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Thermal windows on the body surface of African elephants (*Loxodonta africana*) studied by infrared thermography

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ABSTRACT

In this study, we examined infrared thermograms in the course of time of six African zoo elephants and observed two phenomena. First, we noticed independent thermal windows, highly vascularised skin areas, on the whole elephants' body and second we observed distinct and sharply delimited hot sections on the elephants' pinnae. The frequency of thermal windows increased with increasing ambient temperature and body weight. We assume that the restriction of an enhanced cutaneous blood flow to thermal windows might enable the animal to react more flexibly to its needs with regard to heat loss. With this understanding, the use of thermal windows in heat loss might be seen as a fine-tuning mechanism under thermoneutral conditions.

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1. Introduction

In terms of heat regulation the largest terrestrial animal – the elephant – is a case in point. Owing to its enormous body mass, the small surface-to-volume ratio and the lack of sweat glands (Spearman, 1970; Hiley, 1975; Wright, 1984; Mariappa, 1986), elephants are confronted with unusual problems concerning heat dissipation and drying of the integument (Lillywhite and Stein, 1987). Control of skin temperature (T_s) is an extremely important mechanism in elephants' temperature regulation (Phillips and Heath, 1995) and the most important thermoregulatory organs to use this pathway are the elephants' ears. The ears of the African elephant (*Loxodonta africana*) have a large surface-to-volume ratio as well as an extensive and prominent vascular supply, which predestines these organs for optimal heat dissipation (Wright, 1984). In conjunction with their great importance in thermoregulation, the ears are frequently termed "thermal windows" (Wright, 1984; Williams, 1990). Thermal windows are body areas responsible for heat exchange. This is achieved by modifying and controlling blood flow (via vasoconstriction and vasodilatation) into these areas (Šumbera et al., 2007). The term is also applied to appendages (Williams, 1990; Klir and Heath, 1992) or poorly haired surface regions like the shoulder, the area between the shanks, the eyes, nose, and mouth (Phillips, 1992; Hilsberg, 2000). Thermal windows are not only mentioned in relation to body appendages and do not necessarily include entire organs. For example the trunk of pinnipeds can show thermal windows, which protects these animals for hyperthermia while on land, during exercise or in warmer waters (Krumbiegel, 1933; Øritsland, 1968). Mauck et al. (2003) underlined this from their observation of small and heavily vascularised hot spots on the bodies of harbor seals, harp seals, and gray seals. These independent thermal windows were suggested to facilitate heat dissipation via localized evaporation of water contained in the seal's pelage.

Infrared thermography has already been successfully used to measure T_s in several mammalian species (gerbils: Klir et al., 1988; foxes: Klir and Heath, 1992; bats: Webb et al., 1993; ratites: Phillips and Sanborn, 1994; guanacos: DeLamo et al., 1998; barn owls: McCafferty et al., 1998; seals: Mauck et al., 2003; eland and dairy cattle: Kotrba et al., 2007; mole rats: Šumbera et al., 2007), including elephants (Cena and Clark, 1973; Williams, 1990; Phillips and Heath, 1992; Hilsberg, 2000), and to visualise thermal windows on animal surfaces (seals: Mauck et al., 2003; toucans: Tattersall et al., 2009).

In preliminary examinations on African elephants (Weissenböck, 2006), we observed independent thermal windows on the whole elephant body, similar to those reported in seals (Mauck et al., 2003). We started a detailed study on elephants' thermal windows, which is described here. We used infrared thermography to visualise T_s of African elephants at different ambient temperatures (T_a). We limited our observations to rather low T_as ranging between −6.7 and 20.3 °C. At higher T_as we would have expected full vasodilatation and probably more homogenous T_s

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over the elephant's body, which would not have allowed observing the appearance and disappearance of thermal windows.

We analysed for the presence, chronological development, temperature, and shape of thermal windows on the ears and torso. Furthermore we stated the question, which factors might influence the presence of thermal windows. Therefore, we used statistical tests to verify the influence of T_a, elephants' age, and body weight.

2. Material and methods

2.1. Animal welfare conditions

The observations via infrared thermography focused on the elephant group at the Vienna Zoo, Austria. T_s of four adult female elephants (mean weight 3215 ± 315 kg) and two juvenile elephants (one male, one female; 977 ± 496 kg) were observed. The keepers had direct contact with the group for approximately 1.5 h per day. The elephants spent the night unchained in the indoor enclosure (2100 m^2) within the family and were released to their outdoor enclosure (4700 m^2) for approximately 4 h during the day. The elephants were fed with hay, branches, carrots and apples.

2.2. Data collection and observation procedure

T_s was measured from 12:00 am to 16:30 pm for 11 days between December 2004 and February 2005. The elephants were observed in the following defined situations: (1) indoors, (2) outdoors, and (3) return to indoors.

Infrared images (thermograms) of the body surface were obtained by using a thermographic camera ThermaCAM P60 (FLIR Systems, Portland, OR, USA), with a 24° lens, automatic calibration and a 7.5–13 μm spectral range.

To obtain correct values of T_s by compensating for the effects of different radiation sources the following parameters were supplied for the camera: emissivity of the subject (0.98 as recommended by the manufacturer), reflected temperature, distance between the subject and the camera, and air humidity (RH). In order to allow acclimatization, the thermograms were recorded after 15 min stay in the respective environment. T_a and RH were recorded by a temperature data logger (Gemini Data Loggers Ltd., Chichester, West Sussex, UK) every 20 min. All data loggers, protected by a perforated plastic housing, were placed away from direct sources of heat, sunlight and water, and mounted at a height of approximately 2 m from the ground in the indoor and outdoor enclosure. Special data logging software (Tinytag Explorer, Geminidataloggers Ltd., Chichester, West Sussex, UK) was applied for programming of the loggers and for data analysis.

The infrared pictures were taken at intervals of approximately 20 min in all animals.

The elephants were observed with the thermo-camera at a distance between 5 and 10 m in the indoor enclosure and at 10–30 m in the outdoor facility.

Animals were monitored from lateral sides. They were viewed perpendicularly, to avoid possible errors due to angle distortion. The recordings in the outdoor facility were done without direct exposure of the elephants to the sun, because the enclosure was shadowy during the observations. T_s was recorded while the animals were not subject to any restraint, separation or handling.

2.3. Analysis of thermograms

The analyses of the infrared images were done with the software ThermaCam^{TM}Researcher (FLIR-Systems, Inc. Portland, OR, USA, 2002). In total, 325 thermograms were analysed.

2.3.1. General aspects

T_s of several defined body areas, namely head, proboscis, ear, torso, fore limb, and hind limb was measured. The defined body areas were circumscribed with polygons by hand. The software gave back the minimum, maximum, and mean T_s within the chosen parts of the images. T_s of tail and tusk were not included here.

2.3.2. Definition and analysis of thermal windows

A thermal window, including both entire organs (ears) and small independent hot spots, on the animals' surface, was defined as a restricted area (minimum size: just visible as dot shaped hot spot in a thermogram) which differed by more than 5.0 °C from its adjacent regions. Because of their specific appearance, we examined thermal windows of the elephant's ears and body separately. The surface area "ear" referred to the anterior pinna, and the surface area "body" included the elephant's torso and limbs. It was not possible to separate the torso and the limbs in the analysis because thermal windows are often widely spread and hence cannot be assigned solely to one of the respective body regions. The head and proboscis were excluded from thermographic analyses regarding thermal windows because small independent hot spots could not be clearly differentiated in these areas.

Identified thermal windows were circumscribed with polygons. Individual thermal windows were numbered (from cranial to caudal and ventral to dorsal and in order of their appearance) and their temperature changes were recorded in the course of time. To document the recurrence of thermal windows, we further partitioned each body part into three sections (ventral, middle, and dorsal section). We characterised previously neighboured thermal windows as fused, when there were no transit zones among them and they did not differ more than 1.0 °C in mean T_s.

2.4. Sizing of thermal windows on the pinnae

To determine the relative size of a thermal window and to observe its chronological development we used the software package ImageJ 1.36b (National Institutes of Health 2006, Bethesda, Maryland, USA). We framed the elephant's ear and thermal windows in it with polygons. The sizes of these polygons were returned by the software in pixel-values. Since contortions of the depicted thermal windows at the torso and the limbs were much higher, no sizing was carried out for these regions.

2.5. Statistics

Values are given as means $\pm$ SD, except when otherwise stated. Data were analysed with the statistical package R (R Development Core Team, 2009). To test for the influence of T_a, age, and body weight on T_s, we used linear mixed effect models (lme, library nlme; Pinheiro et al., 2009), with different intercepts for individual as a random effect in order to correct for repeated measurements. The significance of every fixed factor in the lme was assessed using an *F*-test. The "predictors" body weight and age had no significant effect on T_s (all $P \geq 0.1$).

Furthermore, the effects of T_a, age and body weight of the elephants in the presence of thermal windows on the ear and the

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