were used as CT_{min} and CT_{max} (Lowe & Vance, 1955; Ji et al., 1995, 1996, 1997), respectively.

Food intake, food passage time, food assimilation and growth rate. - Skinks were divided into eight groups; each group was placed in 22, 24, 26, 28, 30, 32, 34 and 36 °C constant-temperature rooms, respectively. The fluorescent tubes and room lighting were automatically switched on at 07:30 on a 12L: 12D cycle. Each skink was housed in a 20 x 20 x 20 cm glass terrarium, fasted for 3 days at the test temperature, and then weighed and measured. Final body mass was recorded at the end of a 3-day fast, which terminated each test period.

Prior to feeding the skinks, we marked mealworms by inserting a 3 mm green plastic thread (diameter 0.2 mm) into their abdomen, and force-fed these mealworms to skinks. Unmarked mealworms and water were then provided ad libitum. Tettaria were checked at least five times every day for the presence of faeces and urates and more frequently during the first days for the appearance of plastic threads. Food passage time was defined as the elapsed time from swallowing to the first appearance of plastic threads.

Faeces, urates and mealworms were dried to constant mass in an oven at 65 °C and weighed. Subsamples were burned in a GR-3500 adiabatic calorimeter (Changsha Instruments) and energy densities were obtained. Titrations were performed of the residuals after calorimetry to correct for nitrogenous wastes. The assimilation efficiency (AE) was calculated as: $AE = (I - F - U) / I \times 100\%$ (Kepenik & McManus, 1973; Ji & Wang, 1990; Ji et al., 1993), where I = calories ingested, F = calories in faeces and U = calories in urates. The apparent digestive coefficient (ADC) was calculated as: $ADC = (I - F) / I \times 100\%$ (Harwood, 1979; Ballinger & Holscher, 1983; Waldschmidt et al., 1986).

Statistical analyses. - All data were tested for normality (Kolmogorov-Smirnov test) and homogeneity of variances (F-max test), and transformed when necessary to achieve to conditions for using parametric tests. We precluded using ANCOVA to analyze data, because no linear relationships existed and a significant fraction of variances could be due to inter-individual differences that were preserved across test temperatures. We used one-way ANOVA to determine whether there were differences in food intake, food passage time, ADC, AE and changes in body mass among temperature treatments. Mann-Whitney U-test was used to test differences in T_{sel} , CT_{min} and CT_{max} between male and female *E. chinensis*, because normality assumptions were not met.

RESULTS

There were no between-sex differences in T_{sel} , CT_{min} and CT_{max} (Mann-Whitney U - test, all $P > 0.05$), so we pooled data for both sexes. T_{sel} , CT_{min} and CT_{max} averaged 28.2, 6.2 and 41.1 (°C, respectively (Table 1).

Table 1. The selected body temperature, the critical thermal minimum and the critical thermal maximum ($^{\circ}\text{C}$) of juvenile Chinese skinks, *Eumeces chinensis*.

	T_{set}	C_{Tmin}	C_{Tmax}
Mean	28.2	6.2	41.1
N	22	15	12
1 standard error	0.5	0.1	0.2
Range	23.8-32.4	5.5-7.0	40.0-41.9

We did not find between-sex differences in food passage time, food intake, ADC, AE and change in body mass across the test temperatures (ANOVA, all $P > 0.05$), so we pooled data for both sexes. Temperature significantly affected food passage time ($F_{7,101} = 11.19$, $P < 0.001$), food intake ($F_{7,101} = 18.88$, $P < 0.001$), ADC (arc-sine transformed; $F_{7,101} = 6.59$, $P < 0.001$), AE (arc-sine transformed; $F_{7,101} = 4.32$, $P < 0.001$) and mass change ($F_{7,101} = 10.36$, $P < 0.001$). Food intake generally increased between 22 and 30 $^{\circ}\text{C}$, and decreased at temperatures higher than 30 $^{\circ}\text{C}$ (Table 2). Food passage time remained almost unchanged between 22 and 24 $^{\circ}\text{C}$, sharply decreased between 24 and 26 $^{\circ}\text{C}$, and nearly leveled between 26 and 36 $^{\circ}\text{C}$ (Figure 1). The juveniles gained mass within the temperature range 22-32 $^{\circ}\text{C}$, and lost mass at temperatures higher than 32 $^{\circ}\text{C}$ (Table 2). Although the effects of temperature on ADC and AE were statistically significant, the two variables actually varied slightly with temperature within the range of 22 to 36 $^{\circ}\text{C}$ (Table 2).

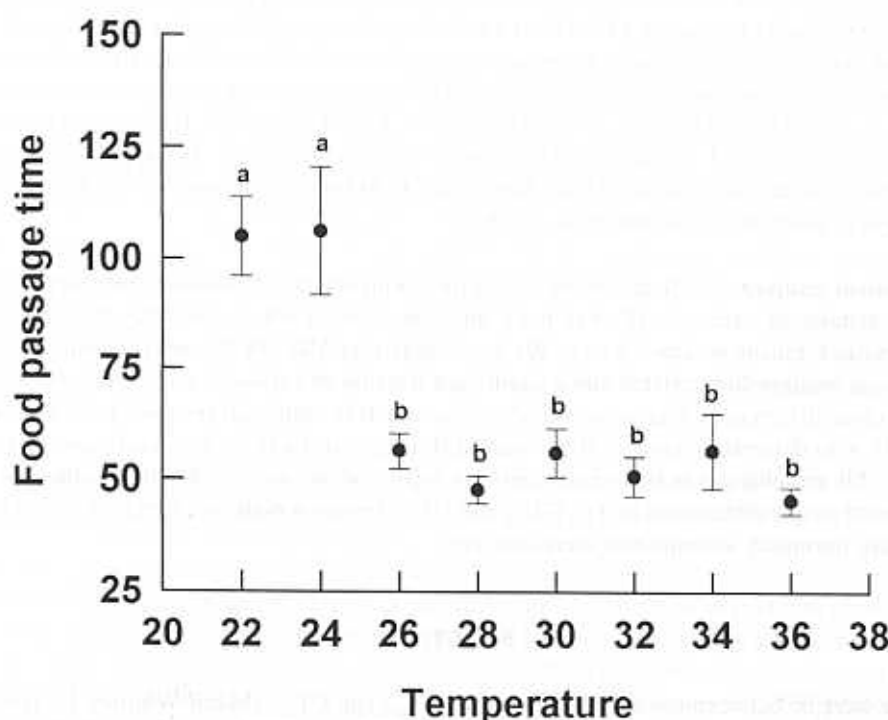


Fig. 1. Food passage time (h) of juvenile *Eumeces chinensis* at different temperatures. Data are expressed as mean \pm 1 standard error. Means with different superscripts differ significantly (Tukey's test, $\alpha = 0.05$).

Table 2. Food intake, ADC, AE and mass changes of juvenile *E. chinensis* at different temperatures. Data are expressed as mean \pm 1 standard error (range). Means with different superscripts differ significantly (Tukey's test, $\alpha = 0.05$).

T (°C)	n	Initial body mass (g)	Food intake (cal/g/d)	ADC (%)	AE (%)	Mass changes (mg/g/d)
22	16	4.7 \pm 0.6 (2.6-11.3)	70.0 ^a \pm 6.2 (17.0-103.3)	93.2 ^{ab} \pm 0.3 (91.0-96.0)	87.8 ^{abc} \pm 0.7 (80.4-92.2)	42.3 ^a \pm 9.0 (-16.3-146.1)
24	14	3.2 \pm 0.2 (2.1-4.4)	109.6 ^{bc} \pm 8.6 (55.7-174.4)	93.4 \pm 0.3 (91.2-94.9)	88.9 ^{ab} \pm 0.3 (86.8-91.1)	42.3 ^a \pm 7.5 (-10.9-79.4)
26	17	5.5 \pm 0.7 (3.1-14.7)	139.9 ^{ab} \pm 14.1 (45.5-279.0)	91.1 ^c \pm 0.4 (89.5-94.6)	86.6 ^{bc} \pm 0.5 (83.7-92.4)	75.7 ^a \pm 11.1 (-13.6-161.8)
28	16	4.3 \pm 0.3 (2.9-7.7)	127.4 ^{ab} \pm 9.9 (62.1-204.3)	92.3 ^{bc} \pm 0.3 (90.0-94.7)	87.8 ^{abc} \pm 0.4 (85.0-90.6)	47.4 ^a \pm 5.8 (-1.8-80.0)
30	12	5.8 \pm 0.6 (4.2-10.5)	171.2 ^a \pm 13.3 (88.7-263.5)	91.6 ^{bc} \pm 0.4 (89.8-94.0)	87.0 ^{ab} \pm 0.5 (84.5-90.6)	90.2 ^a \pm 13.4 (3.3-190.0)
32	10	4.8 \pm 0.3 (3.8-6.6)	136.8 ^{ab} \pm 8.2 (89.0-174.6)	93.9 ^a \pm 0.4 (90.6-95.5)	89.5 ^a \pm 0.5 (85.6-91.8)	52.5 ^a \pm 25.1 (-68.9-218.9)
34	11	7.5 \pm 0.8 (5.1-14.8)	46.2 ^d \pm 7.4 (17.0-81.7)	93.2 ^{ab} \pm 0.7 (90.7-95.3)	85.2 ^c \pm 1.2 (78.3-88.9)	-16.1 ^b \pm 10.9 (-60.0-44.3)
36	11	7.0 \pm 0.9 (4.5-14.9)	45.8 ^d \pm 5.7 (23.4-82.6)	93.9 ^a \pm 0.8 (91.3-96.5)	89.5 ^a \pm 1.2 (84.8-92.4)	-20.3 ^b \pm 5.1 (-48.7-8.3)

DISCUSSION

Selected body temperature is measured in a thermal gradient in the laboratory, indicating the range of body temperatures that ectotherms try to maintain in the absence of abiotic restrictions. The value of T_{sel} can be used to estimate the set points of thermoregulation in field individuals. Based on previous studies, T_{sel} cannot be considered as a fixed characteristic of a species, because it is influenced by many external and internal factors (see Hutchison, 1976), and seasonal shifts in T_{sel} have actually been reported for some lizards, e.g., the wall lizard *Podarcis muralis* (Braña, 1993) and the frilled lizard *Chlamydosaurus kingii* (Christian & Bedford, 1995). CT_{min} and CT_{max} are likewise influenced by many factors (also see Hutchison, 1976). However, our experience indicates that data collected using the same manner can be used to test within and among species differences in T_{sel} , CT_{min} and CT_{max} . The results from our previous work show that lizards using different habitats may differ in thermal requirements and, hence, exhibit differences in T_{sel} , CT_{min} and CT_{max} (Ji et al., 1995, 1996, 1997).

CT_{min} and CT_{max} of juvenile *E. chinensis* are almost the same as those of adults ($CT_{min} = 6.3$ °C and $CT_{max} = 42.3$ °C; Ji et al., 1995), but T_{sel} of juveniles is lower than that reported for adults (31.2 °C; Ji et al., 1995). The difference in T_{sel} between juvenile and adult *E. chinensis* could be a very interesting finding in this study, because the difference presumably reflects ontogenetic shifts in thermal requirements. The difference also implies that juveniles and adults may reduce their competition by using different time and different micro-habitats when and where thermal environments are different.

Numerous studies show influence of temperature on food passage time of lizards (e.g., Harwood, 1979; Waldschmidt et al., 1986; van Damme et al., 1991; Beaupre et al., 1993; Ji et al., 1995, 1996, 1997), but no consistent pattern can be drawn at this time. In the iguanid lizard *Uta stansburiana* (Waldschmidt et al., 1986) and the grass lizard *T. septentrionalis* (Ji et al., 1996), food passage time decreased with increasing body temperature. Food passage time in adult *E. chinensis* decreased nearly linearly within the range of 24 to 30 °C and then leveled at higher temperatures (Ji et al., 1995). A similar pattern was also seen in a viviparous skink, *Sphenomorphus indicus* (Ji et al., 1997). The pattern in juvenile *E. chinensis* seemed to be similar to that seen in adults, but food passage time leveled at a temperature (26 °C) lower than that (30 °C) reported for adults.

The values of ADC and AE are mainly determined by activities of digestive enzymes, food passage time and the type of food consumed (e.g., Andrews & Asato, 1977; Harwood, 1979). As a general principle, activities of digestive enzymes increase with temperature within a certain temperature range, but shorter food passage time at a higher temperature may reduce exposure of food to enzymatic action (Harwood, 1979). Due to this mechanism, many lizards exhibit relative insensitivity of ADC or AE to changes in body temperature (e.g., Dutton et al., 1975; Harwood, 1979; Waldschmidt et al., 1986; Ji & Wang, 1990; van Damme et al., 1991; Beaupre et al., 1993; Ji et al., 1993, 1995, 1996, 1997). The low variation of ADC and AE in juvenile *E. chinensis* is consistent with the pattern seen in other lizards, including adult individuals of the species. However, the temperature range within which ADE and AE remain nearly constant differs between juvenile and adult *E. chinensis*. In adults, food assimilation is greatly impaired at 24 °C (Ji et al., 1995), whereas juveniles can maintain normal ADC and AE even at 22 °C (Table 2). This difference further supports our claim that thermal requirements differ between juvenile and adult *E. chinensis*.

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