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Predicting small endotherm body temperatures from scalp temperatures

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Abstract

We used 2-d to 3-d-old mallard ducklings (*Anas platyrhynchos*) to test whether remote thermographic measurement of scalp temperature could be used to estimate core (cloacal) temperature from a distance. The scalp was exposed by trimming down from an area of $\leqslant 1\,\text{cm}^2$, and surface temperature measured to $\pm 0.12\,^\circ\text{C}$ with a radiometric thermal imager. For wind speeds of up to 2.5 m/s, we found cloacal temperature could be estimated to within 1 °C by using a regression model incorporating only scalp temperature and ambient temperature. The inexpensive method of dyeing the scalp black and painting it with temperature-sensitive cholesteric liquid crystal paint is more difficult and provides less accuracy, but appears to be a useful means for monitoring change in body temperature. These methods allow body temperatures of small or young endotherms to be monitored from distances of up to several meters without surgery or encumbering wires, minimizing stress that may alter behavior patterns and physiological parameters.

Keywords: Temperature; Temperature measurement; Body temperature; Skin temperature; Thermography; Liquid crystals; Ducks; *Anas platyrhynchos*; Convection

1. Introduction

Behavioral and many physiological studies need a non-invasive means to estimate the body temperature of small animals from a distance. A nearby observer may alter behavior, and approaching, handling, or restraining an animal causes an increase in body temperature and heart rate (Southwick, 1973; Heatwole et al., 1979; Cabanac and Gosselin, 1993; Moe and Bakken, 1997; Cabanac and Aizawa, 2000; Cabanac and Bernieri, 2000; Cabanac and Guillemette, 2001). Radiotelemetry implants can be used with animals large enough to carry them (Aldridge and Brigham, 1988; Amlaner, 1989) but require a significant incision and postoperative recovery period (Perry, 1981; Pietz et al., 1993; Wang and Adolph, 1995). This limits their usefulness for studies of neonatal animals, whose physiological characteristics change rapidly during the first few days (Starck and Ricklefs, 1998). Temperature-sensitive passive integrated transponders (PIT tags) are very small (ca. 2 mm diameter × 12 mm long), but still require an incision for implantation and have short transmission ranges ($\leqslant$5 cm, Kort et al., 1997). Radio-telemetry of skin surface temperature avoids surgery, but accuracy is reduced (Willis and Brigham, 2003) and the transmitter may affect behavior (Perry, 1981; Pietz et al., 1993; Rotella et al., 1993).

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Infrared thermometry can measure the temperature of an exposed surface from distances of several meters. Core temperature can be estimated from skin temperature when the core–skin temperature difference is small and predictable. The difference is determined by surface cooling, tissue thickness and tissue perfusion. Thus, the tympanic membrane is frequently used in clinical medicine because it is located close to the brain in a deep depression that shields it from forced convection (Yaron et al., 1995; Stavem et al., 1997). Unfortunately, the tympanum is not easily imaged from a distance. However, the body temperatures of small reptiles have been estimated from skin temperature successfully because only a small amount of heat flows through a thin layer of tissue (Gates, 1968; Jones and Avery, 1989; Tosini and Avery, 1993, 1996; Shine et al., 2002).

We propose that scalp temperature might similarly be used on small birds by trimming feathers from an area of the scalp directly over the brain. The tissue between the brain and skin is thin (Dawson and Whittow, 2000), and thus brain–skin temperature differences are usually small. Convective cooling is a potential source of error, but down surrounding the trimmed spot provides some convection shielding, and air temperature and wind speed data might be used to make corrections (Audet and Thomas, 1996). Alternatively, the trimmed area could be covered with a polyethylene film convection shield glued to the tips of the surrounding feathers.

We tested this approach using 2-d- to 3-d-old mallard ducklings (*Anas platyrhynchos*). Ducklings were studied while exposed to a range of air temperatures and wind speeds to test for errors caused by convection, and while swimming in cold water to test for errors due to head–body temperature differences. We developed models that estimated cloacal temperatures from thermographic scalp temperatures. Finally, we also tested whether temperature-sensitive cholesteric liquid crystal paints might provide an inexpensive alternative to thermography for remote scalp temperature measurements.

2. Materials and methods

2.1. Duckling measurements

All experimental procedures were approved by the Indiana State University Institutional Animal Care and Use Committee, Protocol 01–08:GB. We hatched ducklings from fertilized mallard eggs (Whistling Wings, Hanover, IL, USA). Parents were derived from wild stock (ca. fifth generation). When ducklings were approximately 24 h old, they were transferred from a brooder to a 1.3 m diameter plastic wading pool filled with 6–8 cm of water and equipped with a brooder on a central island. Ducklings were maintained at 27 °C and 12:12 L:D photoperiod with poultry starter available ad libitum. We imprinted ducklings on a mallard hen decoy attached to an arm driven by a 3-rpm motor, which towed the decoy around the pool intermittently (1 min on, 4 min off). Ducklings were tested when 2–3 d old.

The main series of experiments was conducted in a wind tunnel respirometry chamber (Bakken et al., 1989) operated at various air temperatures and wind speeds to test for errors caused by convection conditions. A purpose-built optical tachometer attached to the blower shaft was calibrated using a Prandtl-design Pitot tube and electronic hook gauge to give wind speed accurate to ± 0.05 m/s (Prandtl and Tietjens, 1934). Because metabolic heat production might also be a significant covariate affecting brain–scalp temperature differences, we measured respiratory gas exchange. The open-circuit respirometry procedures and instruments are described elsewhere (Bakken et al., 1999; Banta et al., 2004). Air, floor, and duckling cloacal temperatures were measured with type TT thermocouples. A digital data logger (CR-21X, Campbell Scientific, Logan, UT, USA) recorded all data at 1 min intervals, and oxygen consumption was calculated for each consecutive 2-min interval using Z-transform methods (Bartholomew et al., 1981).

Each duckling was randomly assigned to 1 of 4 air temperatures (5, 15, 25 or 35 °C). Data were collected during 4 consecutive 15 min runs at 4 wind speeds in randomized order (0.5, 1.7, 2.0 and 2.5 m/s) under room illumination (300 lux) during the active phase. A few ducklings were tested again the following day at a new air temperature using a different sequence of wind speeds.

A second series of measurements tested for head–body temperature differences using ducklings swimming at 30 cm/s in the plastic respirometry enclosure of a flow tank (Vogel and LaBarbera, 1978; Fish, 1995). The flow tank was housed in a controlled environment room (model 8083, Hotpack Corporation, Philadelphia, PA, USA). Ducklings were tested at 1 of 6 water temperatures (5, 10, 15, 20, 25, and 30 °C) with air temperatures either 10 or 15 °C above water temperature. Procedures were otherwise similar to the wind tunnel experiment, except that water temperature was recorded in place of floor temperature.

Before each experiment, we weighed the duckling and created a thermography target by using fine embroidery scissors to trim the down from $\leqslant 1\,\text{cm}^2$ of the scalp at a point directly over the brain. We lubricated the rounded sensing junction of a thermocouple with petroleum jelly, inserted it 1.5–2 cm into the cloaca, and secured it by using Skin Bond® adhesive (Smith-Nephew Inc., Largo, FL, USA) to glue several adjacent down feathers over a button attached to the thermocouple. After a 5–10 min recovery period, we placed the duckling in the experimental enclosure. Ducklings were allowed 10 min to