Use of an infrared thermographic camera to measure field body temperatures of small lacertid lizards

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Use of an Infrared Thermographic Camera to Measure Field Body Temperatures of Small Lacertid Lizards

Measuring body temperature is crucial in the study of reptiles, as most of their behaviors and physiological processes depend critically on temperature (Angilletta et al. 2002). Different devices have been used to measure deep body temperature in lizards, including mercury thermometers, thermistors, and thermocouples. However, these devices require the use of invasive and considerably stressful techniques for lizards (Avery 1982; Hare et al. 2007; Langkilde and Shine 2006; Moore et al. 1991). Consequently, remote sensing equipments, such as infrared (IR) thermometers, are increasingly used as a non-invasive alternative to measure body temperature of reptiles in the field (Alberts and Grant 1997; Bucklin et al. 2010; Hare et al. 2007). This equipment is inexpensive, lightweight, and easy to use. However, IR thermometers are problematic when used to measure the surface temperature of small-sized animals. This is because the size of the sensing field often exceeds the surface area of the target body, so temperature readings reflect a composite measure of the target animal and the surrounding substrate (Bucklin et al. 2010; Hare et al. 2007). Thermographic cameras offer a potential alternative that may alleviate this problem.

Thermographic cameras are available to measure surface temperature (T°s) and provide several advantages over other non-invasive methodologies: 1) readings can be taken at distances ranging from a few centimeters to several meters; 2) IR images provide data on the temperature of the animal distinct from its immediate surroundings; 3) depending on the measuring distance and the resolution of the camera, it may be possible to obtain simultaneous readings from several points on the body surface of the focal lizard; 4) moving animals can be easily tracked; and 5) it is generally possible to make adjustments (e.g., correcting for emissivity) after the image is collected. Furthermore, modern IR cameras are portable, relatively cheap, and have higher image resolution than the cumbersome first-generation cameras used until recently in herpetological studies (Jones and Avery 1989; Tosini and Avery 1993, 1996).

One potential drawback of thermographic cameras and other remote-sensing equipment is that they provide a measure of surface temperature, while many behavioral and physiological processes arguably depend on deep body temperature (Angilletta et al. 2002). In small ectothermic animals, deep body temperatures should not differ markedly from body surface temperatures (Bell 1980; Jones and Avery 1989; Tosini and Avery 1993), but it is still important to understand and acknowledge the error committed. In this paper, we evaluate the use of an IR camera to estimate deep body temperatures in small lacertid lizards (adult body weight <10 g).

Materials and methods.—We collected thermographic data from five species of small lacertids: *Podarcis liolepis*, *Po. muralis*, *Psammodromus algirus*, *Ps. Hispanicus*, and *Acanthodactylus erythrurus.* Lizards were captured in Valencia (Spain), except for *P. muralis*, which were captured in the eastern Pyrenees (Angoustrine, France). In the laboratory, lizards were housed individually in holding terraria measuring 40 × 20 × 15 cm. Water was provided *ad libitum* while food (mealworm larvae) was provided every two days. Immediately before each test, lizards were weighed and measured (snout–vent length, SVL). During the experiment, each lizard was placed in a small experimental terrarium (20 × 15 × 15 cm) with a thermocouple probe inserted in its cloaca, and restrained under a 125W infrared spotlight (Exoterra IR lamp) that was initially turned off. The thermocouple probe was connected to a quick-reading thermometer (Omega HH96/T, ± 0.1°C) and provided an estimate of deep (core) body temperature (T°b). Ambient temperature in the test area was constantly monitored with a mercury thermometer placed next to the experimental terrarium while lizard body surface temperatures were recorded with a still IR camera (Fluke Ti25). According to manufacturer specifications, this camera has a thermal sensitivity of ≤ 0.09–30°C (90 mK) and a spatial resolution of the thermal image of 320 × 240 pixels. When room and lizard surface temperatures were similar (± 0.5°C) the lamp was turned on and the lizard was allowed to warm until the temperature of its dorsal surface reached 39–40°C, after which time the lamp was turned off and the lizard was left to cool down in the terrarium. To determine the relationship between T°s and T°b, we measured both temperatures simultaneously at one-minute intervals. Finally, we measured operative temperature (i.e., the predicted equilibrium temperature of a nonregulating ectotherm) inside the experimental terrarium with a thermocouple probe inserted into a hollow copper model measuring 64 mm length x 16 mm Ø (Hertz et al. 1993).

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Table 1. Body mass, snout–vent length (SVL), and mean and standard deviation of the difference between dorsal surface temperature (T°s) and deep body (i.e., cloacal) temperature (T°b) when lizards were warming and cooling for the five species used in this study.

Species	N	Body mass (g) mean [range]	SVL (mm) mean[range]	Warming T°s-T°b ± SD	Cooling T°s-T°b ± SD
Psammodromus algirus	10	6.86 [5.9–9.8]	64.54 [65–74]	1.78 ± 0.48	0.38 ± 0.29
Psammodromus hispanicus	8	1.91 [1.4–1.7]	44.50 [37–46]	1.44 ± 0.46	0.76 ± 0.29
Podarcis muralis	6	6.20 [6.5–9.4]	61.83 [61–71]	1.00 ± 0.40	0.52 ± 0.30
Podarcis liolepis	10	3.28 [2.0–5.7]	52.90 [47–64]	1.34 ± 0.37	1.15 ± 0.45
Acanthodactylus erythrurus	10	8.71 [6.1–11.0]	68.30 [61–71]	1.76 ± 0.92	0.52 ± 0.30

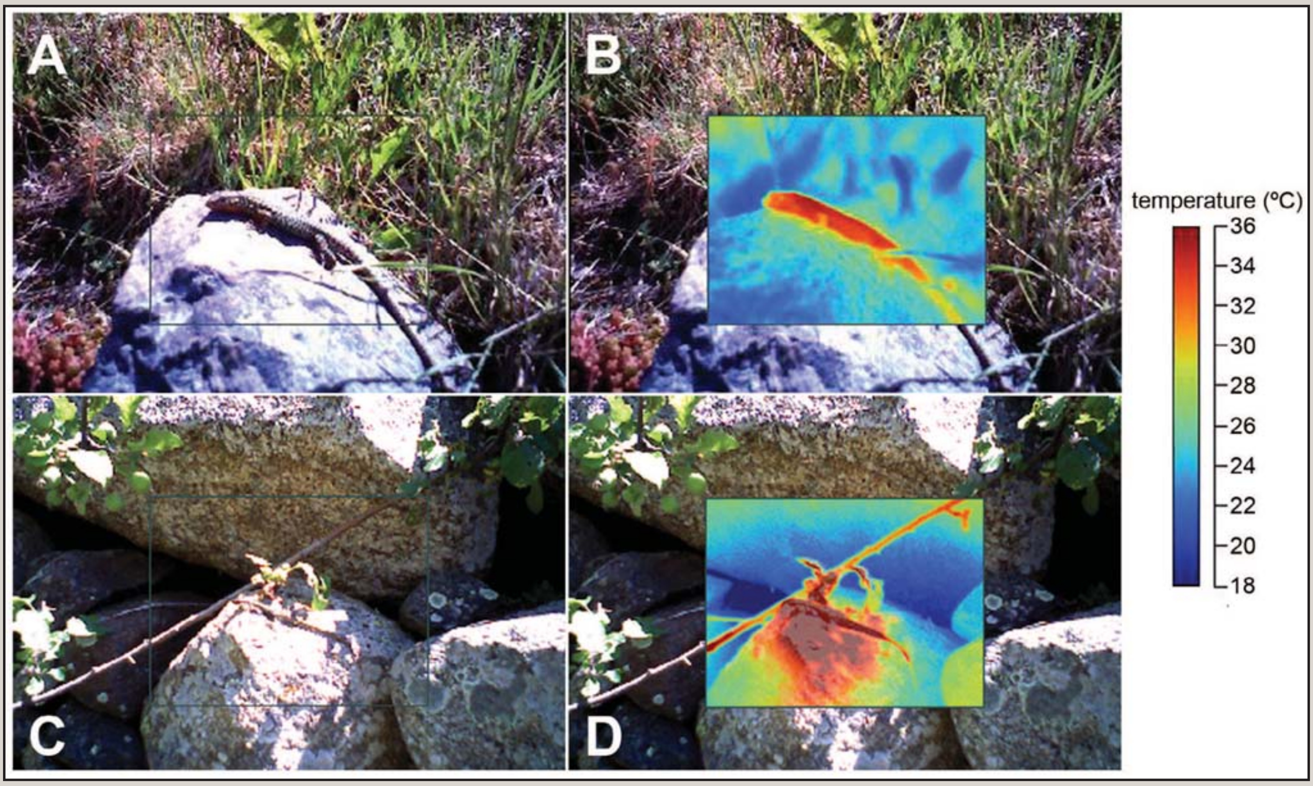

Fig. 1. A standard color digital photograph (A) and the corresponding infrared image (B) of an adult male of *Podarcis muralis* basking in the field. Digital photograph (C) and the infrared image (D) of another adult male in thermal equilibrium. In both cases, digital and infrared images were taken simultaneously with the IR camera. Note the difference in temperature between different lizard body regions (e.g. head, legs, tail). The color scale on the right indicates the surface temperature of the lizard and its immediate surroundings.

It is generally accepted that, regardless of their color, reptiles radiate almost as black bodies with an emissivity of approximately 0.95–1.00 (Carroll et al. 2005). Therefore, for acquisition of thermographic images we set the IR camera emissivity at 0.97. During preliminary trials, we determined that temperature readings varied in the range of ± 0.5°C when emissivity was varied from 0.95 to 1.00. Thermographic images were analyzed using the software provided with the camera (SmartView 2.1, Fluke), which allowed average and maximum-minimum temperature measurements to be determined from a rectangular area approximately equidistant from the insertion of the fore and hind limbs.

We plotted graphs showing variation of T°s and T°b with time when lizards were warming and cooling. To assess the relationship between T°s and T°b we also calculated determination coefficients of the two temperatures using standardized major axis regression (SMA) with (S)MATR software (v.2 Falster et al. 2006).

Results.—Fig. 1 shows two examples of the types of images produced by the IR camera. Fig. 2 presents results for each species showing variation of temperature with time**.** When the lizards were warming, the average error committed estimating T°b from IR images was 1.46 ± 0.53°C (mean ± SD) while the error committed when lizards were cooling was 0.67 ± 0.33°C (see Table 1 for further details). Determination coefficients of the relationship between T°s and T°b ranged from 0.95 to 0.99. This suggests that, in all cases, over 95% percent of the variation in surface temperature can be explained by the correlation between cloacal and surface temperatures.

Discussion.—The present study demonstrates that IR cameras can provide accurate estimates of deep body temperatures of small lizards without the need to capture or chase them. The error committed when estimating T°s and T°b should not be large in small animals due to rapid heat conduction from surface to the body core (Dzialowoski and O'Conner 2001; Seebacher and Shine

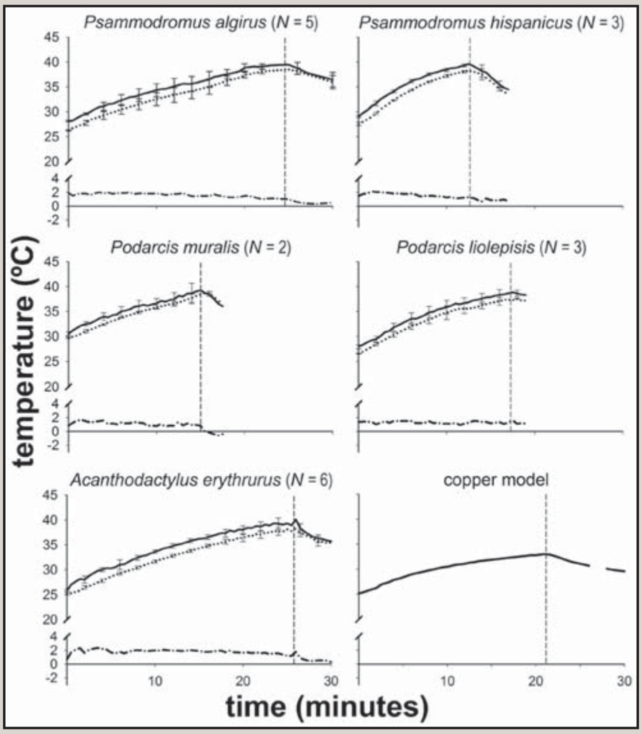

Fig. 2. Graphs showing temperature variation in five lacertid species and a hollow copper model equipped with a thermocouple probe and subject to the same treatment as the experimental lizards. Solid lines represent surface body temperature as determined from IR camera measurements. Dotted lines represent cloacal temperatures obtained by means of a thermocouple attached to a quick-reading thermometer. Differences between surface and deep body temperature are shown by dash-dot lines. The time when the spotlight was turned off is indicated by vertical dashed lines. Note that the sample sizes given differ from those in Table 1 because we have excluded from the graphs some lizards that changed location underneath the spotlight during the experiment causing oscillations in the recorded temperatures. Error bars = ± 1 SD.

2004), as shown in Fig. 2, where the lines representing T°s and T°b variation are roughly parallel and with nearly the same differential across temperatures and lizard species. The large determination coefficients between T°s and T°b ($R^2 > 0.95$) for all the species in our sample corroborate this conclusion. However, we caution that the error committed when estimating deep body temperatures of larger animals with slower rates of heating and cooling will likely be larger and should be determined empirically.

The average difference between T°b and T°s measured from an IR image when animals are basking is 1.46 ± 0.53°C, which is larger than that reported in previous studies (Jones and Avery 1989; Tosini and Avery 1993). However, this error is likely much smaller than the error committed when measuring cloacal temperatures in the field using standard procedures (Avery 1982; Hare et al. 2007). Moreover, when lizards are cooling the average error committed is 0.67 ± 0.33°C, which is similar to the error committed with other non-invasive techniques such as IR thermometers (Alberts and Grant 1997; Bucklin et al. 2010; but see Carretero 2012).

The discrepancies between T°s and T°b are possible because the dorsal skin of basking animals warms faster and may reach higher temperatures than the body core when animals are warming, and because the body core has a higher thermal inertia than the body surface when the animals are cooling (Remmert 1985; Tosini and Avery 1993). The lag between surface and core body temperature, especially during the warming phase of the experiment, reflects a lack of thermal equilibrium which may produce inaccuracies in T°b estimation (Dzialowoski and O'Conner 2001; Seebacher and Shine 2004). Although the error committed in estimating T°b from T°s is bound to be negligible in small animals with low thermal inertia, care should be taken when recording temperatures of lizards that have just started basking or that have recently moved into a new thermal environment and therefore may have not yet reached a steady state.

In conclusion, thermographic cameras are a useful alternative to traditional techniques for measuring body temperature in small reptiles in the laboratory and in the field. Our results demonstrate that, at least for small lizards, thermographic cameras can provide precise and highly accurate estimates of deep body temperature. Although thermographic cameras have several advantages over other non-invasive techniques, perhaps the most important are the ability to simultaneously record thermal data from different parts of the lizard and its surroundings (Fig. 1), and the possibility of acquiring readings from animals at distances large enough to ensure that observer effects are minimal.

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Modification of Camera Traps for the Study of Ectothermic Vertebrates

Camera traps have been used extensively to study animal behavior and ecology (Rowcliffe and Carbone 2008). Recent studies have instituted motion-sensitive camera traps as a method for noninvasive observation of crocodilian behavior (Chenna et al. 2010). However, because these devices are designed to capture images of mammals, the motion sensors on virtually all commercially available cameras are based on infrared energy detection. This presents a problem for the use of these devices for the study of ectothermic vertebrates. Recent data (not shown) collected in our outdoor alligator handling facilities have shown that, while capturing some photos of alligators, these digital camera traps are unreliable due to the fact that temperature differentials between the animal and the environment are often too small to trigger the camera's IR sensor. To resolve this problem, we designed a small electronic circuit that drives an infrared light-emitting diode (IR LED). The circuit, which is powered by tandem 9V batteries, activates the LED for two sec every five min. The IR LED is nestled against the IR detector of the camera and, when stimulated by the circuit, triggers the camera to take a photograph. Therefore, the cameras are stimulated to capture an image approximately every five min, or when triggered by another IR source (endotherm, etc.). We have used this method to monitor nests and to determine the frequency, length of time, and time of day of visits by alligators and by potential predators to nests of alligators.

Materials and Methods

Materials.—Four IR2 game cameras (Wildgame Innovations, Grand Prairie, Texas, USA) were purchased at a local sporting goods store. Plastic dry boxes, 555 timers, capacitors, resistors, and infrared LEDs were purchased from Radio Shack. Nickel-metal hydride rechargeable batteries (C and 9V), and battery charges were purchased from Tenergy Corp. (Fremont, California, USA).

Electronic Circuits.—The camera was triggered by an infrared LED which was controlled by a 555 timer circuit (Figs. 1A, B). It is one of the typical applications of the 555 timer chip. This circuit

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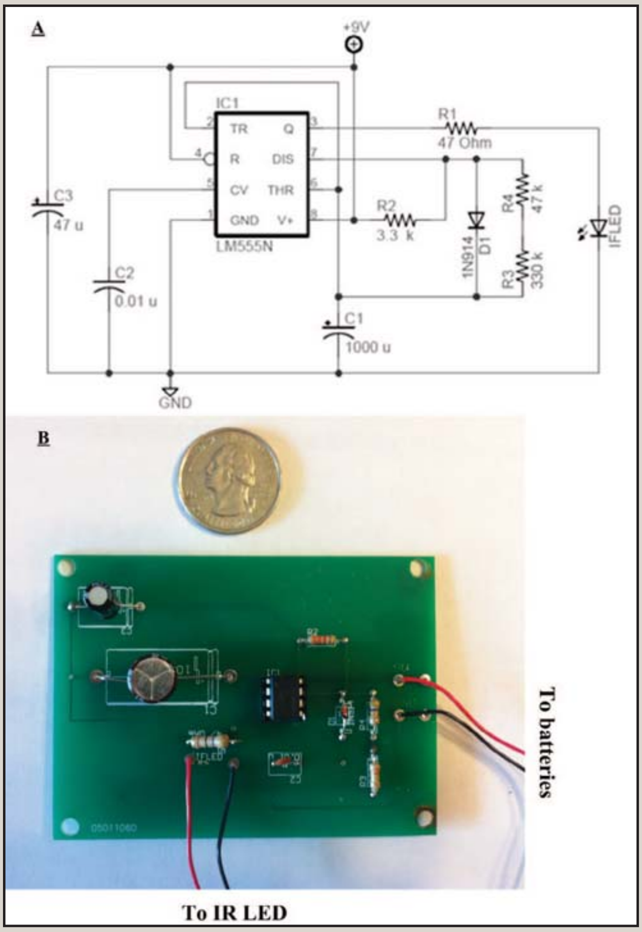

Fig. 1. A) Diagram of the electrical circuit that controlled the camera traps placed at alligator nests. B) Photograph of a finished electrical circuit.