FUR VERSUS FEATHERS: THE DIFFERENT ROLES OF RED KANGAROO FUR AND EMU FEATHERS IN THERMOREGULATION IN THE AUSTRALIAN ARID ZONE

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Fur or feathers provide protection against heat loads from solar radiation for birds and mammals. The red kangaroo (*Macropus rufus*) and the emu (*Dromaius novaehollandiae*) are conspicuous in arid environments of Australia where there is potential for high solar loads. The diurnal *D. novaehollandiae* feeds in the open yet it has a dark coat with a high absorptivity (83%), which contrasts with that of *M. rufus* (61%), but *M. rufus* generally shelters in shade during the day. We examined the effect of coat characteristics on the heat load from solar radiation at skin level. Coat depth and density (thermal conductance or insulation) and the level of penetration of solar radiation into the coat were important determinants of solar heat load. For *M. rufus* less than 25% of incident radiation reached the body at low wind speeds and this diminished to below 15% at moderate wind speeds. In the modest shade *M. rufus* seeks on summer days, their heat load from solar radiation appears minimal. Colour differences among *M. rufus* did not affect thermal load. *D. novaehollandiae* on the other hand is exposed to the full incident solar load in the open but its plumage provides almost complete protection from solar radiation. Solar radiation is absorbed at the feather surface and the insulation provided by the deep coat prevents heat transmission to the skin.

Key words: *Macropus rufus*, *Dromaius novaehollandiae*, fur, plumage, insulation, thermal conductance, reflectance, penetrance, solar radiation, fur colour, thermoregulation.

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TWO very different large native animals occur in the arid rangelands of Australia; kangaroos, notably the red kangaroo (*Macropus rufus*) and the emu (*Dromaius novaehollandiae*), a giant bird. Their coats are obviously different but how this impacts on their adaptation to these thermally harsh conditions is unknown. The functions served by the fur and feathers of homeotherms are varied and complex. Other than insulation against heat loss in the cold, the pelts are involved in physical protection, sensory inputs, water proofing, and of course, cryptic colouration, display or camouflage. A role less often considered is the modulation of radiation interception and heat flow at the surface, particularly solar radiation. In desert regions solar radiation levels can exceed 1000 W m$^{-2}$ for many hours of the day. If fully absorbed such radiation would impose heat loads that are many times the resting metabolism.

Our interest in this aspect of thermal biology originated in studies on the micro-meteorology of habitat selection by arid zone kangaroos (Dawson and Denny 1969). Species of kangaroo are largely nocturnal and in summer seek to avoid high solar heat loads while resting during the day. Of all kangaroo species *M. rufus* inhabits regions with the highest incident solar radiation intensity. It also exists as two colour morphs, ‘red’ (a rusty brown) and ‘blue’ (a smoky grey) with intermediate forms also occurring. The blue form (mostly seen in females) is more common in the southern parts of the species’ range and rare in northern Australia, particularly in the more tropical regions (Dawson 1995). Red fur is more reflective to solar radiation (Dawson and Brown 1970) and was presumed to result in lower solar heat loads to the animal, raising questions about the incidence of the blue morph. In the south of its range *M. rufus* lives in saltbush / bluebush shrublands and the blue colouration provides good cryptic colouration. Also, the blue form is common to females and may have a role in sexual dimorphism. Consequently, it was thought that trade-offs between
competing adaptive forces in coat selection may have out weighed the disadvantages associated with a
darker coat in the less extreme areas of their range.

We accepted these possibilities until we became interested in D. novaehollandiae. While the M. rufus shelter in sparse shade on summer days (Dawson and Denny 1969; Watson and Dawson 1993), D. novaehollandiae are diurnal and spend the daylight hours feeding in the open (Dawson et al. 1984). Yet, the surface layer of the feathers is dark grey to black and apparently not very reflective. Initially, it was considered that dark coloured mammals and birds absorb more radiation and experienced higher heat loads (see references in Maloney and Dawson 1995). If so, dark coloured desert inhabitants would be thermally maladapted. Several authors dismissed the significance of thermal selection (e.g., Cloudsley-Thompson 1979) while others urged that thermal influences not be considered in isolation from other selective pressures (Wunder 1979).

We found from D. novaehollandiae that the situation was complex (Maloney and Dawson 1995). That colour and absorptivity were not the whole story had been suggested by earlier work on solar loads in cattle. Hutchinson and Brown (1969) had examined the implications of forward reflection, sometimes called penetration, of solar radiation into the fur of white cattle with sparse hairs as compared with what happens with black and brown furs. The heat load at the skin depended not only on coat reflectivity, but also on fur thickness and density and additionally, wind speed. Subsequent work by Cena and Monteith (1975) and Walsberg and coworkers (Walsberg and Wolf 1995; Wolf and Walsberg 2000) has supported these ideas. Penetration of solar radiation deeper into the fur or feather coat, partially by re-reflection, is important and markedly influences the solar heat load. Light coloured coats reflect more visible radiation, but not all of it back to the environment, some of it is reflected further into the coat. The penetration of solar radiation deeper into light coloured coats means that the resultant absorbed heat is somewhat protected from loss to the environment by insulation of the coat, while radiation absorbed close to the surface in dark coats is predominantly transferred to the environment. The latter is what we found for D. novaehollandiae (Maloney and Dawson 1995).

In the light of these data from D. novaehollandiae we became interested in the relative roles of the differing body coverings of M. rufus on the thermoregulatory balance, particularly in the sun in summer. We re-examined the thermal and optical properties of the fur of M. rufus and compared their characteristics with those of D. novaehollandiae plumage. We also re-examined the thermoregulatory impact of coat colour of the different morphs within M. rufus.

MATERIALS AND METHODS

Pelts from 10 M. rufus (5 of each of the two colour morphs) were collected in north-western New South Wales (NSW) during summer. They were processed and prepared according to the procedures used for D. novaehollandiae pelts by Maloney and Dawson (1995). Measurements were made on central back fur and largely followed the techniques of Maloney and Dawson (1995).

Spectral reflectances of the pelt samples were measured using an Optronics model 746-IRD spectroradiometer (Optronics Inc, Orlando, FL, USA) with an Optronics Model 740-20 lamp housing attached to the monochromator entrance port and an Optronics Model 740-70 reflectance attachment at the exit port. This reflectance attachment included an integrating sphere coated with barium sulphate paint. Measurements were made with reference to a compressed barium sulphate disc using standard published values for its reflectance. Measurements were made with a 10 nm half band width between 350 and 750 nm, and with a 50 nm half band width between 800 and 2100 nm.

Solar reflectances of the coats were calculated using the relative spectral power of sunlight given by the American Society for Testing & Materials ASTM E424-71. The relative spectral distribution of the ARRI daylit lamp used in the wind tunnel experiment was measured by the spectrophotometric facilities of the Australian Broadcasting Corporation at Gore Hill, NSW. The spectral transmission of the glass used to make the wind tunnel was measured by the spectrophotometric facilities at the School of Optometry, University of NSW. These spectra were used to calculate the relative spectral distribution of light impinging on the pelt sample in the wind tunnel and thus the total reflectivity of the samples in the wind tunnel.

Measurements of thermal conductance (and therefore insulation) of pelts were made by mounting samples on the upper surface of a heat flux transducer / temperature controlled plate apparatus (Fig. 1). The water filled plate was maintained at 38°C. Voltage output from three 2 x 3 cm heat flux transducers (Thermonetics Corporation, USA), embedded in the plate’s upper surface, were logged on a personal computer via a Datataker analog/digital converter (Data Electronics Australia Pty/L, model 100F). Skin surface temperature (T_s) was measured using an Optronics model 746-IRD spectroradiometer (Optronics Inc, Orlando, FL, USA) attached to the monochromator entrance port and an Optronics Model 740-70 lamp housing attached to the monochromator entrance port and an Optronics Model 740-70 reflectance attachment at the exit port. This reflectance attachment included an integrating sphere coated with barium sulphate paint. Measurements were made with reference to a compressed barium sulphate disc using standard published values for its reflectance. Measurements were made with a 10 nm half band width between 350 and 750 nm, and with a 50 nm half band width between 800 and 2100 nm.

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Fig. 1. Experimental set-up for measuring the effects of wind speed on the thermal conductance and solar heat load of animal pelts. Site of anemometer, a. Arrows indicate the direction of wind. The sheet of painted glass has a hole above the coat. Placement of thermocouples is given in the text.

Data logger Isothermal Block and logged on a personal computer via the A/D converter.

Conductance of furs was measured as a function of wind speed inside a glass wind tunnel (Fig. 1). Wind speed was adjusted via a fan controlling air flow through the tunnel and was measured 2 cm above the sample with a Datametrics 810L thermoanemometer. Each sample was measured at six wind speeds (1, 2, 4, 6, 8, and 10 m s⁻¹). Ta was controlled at 20 ± 1°C by placing the wind tunnel inside a temperature controlled room. Thermal conductance (C) was calculated as: \( C = \frac{Q}{T_s - T_a} \), where \( Q \) = heat flow through the sample. The contribution of the air boundary layer to total insulation was obtained from calculations of fur conductance, \( C_p = \frac{Q}{T_s - T_e} \), and air boundary layer conductance, \( C_a = \frac{Q}{T_e - T_a} \).

To examine the impact of solar radiation, the experiments were then repeated with 590 W m⁻² of short wave radiation incident on the sample. Radiation was supplied by an ARRI spotlight (ARRI Daylight 575W). The relative spectral distribution of radiation from this lamp is similar to the solar spectrum (Maloney and Dawson 1995). To minimize heating of the wind tunnel surrounding the sample and transmission of infra-red radiation to the sample from the hot lamp body, a piece of glass, painted black except for a hole allowing light to penetrate in the area of the sample, was placed between the lamp and the wind tunnel. The lamp and second sheet of glass were cooled by forced convection. Radiation at the level of the top of the coat was measured with a CSIRO SR4 radiometer and maintained at 590 W m⁻². The proportional heat load from radiation (PHLR, expressed as a percentage of radiation incident on the coat surface) was calculated as:

\[ \text{PHLR} = \frac{(H_{\text{without radiation}}) - (H_{\text{with radiation}})}{\text{Incident Radiation}} \]

Results were usually analysed using a Two-Way Repeated Measures ANOVA for species or colour morph and wind speed. A Student-Newman-Keuls (SNK) multiple range test was applied when significant differences were indicated by the ANOVA (using Statistica/Mac software). Values are given as mean ± SE. Means considered significantly different have \( p < 0.05 \).

**RESULTS AND DISCUSSION**

To a mammal in open desert the important thermal aspects of fur are its thermal conductance (insulation is the reciprocal of conductance) and its influence on the percentage of heat from solar radiation (%HLR) that reaches the skin, and thereby impacts on the body. For the summer furs of the two colour morphs of *M. rufus* these characteristics are shown in Fig. 2. There was no significant difference between the colour morphs in the conductance of heat through their furs. Conductance generally increased significantly with each increase in wind speed. The %HLR at skin level also was not significantly different between the colour morphs. The %HLR decreased significantly with each increase wind speed.

The result for conductance was not unexpected because conductance is largely dependent on fur depth and fur density. For the red and blue colour morphs of *M. rufus* depths were not different; the pelt depths of red and blue furs were 8.8 ± 1.2 mm and 7.9 ± 1.2 mm, respectively (\( p = 0.7 \); t-test). Densities were also similar (Dawson and Brown 1970). The two fur colours have significantly different reflectance across the solar spectrum, of which about half is outside the visible spectrum (Fig. 3). We measured the reflectance of solar radiation of the red fur as 39.2 ± 0.9% and that of the blue fur as 35.1 ± 1.9% (\( p < 0.05 \)) (Fig. 3). However, the %HLR at skin level was the same (\( p = 0.94 \)). The level of penetration into the different furs largely contributes to this result as outlined below.

Radiation falling on the coat surface can be reflected or absorbed and converted to heat (Fig. 4). The fate of this absorbed heat depends on the relative insulation of the coat from the point of absorption to the environment or to the skin, and thus depends on the wind speed. Forced convection will reduce the insulation provided by the air boundary layer and may also reduce insulation of the coat. The other component, the reflected radiation can be reflected.
Fig. 2. The influence of wind speed on the thermal conductance of the furs of the ‘red’ and ‘blue’ colour morphs of *M. rufus*. Also shown for the two fur types is the effect of wind speed on the amount of solar radiation that reaches the skin as a heat load.

Fig. 3. The variation in the incident solar radiation at different wavelengths together with the reflectance characteristics of ‘red’ and ‘blue’ *M. rufus* fur and *D. novaehollandiae* plumage across the solar spectrum. Values given for the coat types are the % of total solar radiation reflected.

either back to the environment (net reflection) or deeper into the coat where it is absorbed and converted into heat. This forward reflection manifests as penetrance of radiation. The magnitude of penetrance influences where the radiation is ultimately absorbed and depends on hair absorptivity and coat density. The overall situation of the heat gain from radiation can be dealt with in a simple model (Fig. 4). In this model it is assumed that there is an average depth to which solar radiation penetrates before being absorbed, indicated as a single layer, *z*, such that the heat load resulting from this average penetration equals the heat load experienced with non-localised absorption. The heat resulting from radiation absorption at *z* flows either to the environment or to the skin, in inverse proportion to the insulation in each direction. The heat load at skin level which impacts on the body is then given by

\[ HLR = RA(I_c + I_e)/(I_c + I_o) \]

Where *R* = the intensity of radiation incident on the coat, *A* = the coat’s absorptivity, *I_o* = the insulation of...
the coat, $I_c$ = the insulation of the coat between the point of absorption and the coat’s surface, and $I_z$ = the insulation of the air boundary layer.

If $HLR$ is expressed as a % of incident radiation then:

\[
\%HLR = \frac{HLR \times 100}{R} = A\left(I_z + I_e\right)\left(I_c + I_e\right).
\]

We measured all of these components except $I_z$, and so we can calculate $I_z$ and estimate the depth of layer $z$, the average depth of penetration of incident solar radiation. In kangaroos there was no difference between the colour morphs in the penetrance into the furs. It was approximately 1.4 mm or 16 – 18% of fur depth at the lowest wind speed and decreased slightly (though significantly) to 0.8 – 1.0 mm or 9 – 13% of depth at the highest wind speed.

Since coat colour has little influence on the thermal characteristics of $M. rufus$ fur, is it significant in the case of $D. novaehollandiae$ plumage? We have compared data from the ‘red’ $M. rufus$ with that for $D. novaehollandiae$ from Maloney and Dawson (1995). The reflectances of total solar radiation of their back coats were very different (Fig. 3). $M. rufus$ had more than double the reflectance, 39.2 ± 0.9%, of the $D. novaehollandiae$ coat, 17.0 ± 2.0%. In other words $D. novaehollandiae$ plumage, which appears dark grey absorbs 83% of solar radiation as compared with 61% for $M. rufus$. The resultant heat load at the skin of the two species was statistically different at all wind speeds but the pattern was different from what might be anticipated (Fig. 5). For $D. novaehollandiae$ at low wind speed (1 m s$^{-1}$) only 9% of incident radiation reached the skin as a thermal load, as compared with 23% for $M. rufus$. How is this explained given that the reflectance of the $M. rufus$ coat is much greater, meaning that the $M. rufus$ coat absorbed much less heat in total? Penetrance is important but is not the only significant characteristic. The average penetrance of solar radiation for $D. novaehollandiae$ back plumage was 5 mm, but that is only 10% of the coat depth of 45 ± 3.7 mm. The dark layer at the surface of $D. novaehollandiae$ plus other plumage characteristics limits penetrance and results in the solar radiation that is absorbed being converted to heat near the coat surface. Penetration into the more reflective, though dense, $M. rufus$ fur is only 1.4 ± 0.33 mm but that is 16 ± 2.5% of the much thinner (9 mm) coat. The proportion of heat from absorbed sunlight that reaches the skin as compared with that which flows back to the surface and is then lost by radiation and convection depends largely on the ratio $(I_e + I_c)/(I_c + I_e)$, that is, the ratio of penetrance depth (including air insulation) to total coat depth (including air insulation). The effect of this can be seen in Fig. 5, which shows that %HLR is much lower in $D. novaehollandiae$ than $M. rufus$. $D. novaehollandiae$ plumage offers more effective insulation against the absorbed solar radiation.

At higher wind speeds the %HLR for $D. novaehollandiae$ became negligible while for $M. rufus$ it dropped from 23% at 1 m s$^{-1}$ to 11% at 10 m s$^{-1}$ (Fig. 5). The reason for this influence of wind on %HLR is that the insulation of the air boundary is much reduced and heat absorbed near the coat surface is rapidly lost to the environment. Mathematically this reduction in $I_e$ brings the proportion of heat flowing to the skin closer to $I_e/I_c$. 

\[
\begin{align*}
\text{HLR} &\text{= Heat load from radiation at skin surface} \\
R &\text{= Intensity of incident radiation} \\
A &\text{= Absorptivity of coat} \\
I_c &\text{= Insulation of coat} \\
I_e &\text{= Insulation of air boundary layer} \\
I_z &\text{= Insulation of coat between Z and coat surface} \\
\%HLR = &\frac{HLR \times 100}{R} = A\left(I_z + I_e\right)\left(I_c + I_e\right).
\end{align*}
\]

Fig. 4. Simple model of fate of solar radiation incident on fur or plumage.
The boundary layer effect, however, is not the whole story because there was a different response to wind speed between the species (Fig. 5). At lower wind speeds the conductance of the *D. novaehollandiae* coat was significantly lower than that of *M. rufus*, that is, it offered greater insulation. This difference diminished at the two higher wind speeds and the difference between the species became not statistically different. At high wind speeds the *D. novaehollandiae* feathers appeared to become disturbed. We have not estimated the density of *D. novaehollandiae* feathers relative to that of highly dense *M. rufus* hairs, but this effect likely stems from the lower element density of emu feathers compared to kangaroo hairs. The result of feather disturbance means that not only was $I_L$ reduced as wind speed increased, but wind breaking into the actual feather layer also reduced $I_L$. The combined effects reduce the insulation from layer $z$ to the environment considerably and result in the bulk of the heat from absorbed radiation being convected away to the environment. This impact of wind thus extends beyond the influence on the air boundary layer and also affects the thermal conductance (insulation) of the coat itself of the two animals (Fig. 5). The effect on the coat then is influenced by coat structure.

In summary, colour differences among *M. rufus* have little impact on the thermal load from solar radiation. Over the general body fur less than 25% of incident radiation reaches the body as a heat load and this diminishes to below 15% at even moderate wind speeds. Given even the modest shade of small desert trees that *M. rufus* seek on summer days (Dawson 1972; Dawson and Denny 1969), their heat load from direct solar radiation should be minimal. *D. novaehollandiae* on the other hand is often feeding in the open during summer (Dawson et al. 1984) but its plumage provides its body with almost complete protection from solar radiation (Maloney and Dawson 1995). Therefore, in their usual situations on hot summer days both species are largely protected from direct solar heat loads, but with *D. novaehollandiae* active in the open.

While the pelage that we examined was the main body covering, which would play the major role in regard to solar radiation, pelage is not constant over the body, either in depth or reflectance for *M. rufus* (Dawson and Brown 1970) nor *D. novaehollandiae* (Maloney and Dawson 1994). Obviously, the full story of the role of fur or feathers in radiation exchange is quite complex. What happens at the large, lightly-furred tail of *M. rufus*; it is tucked between the legs under the body of a standing kangaroo if thermal loads become extreme (Russell and Harrop 1976). Under similar circumstances the nearly naked legs of *D. novaehollandiae* are generally shaded by the body feathers but in the hottest part of such days *D. novaehollandiae* may resort to sitting in shade, which markedly changes heat transfer characteristics of the body covering (Maloney and Dawson 1994).

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