Do seasonal changes in Svalbard reindeer fur have relevance for heat transfer?

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Abstract: Physical characteristics of Svalbard reindeer (*Rangifer tarandus platyrhynchus*) fur samples were examined with respect to season. A total of 33 dorsal fur sections including adults and calves were investigated. A direct relationship between hair density and heat transfer was not observed, and optimal hair density may depend on an interaction with other fur characteristics. Seasonal changes in fur length and depth were inversely proportional to, and appear to be the main determinants of, seasonal changes in calm air conductance. Fur length and depth, however did not explain the exceptional wind resistance of Svalbard reindeer fur. Since wind has little effect on heat transfer through Svalbard reindeer fur regardless of season or animal age, fur characteristics, which change are not likely critical. Instead, constant physical characteristics, which trap still-air within the fur and resist wind compaction and penetration, are probably responsible. These could include hair stiffness, the crimped wave, hollow hairs, intertwining distal tips and the fine wool fuzz about the hair roots. The extent and means are not well understood at present.

Key words: conductance, physical characteristics, *Rangifer tarandus platyrhynchus*, wind resistance.

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Introduction

Few mammals can compare with Svalbard reindeer in cold tolerance. They have a lower critical temperature (ambient temperature at which metabolic rate must increase to compensate for heat loss and maintain deep body temperature) between –40 and –50 °C in winter and between –10 and –15 °C in summer (Nilssen *et al.*, 1984; Johnson & Mercer, 1993). A major contributor to this extreme cold tolerance is the Svalbard reindeer's excellent fur insulation. Winter fur insulation is about 3 times better than in summer, calf and adult fur have similar insulation values, and Svalbard fur insulates almost twice that of other caribou fur (Cuyler, 1992; Cuyler & Øritsland, 2002). Furthermore, Svalbard fur is wind resistant. Increasing wind speed does not dramatically affect heat loss or decrease insulation appreciably (Cuyler & Øritsland, 2002). Maintaining almost the same insulation value despite strong winds is useful in an environment where windchill can be severe. The physical characteristics of the fur may play an important role in these heat transfer properties.

Heat transfer within fur may be solely due to natural convection of air in the fur and heat conduction among the gas particles (Hammel, 1955). Heat transfer may also be assisted by thermal radiation between the fibres (Cena & Monteith, 1975), in which hair colour may be important, however, radiative heat loss from a reindeer body trunk fur surface is minimal (Johnson & Mercer, 1993). Regardless, rates of heat transfer within a fur are primarily a function of how much still-air a fur can trap and hold.

Rangifer hair is known to be hollow, brittle, stiff, and to stand up like a soft close-packed bristle brush. The hollow hairs are composed of a series of air-filled cavities, which are separated by thin septa throughout the length of each hair (Timisjärvi *et al.*, 1984). The hollow air-filled hair probably increases the amount of still-air in a fur, and the stiffness may prevent hair compaction from wind, thus preserving air in the fur. Other physical characteristics contributing to still-air within the fur could include depth, length, density, and shape.

Fur depth, which can be a function of length, may have a role in holding still-air in the fur. The insulation value of fur increases with its depth and it is well known that fur depth undergoes seasonal changes (Scholander *et al.*, 1950; Schmidt-Nielsen, 1990; Hart, 1956; Lentz & Hart, 1960). Deep winter fur provides greater insulation than short summer fur, *e.g.*, in large mammals summer fur may have only 32% to 52% of the winter insulation value (Hart, 1956). Svalbard reindeer fur is unusually deep compared to Norwegian reindeer fur (Tyler, 1993).

Hair density may also have a role in maintaining the still-air a fur can hold, however, reported effects on insulation are not consistent in the literature. According to Gebremedhin (1987) fur heat loss increases with hair density in Holstein calves. However, Tregear (1965) observed that, inter-specifically, as hair density increased so did insulation; thus, heat loss was less because wind penetration into the fur was reduced. Finally, Lentz & Hart (1960) could observe no direct relation between fur density and heat transfer, although conductance changed with depth and density (Hart, 1956).

This study investigated the seasonal changes in fur characteristics of Svalbard reindeer, both adults and calves. The characteristics described included hair length, density, shape and colour, as well as fur depth and skin thickness.

Material and methods

Whole pelts were collected 26 June, 14 August, 27 October, and on 21 March and 4 April. These represented the calving, summer, autumn and winter seasons respectively. The total was 33 pelts, including 18 adult, 2 sub-adult (less than 2 years old) and 13 calves. All were fleshed, dried and frozen. With one exception all adult fur samples were from females, including several mother-calf pairs. Fur samples of a mother with calf included: August adults 1, 2, 3; October adults 7, 8, 9, 10; and March adults 13, 15, which were also pregnant. Tooth eruption or incisor cementum rings were used to age animals. In addition, given peak calving for Svalbard reindeer occurs between the 2nd and 9th of June (Tyler, 1987), calf age was approximated from that period. The adults ranged in age from 1 to 14 years. Calves ranged from 2-3 weeks to 10 months of age. Fur samples were taken from the dorsal mid-back region. Skin thickness of the samples was measured with digital callipers. Hair length was measured, and manually removing and counting individual hairs from an area of 1 cm^2 determined density.

For terminology, Lentz & Hart (1960) differentiated between guard hairs and under fur, while Timisjärvi *et al.* (1984) referred to all hairs other than wool as guard hairs. In the present study, the term hair was applied to all hair except guard hairs and wool fuzz. The surface of the hair was the surface of the fur. Guard hairs were those few often exceedingly long hairs, which protruded above the fur surface. Wool fuzz was the soft fine fibre intertwining the hair roots near the skin surface. Fur depth was the distance from the skin to the fur surface, and was measured with a needle probe. Hair length was the total real length of the hairs (with their natural crimped wave), and was longer than the depth because the hairs were not perpendicular to the skin. Measurement of skin thickness was by calliper after the skin had been fleshed and dried.

Microsoft excel was used for parametric Student t-tests. These were two-tailed t-tests for differences between two sample means assuming equal variances. The results are presented as t-values, df and P-values. Degrees of freedom are equal to (n-1), where n is the size of the sample. The P-value of a t-test is the probability of obtaining the data by chance given that the null hypothesis is true.

Results

General physical characteristics of mid-back fur samples

Svalbard reindeer hairs are hollow, close-packed, and typically exhibit a crimped wave along much of their length. The crimped wave gave more volume, making the fur bulkier, and appeared to interlock the hairs together. The distal tips of the hairs were fine and often intertwined, which also held the hairs together. The hairs were also stiff and brittle; specifically the winter hairs break easily. Only the June calf fur could be described as soft, and to a lesser extent August calf fur.

Guard hairs were usually white, often for their entire length. The colouration of guard hair tips (the distal 0.5-1 cm), however, ranged from virtually invisible to almost black. Dark tips were most common in summer, but also occurred in winter.

Although skin was light coloured, the skin surface colour of almost all samples was dark, ranging from grey to black.

Wool fuzz, which intertwined the hair roots, was extremely fine and easily overlooked. It was always a dark grey-brown colour, present in all seasons and ages, and never extended further than a maximum 2 cm from the skin surface. Although not quantified, the amount of wool appeared similar for both summer and winter fur samples. The wool was "adhesive", being difficult to remove even from one's fingertips. It appeared to bind the hair roots together. To aid perception of the fine wool fuzz, extra was placed along side the fur sample in figures 3, 4, 6 and 7.

Seasonal physical characteristics of mid-back fur samples

In summer, adults accompanied by calves had significantly lower hair density and length (t = 3.698, df = 4, P < 0.05; t = 3.394, df = 4, P < 0.05 respectively), but no significant difference for depth, than those adults without calves (Table 1). When guard hairs were tested there was no significant difference in guard density (t = 0.962, df = 4, P > 0.1), but there was a significant difference in guard length and depth (t = 3.498, df = 4, P < 0.05; t = 4.824, df = 4, P < 0.01 respectively). Skin thickness was also significantly different (t = 5.518, df = 4, P < 0.05). Summer adults with calves had less dense hair, of shorter length, with shorter guard hairs, and thinner skin, than the young females without calves.

Table 1. Physical properties of adult Svalbard reindeer mid-back fur: all females except sample 11.

Sample Fur	Age	Density [cm^{-2}] Hair	Guard	Total	Length [cm] Hair	Guard	Depth [cm] Hair	Guard	Thickness [mm] Skin	Remarks
SUMMER ADULT										
1	7yrs-2m	1030	32	1062	2.1	3.8	2.0	3.0	0.64	+ calf
2	2yrs-2m	965	39	1004	2.7	4 – 5	1.4	2.5	0.79	+ calf
3	5yrs-2m	858	29	887	2.8	4	1.5	2.8	0.81	+ calf
4	2yrs-2m	1111	50	1161	3.3	5.8	2.0	4.0	1.03	no calf
5	1yrs-2m	1178	51	1229	3.2	5.5	2.0	4.0	1.05	no calf
6	2yrs-2m	1165	25	1190	3.5	4.8	2.5	3.5	1.08	no calf
	Mean	**1051**	**38**	**1089**	**2.9**	**4.7**	**1.9**	**3.3**	**0.90**	
	S.D.	±125	±11	±129	±0.5	±0.8	±0.4	±0.6	±0.18	
AUTUMN ADULT										
7	2yrs-4m	995	33	988	6.3	8 – 10	6	7	0.51	+ calf
8	11yrs-4m	1270	4	1274	6	7.5	5	5.5	0.36	+ calf
9	11yrs-4m	909	0	909	6	none	5	none	0.43	+ calf
10	10yrs-4m	971	8	979	7	7.5 – 9	4.5	5.5	0.43	+ calf
11	1yrs-4m	1251	0	1251	6.5	none	6	none	0.83	male
	Mean	**1079**	**9**	**1080**	**6.4**	**8.3**	**5.3**	**6.0**	**0.51**	
	S.D.	±169	±14	±169	±0.4	±0.8	±0.7	±0.9	±0.19	
WINTER ADULT										
12	13yrs-9m	1523	14	1537	6.3	7.5	5.5	6	0.38	unknown
13	adult	916	40	956	7.5	10 – 13	7	8 – 10	0.58	+ calf/pregnant
14	adult	1175	12	1187	7	8.5	6.5	7	0.58	no calf /pregnant
15	adult	1271	29	1300	6	7 – 9	5.0	6.5	0.31	+ calf/pregnant
16	adult	1073	20	1093	6 – 6.5	8 – 9	5.5	7	0.55	no calf/pregnant
17	adult	1087	15	1102	6 – 6.5	8 – 9	5.5	7	0.54	no calf/pregnant
18	5yrs-10m	1405	24	1429	6.5	8 – 9.5	6	7	0.42	unknown
19	2yrs-10m	1326	33	1359	7.1	8.5 – 11	6	8	0.40	unknown
20	5yrs-10m	1523	40	1563	7	8 – 11	6.5	9	0.35	unknown
	Mean	**1255**	**25**	**1281**	**6.7**	**8.9**	**5.9**	**7.4**	**0.46**	
	S.D.	±210	±11	±211	±0.5	±1.2	±0.6	±1.1	±0.11	

Table 2. Physical properties of Svalbard reindeer calves mid-back fur.

Sample		Density [cm^{-2}]			Length [cm]		Depth [cm]		Thickness [mm]
Fur	Age*	Hair	Guard	Total	Hair	Guard	Hair	Guard	Skin
JUNE CALVES									
1	< 1	3178	82	3260	1.8	4	1.8	3.5	0.30
2	< 1	3016	118	3134	2.5	4	2.5	3.5	0.33
3	< 1	3067	185	3252	2.5	4.2	2.0	3.5	0.32
	Mean	**3087**	**128**	**3215**	**2.3**	**4.1**	**2.1**	**3.5**	**0.32**
	S.D.	±82	±52	±71	±0.4	±0.1	±0.4	±0.0	±0.02
SUMMER CALVES									
4	2	2489	1	2490	3.2	4	2.5	3.0	0.46
5	2	2011	2	2013	3.5	4.5	2.0	2.5	0.77
6	2	1586	103	1689	3.0	4	2.0	2.5	0.80
	Mean	**2029**	**35**	**2064**	**3.2**	**4.2**	**2.2**	**2.7**	**0.70**
	S.D.	±452	±59	±403	±0.3	±0.3	±0.3	±0.3	±0.22
AUTUMN CALVES									
7	5	1184	95	1279	6.5	10	5.5	8.0	0.66
8	5	1525	54	1579	6.5	9.5	5.6	7.5	0.62
9	5	1298	21	1319	6.5	10.5	5.7	8.0	0.50
10	5	1710	35	1745	7	10	6.0	8.5	0.42
	Mean	**1429**	**51**	**1481**	**6.6**	**10**	**5.7**	**8.0**	**0.55**
	S.D.	±235	±32	±221	±0.3	±0.4	±0.2	±0.4	±0.11
WINTER CALVES									
11	10	1856	37	1893	5.5	9	5.0	8.5	0.32
12	10	1784	110	1894	7.5	9.5	7.0	8.5	0.45
13	10	2214	113	2327	6.5	10	6.0	9.5	0.29
	Mean	**1951**	**87**	**2038**	**6.5**	**9.5**	**6.0**	**8.8**	**0.35**
	S.D.	±230	±43	±250	±1	±0.5	±1	±0.6	±0.09

* Calf age in months.

Hair was relatively short and dark in summer, while long and pale in winter. The shortest fur occurred on the youngest calves (June). Greatest fur density and highest total number of guard hairs per square centimetre were also observed on the youngest calves (Table 2).

Summer Adults – August

The skin was thick and a dark grey colour. All hairs were firmly attached to the skin. Dark wool fuzz intertwined about the hair roots. The hairs were stiff, with a crimped wave along their length and very fine intertwining distal tips (Figs. 1 & 2). Hair colour began with light roots, becoming a dark grey-brown, and finishing with very dark distal tips. The guard hairs were white their entire length except for black or dark brown distal tips. Two fur samples, both from adult females with calves, showed incomplete moult since they still possessed old winter guard hairs, which were a dirty yellow-white colour.

Autumn Adults – October

The skin was thinner with colour ranging from grey to almost black. All hairs were firmly attached to the skin. Plentiful dark grey-brown wool fuzz intertwined about the hair roots. The hairs were stiff, with a strong crimped wave along the distal half of their length and sometimes along their entire length (Fig. 3). Hair tips were thin and intertwined. Hair colour began with light white-grey or white roots, becoming a light grey or grey-brown, and darkening towards the distal tips. The guard hairs were white their entire length except for light brown distal tips, which sometimes became extremely fine and virtually invisible.

Winter Adults – March/April

The skin was thin and a dark colour. Hairs were not firmly attached to the skin on all samples. Plentiful dark grey-brown wool fuzz intertwined about the hair roots. The hairs were stiff with a crimped wave, which was sometimes most marked in the mid-section of the hairs (Fig. 4). Hair tips were thin and intertwined. Hair colour began with light white-grey or white roots, becoming a light grey or grey-brown, and darkening towards the distal tips. The guard hairs were numerous and could be extremely long. They were white (or sometimes grey-brown) their entire length. Guard hair could have either dark distal tips or extremely fine and virtually invisible tips.

June Calves

The fur was dense, soft, fuzzy and dark coloured. The skin was thin with a dark surface. All hairs were firmly attached to the skin and were difficult to remove. Plentiful dark wool fuzz intertwined about the hair roots. Hairs exhibited a strong crimped wave, beginning about 7mm from the hair root. Hairs became very crimped or faded into fine intertwining curly wool at the distal tips (Fig. 5). Hair colour began with lighter coloured roots, followed by a dark brown. The guard hairs were numerous and brown with light coloured distal tips.

Summer Calves – August

The fur was soft, thick and very dark coloured. The skin was thick with a dark surface. All hairs were firmly attached to the skin and were difficult to remove. Plentiful dark wool fuzz intertwined about the hair roots. The hairs were soft and fine with intertwining distal tips (Fig. 6). Many began with a thick solid root, while the tip became thin and wool-like. Hairs had a crimped wave, many along their entire length. Hair colour began with light roots, becoming a dark brown, and finishing with very dark distal tips. The guard hairs were often few. These were white or light brown their entire length except for dark distal tips.

Autumn Calves – October

The fur has lost its softness and the individual hairs were stiffer. The skin was thinner with colour ranging from grey to grey-white. All hairs were firmly attached to the skin. Plentiful dark grey-brown wool fuzz intertwined about the hair roots. The hairs had a strong crimped wave along the distal half of their length (Fig. 7). Hair colour began with light roots, becoming a light grey-brown, and darkening towards the distal tips. Guard hairs were white their entire length, although some had dark distal tips.

Winter Calves – March

The skin was thin and a grey-white to dark grey colour. Hairs were firmly attached to the skin on all samples. Plentiful dark grey-brown wool fuzz intertwined about the hair roots. The hairs were stiff with a crimped wave (Fig. 8). Hair colour was lightest at the roots, becoming a light grey-brown, and darkening towards the distal tips. The guard hairs, again numerous, were white their entire length, except when they had dark distal tips.

Season and age differences

Adult fur samples

While hair density did not differ significantly between seasons, summer and winter fur differed significantly on all other characteristics (Table 3). The winter fur samples had denser guard hairs, plus longer hair and guard hair. They also had greater depth for hair and guard hair and thinner skin.

Autumn and winter furs were basically the same. The differences between autumn and winter fur

Table 3. Adults: seasonal comparison of Svalbard reindeer mid-back fur, *P*-values below 0.05 were considered significantly different.

	Adult: Summer versus winter			
	t	*df*	*P*-value	Remarks
Density hair		13	> 0.05	similar
Density guard hair	2.166	13	< 0.05	greatest in winter
Length hair	13.911	13	< 0.001	greatest in winter
Length guard hair	7.621	13	< 0.001	greatest in winter
Depth hair	13.796	13	< 0.001	greatest in winter
Depth guard hair	8.477	13	< 0.001	greatest in winter
Skin thickness	6.078	13	< 0.001	thinnest in winter

Fig. 1. Summer adult Svalbard reindeer fur - female (with calf) in August, incomplete moult.

Fig. 2. Summer adult Svalbard reindeer fur - female (no calf) in August.

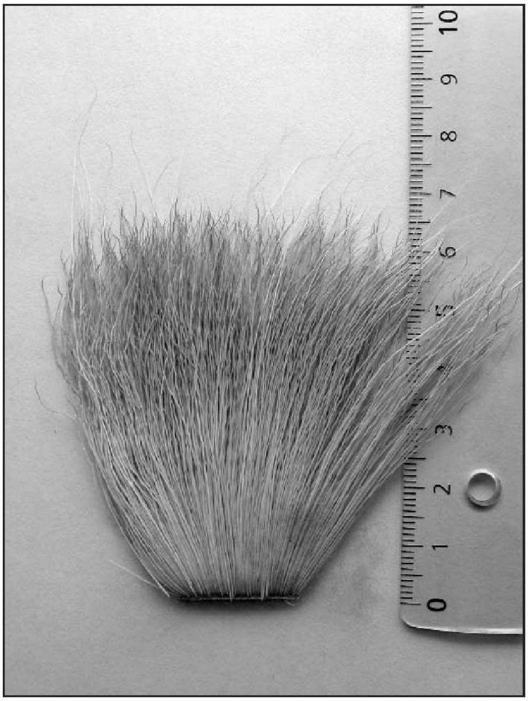


Fig. 3. Autumn adult Svalbard reindeer fur - female in October.

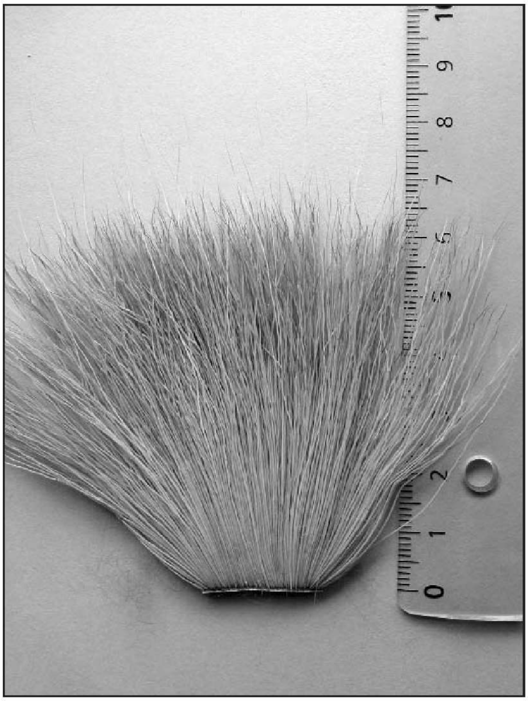


Fig. 4. Winter adult Svalbard reindeer fur - female in March/April.

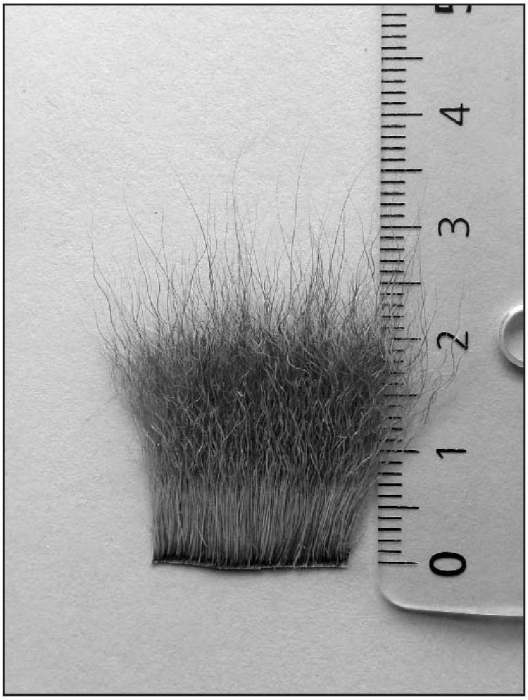
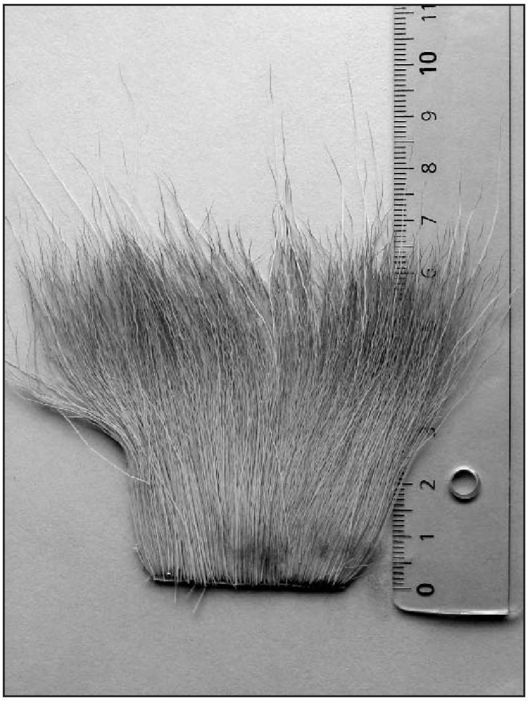


Fig. 5. June calf Svalbard reindeer fur.

Fig. 6. Summer calf Svalbard reindeer fur - in August.



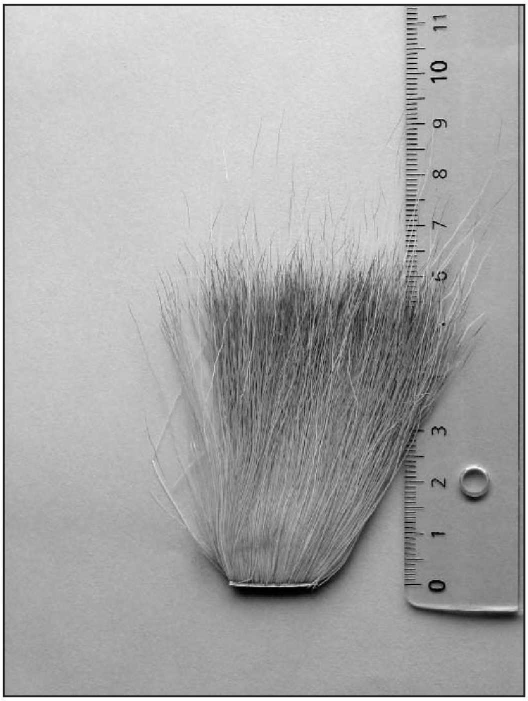


Fig. 7. Autumn calf Svalbard reindeer fur - in October.

Fig. 8. Winter calf Svalbard reindeer fur - in March.

Table 4. Calves: seasonal comparison of Svalbard reindeer mid-back fur, *P*-values below 0.05 were considered significantly different.

	Calf: Summer versus winter			
	t	*df*	*P*-value	Remarks
Density hair		4	> 0.1	similar
Density guard hair		4	> 0.05	similar
Length hair	5.487	4	< 0.01	greatest in winter
Length guard hair	16.00	4	< 0.001	greatest in winter
Depth hair	6.379	4	< 0.01	greatest in winter
Depth guard hair	16.547	4	< 0.001	greatest in winter
Skin thickness		4	> 0.05	similar

samples were not significant ($P > 0.05$) for any of the characteristics except the guard hair density, which was greatest in winter ($t = 2.437$, $df = 12$, $P < 0.05$).

Calf fur samples

Summer and winter fur differed significantly on length and depth, for both hair and guard hair (Table 4). The fur grew longer and deeper from summer to winter.

Hair density in calves gave mixed results. Hair density was not different between summer and either autumn or winter ($P > 0.05$ and $P > 0.1$ respectively). Hair density of June calves, however, was greater than the summer fur ($t = 3.991$, $df = 4$, $P < 0.02$) and autumn or winter fur ($P < 0.001$ and $P < 0.01$ respectively). Also, calf winter fur had greater hair density than autumn fur ($t = 2.934$, $df = 5$, $P < 0.05$). Otherwise, the autumn and winter fur were basically similar. The differences between autumn and winter fur samples were not significant ($P > 0.1$ or 0.05) for any of the characteristics except the hair density. This is in contrast to adults.

Also in contrast to adults was the thickness of calfskin, which did not differ significantly between seasons ($P > 0.1$ or > 0.05). Only the thin June calfskin differed from the summer skin thickness ($t = 3.068$, $df = 4$, $P < 0.05$).

Calves versus Adults

Comparing within season (Table 5), calves always had greater hair density than adults. Summer calf fur was similar to summer adult fur, for all characteristics excepting the aforementioned hair density. Likewise, the winter calf fur was similar to winter adult fur, for all characteristics excepting as before hair density but also guard hair density. Autumn calf fur differed on several characteristics from adult fur. Hair density, guard hair density, plus guard hair length and depth were greater than adult fur. The only characteristics not significantly different between autumn adults and calves were hair length and depth and skin thickness.

Table 5. Comparison of calf and adult samples of Svalbard reindeer mid-back fur, *P*-values below 0.05 were considered significantly different.

	Calf versus Adult					
	Summer		Autumn		Winter	
Density hair	$P < 0.01$	calf greatest	$P < 0.05$	calf greatest	$P < 0.001$	calf greatest
Length hair	$P > 0.1$	similar	$P > 0.1$	similar	$P > 0.1$	similar
Depth hair	$P > 0.1$	similar	$P > 0.1$	similar	$P > 0.1$	similar
Density guard hair	$P > 0.1$	similar	$P < 0.05$	calf greatest	$P < 0.002$	calf greatest
Length guard hair	$P > 0.1$	similar	$P < 0.02$	calf greatest	$P > 0.1$	similar
Depth guard hair	$P > 0.1$	similar	$P < 0.01$	calf greatest	$P > 0.1$	similar
Skin thickness	$P > 0.1$	similar	$P > 0.1$	similar	$P > 0.1$	similar

Table 6. Svalbard adult/calf fur samples and heat transfer: seasonal calm air conductance (C) and response to increasing wind velocity (from Cuyler & Øritsland, 2002).

Fur Sample	Summer calm air C (W·m^{-2}·°C^{-1}) *	Winter calm air C (W·m^{-2}·°C^{-1})	*P* value[1]	Summer wind coefficient slope «*b*»[2]	Winter wind coefficient slope «*b*»	*P* value
Adult	2.09 (n=6)	0.66 (n=9)	P<0.001	0.04 (n=6)	0.03 (n=9)	P>0.1
Calf	2.09 (n=3)	0.65 (n=3)	P<0.001	0.06 (n=3)	0.02 (n=3)	P>0.1
	P=0.998	P=0.893	*P* value	P>0.1	P>0.1	

* Watts per square meter per degree Celsius.

[1] Slope for the linear regression line of heat transfer versus wind velocities between 0 and 10 m^{s-1}.

[2] *P*-values below 0.05 are considered significantly different; *P*-values > 0.05 are not.

Discussion

Hair density was not an important factor for determining fur heat transfer, and neither was skin thickness. Although calm air conductance decreased from summer to winter (Table 6), hair density did not change significantly for either adult or calf fur samples. Within a season calf fur always had higher hair density than adult fur, however, fur heat transfer was similar. This evidence does not support arguments relating increased hair density to decreased fur heat transfer. No direct relationship between hair density and heat transfer was apparent for Svalbard reindeer fur. Skin thickness and calm air conductance decreased from summer to winter. Since a thin skin can be expected to provide less insulation, this suggests that skin thickness is not related to heat transfer. The change in skin thickness may be explained by seasonal changes in fat storage and use.

There may yet be a role for hair density on fur insulation. The soft short June calf furs had greater densities than the stiff long winter calf fur. The relatively short, 3.8 cm, winter fur of adult reindeer (*Rangifer tarandus tarandus*) had hair densities of 1700 to 1900 per cm^2 (Timisjärvi *et al.*, 1984), while the longer, 6.7 cm, winter fur of adult Svalbard reindeer had a much lower mean density, 1255 per cm^2. Optimal density may depend on an inter-play with the other physical characteristics. Fur types that are easily penetrated by wind, *e.g.*, short or soft short furs, may need greater densities (among other characteristics) to minimise disruption of trapped still-air, than fur types not easily penetrated or compacted, *e.g.*, stiff, interlocked, long furs.

The seasonal changes in calm air conductance appear linked to seasonal changes in hair length and depth. Calm air conductance decreases from summer to winter for Svalbard reindeer fur samples, with similar values for both adult and calf fur samples. Hair length and depth increased significantly from summer to winter in all adult and calf fur samples. Furthermore, when comparing calf and adult fur within season, while they may differ in other characteristics, they were similar in hair length and depth. Hair length and depth appear to be major factors determining calm air heat transfer.

Wind typically reduces the insulation value of fur, by causing the rate of heat transfer to increase substantially (Tregear, 1965; Davis & Birkebak, 1975). Svalbard fur, however, has exceptional wind resistance showing little change in rate of heat transfer with increasing wind speed, i.e., wind coefficient (slope b) near zero for regression of heat transfer versus wind velocity (Table 6). Furthermore, there is no significant seasonal change in the effect of wind on insulation regardless of animal age or season. This suggests that seasonal changes in hair length and depth are not the important factors here.

The amount of still-air in a fur affects its insulation value. To maintain this in the face of high wind speed, a fur needs to be resistant to compaction and penetration. Svalbard reindeer have several possible physical characteristics for maximizing and maintaining the amount of trapped still-air in the fur regardless of wind speed. In addition to their well-known hollow hairs, still-air retention between hairs would be fostered by their crimped wave, which adds volume to the fur and interlocks hairs. Furthermore, natural convection of air within the fur may be inhibited. Vertical airflow along the hair column might be hindered by the crimp physically causing a series of small circular eddies and "backwaters" of air. The crimped wave and stiff interlocking hairs likely also aid in maintaining fur shape regardless of wind speed. Likewise, the fine intertwining distal hair tips and the fine wool fuzz winding about the hair roots may also trap still-air in the fur and aid resistance to wind penetration because of interlocking the hairs. These physical characteristics are common to all seasons and ages and therefore may be the determining factors responsible for the exceptional wind resistance regardless of season or age. The exact extent and manner the physical characteristics described in this paper may have contributed is unclear at this time.

Conclusions

No apparent relationship was observed between hair density and heat transfer or wind resistance. Svalbard reindeer hair length and depth appear to be the main determinants of calm air heat transfer, but do not explain the exceptional wind resistance. Since Svalbard fur wind resistance does not change with season or age, the important factors involved are those physical characteristics, which are constant and resist wind compaction and penetration. Fur characteristics, which maintain and enhance the amount of still-air in the fur, could include hair stiffness, the crimped wave, hollow hairs, intertwining distal tips and the fine wool fuzz about the hair roots. Further study is necessary to determine the extent each contributes to maintaining fur insulation.

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