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Body temperature and fur quality in swimming Water-Shrews, *Neomys fodiens* (Mammalia, Insectivora)

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Abstract

Body temperature of the European water-shrew *Neomys fodiens* was reinvestigated with intraperitoneally implanted radiotransmitters. Two animals, caged in outdoor conditions, were tested during February and March. Mean body temperature (Tb) during rest was 37.0 °C, during activity 37.5 °C. During stress of capture Tb increased to 38.4 °C, and during a social confrontation mean Tb was 39.4 °C.

During forced swimming Tb decreased at a rate of 1.1 °C per minute in an animal with wet fur. However, when kept in adequate conditions, animals could maintain their body temperature at a level of about 37 °C in most of the tested situations. In water of 2.6 °C, mean Tb after 6 min of forced swimming or diving was 37.4 °C, comparable to Tb during terrestrial activity. In these animals the fur remained dry even on its surface. The pelt of these shrews has a hydrophobic property which seems to be unique compared to other semiaquatic mammals.

Introduction

European and American water-shrews (*Neomys fodiens* and *Sorex palustris*) have a body weight of 10–20 g and are the smallest semiaquatic mammals. The degree of their adaptation to swimming and diving is a matter of discussion but most authors consider it to be rather weak. This statement can be substantiated for *N. fodiens* by some selected references: An extensive analysis of faeces, sampled over a two years period by Churchfield (1985) showed, that only 50 % of the food items of the water-shrew are aquatic organisms. After Ruthardt and Schröpfer (1985), the water-shrew is only weakly adapted for locomotion in water. Moreover, most of the measured diving sequences in captivity last only 3 to 10 seconds (Köhler 1984; Churchfield 1985; Ruthardt and Schröpfer 1985). The rows of bristles on hands and feet are doubtless an adaptation for swimming, but several authors state that, in swimming water-shrews, the surface of the fur gets wet (Köhler 1984; Ruthardt and Schröpfer 1985). The resulting physiological consequences have been shown by Lardet (1988) to be that during moderate activity in water, the body temperature (Tb) decreases strongly and therefore, extended activity in cold water seems to be impossible for this strict homeothermic shrew.

Similar observations have been published on the American water-shrew *S. palustris*. The surface of the fur also gets wet and in water of 10–12 °C the Tb drops during swimming by 2.0 °C per minute (Calder 1969).

My own experience with the European water-shrew under laboratory conditions (Vogel 1972a, 1972b) and direct observations in nature (Weissenberger et al. 1983) lead me to consider the wetting of the fur to be a consequence of conditions of captivity and experimental design. Therefore, Tb was reinvestigated in a small experimental study, carried out during winter conditions in low water temperature, paying particular attention to the captivity conditions and the technique of temperature monitoring. For comparison, it was also necessary to determine the Tb during rest and activity on land.

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Material and methods

The experiments were carried out with two *Neomys fodiens* (Pennant, 1771), a male (Nr. 1) and a female (Nr. 2) caught in autumn and kept during the experimental period from February to March in an animal house under "outdoor conditions". During the experimental period, both animals had a weight of 16 ± 1 g.

The body temperature was monitored with radio transmitters (Model X of Mini-Mitter Inc., Sunriver, Oregon, USA) with a range of about 30 cm and a battery life of 3 months. Coated with paraffin, their weight is 1.3 g. The recording was carried out with a special receiver (developped by Lavanchy Electronic, CH 1008 Prilly), a timer-counter (Philips, PM 6671) with a frequency-voltage converter and a paper recorder (Tarkan, W+W Recorder 600).

The intraperitoneal implantation was carried out under 2.5 % Fluothan anaesthesia, after the technique of Heldmaier and Steinlechner (1981). In the case of the male, the transmitter stopped after 5 days and had to be replaced. As a consequence of two consecutive operations, the physiological state of this animal was not optimal. The female, caught the 6. XII. 1986, was implanted on 30. XII. 1986. The battery stopped on the 4. IV. 1987. In the night of 4/5. VI, she was paired with a male and on the 24.VI, after a gestation of 20 days (confirming Vogel 1972a), she gave birth to 6 young which were raised successfully. The transmitter was explanted on the 14. IX and the shrew released at the point of capture on the 8. XI. 1987. This life history proves that the transmitter may not disturb fundamental physiological functions such as reproduction and longevity.

Before and after implantation the animals were firstly kept in standard Macrolon cages (40 × 25 cm) and from the onset of the experiments housed in two large PVC terrariums divided into a terrestrial and an aquatic part. The dimension of the terrestrial part was 95 × 55 cm; the bottom was filled up with 10 cm of humid soil composed of earth and turf, and covered with a litter of moss and dead leaves. The aquatic part had the same dimensions and the water was kept at a depth of 15 cm. Bricks and water cress plants gave a rich infrastructure. Large quantities of *Gammarus* were added regularly and exerted a high attraction. A small aquarium heater did not suppress ice formation but prevented total freezing of the water body.

Three types of swimming experiments were conducted:

1. The shrew was released in the aquatic part of the enclosure where it had to swim or dive without possibility of relaxation. As in the experiments of Calder (1969) and Lardet (1988), the time was limited to 6 minutes.
2. The shrew was released during 30 min in the aquatic part and was provided with an opportunity to relax on a stone, the top of which lay 2 cm beneath the water surface.
3. The shrew was totally immersed, with exception of its nose, during at least 10 minutes. For this experiment, a special diving aquarium (50 × 30 × 30 cm) joined to a terrarium (45 × 45 × 30 cm) was used. The passage to the aquarium lay under water and could be closed behind the passing shrew by means of a slide. The surface of the water was covered by a wire mesh which allowed the shrew to breath by pushing its nose through the mesh. In this confinement, the shrew dove for *Gammarus* several hundred times per day, even if the daily food (minced beef and fish) was present in the terrestrial part. As a consequence, even after closure of the slide, the shrew was not very stressed. Special experimental conditions, ambient temperature (Ta), water temperature (Tw) and requisites are mentioned together with the results.

For the determination of a reference body temperature of *Neomys fodiens* during rest and activity in the terrestrial habitat, 6 periods of 24 h were recorded at Ta from −7 to 21 °C. Herein unambigous sequences of behaviour were selected in which the Tb values were taken every 10 minutes. From these data daily mean values with standard deviation were calculated and the significance levels for differences between mean temperatures determined using a t-test.

Results

Body temperature in the terrestrial habitat

The sequence shown in Fig. 1 indicates that the body temperature during rest remains relatively stable, but varies strongly during activity. In cold environments, about 10 min before leaving the nest, the Tb decreases often as much as 1 °C and then increases rapidly. As a consequence of arousal, colder peripheral blood is put in circulation and cools the central part, an effect which is immediately counterbalanced by active thermoregulation.

The mean Tb of the two shrews in different conditions are presented in Table 1. The difference of Tb between activity and rest is significant. The difference between the two

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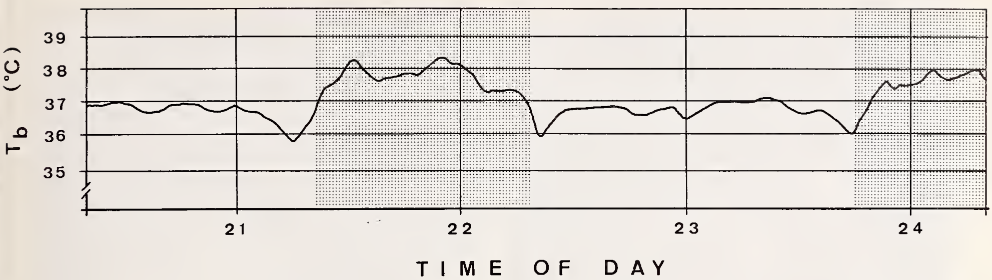

Fig. 1. Body temperature (Tb) of *N. fodiens* kept in outdoor conditions during rest (white part) and during activity (shaded part). Ambient temperature (Ta) is 3 °C

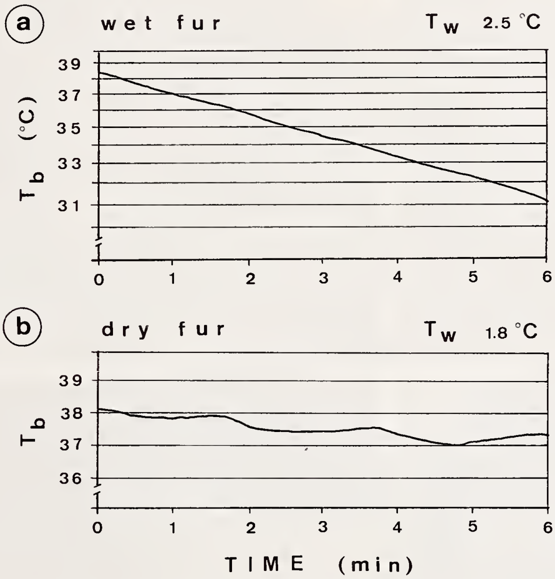

Fig. 2. Body temperature (Tb) of *N. fodiens* during a swimming experiment of 6 min: *a*. Animal with wet fur; *b*. animal with dry fur. Tw: water temperature. The different scales of Tb are dependent of the transmitter

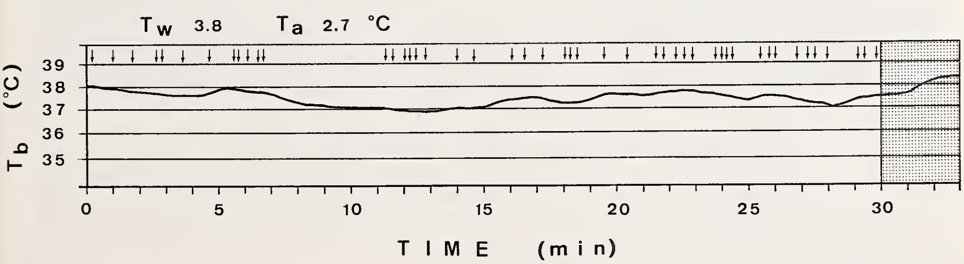

Fig. 3. Body temperature of *N. fodiens* during 30 minutes of enforced water activity. Arrows: diving. Shaded part: increase of Tb after experiment

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Table 1. **Body temperature (mean and SD) of *Neomys fodiens* during terrestrial activity and rest under different conditions**

Ta 21 °C concerns stable indoor conditions, the lower Ta are daily mean temperatures in outdoor conditions

Animal	Ta (°C)	Tb activity	n	Tb rest	n	Significance
Nr 1	21	37.3 ± 0.3	28	37.0 ± 0.2	27	$p<0.001$
Nr 1	5	37.6 ± 0.2	23	37.3 ± 0.2	48	$p<0.001$
Nr 1	0	37.3 ± 0.3	23	36.8 ± 0.3	66	$p<0.001$
Nr 2	21	37.7 ± 0.1	29	37.1 ± 0.3	63	$p<0.001$
Nr 2	4	37.7 ± 0.3	18	36.9 ± 0.2	31	$p<0.001$
Nr 2	–7	37.2 ± 0.7	27	36.9 ± 0.2	52	$p=0.058$
Global mean		37.5 ± 0.4	148	37.0 ± 0.3	287	$p<0.001$

animals is only small and not significant. Therefore, as reference, we can use the global means: a Tb rest of 37.0 °C and a Tb activity of 37.5 °C.

To avoid handling of the animals before the experiment, they were caught with a Longworth trap impregnated with the odour of another shrew. The disturbance of springing the trap and of the succeeding capture (stress) led to an increase in Tb, to a mean of 38.5 °C ± 0.4 (n = 9). It is important to realize that all experiments started with a raised Tb.

Studying the effect of social stress, we put Nr. 2 in the same enclosure as another female and observed them for 30 minutes. Although little direct antagonistic behaviour occurred, mean Tb increased to 39.4 °C and an extreme value of 40.1 °C was observed.

Body temperature in aquatic habitats

In the first type of experiment, the shrews were obliged to swim or dive for 6 min in the standard swimming pool without any support (n = 6). The first trial was done with the animals taken from laboratory conditions. In one of the two animals (Nr. 1), at a Tw of 2.5 °C, Tb dropped linearly by 1.1 °C per minute (Fig. 2a) and continued even after the end of the experience down to 28 °C. The fur of this shrew was as wet as that of the shrew in Fig. 4a.

After improving the maintenance conditions by keeping the shrews outdoors in terrariums on wet soil, and allowing the animals to adapt for some days, Tb dropped only slowly and the fur of the experimental shrews was wet only on the surface (Fig. 4c), or, as in Nr. 2, remained completely dry (Fig. 4 d–f) and the Tb remained above 37 °C (Fig. 2b).

The second experiment, involving forced water activity of 30 min duration, was conducted only once with Nr. 2 (Tw 3.8 °C, Ta 2.7 °C). During this experiment the shrew was observed to dive over 40 times and ate four *Gammarus*. The minimal Tb, recorded after 13 min, was 36.9 °C, and Tb after 30 min was 37.6 °C (Fig. 3).

In the third type of experiment, executed with Nr. 2 in the special diving aquarium, the shrew was blocked under water for 10 minutes. In the first run, with a Tw of 8.5 °C, the shrew found the exit after 12 min and had a Tb of 37.3 °C. In the second run, at Tw of 1 °C, and after 10 minutes of total immersion, the Tb was 36.6 °.

If only the trials with dry or nearly dry fur are considered from all nine experiments and the Tb is taken after 6 min swimming activity (n = 6, mean Tw = 2.6 °C), Tb decreases only 0.2 °C per minute and a mean Tb of 37.4 °C ± 0.4 is observed. This Tb is roughly the same as the normal activity Tb in the terrestrial habitat.

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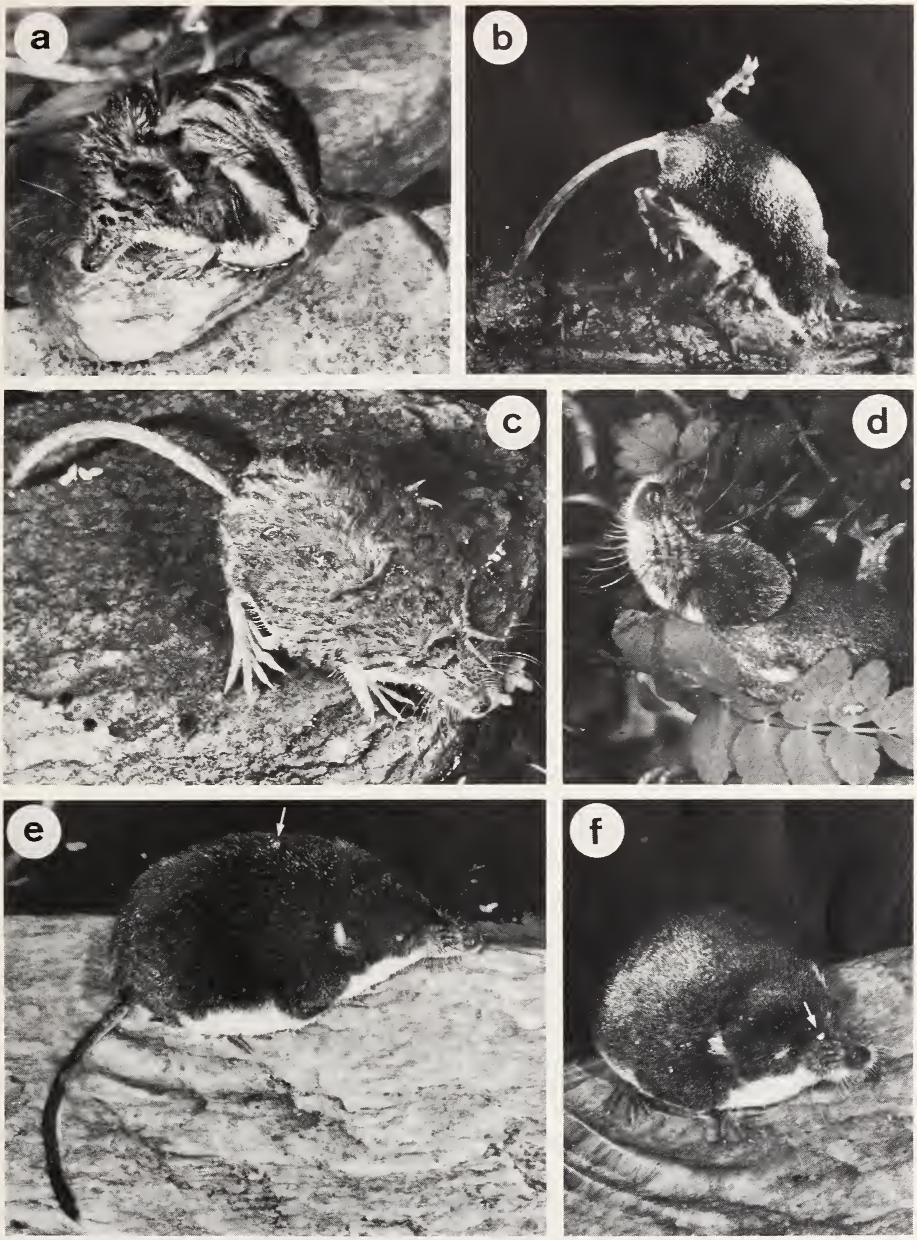

Fig. 4. Neomys fodiens during activity in water: *a.* shrew with wet fur; *b.* diving shrew with air layer in the fur; *c.* shrew with wet hairtips; *d.* the water retracts from dry fur of shrew slowly emerging with olfactive control; *e.* and *f.* dry shrew after diving. Arrow: water droplets adhering on dry fur

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Discussion

After GEBCZYNSKI (1977), the mean body temperature of *N. fodiens* in terrestrial habitats is between 38.3 and 38.7 °C, depending on the season (range 37.4–39.6). These values are 1–1.5 °C above our mean Tb measured during activity with transmitters in undisturbed shrews and could be explained by handling of the shrews and insertion of a rectal thermocouple. This handling stress obviously does have thermogenetic consequences and caused hyperthermia. It could also explain the high Tb of our shrews after capture and, more importantly, the high temperatures observed during social stress.

Our mean value of Tb during activity (37.5 °C) agrees with the mean rectal temperature (37.3 °C) published by NAGEL (1985). The measurements of this author were taken after 1 hour in a respirometric chamber with a rectal thermocouple of rapid reaction. The mean value measured by LARDET (1987) at the onset of his experiments (Tb = 36.1 °C) is about 2 °C lower than our values (Tb stress of 38.5 °C). The rectal probe in his experiments was inserted 15 mm, not deep enough to get a correct Tb. The intercept of his regression lines should be corrected by this amount.

Species of the genus *Sorex* are characterized by the highest Tb known amongst shrews (FREY 1979). However, a Tb of 39.9 °C measured by CALDER (1969) for *S. palustris* is more than 1 °C higher compared to the mean Tb of the European *S. araneus* published by NAGEL (1985). Here too, the stress induced by fixing the rectal probe on the tail may explain the difference.

Our results on the Tb in swimming water shrews differ strongly from those obtained by other authors in similar conditions. CALDER (1969) observed in *S. palustris*, at Tw of 10–12 °C, that Tb drops by 2 °C per minute (CALDER 1969). Lardet (1987) observed in *N. fodiens* under similar conditions (Tw = 5 °C) a decrease of 0.8 °C per minute. The decrease of Tb in our experiments is almost negligible although the water temperature was lower. This contrast can be explained by the difference of fur quality. Therefore, the important decrease of Tb observed by other authors, should be interpreted as an artefact of captivity conditions and it would be astonishing if the high conductance measured by CALDER (1969) on dead immersed shrews is representative of living water-shrews.

The fur of the water-shrew is a highly specialized and very sensitive system which can lose its water-repellent property even as a result of the stress of capture in nature. This explains why the shrews kept by KAHMANN (1955), CROWCROFT (1957), KÖHLER (1984, p. 179 and Figs. 1; 5; 10) and RUTHARDT and SCHRÖPFER (1985) got wet fur. However, LORENZ (1952), ZIMMERMANN (1959, in KÖHLER 1984) and HUTTERER and HÜRTER (1981) stated in agreement with our observations, that the fur of a fit water-shrew remains dry even after extended water activity.

Captivity conditions play an essential role in fur quality. In our department, a study on diving behaviour of *N. fodiens* failed because the shrews didn't show any swimming activity in the confinement of the classical indoor animal room. On the contrary, the pelts of shrews caged under outside conditions in big containers with a deep humid soil, maintain the waterproof property.

Our own observations of other swimming semiaquatic mammals has shown that their fur gets wet on the surface: *Ornithorhynchus, Castor, Ondathra, Myocastor, Lutra, Galemys* and *Micropotamogale*. The latter has over-hairs with an enlarged apical part (VOGEL 1983), a structure, which was also reported for *Potamogale, Desmana, Galemys* and *Ornithorhynchus* by TOLDT (1935). Under water these hairs may protect the under fur from wetting.

The water-repellent property of the fur of the water-shrew is based on another principle. The particular structure of the terminal segment of the guard hairs revealed by scanning electron microscopy (VOGEL and KOEPCHEN 1978; VOGEL and BESANÇON 1979) have been considered by APPELT (1973) and HUTTERER and HÜRTER (1981) to be

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responsible for air retention in the fur (Fig. 4b). If this structure really has the supposed significance, it can fulfill this function only together with other factors. Hair position (tonus of Musculi arrectores pilorum) and skin gland secretion may present such factors.

Shrews are the smallest semiaquatic mammals. Visibly they have developed a particular fur which allows them to keep a normal body temperature even in the coldest water. In fact, SCHLOETH (1980) observed in a mountain river, shrews diving at a Ta of −10 to −15 °C. This suggests a low conductance in water and high maximum heat production, factors which should be studied in adequate conditions.

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Zusammenfassung

Körpertemperatur und Fellqualität tauchender Wasserspitzmäuse, Neomys fodiens (Mammalia, Insectivora)

Die Körpertemperatur der Europäischen Wasserspitzmaus *Neomys fodiens* wurden mittels intraperitoneal implantierter Radiosender untersucht. Zwei unter Außenbedingungen gehaltene Tiere wurden im Februar und März getestet. Die mittlere Körpertemperatur (Tb) in Ruhe betrug 37,0 °C, in Aktivität 37,5 °C. Im Fangstreß stieg Tb auf 38,5 °C, während einer sozialen Konfrontation auf 39,4 °C.

Während erzwungenem Schwimmen nahm die Körpertemperatur bei einem Tier mit nassem Fell um 1,1 °C pro min ab. Wurden die Tiere unter guten Bedingungen gehalten, blieb das Fell trocken und sie konnten ihre Tb in den meisten überprüften Situationen bei 37 °C halten. In Wasser von 2,6 °C betrug die mittlere Tb nach 6 min erzwungenem Schwimmen oder Tauchen 37,4 °C, also praktisch gleich wie bei terrestrischer Aktivität. Der Pelz dieser Tiere wurde auch oberflächlich nicht naß und hat offenbar wasserabstoßende Eigenschaften, die unter semiaquatischen Säugern einmalig sein.

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