Total energy expenditure in the Yakut (Sakha) of Siberia as measured by the doubly labeled water method[1–3]

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ABSTRACT

Background: Populations in transition to a Western lifestyle display increased incidences of obesity, type 2 diabetes, and other chronic diseases; the mechanisms responsible for these changes, however, remain incompletely understood. Although reduced physical activity has been implicated, few studies have accurately quantified energy expenditure in subsistence populations.

Objective: The aim of the study was to examine the relation of total energy expenditure (TEE) and activity [physical activity level (PAL), activity energy expenditure (AEE), and weight-adjusted AEE (AEE/kg)] with body composition and lifestyle in the Yakut (Sakha), an indigenous high-latitude Siberian group.

Design: We measured TEE using doubly labeled water and resting metabolic rate using indirect calorimetry in 28 young adults (14 women and 14 men) from Berdygestiakh, Russia.

Results: The men had higher TEE (12 983 compared with 9620 kJ/d; $P < 0.01$), AEE (5248 compared with 3203 kJ/d; $P < 0.05$), AEE/kg (72.7 compared with 48.8 $kJ \cdot kg^{-1} \cdot d^{-1}$; $P < 0.05$), and PAL (1.7 compared with 1.5; $P = 0.09$) than did the women, although this may reflect, in part, body size and composition differences. Overweight men and women had modestly higher TEEs than did lean participants; when adjusted for body size, activity levels were not significantly different between the groups. Persons with more traditional lifestyles had higher TEEs and PALs than did persons with more modernized lifestyles; this difference correlated with differences in participation in subsistence activities.

Conclusions: Activity levels in the Yakut were lower than those in other subsistence groups, especially the women, and were not significantly different from those in persons in industrialized nations. Persons who participated in more subsistence activities and consumed fewer market foods had significantly higher activity levels. *Am J Clin Nutr* 2006;84:798–806.

KEY WORDS Energetics, total energy expenditure, doubly labeled water, resting metabolic rate, obesity, physical activity, diet, economic development, Yakut

INTRODUCTION

Economic development has been linked to a variety of negative health outcomes, including an increased prevalence of obesity, type 2 diabetes, and hypertension and an elevated risk of cardiovascular disease (1–8). Indigenous high-latitude groups have experienced some of the most dramatic declines in health over the past few decades, including sharp increases in the prevalence of obesity, as a result of lifestyle changes associated with the transition away from traditional economies (6, 9, 10).

The rapid pace of worldwide economic development has recently altered the global burden of disease (11). Chronic diseases, such as cardiovascular disease, type 2 diabetes, and cancer, are presently the leading global cause of death (8, 12). Along with increased tobacco and alcohol consumption, reduced physical activity levels (PALs) and a dietary shift to market foods (MFs) high in saturated fats and refined sugars have been implicated in this health transition (6, 8, 12–14); the mechanisms responsible for this change, however, remain incompletely understood. Although macro-level socioeconomic indicators associated with health transition have been identified, it has been difficult to link specific behaviors and individual lifestyle factors to health change (15–17).

Decreased energy expenditure has been implicated in the health transition associated with economic development, with traditional economies characterized by intensive reliance on human physical labor and relatively simple technology, whereas modernized economies are industrialized, mechanized, and less reliant on human physical labor. Few studies, however, have accurately quantified and compared energy costs of activity between populations at different levels of economic development. In large measure, the major impediment to progress on this issue has been the methodologic challenge of accurately quantifying energy expenditure in free-living human populations; however, this barrier has recently begun to erode with the application of techniques such as the use of the doubly labeled water (DLW) technique. The DLW technique is generally accepted as the most accurate technique for measuring free-living energy costs in humans (18–20). However, although the DLW technique has been extensively used in clinical and nutritional studies in industrialized nations (21, 22), its high cost has limited its use in developing world populations. All published studies to date rely on

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relatively small samples, especially those studies conducted in the developing world (19, 23).

In the present study, we used the DLW technique to measure energy expenditure in the Yakut, an indigenous high-latitude pastoral population from the Sakha Republic of Russia. The purpose of the present study is threefold. First, potential sex differences were investigated by comparing energy expenditure variables between men and women. Second, total energy expenditure (TEE) and patterns of physical activity were compared between normal and overweight persons to examine differences in energy expenditure related to body composition. Finally, the influence of lifestyle on energy expenditure was assessed with the use of extensive information on socioeconomic variables, diet, participation in subsistence activities, and material style of life.

SUBJECTS AND METHODS

Study population

The Yakut (Sakha) are a relatively large indigenous group (≈380,000 persons) that comprises ≈40% of the population of the Sakha Republic of the Russian Federation (24, 25). Genetic studies indicate that the Yakut have close links with other indigenous Siberian groups, including the Evenki, Tuvan, Yukagir, and Buryat, whereas they have a greater separation from Turkish populations (26, 27). The Yakut traditionally practiced a complex and regionally variable subsistence strategy that was primarily structured by local ecological conditions (28). In the Lena River Valley, the primary subsistence activity was transhumant pastoralism (horse and cattle), whereas in remote parts of the boreal forest (taiga), the Yakut subsisted largely by fishing and hunting (28).

After the collapse of the Soviet Union in 1991, economic and political transformations unleashed catastrophic changes on indigenous Siberians who depended on the government for wages and deliveries of food and essential goods (29, 30). Many rural Yakut, like other indigenous Siberians, returned to traditional subsistence practices to meet needs no longer met by the government (31–33). Today, most rural Yakut rely on a mixture of subsistence activities (ie, herding, fishing, hunting, gathering, and horticulture), government wages and pensions, private-sector salaries, and "cottage" industries. Ethnographic studies of the Yakut suggest important differences in subsistence participation between men and women, which are primarily the result of economic changes implemented during the Soviet period.

Subjects

Participants included 28 Yakut adult volunteers (14 women and 14 men aged 19–47 y) who were recruited from the rural Siberian village of Berdygestiakh, located at 62°N latitude and 127°E longitude (total population: 4900). Berdygestiakh is located in the subarctic climatic zone, with a mean annual temperature of −11.0 °C (12.2 °F). All data collection was performed during the late summer (August) of 2003; the mean August temperature in Berdygestiakh is 12.6 °C. All measurements were collected at the Gorny Regional Medical Center in Berdygestiakh. All participants were ethnically Yakut, which was based on self-definition, and reported to be healthy at the time of measurement with no history of metabolic disorders. All women included in the present study were not pregnant and not lactating. To compare lean and overweight persons, the participants were selected according to standard body mass index (BMI) categories (7). The study protocol was approved by the Institutional Review Boards of Northwestern University and the University of Wisconsin, Madison. Verbal, informed consent (in Yakut or Russian, as preferred) was obtained from all participants.

Energy expenditure measurements

Total energy expenditure

TEE was measured by using the DLW technique. This technique has been described in detail elsewhere (19, 20, 34, 35). Immediately after providing a predosing urine sample, body mass was measured and the participants were given a preweighed mixed oral bolus of $^2H_2{}^{18}O$ containing ^2H_2O (99.9 APE; Cambridge Isotopes, Cambridge, MA) and $H_2{}^{18}O$ (10 APE normalized; CortecNet, Paris, France) based on body mass. The approximate doses were 1.8 g $H_2{}^{18}O$ and 0.12 g ^2H_2O/kg total body water. At the time of administration of the DLW dose, all participants were in a postabsorptive state (ie, after a 12-h fast). The first postdose urine sample was collected at ≈24 h after administration of the oral bolus. Urine samples (50–100 mL) were collected in 120-mL containers with airtight screw tops (Sentinel Scientific, Graham, NC) at approximately the same time each day on days 2, 5, 7, and 10 (after participants had voided overnight urine); however, some participants deviated slightly from the collection schedule. TEE measurements are presented as 24-h averages; therefore, the schedule deviations are unlikely to substantially change the results of the present study. Urine (3.5 mL) was transferred immediately (within 15 min) into 4.0-mL cryogenic vials sealed with silicone washers (Corning International, Corning, NY); these vials were stored at −20 °C in a hospital freezer at the Gorny Regional Medical Center. Urine samples remained frozen during transport and were transferred into a −20 °C laboratory freezer until analysis at the University of Wisconsin.

All DLW urine samples were analyzed at the Department of Nutritional Sciences, University of Wisconsin (Madison, WI). The DLW technique was used to estimate TEE (in kJ/d) over a 10-d period with the use of the multisample technique (36). Food quotient was assumed to be 0.86 for calculation of TEE.

Resting metabolic rate

Resting metabolic rate (RMR) was measured via indirect calorimetry by using a MedGraphics VO2000 open-circuit metabolic analyzer (MedGraphics, St Paul, MN), which measures oxygen consumption ($\dot{V}O_2$, in L/min) and carbon dioxide production ($\dot{V}CO_2$, in L/min). Measurements were collected with the use of MedGraphics Breeze Lite software. The AutoCal system (MedGraphics) was recalibrated for gas volume and composition between every participant. Heart rate was simultaneously measured with the use of a Polar S610 heart rate monitor (Polar, Woodbury, NY) to track the participant's anxiety level. Barometric pressure was recorded at the time of each measurement with the use of a Geneq AP8110 barometer (Geneq Inc, Montreal, Canada).

The participants were familiarized with the protocol and equipment before measurements were performed to minimize their anxiety. RMR (in kJ/d) was measured in a thermoneutral laboratory (23–27 °C) with the participants in a postabsorptive condition (after a 12-h fast). The participants rested quietly in a supine position for a minimum of 20 min before measurement. RMR measurements were recorded for a period of 15–20 min while the participant lay relaxed. All RMR measurements were recorded in the morning or early afternoon. Once breathing and heart rate stabilized, $\dot{V}O_2$ and $\dot{V}CO_2$ were recorded every minute for 10 min; the average of each of these measurements was taken. The respiratory quotient was continuously monitored, and an average was calculated for each participant. RMR was calculated by converting $\dot{V}O_2$ to kJ/d based on the respiratory quotient by using the modified Weir formula (37, 38). Additional details on the RMR protocol are described elsewhere (39). No repeat assessments of RMR were included in the present study. However, previous studies have indicated that within-person variation in RMR is typically <8% (40).

Physical activity level

PAL was calculated by dividing TEE by RMR.

Activity energy expenditure

Activity energy expenditure (AEE; in kJ/d) was calculated as TEE − RMR. No adjustment was made to AEE to account for the thermic effect of food because this cost is relatively minor (≈6−10% of TEE), was not measured in the present study, and is fairly constant within a population (19). Because AEE is influenced by body mass, the weight-adjusted AEE (AEE/kg; in $kJ \cdot kg^{-1} \cdot d^{-1}$) was calculated to facilitate comparisons between persons.

Anthropometric measurements and body composition

Anthropometric dimensions were recorded for all participants according to standard procedures. Height was recorded to the nearest 1.0 mm by using a field stadiometer (Seca Corporation, Hanover, MD). Body mass was measured to the nearest 0.1 kg with the use of a Tanita BF-558 electronic scale (Tanita Corporation, Tokyo, Japan). The participants were weighed while wearing light clothing, and a correction of 0.5 kg was made to account for clothing weight. The sum of skinfolds was based on the sum of 4 skinfolds (triceps, biceps, subscapular, and suprailiac), which were measured to the nearest 0.5 mm with Lange skinfold calipers (Beta Technology, Santa Cruz, CA); skinfold-thickness measurements were taken without clothing. All skinfold-thickness measurements were repeated 3 times; the average of the measurements was used. Body composition was assessed by using 2 derived measures: BMI and percentage body fat (BF). BMI was calculated by dividing body mass (in kg) by height^2 (in m). BF was calculated by using isotope dilution, which was measured simultaneously with DLW administration; isotope dilution has been described in detail elsewhere (41, 42). Total body water was calculated from ^{2}H dilution spaces divided by 1.042, which allowed estimation of fat-free mass (FFM) based on a hydration constant (0.73). Fat mass was then calculated as the difference between body mass and FFM; this allowed calculation of BF.

Lifestyle measures

Each participant was administered an extensive questionnaire on socioeconomic status and lifestyle. The participants answered questions about monthly income, occupation, and education level. Lifestyle questions were focused on the extent of participation (in number of days per year) in subsistence activities (ie, tending domesticated animals, haycutting, fishing, hunting, gathering, and horticulture) and ownership of various consumer goods and livestock. The participants were asked about ownership of 20 items (eg, car, television, camera, etc) to assess their material quality of life; additional details are described elsewhere (38). The participants were additionally asked to estimate the number of hours per week that they spent viewing television. Additionally, the participants provided an estimate of their consumption (as a percentage of total consumption) of MF.

A style of life (SOL) scale was created based on a larger sample of persons ($n = 115$) from this population (39) that considered participation in subsistence activities, diet, and ownership of convenience and luxury goods and livestock. Item scores were summed, and a total SOL score was calculated. Items not strongly correlated (ie, <0.15) with the total summed SOL value were not included in the final SOL scale. The final SOL scale, which included 16 items, is presented in **Table 1**.

A subsistence scale was created based on the number of days per year spent in various subsistence activities (ie, hay cutting, fishing, hunting, and gathering) and whether participants were involved in other subsistence activities (ie, horticulture and tending domesticated animals). This 11-point scale ranged from 0 (participating in all of these subsistence activities) to 10 (participating in no subsistence activities).

Statistical methods

Student's *t* tests (two-tailed) were used to assess differences in energy expenditure and anthropometric variables between the men and women. To minimize the effects of sex differences in body size and composition, we examined PAL and AEE/kg in the men and women. However, no consensus exists on the best method for adjusting for the effects of body size and composition in energetics studies. We made additional comparisons of energy variables between the men and women using analysis of covariance (ANCOVA), with measures of body size and composition (ie, body mass, FFM, and fat mass) entered in different models as covariates. Pearson's correlations were used to assess the relation between energy expenditure variables and lifestyle and socioeconomic data. Partial correlation was used to examine the relation of SOL and subsistence, as well as specific lifestyle measures, with energy parameters. Comparisons were considered statistically significant at $P < 0.05$. All statistical analyses were performed using SPSS version 10.0 (SPSS Inc, Chicago, IL).

RESULTS

Individual data for TEE, RMR, activity measures, and body composition are presented for the men and women in **Table 2** and **Table 3**, respectively. Descriptive statistics for age, anthropometric, lifestyle, and energetics data are presented in **Table 4**. No significant differences in age, BMI, or WC were observed between the men and women. The sum of skinfolds and BF were significantly higher in the women than the men. The men had significantly higher mean (±SEM) TEEs than did the women (12983 ± 812 compared with 9620 ± 522 kJ/d; $P < 0.01$). The men had significantly higher mean (±SEM) RMRs than did the women (7735 ± 289 compared with 6418 ± 272 kJ/d; $P < 0.01$). The men had significantly higher mean (±SEM) AEEs than did the women (5248 ± 706 compared with 3203 ± 355 kJ/d; $P < 0.05$). The men had slightly higher mean (±SD) PALs than did the women, but this difference was not statistically significant

TABLE 1
Style of life scale for study participants[1]

Item	Score	Value label	Proportion	Correlation[2]
			%	
Bicycle ownership	0	No	58.1	0.331
	1	Yes	41.9	
Stereo ownership	0	No	10.5	0.269
	1	Yes	89.5	
VCR ownership	0	No	21.0	0.152
	1	Yes	79.0	
Video camera ownership	0	No	80.6	0.252
	1	Yes	19.4	
Computer ownership	0	No	75.0	0.278
	1	Yes	25.0	
Ice cellar ownership	0	Yes	28.2	0.232
	1	No	71.8	
Barn ownership	0	Yes	75.8	0.267
	1	No	24.2	
Tractor ownership	0	Yes	10.5	0.320
	1	No	89.5	
Domesticated animal ownership	0	Yes	48.4	0.274
	1	No	51.6	
Domestic animal tending	0	Yes	36.0	0.413
	1	No	64.0	
Subsistence foraging	0	Yes (> 16 d/y)	43.2	0.244
	1	Yes (1–16 d/y)	48.8	
	2	No	8.0	
Subsistence hunting	0	Yes (> 7 d/y)	28.0	0.552
	1	Yes (1–7 d/y)	7.2	
	2	No	64.8	
Subsistence fishing	0	Yes (> 5 d/y)	28.2	0.491
	1	Yes (1–5 d/y)	17.7	
	2	No	54.0	
Subsistence hay cutting	0	Yes (> 10 d/y)	28.0	0.671
	1	Yes (1–10 d/y)	19.2	
	2	No	52.8	
Market food consumption	0	<51[3]	12.8	0.436
	1	51–75[3]	27.2	
	2	>75[3]	60.0	
Education level	0	Elementary or High School	31.0	0.242
	1	College or University	69.0	

[1] n = 115. Items included in this scale are only those that were strongly correlated with the summed style of life value (39). VCR, video cassette recorder.
[2] Correlation between item and total score.
[3] %.

(1.68 ± 0.33 compared with 1.50 ± 0.20; $P = 0.09$). Finally, the men had a significantly higher mean (±SD) AEE/kg than did the women (72.7 ± 33.2 compared with 48.8 ± 15.5 $kJ \cdot kg^{-1} \cdot d^{-1}$; $P < 0.05$).

In an ANCOVA model with FFM and fat mass as covariates, RMR was not significantly different in the males and females ($P = 0.675$, $r^2 = 0.706$). Similarly, no significant sex differences in TEE were observed when FFM and fat mass were entered as covariates ($P = 0.925$, $r^2 = 0.692$). No significant sex differences in AEE were found when FFM and fat mass were entered as covariates ($P = 0.802$; $r^2 = 0.427$). No significant sex differences in PAL were documented with FFM and fat mass as covariates ($P = 0.903$, $r^2 = 0.197$). However, in an ANCOVA model with body mass as a covariate, RMR differed significantly by sex ($P < 0.01$; $r^2 = 0.695$). Similarly, significant sex differences in TEE were observed with body mass entered as a covariate ($P < 0.01$, $r^2 = 0.660$). Significant sex differences in AEE were documented when body mass was entered as a covariate ($P < 0.05$; $r^2 = 0.394$). However, no significant sex differences in PAL were documented with body mass as a covariate ($P = 0.152$, $r^2 = 0.180$).

Obese and overweight persons (BMI ≥ 25.0; hereafter "overweight") were compared with lean persons (BMI < 25.0) based on standard World Health Organization categories (7). Sample sizes were the following: n = 10 for lean men, 4 for overweight men, 7 for lean women, and 7 for overweight women. The mean (±SD) BMI was 22.6 ± 2.3 in the lean men and 31.4 ± 4.2 in the overweight men. The mean BMI was 21.5 ± 3.5 in the lean women and 32.3 ± 5.5 in the overweight women.

The overweight men had higher mean (±SEM) TEEs than did the lean men, although these differences were not statistically significant (14739 ± 2144 compared with 12281 ± 727 kJ/d; NS). The overweight men had modestly higher mean (±SEM) RMRs than did the lean men, but these differences were not

TABLE 2
Individual data on energy expenditure and anthropometric measurements for the Yakut men[1]

ID	Age	Height	Weight	BMI	SOS	BF	RMR	TEE	PAL[2]	AEE	AEE/kg
	y	*cm*	*kg*	*kg/m²*	*mm*	*%*	*kJ/d*	*kJ/d*		*kJ/d*	$kJ \cdot kg^{-1} \cdot d^{-1}$
1	44	166.9	102.4	36.8	124.3	35.0	9569	19 528	2.04	9959	97.3
7	46	174.9	85.9	28.1	77.5	27.6	7816	15 354	1.96	7538	87.8
14	47	166.6	78.1	28.1	88.5	31.9	7153	9100	1.27	1947	24.9
20	27	171.1	73.1	25.0	75.0	32.7	7316	12 654	1.73	5338	73.0
29	43	164.7	54.7	20.2	25.3	18.2	6231	11 507	1.85	5276	96.5
30	40	166.9	65.8	23.6	49.0	20.4	7898	12 257	1.55	4359	66.2
33	21	176.8	65.4	20.9	31.2	23.8	8213	9013	1.10	799	12.2
41	26	178.9	67.6	21.1	31.7	15.6	7461	12 721	1.71	5260	77.8
43	27	170.3	69.4	23.9	55.8	23.4	7501	16 853	2.25	9352	134.8
45	39	158.2	61.0	24.4	45.0	23.2	6388	10 942	1.71	4554	74.7
60	31	166.4	66.0	23.8	41.2	22.1	7325	14 789	2.02	7464	113.1
61	19	179.2	80.1	24.9	90.5	27.5	9270	12 424	1.34	3154	39.4
62	34	168.2	92.1	32.6	92.3	32.0	9505	14 973	1.58	5468	59.4
76	22	163.6	49.0	18.3	27.7	19.8	6642	9649	1.45	3007	61.4

[1] $n = 14$. SOS, sum of skinfold thicknesses; BF, body fat; RMR, resting metabolic rate; TEE, total energy expenditure; PAL, physical activity level; AEE, activity energy expenditure; AEE/kg, weight-adjusted AEE.
[2] Measured as TEE/RMR.

statistically significant (8511 ± 608 compared with 7425 ± 287 kJ/d; NS). Mean (±SEM) AEEs were not significantly higher in the overweight men than in the lean men (6228 ± 1696 compared with 4856 ± 751 kJ/d; NS). PALs were not significantly different between the overweight and lean men (1.71 ± 0.36 in lean men compared with 1.67 ± 0.33 in overweight men; NS). AEE/kg was modestly higher in the lean men than in the overweight men, although this difference was not significantly different (74.9 ± 34.9 compared with 67.3 ± 32.5 $kJ \cdot kg^{-1} \cdot d^{-1}$; NS). Components of TEE are compared between the overweight and lean men in **Figure 1**.

The overweight women had significantly higher mean (±SEM) TEEs than did the lean women (10994 ± 535 compared with 8246 ± 514 kJ/d; $P < 0.01$). The overweight women had significantly higher mean (±SEM) RMRs than did the lean women (7089 ± 331 compared with 5746 ± 244 kJ/d; $P < 0.01$). Mean (±SEM) AEEs were significantly greater in the overweight than in the lean women (3905 ± 432 compared with 2501 ± 440 kJ/d; $P < 0.05$). PALs were not significantly different between the overweight and lean women (1.56 ± 0.19 in the overweight women compared with 1.43 ± 0.21 in the lean women; NS). Likewise, AEE/kg was not significantly different between the overweight and lean women (48.5 ± 19.8 compared with 49.2 ± 11.4 $kJ \cdot kg^{-1} \cdot d^{-1}$; NS). Components of TEE are compared between the overweight and lean women in Figure 1.

The SOL scale and subsistence scale were used independently to assess the role of lifestyle on energetic parameters (**Table 5**). Analyses were performed with sexes combined. TEE was negatively correlated with SOL score ($P < 0.05$), such that more traditionally living persons had higher TEEs than did persons with a more modern lifestyle. Subsistence score was also negatively correlated with TEE ($P = 0.001$); persons who participated

TABLE 3
Individual data on energy expenditure and anthropometric measurements for the Yakut women[1]

ID	Age	Height	Weight	BMI	SOS	BF	RMR	TEE	PAL[2]	AEE	AEE/kg
	y	*cm*	*kg*	*kg/m²*	*mm*	*%*	*kJ/d*	*kJ/d*		*kJ/d*	$kJ \cdot kg^{-1} \cdot d^{-1}$
2	46	159.8	70.7	27.7	141.3	46.6	7472	9661	1.29	2189	31.0
3	41	153.2	56.7	24.2	90.8	41.2	5961	10 055	1.69	4094	72.2
4	46	159.3	86.4	34.1	133.8	50.2	6007	11 474	1.91	5467	63.3
5	29	153.5	56.1	23.8	99.0	45.9	5422	7422	1.37	2000	35.6
13	34	151.0	55.7	24.4	91.5	41.9	6764	8807	1.30	2043	36.7
15	24	153.6	51.5	21.8	80.3	36.5	5206	9343	1.79	4137	80.3
19	24	165.5	43.9	16.0	29.8	24.3	5261	6522	1.24	1261	28.7
23	42	149.0	71.8	32.3	126.2	47.6	7524	11 516	1.53	3992	55.6
24	19	151.6	52.6	22.9	87.7	37.6	6430	8849	1.38	2420	46.0
25	20	163.0	115.5	43.5	198.0	54.2	8096	13 165	1.63	5069	43.9
35	32	153.1	74.7	31.9	138.5	46.1	6735	9678	1.44	2944	39.4
64	35	155.2	66.0	27.4	84.0	35.8	5924	9473	1.60	3549	53.8
69	19	150.7	39.0	17.2	55.0	27.8	5176	6727	1.30	1551	39.8
81	29	156.2	72.1	29.6	134.2	44.1	7868	11 993	1.52	4125	57.2

[1] $n = 14$. SOS, sum of skinfold thicknesses; BF, body fat; RMR, resting metabolic rate; TEE, total energy expenditure; PAL, physical activity level; AEE, activity energy expenditure; AEE/kg, weight-adjusted AEE.
[2] Measured as TEE/RMR.

TABLE 4
Age, anthropometric, and lifestyle data for the Yakut men and women[1]

Measure	Women (n = 14)	Men (n = 14)
Age (y)[2]	31.4 ± 9.6	33.3 ± 9.8
Height (cm)[2]	155.3 ± 4.9[3]	169.5 ± 6.1
Weight (kg)[2]	65.2 ± 19.5	72.2 ± 14.5
BMI (kg/m^2)[2]	26.9 ± 7.2	25.1 ± 5.0
Waist circumference (cm)[2]	83.0 ± 15.3	87.4 ± 11.9
Sum of skinfold thicknesses (mm)[2]	106.4 ± 42.2[4]	61.1 ± 30.4
Body fat (%)[2]	41.4 ± 8.3[3]	25.2 ± 6.0
TEE (kJ/d)[5]	9620 ± 522[4]	12 983 ± 812
RMR (kJ/d)[5]	6418 ± 272[4]	7735 ± 289
AEE (kJ/d)[5]	3203 ± 355[6]	5248 ± 706
PAL[2,7]	1.50 ± 0.20	1.68 ± 0.33
AEE/kg (kJ · kg^{-1} · d^{-1})[2]	48.8 ± 15.5[6]	72.7 ± 33.2
Style of life score[2]	15.5 ± 2.0[3]	9.7 ± 3.1
Subsistence score[2]	6.4 ± 2.1[3]	2.2 ± 1.3
Market food consumption (%)[2]	81.0 ± 13.2	70.4 ± 20.0

[1] TEE, total energy expenditure; RMR, resting metabolic rate; AEE, activity energy expenditure; PAL, physical activity level; AEE/kg, weight-adjusted AEE.
[2] $\bar{x}$ ± SD.
[3,4,6] Significantly different from the men (Student's t test): [3]$P < 0.001$, [4]$P < 0.01$, [6]$P < 0.05$.
[5] $\bar{x}$ ± SEM.
[7] Measured as TEE/RMR.

in more subsistence activities had higher energy expenditure than did persons who participated in fewer subsistence activities. TEE remained negatively correlated with SOL score ($P < 0.01$) even when partial correlation was used to control for the effects of body mass. TEE was negatively associated with subsistence score ($P < 0.01$) when partial correlation was used to control for the effects of body mass. AEE was also negatively correlated with both SOL score ($P < 0.05$) and subsistence score ($P = 0.01$). Separately, AEE was negatively correlated with SOL score ($P < 0.05$) and subsistence score ($P < 0.05$) when partial correlation was used to control for the effects of body mass. PAL was associated with SOL score ($P = 0.09$) and subsistence score ($P = 0.08$), but in both cases the correlations were not statistically significant. AEE/kg was negatively associated with SOL score ($P < 0.05$) and subsistence score ($P < 0.05$); persons with a more traditional lifestyle had a higher AEE/kg than did persons with a modern lifestyle.

With sexes combined, TEE was negatively correlated with the percentage food purchased at a store (ie, MF; $P < 0.05$; Table 5). TEE was correlated with MF ($P < 0.05$) when partial correlation was used to control for the effects of body mass. AEE was negatively correlated with MF ($P < 0.05$). AEE was also negatively related to MF when partial correlation was used to control for the effects of body mass, but this relation did not reach statistical significance ($P = 0.07$). PAL was negatively correlated with MF ($P < 0.05$). Likewise, AEE/kg was negatively correlated with MF ($P < 0.05$). None of the energy expenditure variables were significantly correlated with the average number of hours spent viewing television per week.

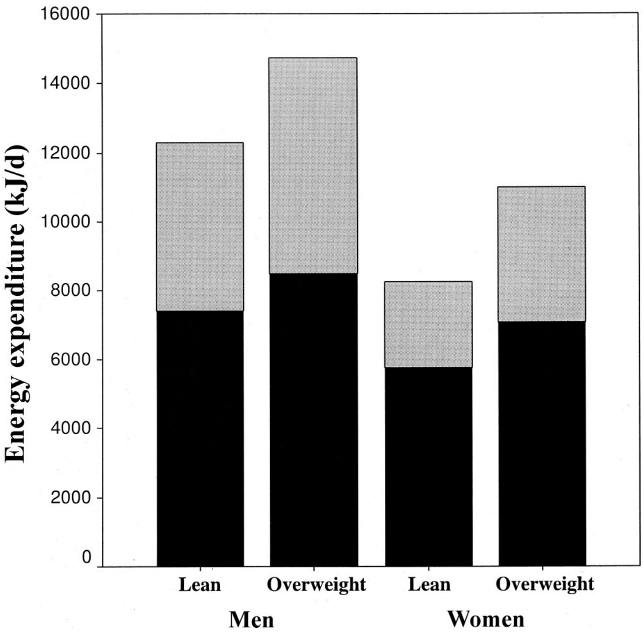

FIGURE 1. Resting metabolic rate (RMR;■) and activity energy expenditure (AEE;▨) in the lean [BMI (in kg/m^2) < 25.0; n = 10] and overweight (BMI ≥ 25.0; n = 4) men and in the lean (n = 7) and overweight (n = 7) women.

DISCUSSION

Sex differences in energy variables

The present study investigated potential sex differences in energy expenditure in the Yakut. The men had significantly higher TEEs and AEEs than did the women, although this in part may reflect sex differences in body size and composition. When body size was adjusted by using PAL or AEE/kg, the men had greater activity levels than did the women. Although imperfect, PAL provides a useful way to adjust for the effects of body size and composition and minimizes the effects of age and sex (21). The sex differences documented in the present study are consistent with predictions, given studies of other indigenous Siberians and ethnographic studies of the Yakut, that men would have higher energy expenditures than would women.

Sex differences in energy expenditure, with higher TEEs and PALs observed in men than in women, were documented with the use of heart rate monitoring in the Evenki reindeer herders of Siberia (9). This primarily reflected differential participation in reindeer herding activities. Sex differences in obesity prevalence are evident in the Nganasan of Siberia; women are significantly fatter than men (43). Furthermore, ethnographic studies conducted on the Yakut suggest sex differences in energy expenditure. Beginning with Soviet collectivization, the men became primarily responsible for herding and hay cutting activities (28, 32, 44). The women became more focused on domestic activities and rarely participated in subsistence activities away from the home. Collectivization also led to travel differences: the women generally remained in villages, while the men traveled seasonally to distant meadows and forests. The Yakut largely continue to adhere to Soviet-era restructuring in the post-Soviet period. Research shows that the men are almost exclusively responsible for hay cutting and other subsistence tasks away from the home (45).

Body composition and energy costs

Energy expenditure studies performed with the DLW technique have generally shown that in the developed world TEE is

TABLE 5
Correlation matrix for energy expenditure and lifestyle variables[1]

	TEE	AEE	AEE/kg	PAL	SOL score	Subsistence score	MF consumption
TEE	1	0.931[2]	0.720[2]	0.767[2]	−0.430[3]	−0.589[2]	−0.399[3]
AEE		1	0.889[2]	0.941[2]	−0.392[3]	−0.476[3]	−0.385[3]
AEE/kg			1	0.945[2]	−0.418[3]	−0.403[3]	−0.425[3]
PAL				1	−0.329	−0.341	−0.385[3]
SOL score					1	0.779[2]	0.496[2]
Subsistence score						1	0.402[3]
MF consumption							1

[1] $n = 28$. Pearson's correlations were used to assess the relation between energy expenditure variables and lifestyle and socioeconomic data. TEE, total energy expenditure; AEE, activity energy expenditure; AEE/kg, weight-adjusted AEE; PAL, physical activity level; SOL, style of life; MF, market food.
[2] $P < 0.01$.
[3] $P < 0.05$.

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substantially higher in obese adults than in lean persons (46–48). This finding contradicts many earlier studies that were based on self-reported energy intake and expenditure data, both of which are problematic (49). TEE in obese persons is elevated for at least 2 reasons. First, RMR increases, in absolute terms, because metabolically active tissue (eg, skeletal muscle) is deposited with the addition of adipose tissue (48). Second, AEE increases as energy costs associated with weight-bearing activities increase. When the effects of body size are adjusted by using PAL, activity patterns are similar in overweight and lean persons (48). In the women, there are no significant differences in PAL between those who are lean and overweight. Activity levels are also similar in the men, except in the morbidly obese men. All previous energetic comparisons of overweight and lean persons were conducted on Western populations; no previous studies have examined this issue in subsistence groups.

The present study compared TEE and physical activity in overweight and lean persons. The overweight men had modestly, but not significantly, higher TEEs and AEEs than did the lean men. When PAL was used to control for the effects of body size and composition, physical activity was nearly identical between the overweight and lean men. However, when AEE/kg was used, the lean persons had modestly, but not significantly, higher activity levels than did the overweight persons. The overweight women had significantly higher TEEs and AEEs than did the lean women; this likely reflects an elevated absolute RMR and greater weight-bearing activity costs. When PAL or AEE/kg were used to control for the effects of body size and composition, physical activity was similar in the overweight and lean persons. These results provide support for previous findings in sedentary groups that document comparable activity levels.

Surprisingly, the present study documented modest activity levels in Yakut men and women, which were broadly similar to those documented in industrialized nations and lower than those of subsistence groups. Because the height of subsistence participation in this group is observed in the summer, PALs are unlikely to be higher during other seasons. The Yakut men had PALs that averaged 1.7, which was similar to average values (1.6–1.8) documented in populations of industrialized nations (21, 22, 50). The Yakut men had PALs well below those documented in Gambian agriculturalists (2.4; measured during harvesting season) (51) and Bolivian Aymara men (2.0; measured during preharvest season) (52). However, the Yakut men had higher TEEs than did the Aymara, which reflects a larger body size and relatively higher RMRs in the Yakut. The Yakut, like other northern populations, show modestly elevated RMR (by 7–21%, depending on reference norms), which is likely a result of cold stress (39, 53–55). Metabolic elevation in high-latitude groups may have the effect of altering PAL values slightly. At present, however, no convention exists for adjusting PAL to reflect atypical RMR. The Yakut men had similar PALs to Nigerian men (1.7; urban workers and rural farmers) (56) and urban Chinese men (1.8) (57). Finally, the Yakut men had modestly higher PALs than did Pima Indian men from the United States (1.6); the latter group, incidentally, has one of the highest prevalence rates of obesity in the world (58, 59).

The Yakut women displayed low PALs (1.5) compared with other groups measured with the use of DLW, even compared with persons in industrialized nations (1.6–1.8) (21, 22, 50). The highest PALs in women documented with the use of DLW were found in the Bolivian Aymara, whose PALs of 2.0 (measured in the preharvest season) (52) reflect their role in subsistence agropastoralism. Gambian agriculturalists had relatively high PALs (1.9) (60, 61). Urban Chinese women had modestly higher PALs (1.7) (57) than did the Yakut women, as did Nigerian women (1.8) (56) and urban Polynesian women living in New Zealand (1.8) (62). Additionally, both Guatemalan (63) and Pima women (59), with PALs of 1.6, had activity levels that were modestly higher than those of the Yakut women. In fact, only Swazi women had lower PALs (1.3) than did the Yakut women, and this group was composed of affluent students enrolled in an urban agricultural school (64).

In light of these results, it is clear that Yakut men and women have activity levels consistent with those found in sedentary populations. Yakut men and women have low PALs compared with other subsistence groups; this is particularly pronounced in the women. These values are unlikely to reflect yearly lows, because summer is a critical time for subsistence activities. Yakut subsistence activities may be more limited in time, intensity, or both than previously believed.

Influence of lifestyle on energy patterns

The present study explored the influence of lifestyle on energy expenditure. Persons with a more traditional lifestyle, which was measured with the use of the SOL index, had higher TEEs and activity levels than did persons with a more modernized lifestyle. This difference likely reflects subsistence participation. To examine this more closely, a subsistence index that summarized subsistence participation documented higher TEEs and elevated activity levels in persons who performed more subsistence tasks per year. The dietary input of MFs was also correlated to expenditure variables; those persons who purchased more food had lower TEEs and decreased activity levels. Finally, the relation between television viewing and energy expenditure was explored, given previous findings that prolonged television viewing was associated with lower TEE, increased risk of obesity, and elevated blood pressure (65–68). None of the energy expenditure variables, however, were significantly associated with television viewing.

The main limitation of our study was its modest sample size; this limited our ability to detect the influence of specific factors on energy expenditure and to detect differences between the Yakut men and women. Nonetheless, we provide preliminary evidence that activity levels in the Yakut are low, especially in the women, compared with other subsistence groups and similar to values documented in industrialized populations. Finally, we suggest an important role for subsistence participation in structuring energy patterns in this population.

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JJS, WRL, and DAS designed the study. JJS and WRL collected anthropometric and metabolic measurements. LAT administered questionnaires to participants. DAS performed the doubly labeled water analyses. JJS, WRL, and DAS performed data analysis and interpretation. JJS wrote the manuscript under the guidance of WRL and DAS. None of the authors had a conflict of interest in relation to this study.

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