



Variation in rhinarium temperature indicates sensory specializations in placental mammals



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ABSTRACT

The rhinarium, a specialized nose-tip characterized by an area of naked and wet skin around the nostrils, is a typical mammalian structure. The type and amount of innervation suggests a sensory role and morphological diversity implies so far unidentified species-specific functional specializations. Rhinaria also vary in temperature and this may be related to the functions of these sensory organs. We performed a comparative study on rhinarium temperature in order to learn more about possible correlations with phylogeny and ecology. We have concentrated on terrestrial carnivorans and large herbivores, but also investigated a number of other species, some of them lacking typical rhinaria. We used infrared (IR) thermography to determine nose skin temperatures from safe distances and without interfering with the animals' behavior. In all groups studied, the temperature of the rhinarium/nose-tip decreased with decreasing ambient temperature. At all ambient temperatures, rhinarium temperature was lower, by 9–17 °C, in carnivorans compared to herbivores. Glires (rodents and lagomorphs), haplorrhine primates, and omnivorous Perisso- and Artiodactyla were intermediate. In strepsirrhine primates, rhinarium temperature was similar to ambient temperature. Our findings in Strepsirrhini are consistent with the hypothesis that their rhinaria have an indirect role in chemical communication. Warm rhinaria in herbivores suggest a tactile function, while the low skin temperatures on carnivoran rhinaria may make the skin particularly sensitive to warming.

1. Introduction

Mammals have many features that are unique to the group and one of them is the rhinarium, which is a specialized nose-tip covered by glabrous and wet skin (Pocock, 1918; Brown, 1972). Rhinaria occur in most mammalian lineages and are only absent in some derived groups, such as cetaceans and haplorrhine primates including humans. There is great interspecific diversity in rhinarium size, shape, subdivision, skin sculpturing, and color (Hill, 1948), suggesting a multitude of different functional specializations. The overall rhinarial patterns are significant for taxonomic studies and the detailed patterning of a nose print is as individual for many mammals as a fingerprint for humans (Brown, 1972).

Situated at the front end of the body and innervated by a sensory branch of the trigeminal nerve, the rhinarium is likely to have a sensory function. Although the rhinarium is part of the nasal region, it has no direct role in olfaction, since nervous connections to the olfactory and accessory olfactory (vomeronasal) system are absent (e.g. Evans and DeLahunta, 2013). In a few cases, it is known that rhinaria or homologous structures have central positions in the sensory equipment

of mammals, such as the tactile tentacles in the rhinarium of the star-nosed mole (Catania, 2000). In other cases, the rhinarium seems to have an accessory role in sensory perception (e.g. Poran, 1998; Ankel-Simons, 2007). In most cases, however, the function of the rhinarium is unknown. Primarily tactile roles have been proposed repeatedly (e.g. Hill, 1948; Barker and Welker, 1969; Halata, 1990), but the physiological results have been inconclusive (Barker and Welker, 1969).

Rhinaria and homologous structures differ not only in morphology, but also in temperature. Reindeer (*Rangifer tarandus*) warm their hairy nose-tips, presumably to maintain tactile sensitivity when foraging for lichens in sub-arctic winter (Ince et al., 2012). The cold noses of dogs are well known, but the function of the prominent dog rhinarium has been elusive, despite dogs having accompanied humans for thousands of years (Ovodov et al., 2011; Thalmann et al., 2013; Freedman et al., 2014). Low skin temperatures interfere with tactile sensitivity (Green, 1977; Stevens and Hooper, 1982; Gescheider et al., 1997), such that a cold rhinarium is unlikely to have a mechanosensory role. Here we performed a comparative study on placental mammals, using infrared (IR) thermography for determining rhinarium temperatures. In species lacking typical rhinaria, the temperature of a corresponding area of the

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nose-tip was determined.

Our aims were to correlate rhinarium temperature with phylogeny and ecology in order to collect information that may shed light on the functions of rhinaria and homologous structures. We concentrated our efforts on terrestrial carnivorans (members of the order Carnivora) and large herbivores (predator and prey) as well as lemurs; the latter because there is a possible functional explanation for the coldness of their rhinaria (see Discussion).

2. Material and methods

2.1. Ethics statement

Our study complied with Swedish animal welfare legislation and was approved by the Malmö/Lund ethical committee (permit nr. M 148-12).

2.2. Experimental animals

We visited eight zoos in Sweden, Denmark, and Germany in order to investigate a large variety of placental mammals. In addition, we performed measurements on farm and pet animals. We studied at least one representative of each major group of terrestrial carnivorans and focused on large herbivores for comparisons. Otherwise, we were opportunistic in the choice of species. Because of the preferences of zoos and their visitors, as well as for practical reasons, our sample is biased toward large species and entirely excludes the second largest placental order, i.e. the Chiroptera. Some species were present in several of the visited zoos and in such cases counted only once in order to avoid pseudoreplication. In the statistical analysis, data points from such species were weighted accordingly, so that all species contributed equally to the final result. All animals were awake and active, appeared healthy, and interference with their behavior was minimal. Data collection was performed from February 2013 to February 2014, both indoors and outdoors under a wide range of ambient temperatures.

2.3. Experimental procedure and thermography

Nose temperature was determined from a distance with thermographic cameras, either a FLIR E30 equipped with an 18 mm lens or a FLIR T640 with either a 24.6 mm or a 41.3 mm lens, depending on animal size and operating distance. The measurement ranges were set to $-20\text{ }^{\circ}\text{C}$ to $+120\text{ }^{\circ}\text{C}$ (E30) and $-40\text{ }^{\circ}\text{C}$ to $+150\text{ }^{\circ}\text{C}$ (T640), measuring accuracy was $\pm 2\text{ }^{\circ}\text{C}$ in both instruments. No attempt was made to correct for errors originating from possible circadian variation in body temperature (ca. $\pm 0.5\text{ }^{\circ}\text{C}$ in humans) (Widmaier et al., 2016) or the noise of about $\pm 1\text{ }^{\circ}\text{C}$ because of differences in measuring distance (ca. 1–10 m) (Faye et al., 2015). Instead, we concentrated on performing measurements on as many animals as possible during each visit at a zoo.

The cameras had recently been calibrated by the manufacturer. Infrared emissivity of human skin is close to 1.0 (Hardy, 1934; Monteith and Unsworth, 1990) and we assumed the same to be the case for animal skin. Emissivity values exist only for dry skin and they may differ for the wet rhinarium surface. However, the emissivity of water is also close to 1.0 (Carbonneau et al., 2012), such that corrections for lower emissivity and ambient temperature were not applied. Measurements were performed with FLIR Tools Plus software (FLIR Systems) by placing a line on the frontal part of the rhinarium/nose-tip and averaging temperature readings along this line. This means that we disregarded possible small-scale temperature variations on the nose. Measurements were conducted in shady areas to avoid reflections of incident sunlight.

Where possible, we studied three individuals and averaged the results to obtain a species-specific data point at a particular ambient

temperature. In a minority of cases, the data points are based on fewer individuals (see [Supplementary material](#); [Table S1](#)). Ambient temperatures were measured in the shade with a digital thermometer (EN 13485, TFA Dostmann, Wertheim, Germany).

Nose external anatomy was photographed with a Nikon D300s digital camera (Nikon, Tokyo, Japan) in combination with a Tamron XR 18–200 mm zoom objective (Tamron, Saitama, Japan).

2.4. Data analysis

Data analysis was performed in Excel (Microsoft, Redmond, USA) and statistical analysis in SPSS (IBM, Armonk, USA). Before analysis, data points were transformed by a regression line fitted to nose temperature as function of ambient temperature from carnivorans and grazers (see below). This simple operation equalized variance of the dependent variable (nose temperature) between these groups without changing their relations to each other, such that a univariate analysis of covariance could be performed. Graphical representations were compiled in CorelDraw (Corel, Ottawa, Canada). Digital images of the external nose anatomy were exported with Nikon ViewNX 2 software. Composite thermo- and photographs were created in Photoshop (Adobe Systems, San Jose, USA).

3. Results

The sample comprises a total of 74 species or subspecies from 32 mammalian families ([Fig. 1](#)). A complete list of species, numbers of individuals studied, and ambient temperatures during measurement, as well as a compilation of photo- and thermographs is available as [Supplementary material](#) ([Tables S1, S2](#)).

3.1. Rhinarium temperatures

Substantial numbers of data points were obtained from the following groups: terrestrial Carnivora, herbivorous Perisso- and Artiodactyla, Glires (Lagomorpha and Rodentia), Strepsirrhini, and Haplorrhini ([Fig. 2](#)). In all of these groups, nose temperature decreased approximately linearly with decreasing ambient temperature. However, herbivorous Perisso- and Artiodactyla had considerably warmer noses than carnivorans, while nose temperatures were intermediate in Haplorrhini, Glires, and omnivorous Perisso- and Artiodactyla. Nose temperatures were close to ambient temperatures in Strepsirrhini. We fitted a regression line to the data points in each group and performed analyses of covariance. First we compared herbivorous Perisso- and Artiodactyla, and found no significant difference ($p=0.13$). We therefore joined these groups to a group of large herbivores (“Grazers”). Comparison of Grazers and Carnivora, with a substantial number of species in each group ([Table S1](#)), revealed a highly significant difference ($p < 0.001$). Rhinarium temperatures in Strepsirrhini did not differ significantly from ambient temperatures ($p=0.68$) in the range covered ($16.0\text{--}26.5\text{ }^{\circ}\text{C}$) ([Fig. 2](#)). Further comparisons were not performed, because we were mainly interested in whether there is a difference between large herbivores and carnivorans, and because few data points could be collected from other groups. Details of the linear regressions and the statistical analysis are given in the [Supplementary tables S3 and S4](#).

3.2. General observations

The species in our sample showed great diversity in the shape, size, fur cover, wetness, and color of the nose tip ([Table S2](#)). Typical rhinaria were most common, but absent in Equidae, Giraffidae, Camelidae, Suidae, and the reindeer, which unlike other Cervidae has a hairy nose tip. In Suidae, the nose disc generally appeared naked, but there were short hair stubs in some individuals.

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