Electronic supplementary material for "Flexible use of peripheral heterothermy is associated with fitness-related outcomes in an Arctic ungulate"

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Supplementary Methods

Biologger implantation

All implants were sterilized with ethylene oxide gas (Anaprolene AN74i 60 L, Andersen Europe, Kortrijk, Belgium) and stored individually in sealed packets until implantation. Prior to the surgical procedure, animals were sedated. The drugs and administration method differed in the two study periods. In 2018, the animals were sedated with intranasal medetomidine (Domitor vet, Orion Pharma Animal Health, Finland; dose ~0.14 mg kg^{-1} body mass, BM) or dexmedetomidine (Dexdomitor vet, Orion Pharma Animal Health, Finland, dose ~0.07 mg kg^{-1} BM). For implantations in 2021, and retrievals in 2022 and 2023, animals were sedated with medetomidine (dose: 0.1 mL kg^{-1}; Domitor vet. Orion Pharma, Finland), which was administered 50/50 intravenously and intramuscularly. In all three years, post-operative analgesia (0.5 mg kg−1 meloxicam; Metacam®, Boehringer Ingelheim Vetmedica GmBH, Germany) was administered intramuscularly prior to surgery. The surgical area was shaved and cleaned with chlorhexidine spirit and local anaesthesia was administered subcutaneously around the planned incision site with 2.5–5 mg of Bupivacaine (Marcaine 5 mg mL^{-1} , AstraZeneca, Cambridge, UK). And a small incision (~1 cm) was made with a scalpel, and the loggers were inserted into the subcutaneous space (subcutaneous chest loggers in 2018 and 2021, and subcutaneous neck loggers in 2022). All incisions were closed with 2-0 monofilament absorbable suture PDS® II (polydioxanone) (Ethicon, Johnson & Johnson, New Brunswick, NJ, United States). Once completed, the anaesthesia was reversed with atipamezole (Antisedan® 5 mg mL^{-1}, Orion Pharma Animal Health, Turku, Finland; 5 mg mg^{-1} for medetomidine and 10 mg mg^{-1} for dexmedetomidine) injected intramuscularly (in 2018 and 2019), and 50/50 intravenously and intramuscularly (2021-2023). The animals were left unrestrained while regaining consciousness and visually monitored until walking/running with normal balance, i.e., walking or running in a straight line (i.e. stumbling/swaying), which happened typically within ~5 min post-injection of the antidote.

The retrieval of the loggers differed between the first (April 2019) and the second (April 2022 and 2023) study periods. In 2019, the animals were manually restrained and only local anesthesia was used (2.5–5 mg of Bupivacaine; Marcaine 5 mg mL^{-1}) together with post-operative analgesia (0.5 mg kg^{-1} meloxicam; Metacam). In 2022 and 2023, the animals were fully sedated with medetomidine as described above, in addition to the local anaesthesia and post-operative analgesia, and the anaesthesia was reversed after surgery, as described above. In all years, the loggers were first located through palpation to determine the incision site. The

surgical site was cleaned with chlorhexidine spirit. A ~0.5 cm incision was made through which the logger was pushed out. When retrieving the subcutaneously implanted chest loggers, the incisions were left to heal without suture provided no other tissue apart from the skin had been cut. In all other cases, the incisions were closed with 2-0 monofilament absorbable suture. For the 20 animals which had neck logger implanted strictly subcutaneously in 2022, the logger was pushed into the subcutaneous space at an upward angle from the incision site. For every incision made on the neck, a small muscle biopsy (~100 mg) was collected from the surgical site as part of a separate study. In some cases, one or two stitches were made to close the muscle tissue prior to suturing the skin using 2-0 monofilament absorbable suture (polydioxanone).

Defining active and resting bouts

To define active and resting bouts, we used the sum of activity in X- and Y-directions. Some of the collars used in 2018–2019 only recorded activity in these two axes, so although all collars deployed in 2021 record activity in three axes, we used only data from X and Y for consistency across years. We plotted a histogram of the sum of activity in both axes and visually defined a point in between the bimodal curves. In a previous study of wild mountain reindeer in Norway using the same collars as in the present study, inactivity has been confirmed to correspond with values below 25 in each axis [1]. To be conservative about our threshold for inactivity, we used 25 as the threshold for inactivity in both axes (i.e., sum of X and Y). In 6 cases, there were errors in the activity file downloaded directly from the collar unit. In these cases, we used the raw acceleration data recorded at 8Hz and converted this to 5-minute values using the software "MotionDataMonitor" (Vectronic Aerospace GMBH). This software converts the raw acceleration data to 5-minute values that represent the sum of activity in the past 5 minutes, similar to what is normally done in the collar. The distribution of the 5-min values converted from the acceleration data were on average lower, but the point in between the bimodal curves was also around 25 for the sum of activity in both axes.

References

1. Lyftingsmo E. 2016 Combining GPS activity measurements and real-time video recordings to quantify the activity budget of wild reindeer (Rangifer tarandus). Norwegian University of Life Sciences. See http://hdl.handle.net/11250/2449765.

Supplementary figures

Figure S1

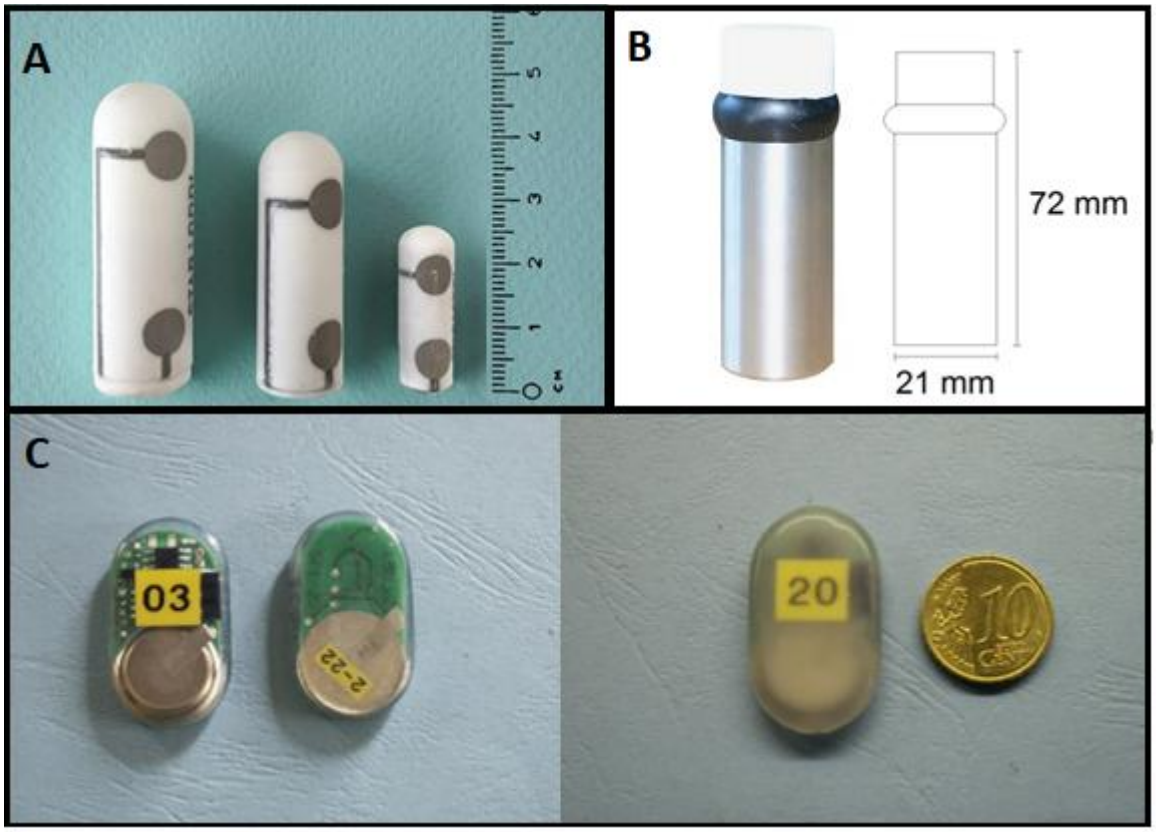


Figure S1. (A) DST Centi-HRT (left). Photo: Star-Oddi. (B) Photo and schematic of the rumen logger (RIT; Vectronic Aerospace). (C) MCP9802 loggers (Microchip Technology Inc., Chandler, AZ, USA) before (left) and after (right) coating with surgical wax. The photo on the right includes a 10-cent Euro coin for size comparisons. Photo: Gerhard Fluch.

Figure S2

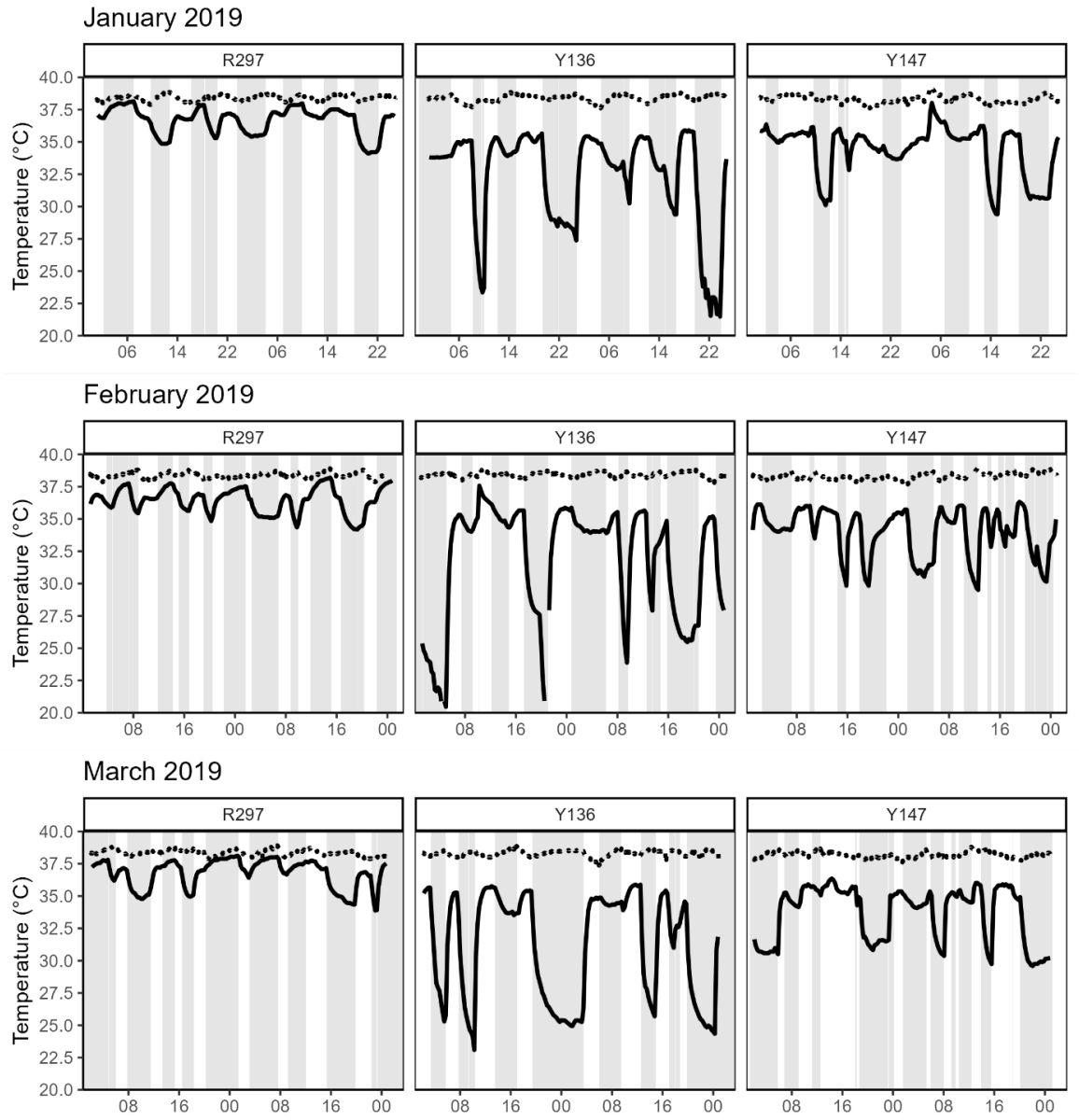


Figure S2. Fluctuations in body temperatures recorded in female Svalbard reindeer over 48 h in mid-January 2019 (top row), mid-February 2019 (middle row), and mid-March 2019 (bottom row), from three different individuals. The grey shaded regions indicate inactive bouts, while the white regions represent active bouts. The dotted lines represent temperature in the rumen and solid lines represent temperatures measured subcutaneously in the chest. Data from December 2018 for ID Y147 is also shown in Figure 1a in the main text.

Figure S3

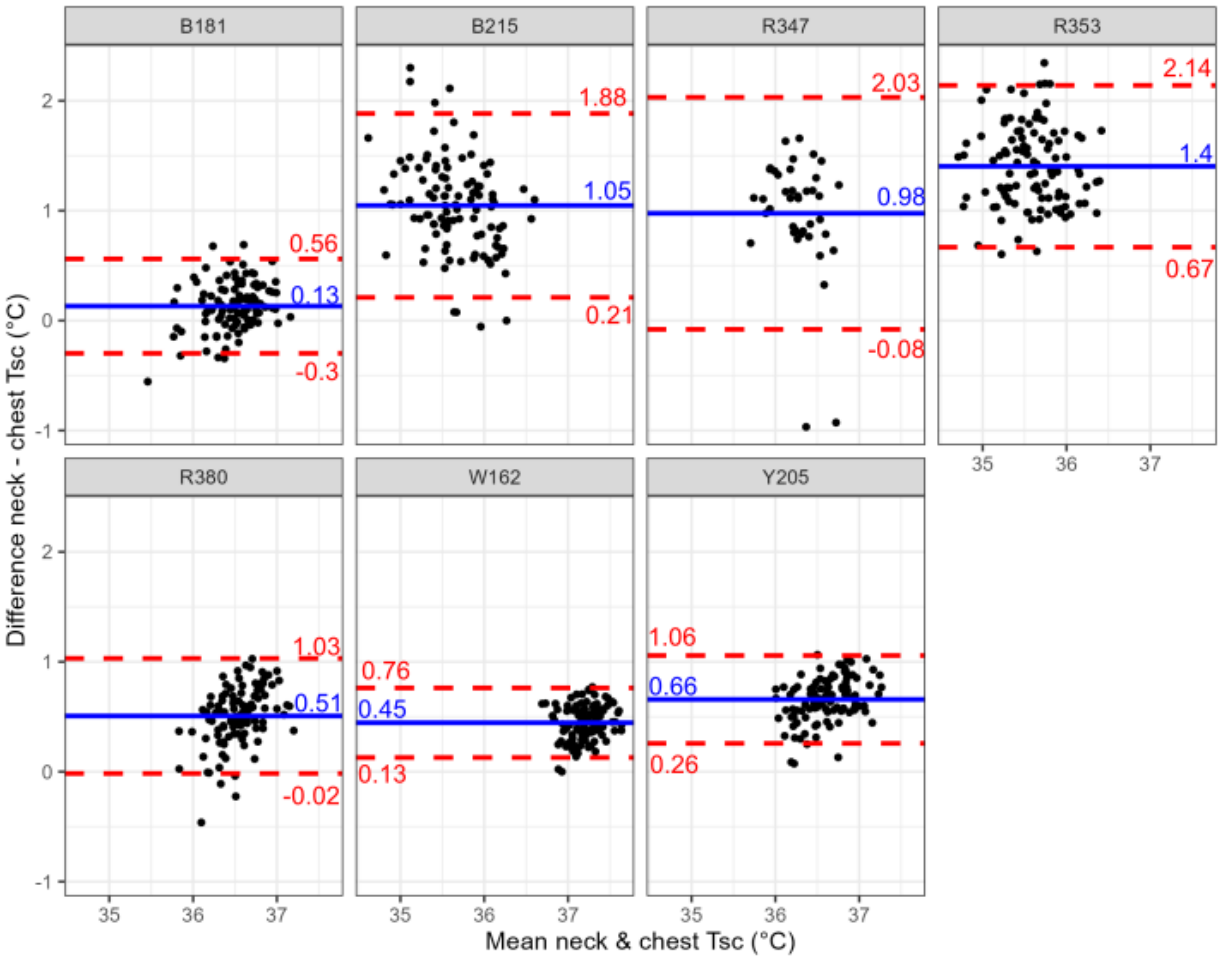


Figure S3. Bland-Altman plots for daily median T_{sc} measured on the neck and on the chest for 7 individuals from which we successfully retrieved data for both locations recorded during overlapping time periods. The blue line and numbers indicate the mean difference between the two measurements and the dotted red lines and numbers represent plus and minus 1.95*SD of the differences.

Figure S4

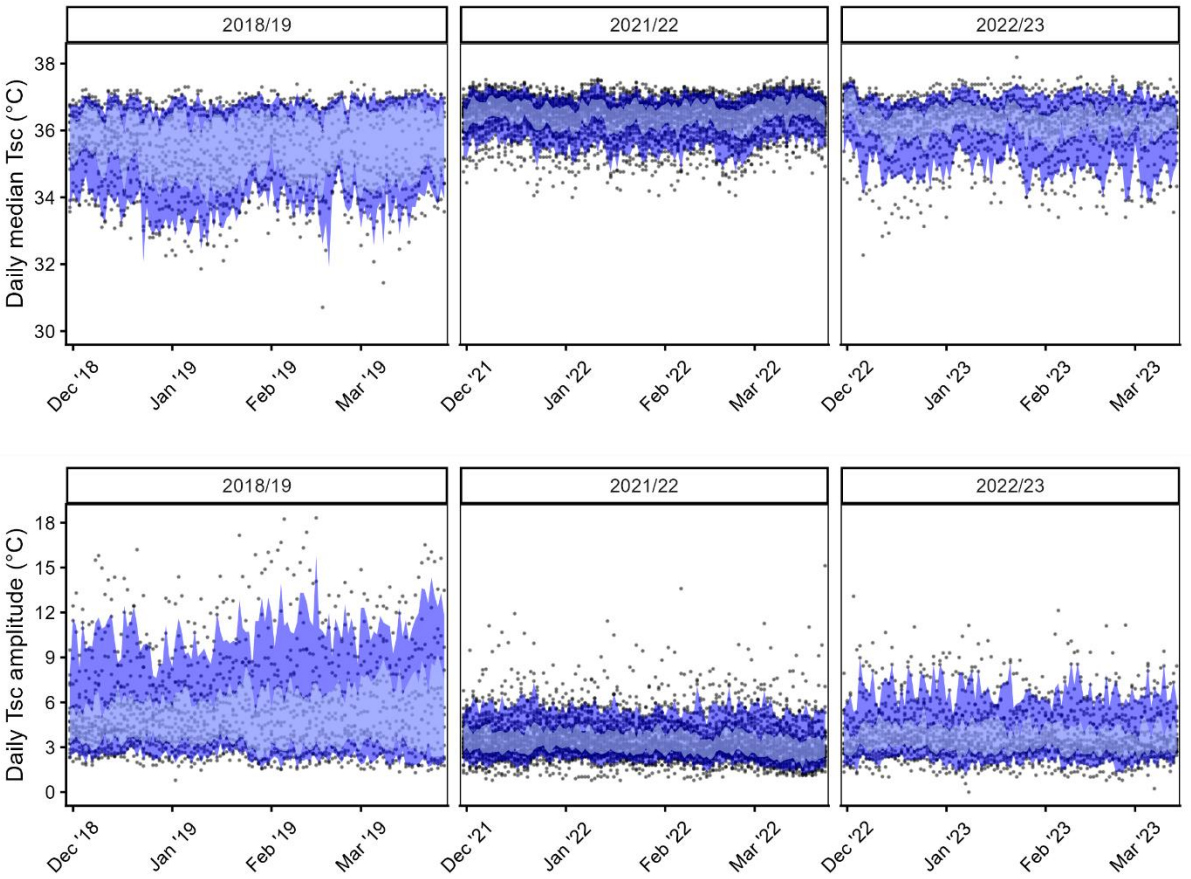


Figure S4. (A) Daily median T_{sc} and (B) daily T_{sc} amplitude measured on the chest, shown for each winter (2018/19, 2021/22 and 2022/23) in adult female Svalbard reindeer. The wide, dark blue ribbon covers the 0.05 and 0.95 quantiles, while the light blue ribbon covers the 0.25 and 0.75 quantiles across all individuals for each given winter. Each point represents a single daily median T_{sc} or daily T_{sc} amplitude value for an individual.

Supplementary tables

Table S1

Overview of year implanted, logger type, body placement, number of individuals instrumented, and number of units retrieved with useful data. The final column denotes the number of ID-years used in analyses - individuals with either missing biometrics information (i.e., not captured) or with missing activity data (malfunctioning collar) were excluded. Retrieval rates varied for multiple reasons: some individuals were not recaptured, some loggers were not found during recaptures or in the carcass in the case of a death, and some loggers malfunctioned and hence did not provide sufficient or useful data.

Year implanted	Logger type	Body placement	Individuals instrumented	Units retrieved	ID-years in analyses*
2018	RIT (Vectronic Aerospace)	Rumen	11	8	4
2018	DST Centi-HRT (Star Oddi)	Chest, left side of sternum towards the axilla, subcutaneous	34	30	15
2021	DST Centi-HRT (Star Oddi)	Chest, left side of sternum towards the axilla, subcutaneous	60	53	38 (16)
2022	MCP9802 (Microchip Technology Inc)	Neck, left side, subcutaneous	20	13	7

**Number in parentheses indicate individuals with 2 years of data spanning both 2021/22 and 2022/23.*

Table S2

Overview of all individuals used in the analyses, data availability (number of days with temperature data recorded on the chest), biometrics, and reproductive state per year. The columns show the animal identity (ID), year of birth (Cohort), each data period (Winter), and the number of days with data available for the mixture model analyses. BM is the body mass (kg) recorded during capture at the end of the winter, adjusted for date of capture. Leg refers to hind leg length (mm) measured during capture at the end of winter. Preg gives the pregnancy status during capture in winter (1 = pregnant, 0 = not pregnant). Calf refers to calf status in August (1 = calf at heel, 0 = no calf at heel). One individual was of unknown cohort, resulting in two ID-years with missing age.

ID	Cohort	Winter	N days	BM	Leg	Preg	Calf
B181	2014	2021/22	114	52	280	1	1
		2022/23	105	52.5	282	1	
B213	2014	2021/22	114	56	281	1	1
		2022/23	105	54.5	285	1	0
B215	2014	2021/22	114	49	283	1	
		2022/23	105	58	284	1	1
B241	2016	2021/22	114				1
B243	NA	2021/22	114	59	291	1	1
		2022/23	105	57.5	289	1	
B244	2016	2021/22	114	56	288	1	1
B248	2017	2021/22	114	47.5	273	1	0
		2022/23	98				0
B250	2016	2021/22	89	55.5	280	1	1
G120	2011	2018/19	118				1
		2021/22	114	51	284	1	
G134	2011	2021/22	114	49	288	1	
G140	2011	2018/19	118	61.25	294	1	
G148	2011	2021/22	114				0
		2022/23	105	51.5	284	1	
G152	2011	2018/19	86	46.25	279	1	
G193	2016	2021/22	114				1
		2022/23	105	59	294	1	
R287	2011	2021/22	114	51.5	280	0	0
R289	2011	2018/19	50	46.75	272	1	1
		2021/22	114	48	273	1	0
R290	2011	2018/19	118	42.75	283	0	0
		2021/22	98				0
R291	2011	2021/22	114	55.5	283	1	1
R297	2012	2018/19	109				
R310	2012	2021/22	114	48	280	0	0
R312	2012	2021/22	114	55	288	1	1
R318	2012	2018/19	118				1

R320	2012	2018/19	118	44.75	280	1	0
		2021/22	114	43.5	285	0	0
R327	2012	2021/22	62				
R347	2017	2021/22	114	63.5	294	1	1
R353	2017	2021/22	114	49	266	0	0
		2022/23	105	56	265	1	1
R355	2017	2021/22	114	53	289	1	
R380	2017	2021/22	114	51.5	279	0	0
		2022/23	105	58	276	1	
R397	2017	2021/22	114				1
		2022/23	105	45.5	280	0	0
R399	2017	2021/22	114	47.5	280	1	1
		2022/23	105	46.5	276	1	0
W125	2010	2021/22	114	59.5	289	1	
W137	2010	2018/19	117				
W139	2010	2018/19	118	53.75	283	1	
W150	2010	2021/22	114	45	271	1	
W162	2015	2021/22	114	58.5	283	1	1
		2022/23	105	52.5	281	1	0
W170	2015	2021/22	114	53	290	1	1
W172	2015	2021/22	114	55.5	285	0	0
		2022/23	105	58	276	0	0
W194	2015	2021/22	114	55	279	1	
W217	2015	2021/22	114	54.5	280	1	1
		2022/23	105	46	279	0	0
Y134	2013	2018/19	81	45.25	287	0	0
Y136	2013	2018/19	118	54.25	277	1	1
		2021/22	114	58.5	277	1	1
Y137	2013	2018/19	52	56.25	288	1	1
Y147	2013	2018/19	118	49.75	287	1	1
		2021/22	114	45.5	289	0	0
Y159	2013	2021/22	114	60.5	286	1	
Y175	2013	2018/19	118	43.75	283	1	
Y205	2013	2021/22	114	54	283	1	
		2022/23	105	60	284	1	
Y207	2013	2021/22	114				
		2022/23	105	60.5	291	1	

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Table S3

Descriptive statistics of all adult female Svalbard reindeer captured in late winter of 2019, 2022 and 2023 in Nordenskiöld Land, Svalbard as part of a long-term capture-mark recapture. The table presents mean ± SD and range of body masses (in kg, in parentheses), adjusted for date of capture of adult females above 3 years of age. The proportion pregnant females were determined from ultrasound scan at capture, whereas the proportion of females with calves, a measure of reproductive success in August, was determined from the summer census of marked females. The sample sizes in the header for each year are the number of marked adults (> 2 years) captured in April. The numbers following the ratio of females with calves indicate the number of females that were captured in late winter (March/April) and seen in August the same year. Following these values are the body masses, proportion of pregnant females and proportion of females with calves for the females included in analyses in the present study. For the estimates of the proportion of pregnant females, the values exclude missing data, i.e., it is the proportion of known pregnancies against known non-pregnant individuals. There were 4 individuals in 2019 and 7 in 2022 from whom we did not record pregnancy status. For the proportion of females with calves, the ratio is based on the females observed with or without a calf as well as six individuals that were known to not be pregnant (but not observed in the autumn). There were 6, 16, and 7 unobserved females in the three years 2019, 2022, and 2023, respectively, of which 5 in 2022 were known to not be pregnant.

Marked adult females (>2 years)	**2019 (N = 77)**	**2022 (N = 105)**	**2023 (N = 77)**
Body mass (kg)	49.8 ± 4.4 (39.7–60.9)	52.3 ± 4.7 (39.3–64.2)	52.5 ± 4.7 (41.6–64.4)
Proportion of pregnant females	0.82	0.81	0.76
Proportion of females with calf	0.65 (N = 37)	0.64 (N = 53)	0.19 (N = 37)
Females in this study	**2018/19 (N = 15)**	**2021/22 (N = 38)**	**2022/23 (N = 16)**
Body mass (kg)	49.5 ± 6.0 (42.8–61.2)	52.9 ± 4.9 (43.5–63.5)	54.4 ± 5.1 (45.5–60.5)
Proportion of pregnant females	0.82	0.77	0.80
Proportion of females with calf	0.67	0.59	0.22

Table S4

Thermoregulatory tactic classification using the mixture regression model of individual reindeer each winter: blue shading = less heterothermic tactic, green shading = more heterothermic tactic. Numbers show the winter median T_{sc} and winter median daily T_{sc} amplitude, with the range of daily values shown in parentheses (min–max).

Animal ID	2018/19		2021/22		2022/23	
	Median	Amplitude	Median	Amplitude	Median	Amplitude
B181			36.7 (36–37.2)	3.1 (1.9–4.9)	36.6 (35.6–37.3)	3.0 (2–5.1)
B213			37.2 (36.6–37.5)	2.5 (1.1–3.6)	37.2 (36.7–38.2)	2.4 (1.5–5.4)
B215			36.8 (35.8–37.4)	6.4 (3–15.1)	36.0 (34.6–36.9)	7.2 (3.2–12.1)
B241			35.9 (35.3–36.6)	4.2 (2.6–6.2)		
B243			36.5 (35.9–37.1)	3.1 (1.5–5.2)	36.3 (35.3–37.1)	3.4 (1.8–5.6)
B244			36.6 (35.8–37.1)	2.9 (1.2–4.4)		
B248			37.2 (36.8–37.5)	1.4 (0.8–2.3)	37.1 (36.5–37.6)	1.5 (0.2–2.7)
B250			37.0 (36.4–37.5)	2.4 (1.3–3.5)		
G120	34.5 (32.4–35.7)	9.3 (4.7–14.1)	36.1 (35.2–36.7)	3.4 (2–5.1)		
G134			36.9 (36.2–37.3)	3.6 (1.5–5.3)		
G140	35 (33.1–36)	7.7 (2.5–12)				
G148			36.8 (36.2–37.2)	2.2 (0.9–4.2)	36.5 (35.8–37.1)	2.7 (1.3–4)
G152	33.8 (32.3–35.9)	5.7 (3.5–8.1)				
G193			35.1 (34–36.3)	4.5 (2.6–8.2)	34.3 (32.3–35.7)	5.0 (2.6–8.6)
R287			37.1 (36.5–37.4)	2.8 (1.4–4.3)		
R289	33.7 (32.1–35.1)	5.3 (3.5–8.5)	36.5 (35.6–37)	3.5 (1.3–6)		
R290	36.7 (36–37.3)	2.4 (1.3–4.3)	36.2 (35–36.8)	3.1 (1.6–5.7)		
R291			36 (35.3–36.7)	3.7 (2.3–6.5)		
R297	36.8 (35.1–37.4)	3.6 (1.9–5.8)				
R310			36.0 (35–37.1)	5.9 (3.8–11.1)		

R312			37.0 (36.4–37.3)	4.1 (1.9–9.8)		
R318	34.1 (32.6–35.6)	4.6 (3.3–6.7)				
R320	35.3 (33.7–37)	5.7 (2.9–8.5)	36.8 (36.2–37.5)	2.3 (0.8–3.3)		
R327			36.2 (35.4–36.8)	3.2 (1.7–6.2)		
R347			35.7 (34.4–36.5)	4.2 (2.4–8.1)		
R353			35.3 (34.5–36)	4.7 (2.4–7.2)	35.0 (33.7–36)	5.0 (3.2–7.7)
R355			36.8 (35.9–37.5)	2.9 (1.5–4.7)		
R380			36.5 (35.9–37)	2.9 (1.2–4.8)	36.5 (35.8–37.2)	3.0 (1.5–4.6)
R397			36.5 (35.9–37.1)	2.6 (1.5–4.1)	36.6 (35.6–37.4)	3.1 (1.4–4.9)
R399			36.1 (35.3–36.8)	3.2 (1.9–5.7)	36 (34.8–36.6)	3.3 (2–6.2)
W125			36.6 (35.7–37.2)	4.3 (2–11.9)		
W137	36.8 (36–37.4)	2.6 (1.4–5)				
W139	36.8 (34.9–37.2)	3.2 (1.6–5.3)				
W150			36.8 (36.1–37.5)	2.9 (1.3–6)		
W162			36.9 (36.5–37.4)	2.7 (1.1–5.5)	37 (36.4–37.6)	2.3 (1.4–3.9)
W170			36.7 (35.6–37.4)	3.9 (1.1–7.1)		
W172			36.9 (36.2–37.1)	2.6 (1.6–4)	36.7 (36–37.1)	3.2 (1.6–4.8)
W194			36.1 (35.3–36.7)	3.8 (1.6–5.5)		
W217			35.5 (34.7–36.2)	4.3 (2.3–7.9)	35.8 (34.7–36.5)	3.7 (2.1–5.8)
Y134	36.5 (35–37.2)	2.8 (1.8–4.4)				
Y136	34.1 (29.8–35.7)	12.8 (6.3–18.3)	36.6 (35.8–37.1)	4.0 (2–6.8)		
Y137	35 (33.9–35.7)	3.6 (1.8–6.2)				
Y147	35.0 (33.5–36.3)	6.6 (4.4–9)	36.7 (35.9–37.3)	2.1 (1–3.7)		
Y159			36.1 (35.5–36.7)	3.1 (1.3–5.3)		
Y175	35.9 (34.5–37.4)	3.1 (1.7–6.1)				
Y205			36.7 (36.1–37.1)	2.5 (1.7–4.8)	36.3 (35.5–37.2)	3.2 (1.4–5.1)
Y207			35.7 (34.1–36.3)	5.1 (2.9–8.4)	35.2 (33.4–36)	5.0 (2.9–6.8)

Table S5

Estimates and 95% confidence intervals for the parameters included in the joint mixture model including both daily median T_{sc} and daily T_{sc} amplitude as the responses and according to each group defined by the model. The standard deviation (SD) for the random intercept and the residuals is shown. For daily T_{sc} amplitude, estimates are shown on the inverse link scale.

	Less heterothermic group		**More heterothermic group**	
Predictors	**Daily Median Tsc Estimates [CI]**	**Daily Tsc Amplitude Estimates [CI]**	**Daily Median Tsc Estimates [CI]**	**Daily Tsc Amplitude Estimates [CI]**
(Intercept)	36.37 [36.07 – 36.67]	0.343 [0.278 – 0.407]	34.52 [34.13 – 34.91]	0.155 [0.130 – 0.179]
Days since Dec 1st	0.04 [0.03 – 0.05]	0.027 [0.025 – 0.029]	0.03 [0.01 – 0.04]	0.002 [0.000 – 0.003]
Collar-recorded temperature	0.15 [0.14 – 0.16]	0.015 [0.013 – 0.017]	0.21 [0.19 – 0.23]	-0.001 [-0.002 – 0.001]
Proportion of time active	0.01 [0.01 – 0.02]	0.007 [0.004 – 0.009]	0.16 [0.14 – 0.18]	0.006 [0.004 – 0.008]
Year [2021/22]	0.28 [-0.06 – 0.63]	0.030 [-0.043 – 0.103]	1.48 [0.99 – 1.97]	0.067 [0.036 – 0.098]
Year [2022/23]	0.11 [-0.28 – 0.49]	0.013 [-0.067 – 0.094]	0.45 [-0.23 – 1.12]	0.028 [-0.015 – 0.071]
SD of the random intercept (~1 | id_year)	0.41	0.035	0.56	0.086