Comparison of energy expenditure by the doubly labeled water technique with energy intake, heart rate, and activity recording in man[1-3]

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ABSTRACT Average daily energy expenditure determined by the doubly labeled water technique (dlwEE) was compared in six subjects (aged 20–30 y) over 2 wk under usual living conditions; average food energy intake and energy expenditure estimated from individual diary records of physical activity. In addition, energy expenditure was estimated from 24-h heart rate recordings carried out on two randomly chosen days of the 2-wk period. The group means of the dlwEE were 1.94 ± 0.24 ($\bar{x}$ ± SD) times larger than resting metabolic rate (=1.94 met) and nearly identical to the average daily energy intake (1.93 ± 0.23 met). Energy expenditure estimated from the diaries of activity and from the 24-h heart rate recording varied between 1.67 and 2.24 met depending on the calculation procedure. The dlwEE (1.94 ± 0.24 met) is much higher than that recently determined for sedentary people (1.25 met) and thus explains that young students may achieve body weight balance with a relatively high daily food energy intake. *Am J Clin Nutr* 1989;49:1146–54.

KEY WORDS Energy expenditure, deuterium, oxygen-18, food energy intake, physical activity by diary and 24-h heart rate recording

Introduction

There is a need for studies on long-term energy expenditure (EE), eg, for revealing early changes underlying development of obesity (1, 2), and for the elucidation of the energy balance under extreme occupational and sporting activities (3). The ideal method for this is the doubly labeled water technique (4, 5), which has been validated with respiratory gas analysis in several species (6, 7) and in man (8–14). As the availability of the large amounts of stable water isotope $^2H_2{}^{18}O$ is restricted and costs are high, there is a need for alternative methods, particularly when studies in larger groups of human subjects are intended.

In the present study we used the doubly labeled water technique as a reference method and compared it over 2-wk periods with *1*) energy intake balance method over the full period; *2*) energy expenditure estimated from a heart rate recording, made on 2 d within the period on the basis of four different derived heart rate (HR)–$\dot{V}O_2$ regression equations; and *3*) energy expenditure estimated from activity recording made by the subjects themselves over the full period.

Subjects and methods

Subjects

Six healthy subjects, four males and two females (age: average 23.7 y, range 20–30 y; height: average 179 cm, range 170–192 cm; $\dot{V}O_2$max: 49.1 mL·min^{-1}·kg^{-1}, range 40.7–60.6 mL·min^{-1}·kg^{-1}) volunteered to participate in this study. They were selected from university students who had responded to an announcement of the project within the university area; also, financial compensation for the time commitment was offered. Only six students could take part in the isotope study owing to the limited amount of stable isotopes (unforeseen worldwide lack of production capacity at the time of the study). Thyroid status (triiodothyronine [T_3], thyroxine [T_4], and thyrotropin [TSH]) was normal in all the subjects examined.

After having been informed about the general purpose, procedures, and risks of the experiments each subject gave her or his written consent. The project was approved by the Ethic Commission of the University of Giessen.

Methods

Blood and urine samples were taken for isotope determination on days 0 (evening before night spent in the institute) (**Fig 1**) and on days 1, 8, and 15 of the 2-wk observation period;

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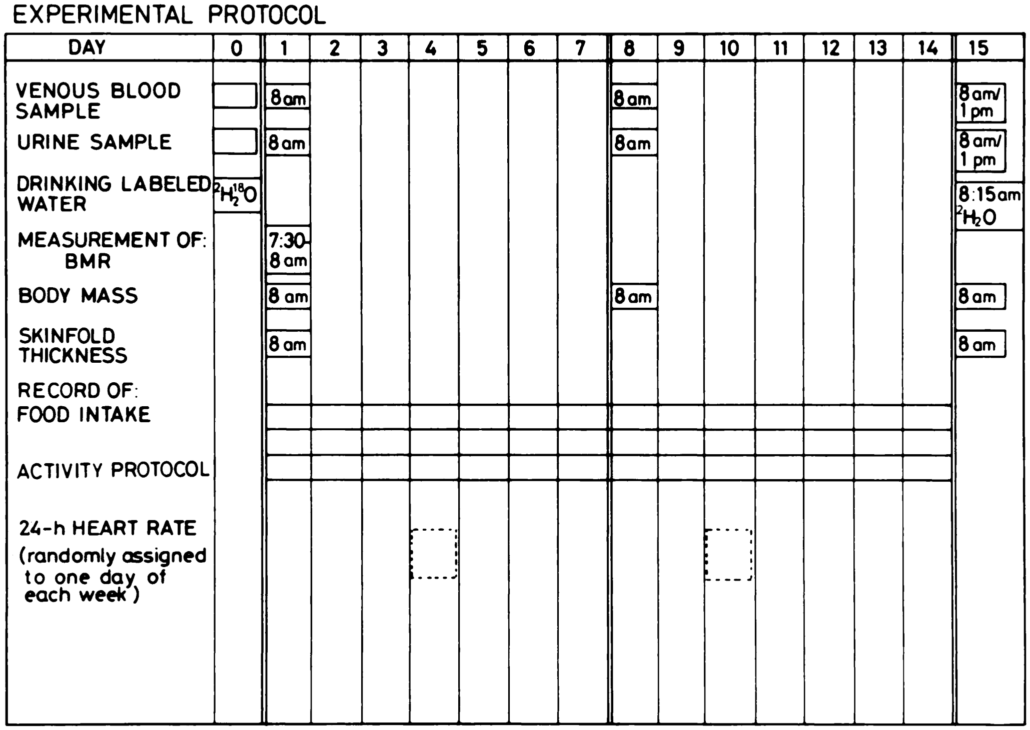

FIG 1. Outline of the experimental protocol.

body mass was determined on the same days. Skinfold thickness (sum of four sites) (15), as an estimate of body fat content, was determined on days 1 and 15. Daily food energy intake (EI) and physical activity were recorded by the subjects throughout the 2-wk observation period (see below). On one randomly chosen day within each of the two observation weeks, 24-h HR recordings were made.

The subjects spent the night preceding the beginning of the observation period in the institute; they drank the water containing $^2H_2{}^{18}O$ between 2200 and 0000. Thereafter the subjects went to bed. While asleep their $\dot{V}O_2$, $\dot{V}CO_2$, HR, and electrical muscle activity (from latissimus dorsi muscles) were continuously recorded. The basal metabolic rate (BMR) was determined from a 30-min record of $\dot{V}O_2$ between 0700 and 0730 after the subjects had awoken in the morning.

On day 15 of the observation period the subjects drank a solution of ^2H_2O for the final determination of total-body water (TBW).

Average daily energy intake. EI was measured with the food record technique. The subjects were asked to record quantitatively all items of food and drink for the whole 2-wk period. A trained nutritionist gave instructions on filling in specially designed diaries. The food items were weighed raw or cooked as available to the subjects and leftovers were subtracted. Total daily EI was calculated by one of the investigators from a standard food composition table (16). For composite meals the nutritive values were taken from the producers' specifications.

Average daily energy expenditure by the doubly labeled water technique. Isotopes were administered in a preweighed dose: 145–155 g of a solution containing nine atom percent excess ^{18}O and seven atom percent excess ^2H. Isotope abundances were measured in urine with an Aqua Sira® mass spectrometer from VG-Isogas Ltd, Middlewich, Cheshire, England. Carbon dioxide production was calculated from isotope ratios in baseline, 1-d, 8-d, and 15-d samples (Fig 1) with the equation from Schoeller et al (11). CO_2 production was converted to EE by using a respiratory quotient of 0.85, the average food quotient of our subjects maintaining energy balance.

Energy expenditure estimated by recording of physical activity. The determination of physical activity was based on recording of 24-h HR on 1 d of each of the two observation weeks (procedures 1–4) and on formal daily records (diary) of activities according to the procedure described by Bouchard et al (17) (procedures 5 and 6).

Activity from 24-h heart rate recording. A light-weight small box (format of a pocket calculator) was attached around the abdomen by a belt and connected to chest electrodes for picking up the electrocardiogram (ECG). The QRS intervals were averaged over 1-min periods; these values were stored in a random access memory, read afterwards by a computer, and recorded. For an estimate of the EE from the 24-h HR records we used, as have others, four different calculations, the results of which will be compared. The procedures (**Fig 2**) are based on 24-h HR records and on the individual relationship between HR and $\dot{V}O_2$ (cf 18, 19) determined in a preliminary experiment (calibration experiment) in a climatic chamber at neutral ambient temperature (cf 20). An open system method was used as in previous studies (21) to measure $\dot{V}O_2$. For collecting the expired gas with the fresh air stream, a hood (a tent in the overnight experiments) was placed over the subject's head. $\dot{V}O_2$ and HR were recorded at different levels of activity: quiet sitting, slight voluntary movements during sitting, quiet standing, slight movements during standing, and pedaling a cycle ergometer beginning with 0 load (HR_0) followed by increasing loads corresponding to 20%, 40%, 60%, and 80% of $\dot{V}O_2max$, which had been determined in another session.

Procedure 1

A first order regression of $\dot{V}O_2$ on HR was calculated for each subject. The average $\dot{V}O_2$, from which EE was calculated

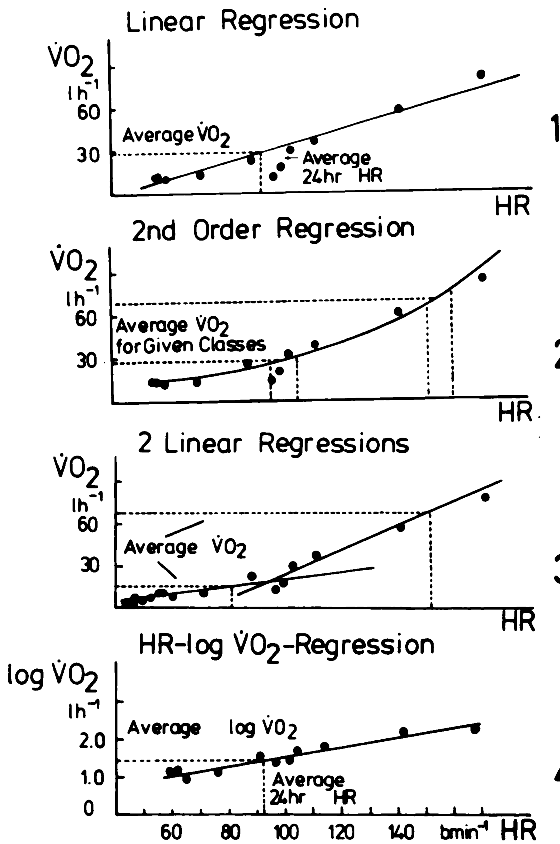

FIG 2. Schematic illustration of the relationship between heart rate (HR) and oxygen uptake ($\dot{V}O_2$) calculated from the data points (●) obtained in a calibration experiment. The demonstrated four different fittings were used for estimating energy expenditure from 24-h HR records. For graphical clarity only a few HR classes were drawn as examples. In graph 3, data from overnight experiments with very low heart rates (~50 bpm) were included.

employing a caloric equivalent of 4.87 kcal/L O_2, was obtained by reading the $\dot{V}O_2$ at the intersection with the average 24-h HR value and integration over 24 h (Fig 2).

Procedure 2

A second order regression of $\dot{V}O_2$ on HR was calculated for each subject and classes of HR (intervals of 10 bpm each) were formed from an HR histogram. For the mean value of each HR class the corresponding mean $\dot{V}O_2$ was read from the regression line (Fig 2). The number of minutes spent in each HR interval was multiplied by the corresponding $\dot{V}O_2$ (expressed per minute).

Procedure 3

Two regression lines (graph 3, Fig 2) were calculated for $\dot{V}O_2$ on HR in the calibration experiment, one for the data obtained during rest and slight activity and the other for the data determined during exercise on the cycle ergometer. For each subject the HR was determined that was attained while pedaling on the cycle ergometer at HR_0. HR_0 ranged between 67 and 96 bpm in the six subjects; the individual values of HR_0 were 16–69% higher than the resting HR. For the HR values below and above HR_0, $\dot{V}O_2$ was determined by using the respective regression equations (graph 3, Fig 2).

Procedure 4

Procedure 4 was the same as for procedure 1 but log $\dot{V}O_2$ was used instead of $\dot{V}O_2$.

Evaluation of activity diary

For the estimation of the average daily activity the subjects were given a table grouping various kinds of physical activities (sitting, standing, shaving, fast cycling, etc) in 12 categories numbered 1 through 12 according to their energy demands as available from the literature (22–24). For every 15-min period during wakefulness the subjects chose a number corresponding to their average physical activity during that time period and recorded it in their diaries.

Periods of sleeping and quiet lying were assigned the number 1, periods of heavy exercise (playing squash, sport competitions, etc), the number 12.

Procedure 5

From the integrated numbers the average daily energy expenditure (ACT-EE) was estimated by multiplying the integrated 24-h activity score with the resting metabolic rate (RMR) that was determined at the beginning of the calibration experiments after a 30-min rest at neutral temperature.

Procedure 6

Procedure 6 was the same as procedure 5 but instead of RMR the BMR was determined after waking in the morning before the beginning of the 2-wk observation period.

Results

The average body mass of the six subjects was identical at the beginning and end of the 2-wk observation period. Also, body composition did not substantially change during this period as can be seen from the small changes in TBW and the calculated fat content (**Table 1**). Fat content was also estimated from the skinfold thickness (*see* Methods); TBW was calculated according to the equation TBW = 0.73(body mass − fat mass). The values for TBW thus obtained (**Table 2**) were nearly identical with those determined by the isotope dilution method (Table 1); again there was no difference between the average values at the beginning and end of the observation period.

Average daily EI as presented in **Table 3** was calculated separately for the first and second week, as well as for the total 2-wk observation period, in correspondence with the EE measured by the doubly labeled water technique (dlwEE). On average, the recorded food EI agrees very well with dlwEE. This is true for both the first and second week of observation. When viewing the individual values, however, there are considerable differences between EI and dlwEE. In subjects 2 and 3 EI exceeds dlwEE by 16.9% and 17.9%, respectively (for the 2-wk period); there was also excess food energy input if week 1 and 2 were considered separately. In subjects 4 and 5 EI fell short of dlwEE by 20.0% and 16.5%, respectively (2 wk average) and the values for weeks 1 and 2 were not

TABLE 1
Body composition at the beginning (day 1) and end (day 15) of the 2-wk observation period*

Subject	Sex	Body mass			Total-body water			Fat mass	
		Day 1	Day 15	Difference	Day 1	Day 15	Difference	Day 1	Day 15
		kg		%	*kg*		%	*kg*	
1	M	87.7	87.4	−0.3	50.9	50.1	−1.6	18.0	18.8
2	M	67.0	67.1	+0.1	43.0	43.4	+0.9	8.1	7.6
3	M	77.8	77.8	±0	49.3	50.6	+2.6	10.3	8.5
4	M	66.0	65.7	−0.5	39.6	40.0	+1.0	11.8	10.9
5	F	62.1	62.0	−0.2	34.3	34.2	−0.3	15.1	15.2
6	F	61.8	62.6	+1.3	37.2	37.7	+1.3	10.8	11.0
$\bar{x}$		70.4	70.4	+0.07	42.4	42.7	+0.65	12.35	12.0
SD		10.3	10.1	0.64	6.6	6.7	1.44	3.6	4.3
SEM		4.2	4.1	0.26	2.7	2.7	0.59	1.5	1.7

* Total-body water (TBW) is calculated from $^2H_2{}^{18}O$ dilution for day 1 and from ^2H_2O dilution for day 15 (^{18}O space/1.01 and ^2H space/1.04). Fat mass = body mass − TBW/0.73.

very different from those. In subjects 1 and 6 the deviations calculated from the first and second week went into different directions and appeared to be unsystematic; their 2-wk EI compared favorably, however, with the dlwEE.

The group means of the daily dlwEE as well as of the EI were larger by a factor of 1.94 than the RMR measured at the beginning of the calibration experiments (**Table 4**). On average the mean RMR did not exceed the standard value for the BMR given by Boothby et al (25) (42 W/m^2 for females, 47 W/m^2 for males, age range 20–28 y). In subject 5 (female) the RMR amounted to only 35.3 W/m^2 (triplicate determination) and was thus 14% lower than the value predicted by the Boothby standard tables although her thyroid status was normal. The average activity of the six subjects thus amounted to nearly 2 met (1 met = RMR) and this corresponds to moderate physical activity according to the criteria of the World Health Organization (WHO) (26).

TABLE 2
Fat mass estimated from skinfold thickness (16) and total body water calculated from fat mass for days 1 and 15 of the 2-wk observation period

Subject	Sex	Fat mass		Total-body water		Difference
		Day 1	Day 15	Day 1	Day 15	
		kg		*kg*		%
1	M	18.7	18.8	50.4	50.1	−0.6
2	M	8.0	7.8	43.1	43.3	+0.5
3	M	9.4	9.6	49.9	49.8	−0.2
4	M	6.1	6.4	43.7	43.3	−0.9
5	F	14.2	14.5	35.0	34.7	−0.9
6	F	11.1	10.8	37.0	37.8	+2.1
$\bar{x}$		11.25	11.32	43.2	43.2	0
SD		4.6	4.6	6.4	6.2	0
SEM		1.9	1.8	2.6	2.5	0

The correlation coefficients ($r = 0.72$ and $r = 0.88$, Table 4) indicate a close relationship between RMR on the one hand and dlwEE and EI on the other hand.

The average daily EE as calculated from 24-h HR records (HR-EE), following procedures 1 through 4, and as estimated from subjective activity recording (ACT-EE, procedures 5 and 6) may be compared by referring to **Table 5**, with the EE rates determined by the dlwEE as well as with the daily food EI. The average values come close to dlwEE and EI. According to an analysis of variance (Friedman test; Wilcoxon-Wilcox test as follow-up) there were no significant differences between average dlwEE (as well as EI) on the one hand and each of the six estimated average values of EE on the other hand (Table 5). Significant differences ($p < 0.05$) were only found between procedure 6 and procedures 2 and 3, and ($p < 0.01$) between procedures 3 and 4.

For ranking the reliability in predicting EE, we also calculated the correlation coefficients for the regressions of HR-EE and ACT-EE, obtained from procedures 1–6, on dlwEE. As shown in **Table 6** the correlations between dlwEE on the one hand and EE calculated by procedures 3, 4, and 6, on the other hand, were statistically significant. The respective percentage deviations of HR-EE and ACT-EE from the individual dlwEE are listed in **Table 7**.

As shown in **Table 8** EE estimated from HR (HR-EE, procedures 1–4) and subjective activity recording (ACT-EE, procedures 5 and 6) was between 1.67 and 2.24 times larger, respectively, than RMR (Table 4), ie, they are scattering around those obtained by the doubly labeled water technique and the EI recordings (Table 4).

Discussion

This study showed that in a group of young male and female students, average daily EE determined by the

TABLE 3
Average daily energy expenditure determined by the doubly labeled water technique (dlwEE) and average daily energy intake (EI) estimated from dietary intake

		Week 1			Week 2			2 wk		
Subject	Sex	dlwEE	EI	Difference	dlwEE	EI	Difference	dlwEE	EI	Difference
		MJ/d [kcal/d]		%	*MJ/d [kcal/d]*		%	*MJ/d [kcal/d]*		%
1	M	16.5 [3938]	17.7 [4224]	+7.3	16.9 [4033]	15.4 [3675]	−8.9	16.7 [3986]	16.6 [3962]	−0.9
2	M	12.3 [2936]	14.3 [3413]	+16.2	11.3 [2697]	13.3 [3174]	+17.7	11.8 [2816]	13.8 [3294]	+16.9
3	M	13.9 [3317]	17.6 [4200]	+26.6	14.1 [3365]	15.4 [3675]	+9.2	14.0 [3341]	16.5 [3938]	+17.9
4	M	15.0 [3580]	10.8 [2578]	−28.0	15.0 [3580]	13.2 [3150]	−12.0	15.0 [3580]	12.0 [2864]	−20.0
5	F	10.6 [2530]	8.8 [2100]	−17.0	11.2 [2673]	9.4 [2243]	−16.1	10.9 [2601]	9.1 [2172]	−16.5
6	F	11.7 [2792]	10.7 [2554]	−8.5	10.7 [2554]	13.0 [3103]	+21.5	11.2 [2673]	11.9 [2840]	+6.3
$\bar{x}$		13.33 [3181]	13.32 [3179]	−0.6	13.20 [3150]	13.28 [3169]	+1.9	13.27 [3167]	13.31 [3177]	+0.62
SD		2.2 [525]	3.8 [907]	20.8	2.5 [597]	2.2 [525]	16.3	2.4 [573]	2.9 [692]	16.0
SEM		0.9 [214]	1.6 [382]	8.5	1.0 [239]	0.9 [215]	6.6	1.0 [239]	1.2 [286]	6.6

TABLE 4
Two weeks' average daily energy expenditure by the doubly labeled water technique (dlwEE) and average daily energy intake (EI) compared with resting metabolic rate (RMR)*

Subject	Sex	RMR	dlwEE	EI	dlwEE/RMR	EI/RMR	RMR/BSA
			MJ/d [kcal/d]		*met*†	*met*†	*W/m²*
1	M	7.39 [1764]	16.7 [3986]	16.6 [3962]	2.26	2.25	41.2
2	M	7.15 [1706]	11.8 [2816]	13.8 [3294]	1.65	1.93	44.9
3	M	7.94 [1895]	14.0 [3341]	16.5 [3938]	1.76	2.10	44.2
4	M	7.54 [1800]	15.0 [3580]	12.0 [2864]	1.99	1.59	49.0
5	F	4.99 [1191]	10.9 [2601]	9.1 [2172]	2.18	1.82	35.3‡
6	F	6.21 [1482]	11.2 [2673]	11.9 [2840]	1.80	1.91	40.8
$\bar{x}$		6.87 [1640]	13.3 [3174]	13.3 [3174]	1.94	1.93	42.6
SD		0.99 [236]	2.1 [501]	2.7 [644]	0.24	0.23	4.6
SEM		0.45 [107]	1.0§ [239]	1.2‖ [286]	0.1	0.1	1.9

* For comparison with standard values, RMR is also given in relation to Du Bois surface area (BSA).
† Multiple of RMR.
‡ Triplicate determination.
§ $r = 0.72$, regression on RMR.
‖ $r = 0.83$, regression on RMR.

TABLE 5

Average daily energy expenditure determined by the doubly labeled water technique (dlwEE) compared with daily energy intake (EI) estimated from dietary intake and daily energy expenditure estimated from heart rate recording (HR-EE) and from the two weeks' activity diary (ACT-EE)

				HR-EE Procedures				ACT-EE Procedures	
Subject	Protocol week	dlwEE	EI	1	2	3	4	5	6
					MJ/d [kcal/d]				
1	1	16.5	17.7	16.1	16.7	17.0	13.0	13.3	16.2
		[3938]	[4224]	[3842]	[3986]	[4057]	[3103]	[3174]	[3866]
	2	16.9	15.4	21.9	21.7	22.9	15.7	13.8	16.7
		[4033]	[3675]	[5227]	[5179]	[5465]	[3747]	[3294]	[3986]
2	1	12.3	14.3	12.5	14.0	14.9	11.1	12.7	10.8
		[2936]	[3413]	[2983]	[3341]	[3556]	[2649]	[3031]	[2578]
	2	11.3	13.3	12.5	14.3	15.3	11.1	13.3	11.3
		[2697]	[3174]	[2983]	[3413]	[3652]	[2649]	[3174]	[2697]
3	1	13.9*	17.6*	—	—	—	—	17.8*	17.8*
		[3317]	[4200]					[4248]	[4248]
	2	14.1	15.4	14.9	16.6	16.6	13.1	17.1	17.2
		[3365]	[3675]	[3556]	[3962]	[3962]	[3126]	[4081]	[4105]
4	1	15.0	10.8	11.9	12.7	14.7	10.7	13.3	11.2
		[3580]	[2578]	[2840]	[3031]	[3508]	[2554]	[3174]	[2673]
	2	15.0	13.2	12.7	13.3	14.3	11.0	13.9	11.6
		[3580]	[3150]	[3031]	[3174]	[3413]	[2625]	[3317]	[2768]
5	1	10.6	8.8	10.9	10.6	10.4	8.4	9.6	10.2
		[2530]	[2100]	[2601]	[2530]	[2482]	[2005]	[2291]	[2434]
	2	11.2	9.4	14.5	14.7	13.6	10.1	8.9	9.5
		[2673]	[2243]	[3461]	[3508]	[3246]	[2411]	[2124]	[2267]
6	1	11.7	10.7	13.9	14.6	13.6	10.7	11.1	10.0
		[2792]	[2554]	[3317]	[3484]	[3246]	[2554]	[2649]	[2387]
	2	10.7	13.0	15.8	16.2	15.8	11.5	11.0	10.0
		[2554]	[3103]	[3771]	[3866]	[3771]	[2745]	[2625]	[2387]
							$p < 0.05$		
						$p < 0.01$			
$\bar{x}$		13.2	12.9	14.3	15.0	15.4	11.5	12.5	12.2
		[3150]	[3079]	[3413]	[3580]	[3675]	[2745]	[2983]	[2912]
SD		2.4	2.8	3.0	2.9	3.1	1.8	2.3	2.9
		[573]	[668]	[716]	[692]	[740]	[430]	[549]	[692]
SEM		0.7	0.8	0.9	0.9	0.9	0.6	0.7	0.9
		[167]	[191]	[215]	[215]	[215]	[143]	[167]	[215]

* Not included in means and statistical evaluation (Friedman test, Wilcoxon-Wilcox test).

doubly labeled water method is about twice as large as the RMR and the interindividual variation of this factor is relatively small (SD 12%). In comparison with this, a group of Tour de France racers recently examined by using the same method (3) reached average daily metabolic rates of between 4.3 and 5.3 times BMR. In the latter study food EI protocols did not match the average daily metabolic rate but were systematically lower than the EE. This discrepancy showed a systematic increment from the first to the third observation interval; finally the average daily EI was by 35% lower than the EE determined by the doubly labeled water technique. In contrast, in the present study mean food EI matched fairly well the mean dlwEE (Table 3). It would thus appear possible, constancy of body mass provided, to predict from the EI the EE of even small groups (n = 6) quite exactly but for single individuals discrepancies in the order of 20% to 30% must be expected (Table 3).

In many previous studies the feasibility and reliability of predicting EE from HR recordings has been thoroughly investigated (18, 19, 20, 27–29 and others). There is general agreement that results of any relevance can only be obtained on the basis of individual calibration experiments in which the relationship between HR and metabolic rate is characterized under laboratory conditions. Here it must be taken into account, however, that even in the single individual the calibration curve may change from one day to another (29) and the more so under field conditions.

Furthermore, it must be considered that under resting conditions as well as with slight activities, considerable variations in HR may be encountered that are not ac-

TABLE 6
Correlation coefficients for the calculated regressions between average daily energy expenditure by the doubly labeled water technique (dlwEE), the average daily energy intake calculated from dietary intake (EI), as well as for the daily energy expenditure (EE) calculated by procedures 1–6

		Energy expenditure					
		HR-EE				ACT-EE	
	EI	1	2	3	4	5	6
dlwEE	0.62*	0.53	0.54	0.69*	0.73*	0.57	0.72†
EI	—	0.54	0.66*	0.72†	0.80*	0.79†	0.84‡
HR-EE 1		—	0.97‡	0.90‡	0.89†	0.23	0.63*
HR-EE 2			—	0.95‡	0.95‡	0.38	0.81†
HR-EE 3				—	0.98‡	0.53	0.74†
HR-EE 4					—	0.63*	0.84†
ACT-EE 5						—	0.62*

* $p < 0.05$.
† $p < 0.01$.
‡ $p < 0.001$.

companied by proportional changes in metabolic rate. To cope with these problems various types of higher-order regressions were calculated to fit the data obtained from the calibration experiments (20, 27, 30) or several linear regressions were used (18, 28).

In the present study the group means of EE according to the four HR-related procedures listed in Table 5 are scattering around the EE measured by the doubly labeled water technique (will be referred to as dlw value) but the deviations are not statistically significant ($p > 0.05$). Procedure 4 (log function) yielded a 12.7% lower (Table 7) and procedure 1 (linear function) a 9.8% higher value than did the doubly labeled water technique. Larger deviations were obtained by using procedure 3 and 4 (+15.3% and +17.2%, respectively). Considering the percentage deviations from the reference value as well as the correlation coefficients of the regression equations (Table 6), procedure 4 would be preferable to the other three HR-related procedures; a log function was also preferred by other investigators (30). However, it must be admitted that this as well as previous studies quoted above show that HR recordings can only provide a very rough estimate of EE, even though elaborated calibration and evaluation measures are employed as in the present study.

TABLE 7
Percentage deviations of energy expenditure*

		Procedure					
Subject	Protocol week	1	2	3	4	5	6
				%			
1	1	−2.4	+1.2	+3.0	−21.2	−19.4	−1.8
	2	+29.6	+28.4	+35.5	−7.1	−18.3	−0.1
2	1	+1.63	+13.8	+21.1	−9.8	+3.3	−12.2
	2	+10.6	+26.5	+35.4	−1.8	+17.7	±0
3	1	—	—	—	—	—	—
	2	+5.7	+17.7	+17.7	−7.1	+21.3	+22.0
4	1	−20.7	−15.3	−2.0	−28.7	−11.3	−25.3
	2	−15.3	−11.3	−4.7	−26.7	−7.3	−22.7
5	1	+2.8	±0	−1.9	−20.8	−9.4	−3.9
	2	+29.5	+31.2	−21.4	−9.8	−20.5	−15.1
6	1	+18.8	+24.8	+16.2	−8.5	−5.1	−14.5
	2	+47.7	+51.4	+47.7	+7.5	+2.8	−7.0
$\bar{x}$		+9.8	+15.3	+17.2	−12.2	−4.2	−7.3
SD		20.3	20.1	17.5	11.0	14.2	13.0
SEM		6.1	6.1	5.3	3.3	4.3	3.9

* Estimated from heart rate (HR-EE) by procedures 1–4 and from activity scoring (ACT-EE) by procedures 5 and 6, from average daily energy expenditure determined by the doubly labeled water technique (dlwEE).

TABLE 8
Average daily energy expenditure in met based on the estimates of energy expenditure by 24-h heart rate recordings (HR-EE, procedures 1–4) and by the 2-wk activity diary (ACT-EE, procedures 5 and 6) listed in Table 5 and the resting metabolic rate given in Table 4*

	met
HR-EE	
Procedure 1	2.08
Procedure 2	2.18
Procedure 3	2.24
Procedure 4	1.67
ACT-EE	
Procedure 5	1.82
Procedure 6	1.78
dlwEE	1.94
EI	1.93

* For comparison the met values derived from the doubly labeled water technique (dlwEE) and from energy intake (EI) are given.

The figures for EE estimated on the basis of subjective activity recording (procedures 5 and 6) compare rather favorably with the dlw value. Considering the correlation coefficient of the regression equation (Table 6), procedure 6 would appear to be preferable to procedure 5; by using procedure 6 average EE would be less underestimated (1.78 met vs the dlw value of 1.94 met) than with the HR-related procedure 4 (1.67 met, Table 8).

The mean TBW derived from measurement of skinfold thickness (15) matched closely that determined by the dilution method (cf Tables 1 and 2). This was even true for comparison on an individual basis with only one exception (subject 4). In subject 3 total water mass determined by the dilution method increased during the 2-wk observation period from 49.3 to 50.6 kg (+2.6%) whereas no such difference was found by skinfold measurements (Table 2). On the whole the results suggest that there was no substantial change in both body mass and body composition during the observation period.

Although both the dilution and skinfold thickness method appear to be rather reliable, the small errors possibly encountered with these methods are critical for the determination of the food energy balance if the studies are based on periods of no more than a few days. The exchange of 1 kg muscle mass for 1 kg adipose tissue, for example, would increase body energy content by 28 MJ (6683 kcal), ie, the food energy intake of ~2 d under the activity conditions of the subjects examined in this study. On the other hand changes of this size are not very probable if body weight remains constant and if there are no marked changes in the way of living (eg, loss of exercise training).

The dlw technique was recently used to examine the EE under two defined laboratory conditions (14). In one group doing mainly desk work, dlwEE (= average daily metabolic rate [ADMR] in the authors' terminology) was found to be 1.4 ± 0.09 times the sleeping rate. Sleeping metabolic rate has been frequently shown to be lower than BMR and according to one study (31), sleeping metabolic rate measured at 0600 amounted to ~90% of BMR. The dlwEE of the sedentary group would thus be ~1.25 times BMR. The subjects of the second group of that study were performing heavy cycle ergometer work for 5 h/d; their dlwEE amounted to 2.61 ± 0.25 times sleeping metabolic rate, ie, 2.35 times BMR. The dlwEE of the above mentioned Tour de France racers (3) amounted to 4.3–5.3 met. In another field study dlwEE measured in 12 women averaged 1.38 times the BMR (32). Including the data from the present study (1.94 met [Table 4]) there is now a wide spectrum of data obtained by the modern water isotope technique that provides a basis for the estimation of energy demand in dependence of physical activity.

In a previous study (2, 31) two groups of students (n = 6 each) had similar EI to RMR quotients and similar average daily EIs (11.7 [2792] and 12.2 MJ/d [2912 kcal/d]) as in the present series; they were referred to as large eaters because they were opposed by two other groups with mean EIs of 7.6 (1814) and 6.6 MJ/d (1575 kcal/d), respectively, and which were thus referred to as small eaters. No indication was found for the existence of nonshivering thermogenesis in response to cold, which could have contributed to the energy balance in the group of large eaters (cf 33).

Viewing the reported results together with the present ones it appears to be safe to conclude that average daily EEs in the order of nearly two times BMR are quite normal in young people, even without regular sport activities. They can thus easily afford daily food EIs of 11–13 MJ/d (2625–3103 kcal/d) without gaining weight. By contrast, the apparently low food EI found in the two groups of small eaters (7.6 [1814] and 6.6 MJ/d [1575 kcal/d]) was close to their BMRs (7.2 [1718] and 7.4 MJ/d [1766 kcal/d]), ie, even lower than in the sedentary laboratory group studied by Westerterp et al (14). As a consequence one would have to assume that their food intake was rated, voluntarily or unconsciously, by 25% too low, because neither their BMR nor their sleeping metabolic rate were reduced (2, 31). For the understanding of the genesis of obesity it would be of great interest to continue the search for young small eaters (as judged from food intake recording) and to examine their average daily metabolic rate by the doubly labeled water technique.

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