Original Research Article

Seasonal Variation in Basal Metabolic Rates Among the Yakut (Sakha) of Northeastern Siberia

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ABSTRACT: Objectives: Previous research has shown that indigenous circumpolar populations have elevated basal metabolic rates (BMRs), yet few studies have explored whether metabolic rates increase during the winter. This study addresses this gap by examining seasonal variation in BMR and its associations with thyroid function and lifestyle factors among the Yakut (Sakha) of Siberia.

Methods: Anthropometric dimensions, BMR, and thyroid hormone levels (free triiodothyronine [fT3], free thyroxine [fT4], thyroid-stimulating hormone [TSH]) were measured on two occasions (July/August, 2009 and January 2011) on a sample of 94 Yakut (Sakha) adults (35 men, 59 women) from the rural village of Berdygestiakh, Sakha Republic, Russia.

Results: Seasonal changes in BMR varied by age. Younger Yakut adults (19–49 years) showed significant elevations in winter-time BMR of 6% ($P < 0.05$), whereas older individuals ($\geq$50 years) showed modest declines (2%; n.s.). Both younger and older Yakut men and women showed increased respiratory quotients during the winter. FT3 and fT4 levels significantly declined during the winter in both younger and older Yakut men and women ($P < 0.05$). Lifestyle factors were significant predictors of BMR variation, particularly among older men and women.

Conclusions: Among the Yakut, increased wintertime BMR was observed among younger but not older adults, whereas all adults showed sharp reductions in free thyroid hormone levels during the winter. Among men, greater participation in subsistence activities was associated with increased BMRs and greater fat oxidation. Among women, variation in food use had the strongest impact on metabolic function. Am. J. Hum. Biol. 00:000–000, 2014.

Indigenous circumpolar populations are exposed to a suite of ecological stressors (e.g., severe cold, seasonal changes in photoperiod) that exert a strong influence on physiology and metabolism. Since the early 20th century, research among native northern peoples has suggested that they have elevated basal metabolic rates (BMRs) as an adaptation for increasing heat production in the face of chronic and severe cold stress (Brown et al., 1954; Crile and Quiring, 1939; Heinbecker, 1928; Rabinowitch and Smith, 1936; Roberts, 1978). Recent studies in North America (Rode and Shephard, 1995) and in Siberia (Galloway et al., 2000; Leonard et al., 1999, 2002, 2005; Snodgrass et al., 2005) have confirmed earlier findings, demonstrating that the BMRs of native circumpolar populations are systematically elevated relative to international norms for body mass, fat-free mass, and surface area.

Yet, while there is considerable evidence indicating elevated metabolic rates among indigenous circumpolar populations, few studies have examined seasonal variation in BMRs in these groups to determine whether metabolic rates increase during the winter months. Early work among the traditional Ama divers of South Korea showed evidence for significant wintertime increases in BMR (Kang et al., 1963). Other studies of seasonal changes in metabolic rates in high latitude environments have been conducted among military and scientific personnel stationed in Antarctic bases (Duncan, 1988; Junghans et al., 2012; Lewis et al., 1961; Reed et al., 2001; Wilson, 1956) or among urban populations living in northern cities in Europe (Haggarty et al., 1994; Plasqui et al., 2003) and Asia (Kashiwazaki, 1990; Osiba, 1957). This research provides an inconsistent picture of the impact of seasonal changes in temperature on metabolic rates, with some studies showing significant winter-time increases in metabolic rate (Kashiwazaki, 1990; Osiba, 1957; Plasqui et al., 2003; Reed et al., 2001), while others have shown the opposite trend (Duncan, 1988; Junghans et al., 2012; Wilson, 1956), or no significant seasonal effect (Haggarty et al., 1994; Lewis et al., 1961; Park et al., 1983). Some of the differences in seasonal patterns of metabolic rates among high latitude groups likely reflect variation in the severity of climate and differences in activity patterns and cold exposure during the winter months. Lifestyle variation within circumpolar communities has been found to moderate intra-population variation in acclimatization to cold stress (Andersen et al., 2012; Levy et al., 2013).

A related issue is seasonal change in thyroid hormone activity. Previous research among residents and sojourners in high latitudes has documented a pattern of physiological changes in response to severe cold exposure and reduced photoperiod known as the "polar T3 syndrome" (see Palinkas and Suedfeld, 2008; Reed et al., 1986,

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1990a,b). This suite of responses is characterized by increased rates of uptake of triiodothyronine (T3) and thyroxine (T4) exceeding production during the winter, generally leading to reduced circulating levels of free T3 and T4 (fT3 and fT4) (Harford et al., 1993; Reed et al., 1990a,b). Yet, while seasonal variation in thyroid function has been relatively well studied in high latitude groups, minimal research has examined seasonal changes in both thyroid hormone levels and metabolic rate in the same individuals (but see Plasqui et al., 2003; Reed et al., 2001;).

Thus, the goal of this study is to directly examine seasonal variation in BMR and its association with thyroid hormone levels and lifestyle factors among the indigenous Yakut (Sakha) of Northeastern Siberia. Recent work among the Yakut has documented evidence of the "polar T3" response pattern in both men and women (Levy et al., 2013). We therefore expect that the Yakut will also show elevated BMRs and declines in thyroid hormone levels (fT3 and fT4) during the winter, in response to extreme cold stress. In addition, we expect that variation in BMR will be modified by lifestyle factors such that individuals with greater participation in traditional subsistence activities will have further upregulated metabolic rates during winter months.

METHODS

Study population

The Sakha Republic (Yakutia), located in northeastern Siberia, is an autonomous state within the Russian Federation. The majority of the population of the Sakha Republic is ethnically Yakut (Sakha), an indigenous population of around 400,000 individuals (Sorensen, 2003). The Sakha Republic consists of boreal forest (*taiga*) and Arctic tundra, and has an extreme subarctic climate characterized by long cold winters and short, warm summers. Mean monthly temperatures in the region range from a low of −38.6°C (−37.5F) in January to a high of 19.5°C (67.1F) in July. During the summer data collection period (July/August 2009) daily high temperatures averaged 23.5°C (74.3F) and daily lows averaged 12.9°C (55.3 F). During the winter data collection period of January 2011, mean daily high and low temperatures were −34.3°C. (−29.7F) and −39.6°C (−39.2F), respectively (data from: http://weatherspark.com/history/33774/2011/Yakutsk-Sakha-Yakutiya-Russian-Federation).

Beginning in the 1930s, the Soviet government forcibly organized Yakut families into herding and farming collectives in order to end "backward" nomadism and promote "civilization" (Forsyth, 1992). Lifestyle changes during the Soviet era were particularly dramatic for women since the organization of herding collectives stripped women of their livestock and hay-cutting responsibilities and relocated women to villages in order to focus on raising children and conducting wage labor (Snodgrass, 2004). During this time, the Soviet government made promises of technological modernization, but few came to fruition. At the end of the Soviet era, less than 1% of homes in Siberia had running water or central heat (Sorensen, 2003).

At present, Yakut villagers now face a variety of challenges and opportunities related to defining new subsistence lifeways (Crate, 2006; Jordan and Jordan-Bychkov, 2001). The social, political and economic changes associated with the collapse of the Soviet Union have resulted in the emergence of heterogeneous lifestyles among indigenous Siberians, both within communities and within families (Snodgrass, 2004; Sorensen et al. 2005). Currently, the majority of Yakut who live in rural villages depend on a mixed cash economy that consists of a combination of traditional subsistence practices, such as hunting, fishing, foraging and raising cattle, and cash inputs (Crate, 2006; Jordan and Jordan-Bychkov, 2001; Sorensen, 2003; Snodgrass et al., 2005). These lifestyle changes have resulted in shifts in diet and activity patterns that have contributed to rising rates of obesity and other chronic health problems, particularly among women (Sorensen et al., 2005; Snodgrass et al., 2006, 2008, 2010).

Participants

Data were collected from participants of the rural community of Berdygestiakh (62° N; 127° W; population 4,900), in the Gorny *ulus* of the Sakha Republic (Yakutia) (Cepon et al., 2011; Snodgrass et al., 2005). The sample includes 35 men and 59 women who were measured on two occasions: July/August of 2009 (summer) and January of 2011 (winter). The subjects ranged in age from 19 to 74 years at the time of the first measurement. All data were collected at the Gorny Regional Medical Center in Berdygestiakh. Participants were recruited on a voluntary basis based on word of mouth and advertising of the study in the community. Conditions in this remote part of Siberia prevent the recruitment of a truly random sample. Therefore, the study sample may be biased toward individuals who are open to health and physiological research and have the resources and time available to visit the health clinic. All participants were healthy at the time of measurement (with no known acute or chronic conditions), and pregnant or lactating women were excluded. The study protocol was approved by the Institutional Review Board of the University of Oregon.

Anthropometry

Anthropometric dimensions were collected by one trained observer (LAT) in each field season following procedures of Lohman et al. (1988). Stature was measured to the nearest 1.0 mm using a field stadiometer (Seca Corporation, Hanover, MD). Body weight was calculated to the nearest 0.1 kg using a Tanita digital bioelectrical impedance analysis (BIA) scale (Tanita Corporation, Tokyo, Japan). Percent body fat was measured using BIA. Body mass index (BMI) was calculated by dividing an individual's mass in kilograms by height in meters squared (kg/m^2). In addition, body weight and body fat data were used to calculate fat mass (kg) and fat-free mass (FFM; kg).

Basal metabolic rate

Basal metabolic rates (kcal/d) were measured using open circuit indirect calorimetry under thermoneutral conditions (23−27°C), with participants having fasted for 12 h. MedGraphics VO2000 metabolic analyzers (St. Paul, MN) were used to assess oxygen consumption (VO_2, l/min) and CO_2 production (VCO_2, l/min). Heart rate (HR; beats/min) was simultaneously measured using a Polar S610 heart rate monitor (Woodbury, NY) in order to record participant anxiety. Participants had rested quietly in a supine position for at least 20 min prior to BMR measurement. BMR measurements were recorded for 15–20 min

TABLE 1. *Seasonal changes in mean (±SD) anthropometric dimensions, basal metabolic measurements, and thyroid hormone levels in Yakut men*[a]

Measure	19–49 years n	19–49 years Summer	19–49 years Winter	50 years and older n	50 years and older Summer	50 years and older Winter	Total sample n	Total sample Summer	Total sample Winter
Anthropometric:									
Weight (kg)	14	65.0 ± 10.6	65.1 ± 10.7	21	70.1 ± 12.2	70.2 ± 11.5	35	68.0 ± 11.7	68.1 ± 11.3
BMI (kg/m^2)	14	22.8 ± 4.4	23.0 ± 4.6	21	25.7 ± 3.4	25.8 ± 3.4	35	24.6 ± 4.0	24.7 ± 4.1
Percent Body Fat (%)[b]	14	18.5 ± 8.5	18.5 ± 8.7	21	25.2 ± 5.6	25.3 ± 5.6	35	22.5 ± 7.5	22.6 ± 7.7
Fat mass (kg)	14	12.7 ± 7.3	12.7 ± 7.5	21	18.1 ± 6.8	18.2 ± 6.5	35	15.9 ± 7.4	15.9 ± 7.4
Fat-free mass (kg)	14	52.3 ± 5.3	52.4 ± 5.5	21	52.0 ± 6.6	52.0 ± 6.4	35	52.1 ± 6.0	52.2 ± 6.0
Metabolic:									
HR (b/min)	14	65.9 ± 11.2	64.3 ± 8.2	21	64.7 ± 9.1	63.0 ± 12.3	35	65.2 ± 9.8	63.5 ± 10.7
BMR (kcal/day)	14	1565 ± 310	1656 ± 273	21	1529 ± 355	1523 ± 319	35	1543 ± 334	1576 ± 304
RQ (VCO_2/VO_2)	14	0.81 ± 0.09	0.85 ± 0.08	21	0.79 ± 0.09	0.83 ± 0.11*	35	0.80 ± 0.09	0.84 ± 0.10*
Thyroid:									
TSH (mIU/l)	13	1.1 ± 0.7	1.3 ± 0.7	19	1.2 ± 0.6	1.3 ± 0.7	32	1.2 ± 0.6	1.3 ± 0.7
Free T4 (pmol/l)	13	16.5 ± 2.9	14.1 ± 1.5*	19	16.0 ± 3.2	13.4 ± 1.9***	32	16.2 ± 3.0	13.7 ± 1.8***
Free T3 (pmol/l)	13	4.4 ± 0.5	3.5 ± 0.7**	19	4.9 ± 0.7	4.0 ± 1.1**	32	4.7 ± 0.7	3.8 ± 0.9***

[a]Seasonal differences are significant at: *$P < 0.05$ **$P < 0.01$ ***$P < 0.001$.
[b]Percent body fatness from bioelectrical impedance analysis (BIA).

while the participant was lying relaxed in a supine position. All BMR measurements were taken in the morning or early afternoon. The respiratory quotient ($RQ = VCO_2/VO_2$) was continuously recorded during the metabolic study. BMR was calculated by converting VO_2 based on RQ using the modified Weir formula (McArdle et al., 2001; Weir, 1949). The percentages of resting energy derived from carbohydrate and fat metabolism were calculated from RQs following the equations presented by Elia and Livesey (1988).

Thyroid hormones

Whole blood samples were obtained by a trained nurse using venipuncture from subjects in a fasted state in the morning because thyroid hormones increase after consuming a large meal and exhibit a circadian rhythm in which TSH and fT3 peak at night and drop in the afternoon (Danforth, 1989; Russell et al., 2008). Whole blood samples were immediately centrifuged and the plasma fraction was separated and stored at −20°C until laboratory analysis of thyroid hormones. Free T3, fT4, and TSH levels were determined using enzyme immunoassay with XEMA assay kits (Moscow, Russia). All laboratory analyses were conducted during the season in which they were collected in the Yakutsk Medical Center Department of Endocrinology (Yakutsk, Russia) under the supervision of Dr. Elizaveta Popova.

Lifestyle data

Each participant was given an extensive, standard questionnaire about socioeconomic status (SES) and lifestyle administered by a single interviewer. The survey asked about monthly income, occupation, and education level. In addition, to assess their material style of life, participants were asked about their ownership of 20 items: car, motorcycle, bicycle, television, stereo, VCR, video camera, camera, computer, telephone, washing machine, bath house, ice cellar, barn, tractor, house, cows, horses, pigs, and chickens. For each item, subjects were asked whether they owned it and, if so, how many they owned.

The questionnaire also asked about participation in various daily activities. Subjects were asked to estimate how many hours per day they spent watching television, and about their participation in various subsistence activities (i.e., tending animals, hay cutting, fishing, hunting, gathering, and farming). To assess the impact of lifestyle on diet, participants were asked to estimate the percentage of their food that came from market sources.

A style of life (SOL) scale was created based on that of Bindon et al. (1997) to consider participation in subsistence activities, diet, and ownership of common consumer goods and livestock. Low SOL scores indicate more traditional ways of life (e.g., participation in more subsistence activities, less market food consumption, less formal education, and fewer consumer goods), whereas a high SOL suggests greater integration to the market. The individual components of the SOL score are presented and discussed in more detail in Cepon et al. (2011:161).

Statistics

Statistical analyses were performed using SPSS 21.0. Paired t-tests were used to examine seasonal changes in body size and composition, metabolic parameters, and thyroid hormone levels. Pairwise correlations were used to examine the influence of thyroid hormones levels and lifestyle factors on basal metabolism.

RESULTS

Seasonal changes in body composition, basal metabolism, and thyroid function

Tables 1 and 2 present descriptive statistics of seasonal changes in anthropometric, metabolic, and thyroid hormone measures for Yakut men and women, respectively. Given the wide range of ages in the study participants, we divided the sample into younger (19–49 years) and older (50 years and older) cohorts. Both men and women show small seasonal changes in body weight and body composition. On average, both younger and older Yakut men gained only 0.1 kg between the summer and winter measurements with none of the anthropometric dimensions showing significant seasonal change. Among women, the younger cohort showed significant increases in weight (+1.5 kg; $P < 0.05$), BMI (+0.6 kg/m^2; $P < 0.05$) and FFM (+0.5 kg; $P < 0.05$) during the winter, whereas older

TABLE 2. *Seasonal changes in mean (±SD) anthropometric dimensions, basal metabolic measurements, and thyroid hormone levels in Yakut women*[a]

	19–49 years			50 years and older			Total sample		
Measure	n	Summer	Winter	n	Summer	Winter	n	Summer	Winter
Anthropometric									
Weight (kg)	29	58.7 ± 8.9	60.2 ± 9.1*	30	61.1 ± 10.0	61.3 ± 9.7	59	60.0 ± 9.5	60.8 ± 0.3*
BMI (kg/m^2)	29	24.0 ± 3.4	24.6 ± 3.7*	30	26.3 ± 3.5	26.3 ± 3.4	59	25.2 ± 3.6	25.5 ± 3.6*
Percent Body Fat (%)[b]	29	30.7 ± 6.9	31.6 ± 7.0	30	35.1 ± 5.5	35.3 ± 5.4	59	32.9 ± 6.6	33.5 ± 6.5
Fat mass (kg)	29	18.6 ± 6.6	19.6 ± 7.0	30	21.9 ± 6.9	22.1 ± 6.7	59	20.3 ± 6.9	20.9 ± 6.9
Fat-free mass (kg)	29	40.1 ± 2.8	40.6 ± 2.8*	30	39.2 ± 3.7	39.2 ± 3.3	59	39.7 ± 3.3	39.9 ± 3.2
Metabolic									
HR (b/min)	29	62.3 ± 7.0	63.8 ± 7.0	30	65.4 ± 9.3	66.9 ± 7.1	59	63.9 ± 8.3	65.4 ± 7.2
BMR (kcal/day)	29	1287 ± 202	1370 ± 214*	30	1282 ± 248	1234 ± 222	59	1284 ± 225	1301 ± 227
RQ (VCO_2/VO_2)	29	0.80 ± 0.12	0.83 ± 0.09	30	0.79 ± 0.10	0.83 ± 0.10	59	0.80 ± 0.11	0.83 ± 0.10*
Thyroid									
TSH (mIU/l)	28	1.6 ± 1.2	2.1 ± 1.8	28	1.6 ± 2.6	1.7 ± 1.9	56	1.6 ± 2.0	1.9 ± 1.8
Free T4 (pmol/l)	28	15.6 ± 3.4	13.4 ± 2.4**	28	14.9 ± 4.0	13.1 ± 2.9**	56	15.3 ± 3.7	13.2 ± 2.6***
Free T3 (pmol/l)	28	4.4 ± 0.7	3.5 ± 0.7***	28	4.8 ± 1.5	3.8 ± 2.2***	56	4.6 ± 1.2	3.6 ± 1.6***

[a]Seasonal differences are significant at: $^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$.
[b]Percent body fatness from bioelectrical impedance analysis (BIA).

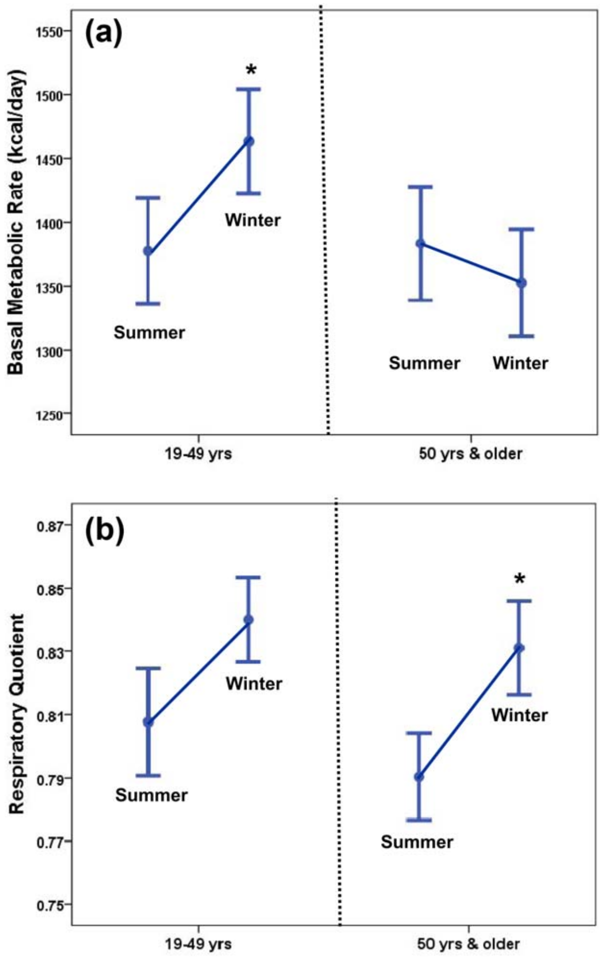

Fig. 1. Seasonal changes in mean (±SE) (a) BMR (kcal/day) and (b) respiratory quotient (RQ) in younger (19–49 years) and older (≥50 years) Yakut adults (sexes combined). The younger group shows significant increases in winter-time BMRs of 6%; ($P < 0.05$), whereas the older groups shows a modest declines of 2% (n.s.) Both groups have increased RQs during the winter ($P = 0.06$ for the younger group; $P < 0.05$ for the older group).

women showed no significant changes in any of the anthropometric parameters.

Seasonal changes in BMR varied sharply by age. Younger men and women both showed increased winter-time BMRs (+5.8% in males; $P = 0.11$; +6.5% in females; $P < 0.05$), while the older individuals showed modest declines (−0.4% in men, n.s.; −3.8% in women; n.s.). RQ values consistently increased during the winter in each of the age- and sex-specific groups, suggesting increased reliance on carbohydrates as fuel.

Figure 1 compares seasonal changes in (a) BMR and (b) RQ in younger and older Yakut adults (men and women combined). The changes in BMR have been adjusted for differences in FFM. Overall, the younger group shows a significant winter-time increase in BMR of 6% ($P < 0.05$), whereas the older cohort shows a small, nonsignificant decline (−2%). In contrast, both groups have increased RQs during the winter ($P = 0.06$ for the younger cohort; $P < 0.05$ for the older). These higher resting RQ levels suggest reduced fat oxidation and greater utilization of carbohydrates as metabolic fuel during the winter months. During the summer, fat oxidation accounted for about 66% and 71% of basal energy expenditure in the younger and older cohorts, respectively. During the winter these values declined by 12% (to 54%) in the younger group and by 14% (to 57%) in the older group.

Thyroid hormone levels showed the greatest and most consistent pattern of seasonal changes. Each of the four age- and sex-specific groups had large and significant ($P < 0.05$) declines in fT3 and fT4 levels during the winter. Conversely, TSH levels showed modest increases during the winter across all age/sex groups, but none of these changes were statistically significant.

Table 3 shows the correlations of seasonal changes in basal metabolism (ΔBMR and ΔRQ) with seasonal changes in thyroid function in each of the age- and sex-specific groups. Correlations between BMR and thyroid measures are stronger in the younger cohort for both men and women. Among younger Yakut men, changes in BMR are positively correlated with changes in fT3 levels ($r = 0.46$; $P < 0.05$). Among younger women, seasonal changes in both BMR and RQ are inversely related to changes in fT4 levels ($r = -0.27$, -0.25; $P < 0.10$). Among

TABLE 3. Correlations[a] of seasonal changes in metabolism (ΔBMR and ΔRQ) with seasonal changes in thyroid hormone levels in Yakut men and women

Measure	ΔBMR[b]	ΔRQ
Men		
19−49 years		
ΔTSH	0.11	0.36
ΔFT4	−0.08	−0.22
ΔFT3	0.46*	0.04
50 years and older		
ΔTSH	−0.03	−0.15
ΔFT4	0.02	−0.08
ΔFT3	0.17	−0.13
Women		
19–49 years		
ΔTSH	0.07	0.14
ΔFT4	−0.27†	−0.25†
ΔFT3	−0.05	−0.07
50 years and older		
ΔTSH	0.25†	−0.14
ΔFT4	0.15	0.24
ΔFT3	−0.19	0.01

[a]Significance (1-tailed): †$P < 0.10$; *$P < 0.05$.
[b]Adjusted for fat-free mass.

TABLE 4. Selected socioeconomic measures in Yakut men and women[a]

	19−49 years		50 years and older	
Measure	n	Mean ± SD	n	Mean ± SD
Men:				
Hay cutting (days/year)	13	18.1 ± 17.5*	17	12.2 ± 13.6*
Percent store food (%)	13	72.7 ± 18.1	17	75.0 ± 19.0
TV watching (hours/week)	13	20.2 ± 11.1	17	17.8 ± 9.8
SOL	13	11.6 ± 3.6**	17	10.8 ± 4.8**
Women:				
Hay cutting (days/year)	27	4.9 ± 13.0	25	5.3 ± 11.9
Percent store food (%)	27	81.2 ± 15.4	25	74.4 ± 20.1
TV watching (hours/week)	27	15.9 ± 12.5	25	15.1 ± 10.3
SOL	27	15.4 ± 2.3	25	14.3 ± 2.7

[a]Sex differences are significant at: *$P < 0.05$; **$P < 0.01$.

older Yakut women, changes in BMR are positively correlated with changes in TSH levels ($r = 0.25$; $P < 0.10$).

Socioeconomic and lifestyle influences on seasonal changes

Table 4 presents the descriptive statistics for selected socioeconomic and lifestyle factors, including: days of hay cutting per year, percent of diet from store-bought foods, hours of TV watched per week, and the material SOL scale. Within sexes, none of the lifestyle variables significantly differ between the older and younger cohorts. Within each age cohort, men spent more time in subsistence hay cutting each year than women (18.1 vs. 4.9 days [19–49 years]; 12.2 vs. 5.3 days [≥50 years]; $P < 0.05$), and had significantly lower SOL scores (11.6 vs. 15.4 [19–49 years]; 10.8 vs. 14.3 [≥50 years]; $P < 0.01$). In contrast, food use patterns and TV watching habits did not differ between the sexes.

Table 5 presents the correlations of the lifestyle variables with basal metabolic parameters—both the seasonal changes in BMR and RQ values and the mid-season averages. Among men, the lifestyle factors are stronger predictors of metabolic function in the older cohort. In this group, mean BMR is positively correlated with days of hay cutting ($r = 0.41$; $P < 0.05$) and negatively correlated with store food consumption ($r = -0.50$; $P < 0.05$), hours of TV viewing ($r = -0.36$; $P < 0.10$) and the SOL index ($r = 0.50$; $P < 0.05$). In addition, among older Yakut men, mean RQ is inversely related to days of hay cutting ($r = -0.38$; $P < 0.10$), and surprisingly, seasonal change in BMR is positively correlated with hours of TV viewing ($r = 0.40$; $P < 0.10$). Among younger men, mean RQs are negatively correlated with days of hay cutting ($r = -0.58$; $P < 0.05$), and positively correlated with hours of TV ($r = 0.60$; $P < 0.01$).

TABLE 5. Correlations[a] of metabolic parameters with lifestyle socioeconomic measures in Yakut men and women

Measure	ΔBMR[b]	BMR.mean[b]	ΔRQ	RQ.mean
Men				
19−49 years:				
Log-Hay cutting	0.25	−0.11	−0.18	−0.58*
%Store food	0.11	0.15	−0.13	0.08
TV hours	0.15	0.34	−0.28	0.70**
SOL	−0.08	0.02	0.21	0.29
50 years and older:				
Log-Hay cutting	−0.21	0.41*	−0.20	−0.38†
%Store food	0.08	−0.50*	0.02	−0.08
TV hours	0.40†	−0.36†	0.18	−0.07
SOL	0.11	−0.50*	0.01	0.16
Women				
19−49 years:				
Log-Hay cutting	−0.23	0.24	0.11	−0.14
%Store food	0.03	0.27†	0.16	0.34*
TV hours	0.03	−0.08	−0.06	−0.09
SOL	0.07	−0.18	0.04	0.03
50 years and older:				
Log-Hay cutting	0.36*	0.01	0.29†	0.11
%Store food	−0.33*	0.12	−0.11	0.22
TV hours	0.25	0.10	−0.02	0.01
SOL	−0.18	0.14	0.02	0.06

[a]Significance (1-tailed): †$P < 0.10$; *$P < 0.05$; **$P < 0.01$.
[b]Adjusted for fat-free mass.

Among women, use of market foods and days of hay cutting are the most consistent predictors of metabolic variation. Store food consumption is positively correlated with mean BMR ($r = 0.27$; $P < 0.10$) and mean RQ ($r = 0.34$; $P < 0.05$) in the younger group, and negatively correlated with seasonal change in BMR in older cohort ($r = -0.33$; $P < 0.05$). Hay cutting is positively correlated with seasonal changes in BMR ($r = 0.36$; $P < 0.05$) and RQ ($r = 0.29$; $P < 0.10$) among older women.

DISCUSSION

This study examined seasonal changes in BMR among the Yakut of Siberia, and explored the influence of thyroid hormones levels and lifestyle factors on shaping these patterns of seasonal change. We found marked age differences in seasonal changes in metabolic rates. Younger Yakut (under 50 years) showed significant increases in BMR of 6% during the winter, while older individuals showed small declines of 2%. Across the entire sample, basal RQ values significantly increased during the winter, suggesting greater reliance on carbohydrates as metabolic fuel.

The Yakut also showed remarkably little change in body weight or composition over the 17 months between the summer and winter measurements. Both younger and older men gained an average of only 0.1 kg between the summer and winter measurements. Among women, the

TABLE 6. Comparative data on seasonal changes in body weight (kg) and basal metabolic rate (kcal/day)

Location/Reference	Group	Sex	Age* (yr)	*n*	Body weight (kg)		BMR (kcal/day)	
					Summer	Winter	Summer	Winter
Antarctica (Reed et al. 2001)	US	M/F	32.0	5M/1F	83.4	77.6*	1716	1889*
Antarctica (Duncan, 1988)	British	M	27.5	6	75.7	75.5	1941	1447*
Antarctica (Junghans et al. 2012)	German	M	36.7	3	72.3	74.0	2775	2072*
Korea (Kang et al., 1963;	Ama divers	F	36.0	20	54.7	–	1341	1722*
Sung et al., 1963)	non-divers	F	31.0	20	54.0	–	1326	1326
Korea (Park et al., 1983)	Ama divers	F	41.6	16	56.0	54.8	1507	1446
	non-divers	F	38.0	16	56.4	52.5*	1409	1407
Japan, (Itoh, 1974)	Ainu	M	–	14	57.1	–	1444	1490
Japan (Osiba, 1957)	Japanese	M	30.0	9	–	–	1232	1468*
Japan (Kashiwazaki, 1990)	Japanese	M	–	75	–	–	1276	1369*
		F	–	48	–	–	1036	1130*
UK (Haggarty et al., 1994)	British	M	38.0	9	66.6	66.6	1718	1708
Netherlands (Plasqui et al., 2003)[b]	Dutch	M	26.0	10	69.2	–	1569	1668*
		F	25.0	15	64.4	–	1425	1476*
Russia/Siberia (present study)	Yakut, 19−49 y	M	38.1	14	65.0	65.1	1565	1656
		F	40.5	29	58.7	60.2*	1287	1370*
	Yakut, 50$^+$ y	M	60.3	21	70.1	70.2	1529	1523
		F	56.7	30	61.1	61.3	1282	1234

Significant seasonal changes.
[a]Mean age (years) for the sample.
[b]This study measured sleeping metabolic rate (SMR; kcal/day).

younger cohort showed larger winter-time weight gains than their older peers (1.5 vs. 0.2 kg).

The largest seasonal changes were seen in serum concentrations of fT3 and fT4. Consistent with previous research on the "polar T3 syndrome" (see Levy et al., 2013; Reed et al., 1986, 1990b), Yakut men and women showed marked winter declines in fT3 and fT4 in both the younger and older cohorts. This pattern of seasonal change suggests increased production and tissue-level uptake of thyroid hormones during the extreme winter cold. Changes in metabolic rate and RQ were more strongly correlated with changes in thyroid hormone levels in the younger group.

This study also demonstrated the important role that cultural and lifestyle factors play in mediating seasonal metabolic responses to climatic stress. . Among men, greater participation in outdoor subsistence activities (i.e., hay cutting) was associated with increased BMR and greater fat metabolism (lower RQs). Conversely, markers of a more modernized/Western lifestyle (i.e., consumption of store foods, SOL index) were associated with reduced average BMRs among older men. Among women, the associations between lifestyle and metabolic variables were generally weaker, owing partly to the lower levels of participation in some aspects of traditional subsistence practices. Dietary factors showed the strongest correlations with BMR and RQ in women. Greater consumption of store-bought food was associated with higher average BMRs and increased carbohydrate utilization (higher mean RQs) in younger women, but was associated with depressed winter-time increases in BMR among older women.

Table 6 presents comparative data on seasonal variation in BMRs of selected high latitude populations. Those studies included in Table 6 presented summer and winter-time BMRs on the same samples. In addition, all but two of the studies (Kashiwazaki, 1990; Osiba, 1957) presented data on mean body weights for at least one season. The comparative data were derived from three studies of indigenous Asian populations (the Ama and Ainu; Kang et al., 1963; Itoh, 1974; Park et al., 1983), two studies of urban European populations (Plasqui et al., 2003; Haggarty et al., 1994), two studies of urban Asian populations (Kashiwazaki, 1990; Osiba, 1957), and three studies of military and scientific personnel in Antarctic (Duncan, 1988; Junghans et al., 2012; Reed et al. 2001). These data provide a mixed picture of the extent to which BMR is influenced by seasonal fluctuations in temperature. Of the 10 other studies presented in Table 6, five show significant winter increases in BMR, two provide evidence of winter declines, and the remaining three show no significant seasonal changes in BMR.

Variation in outdoor activities and exposure to cold likely explains much of variation in responses noted in Table 6. Simpson (2010) notes that among sojourners to Antarctica, declines in BMR during the winter are often observed due to reduced outdoor activities and greater sedentary behavior. This pattern is evident in two of the three Antarctic studies in Table 6 (Duncan, 1988; Jungahns et al., 2012), with both showing sharps declines in BMR during the winter. In contrast, the subjects in the Reed et al. (2001) study were regularly engaged in outdoor activities during the polar winter, and showed significant increases in winter-time BMR of 13%, after adjusting for differences in body mass.

Among urban populations of the industrialized world, research in Europe (Plasqui et al., 2003) and in Japan (Kashiwazaki, 1990; Osiba, 1957) provides evidence for significant seasonal changes in BMR. Osiba (1957) showed large (19%) winter increases in BMR in small sample of Japanese men. A subsequent meta-analysis by Kashiwazaki (1990) of a larger sample of Japanese adults showed more modest increases of 7% in men and 9% in women. Recent work by Plasqui et al. (2003) found winter-time increases in BMR of 6% and 4% in Dutch young men and women, respectively.

Very few studies have examined seasonal variation in BMR among more traditional, indigenous circumpolar populations of America and Eurasia. Research by Itoh (1974) on a sample of 14 Ainu men from northern Hokkaido showed small, non-significant increases in winter

BMRs. The most compelling evidence for marked seasonal changes in BMR in an indigenous group comes from research conducted among the traditional female divers of South Korea, the Ama. Kang and colleagues (1963) measured seasonal changes in core temperature and BMR in a sample of 20 Ama divers and in 20 nondiving women as controls. They found that Ama women showed a dramatic 28% rise in BMR during the winter, while the nondiving women had lower average BMRs and showed no seasonal change in metabolic rate. These findings clearly demonstrated that repeated exposure to severe seasonal cold stress (i.e., diving in winter water temperatures of 10°C) elicits marked increases in BMR in humans.

Subsequent research among the Ama underscored the importance of technology in mediating metabolic adaptations to cold. In the early 1980s, Park et al. (1983) conducted a follow up study among 16 Ama women who were now wearing wet suits, rather than their traditional cotton swimsuits. These women showed no winter-time increase in BMR, and had metabolic responses that were more similar to their nondiving peers.

In reviewing these comparative data, it is clear that most of the previous research on BMR in high latitude groups has been done on samples that are similar in age to the younger Yakut men and women of this study. While these comparative data document considerable variation in human metabolic responses to seasonal changes in temperature (from 25% declines in Antarctic sojourners [Duncan, 1988: Junghans et al., 2012 to 28% increases among traditional Ama divers [Kang et al., 1963]), the majority of the research found metabolic increases of 4–10% during the winter months. In this light, the winter-time elevations in BMR observed in the younger Yakut (+6%) are similar to those reported by Plasqui et al. (2003) for young Dutch adults (+4 to +6%), and Kashiwazaki (1990) for Japanese adults (+7 to +9%).

Of the comparative studies shown in Table 6, only Osiba (1957) and Plasqui et al. (2003) reported RQ values, and both found no seasonal change. Experimental research on acute cold exposure in humans has indicated that increased thermogenesis results in disproportionate increases in fat metabolism relative to carbohydrate metabolism resulting in declines in RQ (Haman et al., 2002; Itoh, 1974; Tikuisis et al., 2000). In this context, the significant increases in winter RQs shown in this study are surprising, and suggest that lifestyle and dietary factors are playing important roles in shaping substrate use under basal conditions. Indeed, the food use patterns presented in Table 4 clearly show that the Yakut are increasingly adopting a more urbanized diet that contains more processed foods with higher levels of simple carbohydrates. Among women, greater use of store bought food was positively correlated with mean RQ values. For men, variation in subsistence activity patterns significantly shapes variation in RQ. In both the younger and older more time spent in subsistence hay cutting was associated with significantly lower mean RQ values, indicative of enhanced fat oxidation.

Another potential influence on RQ is changes in photoperiod. Recent studies have shown that nighttime eating is associated with increased RQs and reduced fat oxidation (Gluck et al., 2011; Hibi et al., 2013). Consequently, it is possible that changes in both day lengths and in food consumption patterns act jointly to promote increased RQs during the winter among the Yakut.

There is also relatively little data on seasonal changes in thyroid hormone levels in association with seasonal changes in BMR. Early research by Osiba (1957) measured protein bound iodine levels as proxy for total T4, and found significant winter-time rises in association with increases in BMR. More recently, research by Reed et al. (2001) and Plasqui et al. (2003) has examined seasonal changes in free thyroid hormone levels and found patterns similar to those presented in this study. Reed and colleagues (2001) found marked winter declines in fT4 levels (12.9 pmol/l [winter] vs. 13.6 pmol/l [summer]; $P < 0.05$) and small drops in fT3 levels (3.82 vs. 3.90 pmol/l; n.s.) among military and scientific personnel overwintering in Antarctica. Plasqui et al. (2003) documented significant reductions in fT4 levels during the winter for Dutch men (13.1 vs. 14.0 pmol/l; $P < 0.05$), and small increases in fT4 levels for Dutch women (12.6 vs. 12.1 pmol/l; n.s.); however, these changes were not significantly correlated with seasonal changes in BMR.

The absence of winter-time increases in BMR in the older Yakut men and women of this study is surprising, particularly since their seasonal changes in thyroid hormone levels were similar to those of their younger counterparts. Seasonal changes in body composition (i.e., greater body fatness or reductions in muscle mass during the winter) do not appear to play a role given the remarkable stability of body weight and composition in older Yakut men and women. It is debated whether age-related decreases in cold-induced thermogenesis exist independently of age-related decreases in fat-free mass; however, recent work suggests that the presence of adult brown adipose tissue, a highly thermogenic form of fat, decreases with age (Florez-Duquet and McDonald, 1998; Kenney and Munce, 2003; Yoneshiro et al., 2011). Some of the differences in responses between older and younger Yakut may also reflect differences in daily activity and time spent outside the home. Recent work on physical activity patterns in this population using accelerometry found significant age-related declines in moderate to vigorous physical activity among the sample of 68 Yakut adults (32 men; 36 women; Wilson et al., in press).

In addition, we have also found high levels of autoimmune thyroid disorders in this population. In a study of 281 adults (138 men; 143 women) from this community, Cepon et al. (2011) found elevated levels of anti-thyroid peroxidase antibodies (ATPOAb) in 6% of Yakut men and 22% of Yakut women. These findings suggest that the dramatic seasonal changes in thyroid function evident in the Yakut may place them at particular risk for developing thyroid disorders. Our future research will directly explore the potential impact of thyroid disorders on seasonal changes in metabolism.

There are several limitations to this study. First, the winter and summer data were not collected within the same year, but rather 1.5 years apart. The time lapse in data collection and analysis may be a source of error in the thyroid hormone measures, due to between-assay variation. Additionally, as noted above, the mean age of the sample for this study is considerably older than most previous studies of seasonality in BMR. The older age distribution of the current study partly reflects demographic variation in lifestyle and activity patterns within the community. Younger adults are more likely to spend time away from their households or the community, thus reducing their likelihood of being included in both the summer and winter waves of data collection. Finally, we did not have a direct measure of daily cold exposure for the subjects in this study; however, it does appear that the questions about subsistence practices captured some of the variation in this parameter.

In sum, this study is the first to document seasonal change in BMR and its associations with thyroid function and lifestyle factors in an indigenous circumpolar population. The Yakut showed marked age differences in seasonal changes in BMR, with younger adults displaying significant increases in winter-time BMRs, while older adults showed modest, nonsignificant declines. Across the entire sample, basal RQ values significantly increased during the winter, suggesting greater reliance on carbohydrates as metabolic fuel. The most dramatic seasonal fluctuations were observed in thyroid hormone levels, with fT3 and fT4 levels significantly declining during the winter in men and women of both age groups. This study also demonstrated the importance of lifestyle factors in mediating seasonal metabolic responses to climatic stress. Among men, greater participation in traditional subsistence activities was associated with elevated BMRs and increased levels of fat metabolism. Among women, dietary factors had the strongest influence on metabolic variation.

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