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Twenty-four-hour analysis of elevated energy expenditure after physical activity in a metabolic chamber: models of daily total energy expenditure¹⁻³

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ABSTRACT

Background: The Institute of Medicine proposed that 15% of energy expenditure (EE) as excess post-exercise oxygen consumption should be added to additional physical activity energy expenditure (Δ PAEE) to estimate total EE. However, the magnitude of elevated post-physical activity energy expenditure (EPPE) under normal daily living conditions has not been examined.

Objective: We examined the effects of EPPE on 24-h EE by modeling standard living conditions in a metabolic chamber.

Design: Eleven Japanese men completed three 24-h metabolic chamber measurements: a control day (C-day), a day with high-frequency moderate-intensity physical activity (M-day), and a day with high-frequency vigorous-intensity physical activity (V-day).

Results: Mean (\pm SD) 24-h EE for the C-day, the M-day, and the V-day was 2228 ± 143 kcal, 2816 ± 197 kcal, and 2813 ± 163 kcal, respectively. No significant difference was observed in 24-h EE between an M-day and a V-day. Mean EPPEs on the M-day and the V-day did not significantly contribute to increasing 24-h EE. Relative EPPEs to Δ PAEEs were $6.2 \pm 13.9\%$ (M-day) and $5.1 \pm 9.2\%$ (V-day). However, EPPE/24-h EE was negatively correlated with maximal oxygen uptake on the V-day ($r = -0.68$, $P = 0.02$), although no significant correlation between these variables was observed on the M-day ($r = -0.41$, $P = 0.21$).

Conclusions: These results suggest that EPPE has a small effect on 24-h EE in the course of normal daily activities, findings that do not support the proposition by the Institute of Medicine for estimating TEE. However, persons with low physical fitness levels could enhance EE as EPPE by increasing vigorous-intensity daily physical activity. *Am J Clin Nutr* 2008;87:1268-76.

INTRODUCTION

The prevalence of obesity has been increasing over the past few decades (1). The increase in weight or body fat is explained by a chronic imbalance between energy expenditure (EE) and energy intake. It is reported that regular exercise could play a major role in the control of body weight (2). Exercise (or physical activity) contributes to weight maintenance or weight reduction in several ways. First, thermogenesis is retained by maintaining fat-free mass. Second, EE is increased through exercise itself corresponding to work. Finally, increased EE may be induced by excess post-exercise oxygen consumption (EPOC) (3, 4).

EPOC is due to elevated oxygen consumption during the post-exercise period and consists of a rapid component and a prolonged component (5). The rapid component decays within approximately 1 h, followed by the prolonged component, which lasts for several hours. Many laboratories have examined the relation between exercise duration or intensity and the magnitude of EPOC (4, 6). According to Bahr and Sejersted (7), exercise intensity is curvilinearly related to EPOC. They suggested that exercise intensity must exceed 40% to 50% of maximal oxygen uptake ($\dot{V}O_{2max}$) to produce the prolonged component of EPOC, whereas 30% of $\dot{V}O_{2max}$ produces the rapid component of EPOC (7). Furthermore, it has been suggested that exercise duration has a linear relation to the magnitude of EPOC (8).

Physical activity thermogenesis can be divided into volitional exercise thermogenesis (sports and fitness-related activities) and nonexercise activity thermogenesis (9). It is generally accepted that obesity could be reduced through exercise or physical activity. That is, persons should increase total energy expenditure (TEE) by a range of physical activities including daily activities such as cleaning and gardening (10, 11). Levine et al (12) suggested that increasing nonexercise activity thermogenesis could be a strong contributor to preventing obesity. To support this proposition, it is important to verify the effects of additional EE after physical activity (elevated post-physical activity energy expenditure, or EPPE). There are no data on the effect of EPPE on 24-h EE under normal living conditions. Nevertheless, the Institute of Medicine proposed that 15% of EE as EPOC should be added to the additional physical activity energy expenditure (Δ PAEE) from sedentary conditions to estimate TEE, because adjustment for EPOC and dietary induced thermogenesis is expected to improve the underestimation of TEE by the factorial method compared with TEE measured by doubly labeled water (13, 14). Although it has been reported that these adjustments improved estimates of TEE (15, 16), they could be inappropriate

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for other studies in which TEE was not underestimated (17, 18). The purpose of this study was to examine the effects of EPEE on 24-h EE by modeling normal living conditions in a metabolic chamber.

SUBJECTS AND METHODS

Subjects

Eleven Japanese men participated in this study. All subjects were adults (≥ 20 y) and lacked chronic diseases that could affect metabolism or daily physical activity. They had not participated in regular intensive sports or physical activity for the past year but were able to complete a jogging regimen (8.0 km/h). The descriptive characteristics of the study subjects are presented in **Table 1**. Informed consent was signed by all subjects. The study protocol was approved by the Ethical Committee of the National Institute of Health and Nutrition.

Experimental design

Weight, height, and body composition were measured while the men were in a fasting state. Each subject completed a 24-h metabolic chamber measurement under 3 different protocols so that we could examine the effects of physical activity intensity: a control day (C-day); a day with high-frequency, moderate-intensity physical activity (M-day); and a day with high-frequency, vigorous-intensity physical activity (V-day). A test for peak oxygen uptake and metabolic chamber measurements were done at intervals of 2 to 3 d, but within 14 d to avoid metabolic influences from other protocols. We instructed the subjects to live under normal daily conditions during the measurement period (within 14 d) to maintain the same conditions, weight, and body composition for each measurement day. The order of the 3-d metabolic chamber measurements was randomly assigned to each subject.

Anthropometry and body composition

A digital scale was used to measure body weight to the nearest 0.1 kg while the subjects were dressed in light clothing. Barefoot standing height was measured to the nearest 0.1 cm by using a wall-mounted stadiometer. Body mass index was calculated as body weight (kg) divided by height squared (m^2).

Lean soft tissue mass, fat mass, and bone mineral content were measured by dual-energy X-ray absorptiometry (QDR-4500A scanner; Hologic, Waltham, MA). The subjects were positioned for whole-body scans according to the manufacturer's protocol. They lay in a supine position on the scanner table with their limbs

close to their bodies. Fat-free mass was defined as the sum of lean soft tissue mass and bone mineral content.

Peak oxygen uptake

Peak oxygen uptake ($\dot{V}O_{2peak}$) was measured by use of an incremental running test on a treadmill (TREAD-MILL; Nishikawa Iron Works, Kyoto, Japan). The subjects warmed up at 160, 180, or 200 m/min at a fixed 0° grade for 5 min. The treadmill speed increased at a rate of 10 m/min for each successive minute of running until fatigue, defined as the speed at which the subject could no longer continue to keep up with the treadmill. Heart rate and rating of perceived exertion were monitored continuously. The rating of perceived exertion was obtained by using the modified Borg scale (19). Oxygen uptake was measured over 30-s intervals after the rating of perceived exertion reached 15. Subjects breathed through a low-resistance 2-way valve, and the expired air was collected in Douglas bags. Expired oxygen and carbon dioxide gas concentrations were measured by mass spectrometry (ARCO-1000A; Arco System, Kashiwa, Japan), and gas volume was determined by using a certified dry gas meter (DC-5; Shinagawa, Tokyo, Japan). For each measurement, the gas analyzer was initially calibrated by using a certified gas mixture and atmospheric air. The highest value of $\dot{V}O_2$ during the exercise test was designated as $\dot{V}O_{2peak}$.

Metabolic chamber

An open-circuit indirect metabolic chamber was used to evaluate 24-h EE, basal metabolic rate (BMR), and sleeping metabolic rate (SMR) (20, 21). Briefly, the respiratory chamber was an airtight room (20 000 L) equipped with a bed, desk, chair, TV with video deck, CD player, telephone, toilet, sink, and treadmill. The temperature and relative humidity in the room were controlled at $25^\circ C$ and 55%, respectively. The oxygen and carbon dioxide concentrations of the air supply and exhaust were measured by mass spectrometry. For each experiment, the gas analyzer (ARCO-1000A-CH; Arco System, Kashiwa, Japan) was initially calibrated by using a certified gas mixture and atmospheric air. The flow rate exhausted from the chamber was measured by pneumotachography (FLB1; Arco System). The flow meter was calibrated before each measurement, and the flow rate was maintained at ≈ 90 L/min (ATP). $\dot{V}O_2$ and carbon dioxide production ($\dot{V}CO_2$) were determined by the flow rate of exhaust from the chamber, and the concentrations of the inlet and outlet air of the chamber, respectively (20). EE was estimated from $\dot{V}O_2$ and $\dot{V}CO_2$ by using Weir's equation (22). The accuracy and precision of our metabolic chamber for measuring EE as determined by the alcohol combustion test was $99.8 \pm 0.5\%$ (mean \pm SD) over 6 h and $99.4 \pm 3.1\%$ over 30 min.

Spontaneous physical activity was evaluated by using a motion-detecting system. The chamber had 2 independent sensors of passive infrared type (Matsushita Automation Controls Co, Ltd, AMP2009B01, Tokyo, Japan) that detected movement at speeds >7 cm/s. When at least 1 sensor detected movement, the movement was regarded as positive. The system provided percentage of time when movement was observed in each minute, and averaged spontaneous physical activity over each 15-min interval was used for analyses.

TABLE 1
Physical characteristics of the subjects¹

	$\bar{x} \pm SD$ (range)
Age (y)	24.7 \pm 5.8 (20–40)
Height (cm)	168.1 \pm 3.9 (163.5–174.1)
Weight (kg)	64.5 \pm 7.9 (50.6–74.0)
BMI (kg/m^2)	22.8 \pm 2.8 (18.7–27.2)
Body fat (%)	16.4 \pm 4.6 (10.3–22.8)
$\dot{V}O_{2peak}$ (L/min)	3.03 \pm 0.57 (1.99–3.98)
$\dot{V}O_{2peak}$ ($mL \cdot min^{-1} \cdot kg^{-1}$)	47.3 \pm 8.3 (29.2–59.1)

¹ $n = 11$. $\dot{V}O_{2peak}$, peak oxygen uptake.



Design for timetables in the metabolic chamber

Physical activity level (PAL), which is calculated as TEE divided by BMR, has been categorized by the Institute of Medicine as low active (average: 1.5; range: 1.4–1.59), active (average: 1.75; range: 1.6–1.89), and very active (average: 2.2; range: 1.9–2.49) (14). The 2005 Japanese Dietary Reference Intakes reported similar categorization (23). Therefore, C-day was designed to correspond to a PAL of 1.4–1.59 including reference physical activity. On the basis of the C-day, we modeled M-day and V-day as follows: 1) comparable PAL between M-day and V-day for comparing with these EPEEs, 2) PALs to include the normal human range, and 3) actual percentages of low-, moderate-, and vigorous-intensity physical activity encountered in daily living (24, 25).

In the present study, we sought to model normal daily living in the metabolic chamber. Daily living activities consist of various

physical activities, such as cleaning, cooking, washing, and gardening. However, it is very difficult to prescribe daily physical activity strictly, as well as to continue them for extended periods of time. Therefore, daily physical activity was substituted as follows: slow walking [3.2 km/h, 2.5 metabolic equivalents (METs)] as low-intensity physical activity, brisk walking (5.6 km/h, 3.8 METs) as moderate-intensity activity, and jogging (8.0 km/h, 8.0 METs) as vigorous-intensity activity (26). Note that physical activities in the course of daily living are carried out at high frequencies, but are relatively short in duration. For that reason, each activity was limited to a period of 15 min, which is the minimum duration required by our instrument to measure EE with high accuracy.

The schedules in the metabolic chamber are shown in **Table 2**. The subjects entered the chamber at 1750 and stayed until 1805 the next day. Sampling data were collected between 1800 and

TABLE 2
Timetables for each modeling day in the metabolic chamber¹

Time	C-day	M-day	V-day
1750	Entry into a room	Entry into a room	Entry into a room
1800	Sit quietly	Sit quietly	Sit quietly
1815		Walking (5.6 km/h)	Walking (5.6 km/h)
1830		Sit quietly	Sit quietly
1845	Dinner → Sit quietly	Dinner → Sit quietly	Dinner → Sit quietly
1930		Walking (5.6 km/h)	Walking (5.6 km/h)
1945		Sit quietly	Sit quietly
2000		Walking (5.6 km/h)	
2015		Sit quietly	
2100	Walking (3.2 km/h)	Walking (3.2 km/h)	Walking (3.2 km/h)
2130	Sit quietly	Sit quietly	Sit quietly
2215		Walking (5.6 km/h)	
2230		Sit quietly	
2245		Walking (5.6 km/h)	
2300		Sit quietly	
2400	Go to sleep	Go to sleep	Go to sleep
700	Get up → Basal metabolic rate	Get up → Basal metabolic rate	Get up → Basal metabolic rate
800	Sit quietly	Sit quietly	Sit quietly
815	Breakfast → Sit quietly	Breakfast → Sit quietly	Breakfast → Sit quietly
900		Walking (5.6 km/h)	Walking (5.6 km/h)
915		Sit quietly	Sit quietly
925	Stretching	Stretching	Stretching
930	Sit quietly	Walking (5.6 km/h)	Jogging (8.0 km/h)
945		Sit quietly	Sit quietly
1030	Walking (5.6 km/h)	Walking (5.6 km/h)	Walking (5.6 km/h)
1100	Sit quietly	Sit quietly	Sit quietly
1140	Stretching	Stretching	Stretching
1145	Sit quietly	Walking (5.6 km/h)	Jogging (8.0 km/h)
1200		Sit quietly	Sit quietly
1215		Walking (5.6 km/h)	
1230		Sit quietly	
1245	Lunch → Sit quietly	Lunch → Sit quietly	Lunch → Sit quietly
1355	Stretching	Stretching	Stretching
1400	Sit quietly	Walking (5.6 km/h)	Jogging (8.0 km/h)
1415		Sit quietly	Sit quietly
1455	Stretching	Stretching	Stretching
1500	Jogging (8.0 km/h)	Jogging (8.0 km/h)	Jogging (8.0 km/h)
1515	Sit quietly	Sit quietly	Sit quietly
1600		Walking (5.6 km/h)	Walking (5.6 km/h)
1615		Sit quietly	Sit quietly
1805	Exit from a room	Exit from a room	Exit from a room

¹ C-day, a control day; M-day, a day with high-frequency, moderate-intensity physical activity; V-day, a day with high-frequency, vigorous-intensity physical activity.



1800 (24 h). The subjects went to bed at 2400 and were gently awakened at 0700 (7 h). The mean metabolic rate during this period was used as the SMR. After getting up, the subjects were permitted to use the toilet and were required to return to bed immediately. Then, the subjects remained in a supine position without movement until 0800. BMR was determined as the mean metabolic rate between 0715 and 0800. Except for prescribed physical activity and using the toilet, the subjects were only permitted to carry out light activities in a sitting position, such as reading, writing, and viewing television. Sleeping was not permitted. Meals were given 3 times a day to provide the predicted BMR (23) multiplied by the estimated PAL of 1.75, as an intermediate value for C-day and M-day (or V-day) modeling. Ratios of protein to fat to carbohydrate in total energy intake per day were 18:20:62. The same meals were provided on each of the 3 d to unify dietary induced thermogenesis.

Calculation of elevated post-physical activity energy expenditure

We estimated EPEE on the M-day and the V-day as measured 24-h EE minus predicted 24-h EE without EPEE. Predicted 24-h

EE without EPEE was obtained from a model based on the C-day with use of the factorial method (Figure 1). That is, 24-h EE without EPEE for M-day and V-day was predicted by the 24-h EE for the C-day plus the reference EE for brisk walking and jogging. The reference EEs for brisk walking (5.6 km/h) and jogging in this model were calculated from each activity during C-day. To calculate steady state values for EE for these activities, EE values for the first 3 min and the last 1 min during the 2 reference activities were removed, and mean EE in the remainder was extended to 15 min (27, 28). Furthermore, for comparing with relative EE as EPOC to additional physical activity energy expenditure (Δ PAEE) in the US and Canada DRI equation, Δ PAEE was calculated as the predicted 24-h EE without EPEE on the M-day or V-day minus the 24-h EE for the C-day.

Statistical analysis

We performed a power calculation ($\alpha = 0.05$ and $\beta = 0.80$) to determine whether the EPEE value corresponded to 15% of Δ PAEE, which was ≈ 100 kcal in our subjects. Data from previous observations showed that the SD for the 24-h EE measurement in our metabolic chamber is ≈ 75 kcal. From this power

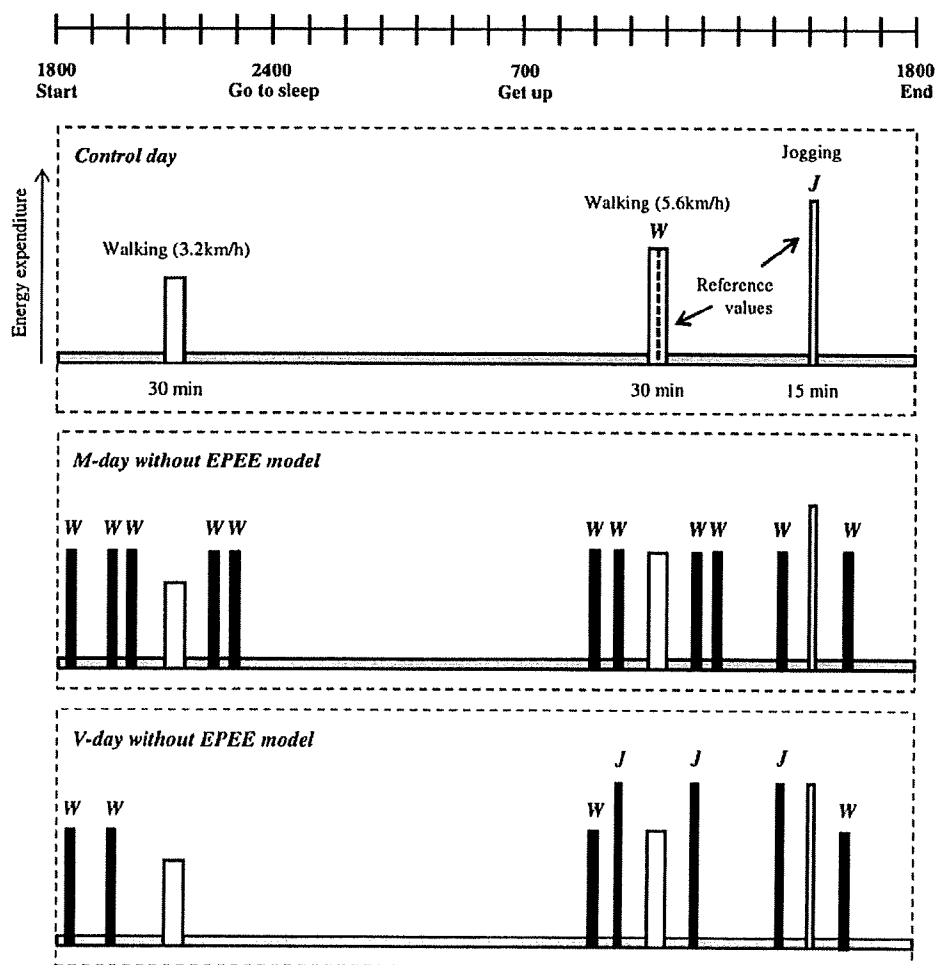


FIGURE 1. Model for predicting 24-h energy expenditure (EE) without elevated post-physical activity energy expenditure (EPEE). M-day, a day with high-frequency, moderate-intensity physical activity; V-day, a day with high-frequency, vigorous-intensity physical activity; W, reference energy expenditure for walking (5.6 km/h); J, reference energy expenditure for jogging; empty bar, actual energy expenditure by the prescribed physical activity for each day; filled bar, reference energy expenditure for brisk walking (5.6 km/h) or jogging.

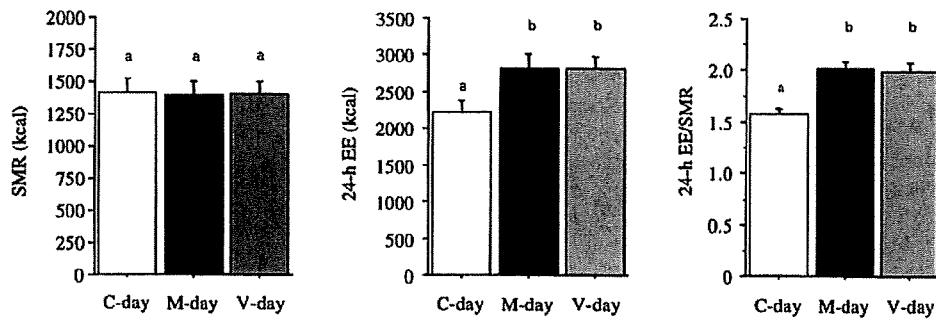


FIGURE 2. Sleeping metabolic rate (SMR), 24-h energy expenditure (24-h EE), and 24-h EE/SMR for each modeling day ($n = 11$). C-day, a control day; M-day; a day with high-frequency, moderate-intensity physical activity; V-day, a day with high-frequency vigorous-intensity physical activity. Error bars indicate SD. Bars with the same letter were not significantly different by one-way ANOVA with Scheffe's post hoc test ($P < 0.05$).

calculation, we determined that ≥ 9 subjects were needed. All values are presented as means \pm SDs. Differences were considered to be statistically significant if the P value was < 0.05 . The SMR, 24-h EE, and 24-h EE/SMR values obtained in the 3 protocols were compared by one-way analysis of variance, and significant differences were analyzed by using Scheffe's post hoc test. Differences between actual 24-h EE and predicted 24-h EE without EPEE on M-day or V-day were assessed by the paired t test. Differences in any variable between M-day and V-day were assessed by the paired t test. Correlations between EPEE on the M-day or the V-day and $\dot{V}O_{2peak}$ or body composition were assessed by Pearson's correlation coefficients (r). All statistical analyses were performed by using SPSS version 14.0J for WINDOWS (SPSS Inc, Chicago, IL).

RESULTS

All subjects completed the 3-d metabolic chamber measurements according to prescribed timetables. The subjects' average total energy intake was 2685 ± 303 kcal, and this did not differ between the 3 d in each subject, because they ate all provided meals completely. Mean $\dot{V}O_{2peak}$ was 47.3 ± 8.3 mL \cdot min $^{-1}$ \cdot kg $^{-1}$. Relative physical activity intensities for slow walking, brisk walking, and jogging were $21.4 \pm 5.1\%$, $33.3 \pm 7.0\%$, and $65.0 \pm 14.1\%$ of $\dot{V}O_{2peak}$, respectively.

Mean SMR, 24-h EE, and 24-h EE/SMR are shown in Figure 2. Twenty-four-hour EE for C-day, M-day, and V-day was 2228 ± 143 kcal, 2816 ± 197 kcal, and 2813 ± 163 kcal, respectively. No significant differences were observed in 24-h EE values between M-day and V-day, although there were significant differences between C-day and M-day or V-day. There were no significant differences between SMR values (or BMR values) for the 3-d periods for the subjects. CVs for SMR and BMR over 3 d were 1.0% and 1.7%, respectively. Twenty-four-hour EE/SMR for 3 d was 1.58 ± 0.06 for C-day, 2.02 ± 0.07 for M-day, and 2.00 ± 0.08 for V-day.

There were no significant differences between the measured 24-h EE value and the predicted 24-h EE value without EPEE for M-day or V-day (Table 3). Mean EPEE values for M-day and V-day were not significantly different. Relative EPEE values to measured 24-h EE values were $1.2 \pm 2.7\%$ and $1.0 \pm 0.8\%$. Furthermore, relative EPEEs to Δ PAEEs were $6.2 \pm 13.9\%$ and $5.1 \pm 9.2\%$, respectively.

Mean percentages of spontaneous physical activity during prescribed physical activity (slow walking, brisk walking, and

jogging) for the 3 d were $\approx 100\%$. There were no significant differences in mean percentages of spontaneous physical activity for resting periods for the 3 d (C-day: $38.1 \pm 9.0\%$; M-day: $43.8 \pm 5.6\%$; V-day: $40.4 \pm 8.2\%$).

The relations between EPEE/24-h EE and $\dot{V}O_{2peak}$ or fat-free mass for M-day or V-day are shown in Figure 3 and Figure 4. EPEE/24-h EE for V-day was negatively correlated with $\dot{V}O_{2peak}$, whereas no significant correlation between these variables was observed for EPEE/24-h EE for M-day. As for the relation between EPEE/24-h EE or EPEE and fat-free mass, no significant correlations were observed for either M-day or V-day. Also, fat mass and body mass indexes were not significantly correlated with EPEE/24-h EE or EPEE for either day. The correlation coefficients for EPEE versus between-day SMR difference were 0.31 (NS) and 0.63 ($P < 0.05$) for M-day and V-day, respectively.

DISCUSSION

This investigation examined the effects of EPEE on 24-h EE by modeling normal living activities in a metabolic chamber.

TABLE 3

Elevated post-physical activity energy expenditure (EPEE) for the M-day and the V-day¹

	M-day ²	V-day ²
Predicted 24-h EE without EPEE (kcal) ³	2781 \pm 185	2784 \pm 167
Measured 24-h EE (kcal)	2816 \pm 197 ⁴	2813 \pm 163 ⁴
Δ PAEE (kcal) ⁵	553 \pm 53	556 \pm 49
EPEE (kcal) ⁶	35 \pm 78	29 \pm 53
EPEE/measured 24-h EE \times 100 (%)	1.2 \pm 2.7	1.0 \pm 0.8
EPEE/ Δ PAEE \times 100 (%)	6.2 \pm 13.9	5.1 \pm 9.2

¹ All values are $\bar{x} \pm$ SD. M-day, a day with high-frequency, moderate-intensity physical activity; V-day, a day with high-frequency, vigorous-intensity physical activity; 24-h EE, 24-h total energy expenditure; Δ PAEE, additional physical activity-induced energy expenditure.

² There was no significant difference in each variable between the M-day and the V-day by paired t test ($P < 0.05$).

³ Values were calculated on the basis of a control day.

⁴ There was no significant difference between predicted 24-h EE without EPEE and measured 24-h EE on the M-day or the V-day by paired t test ($P < 0.05$).

⁵ Predicted 24-h EE without EPEE minus control day.

⁶ Measured 24-h EE minus predicted 24-h EE without EPEE.



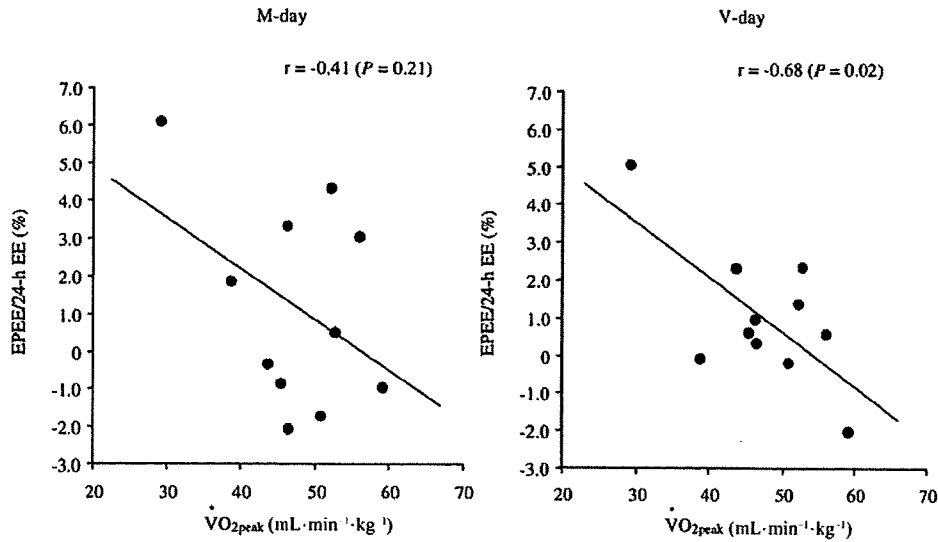


FIGURE 3. Relation between elevated post-physical activity energy expenditure (EPEE) and peak oxygen uptake (VO_{2peak}) for the M-day (a day with high-frequency, moderate-intensity physical activity) and the V-day (a day with high-frequency, vigorous-intensity physical activity). 24-h EE, 24-h energy expenditure.

There was no significant additional EE as EPEE in total 24-h EE when the subjects spent 24 h in a metabolic chamber under conditions that were ≈ 2.0 for 24-h EE/SMR (similar to PAL) for high-frequency, moderate-intensity or vigorous-intensity physical activity. However, subjects with low physical fitness may produce significant additional EE as EPEE by increasing daily vigorous-intensity physical activity.

Although EPOC has been studied in depth, most analyses examined the effects of EPOC after a single bout of exercise (4, 6). However, if one is to understand the effects of EPOC in weight reduction or maintenance, it is important to investigate the magnitude of EPOC after physical activity under normal

living conditions. Previous studies suggested that EPOC after a single bout of exercise was generated in proportion to exercise duration, when exercise intensity exceeds about 50–60% $\dot{V}O_{2max}$ (6–8). Almuzaini et al (29) reported that dividing a 30-min exercise session into 2 parts significantly increased the magnitude of EPOC. However, this study was limited to the 40-min period after exercise, and the difference between EPOC values was only ≈ 10 kcal. Normal daily activity conditions evidently differ from those experimental conditions, because in the normal course of daily activity, people engage in a wide range of physical activity, the intensity of which vary from light to vigorous (26). The duration of most of these activities

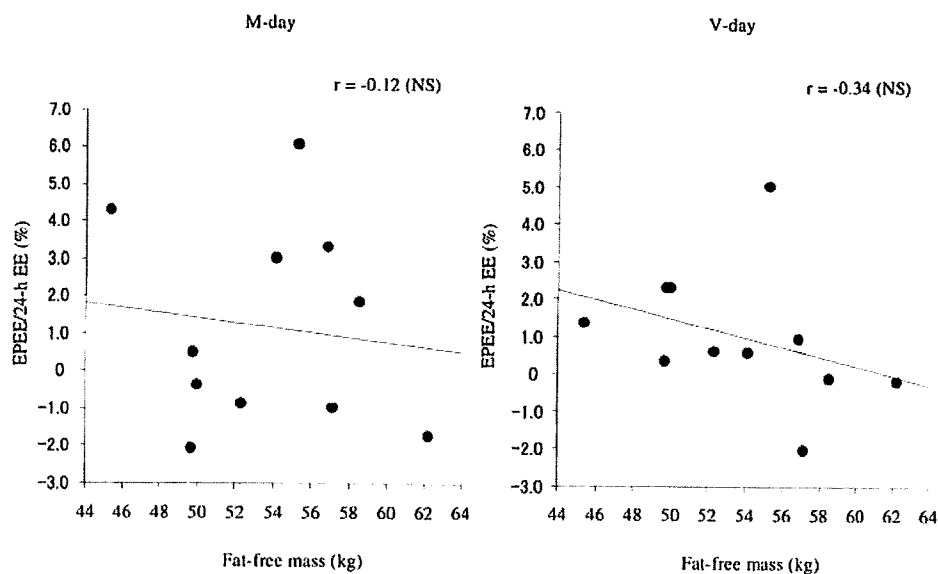


FIGURE 4. Relation between elevated post-physical activity energy expenditure (EPEE) and fat-free mass for the M-day (a day with high-frequency, moderate-intensity physical activity) and the V-day (a day with high-frequency, vigorous-intensity physical activity). 24-h EE, 24-h energy expenditure. There were no significant correlations between EPEE and fat-free mass for any day ($P < 0.05$).

and the intervals between moderate-to-vigorous physical activity are short, but their frequencies are high. This situation requires examination of the effects of EPEE (similar to, but a broader component than EPOC) on 24-h EE under normal activity conditions.

If significant EPEE by combined physical activity in daily living exists, one reason might be that the total duration of all physical activity amounted to several hours per 24 h, even though each activity was short. Furthermore, short intervals between physical activities with high frequencies may produce higher EPEE than the EPEE induced by a prolonged, single bout of exercise. However, the present study failed to identify any significant additional EE as EPEE in the 24-h EE. That is, multiplying short-duration physical activities with short intervals between activities may not contribute much toward increasing the 24-h EE, compared with prolonged physical activity, even if persons perform these short-duration physical activities with high frequencies during a 24-h period. The Institute of Medicine has proposed that 15% of EE as EPOC to Δ PAEE from sedentary condition should be added in estimating total energy expenditure (14). This proposition is based on the report by Bahr et al (13), which compared EPOC magnitudes between 20, 40, and 80 min of ergometer exercise at 70% $\dot{V}O_{2max}$. As a result, each EPOC was \approx 15% of exercise-induced EE for 12 h after the exercise sessions. However, this evidence was obtained from a single-bout trial. In our experimental design, normal daily activity conditions were modeled, and EPEE resulted in $6.2 \pm 13.9\%$ (M-day) and $5.1 \pm 9.2\%$ (V-day) of Δ PAEE. Therefore, the equation estimating TEE proposed by the Institute of Medicine, which adds 15% EE as EPOC to Δ PAEE, would overestimate 24-h EE.

Previous studies using a single round of exercise suggest that one possible explanation for not observing significant EPEE in daily activity was that many daily activities do not reach the intensity threshold of 50–60% $\dot{V}O_{2max}$ (7, 8). We adopted brisk walking (3.8 METs) as a moderate-intensity physical activity and jogging (8.0 METs) as a vigorous-intensity physical activity. Note that Pate et al (30) have defined that moderate-intensity physical activity ranged from 3 to 6 METs and vigorous-intensity physical activity was >6 METs. The relative exercise intensities of brisk walking and jogging were $33.3 \pm 7.0\%$ and $65.0 \pm 14.1\%$, respectively. Brisk walking did not reach 50–60% $\dot{V}O_{2max}$ as the intensity threshold for producing EPOC. On the other hand, Melanson et al (31) reported that if energy expenditures were matched between high-intensity exercise and low-intensity exercise with well-controlled conditions in a metabolic chamber, no significant difference was observed in 24-h EE values between these 2 conditions. Saris and Schrauwen (32) reported that in obese subjects, no significant differences in 24-h EE values were observed between the day with high-intensity interval exercise and the day with low-intensity endurance exercise when the exercise sessions were equicaloric in energy expenditure. From our results and previous studies, it appears that exercise or physical activity intensity does not influence the contribution of EPOC to 24-h EE. However, a significant difference of EPOC magnitude may be found between high- and low-intensity exercise when one measures EPOC within several hours of a single-bout trial.

The inclusion (or lack thereof) of oxygen deficit in calculations of EPOC may contribute to discrepancies among studies. Most studies with a single-bout trial compared EPOC to oxygen

consumption during an exercise bout (4, 6), in which case oxygen deficit is not taken into account. On the other hand, we discuss EPEE without EE equivalent to oxygen deficit, by extrapolating steady state EE (excluding EE in the first 3 min and the last 1 min) to the whole EE in each physical activity period. Although total EPOC is greater than oxygen deficit, a large part of the rapid component of EPOC is explained by oxygen deficit during the exercise (5). If we consider the extra energy expenditure due to exercise or physical activity in 24-h EE, such as the estimation of TEE in the Institute of Medicine (14), EE corresponding to oxygen deficit should be excluded. However, the study by Bahr et al (13) discussed the contribution of EPOC to EE during an exercise bout, so adding 15% as EPOC to Δ PAEE should lead to overestimation of TEE.

Although EPEE did not contribute to a significant increase in 24-h EE in the present study, EPEE/24-h EE for V-day was significantly correlated with $\dot{V}O_{2peak}$. That is, a person with low fitness may generate more EPEE by increasing daily physical activity. Short and Sedlock (33) reported that even though EE during exercise in trained subjects was much higher than that in untrained subjects, EPOC was similar between the groups if different subjects exercised at the same relative intensity of 70% $\dot{V}O_{2peak}$. When compared with subjects with higher $\dot{V}O_{2max}$, those with lower oxygen uptake produced more lactate, a major biochemical component of EPOC (34). Therefore, a negative relation between $\dot{V}O_{2peak}$ and EPEE/24-h EE observed in the present investigation is reasonable.

Trained individuals have better thermoregulatory capacities than do untrained individuals because physical training enhances the sweating mechanism at a given level of the central sweating drive (35). Therefore, elevated body temperature in untrained individuals could last longer than in trained individuals (36). These phenomena require extra oxygen consumption for recovery. Therefore, fitness level may contribute to the magnitude of EPEE. On the other hand, there was no significant relation between EPEE/24-h EE for the M-day and $\dot{V}O_{2peak}$. In other words, it is assumed that exercise duration (with relative intensity over the threshold for producing the slow component of EPOC) may be longer in less fit subjects than in fit subjects, leading to more slow-component production in less fit subjects. However, the relative intensities of the 3 physical activities in this study were different in individuals, because these physical activities were prescribed by the same absolute intensities. Interestingly, EPEE was negative on both the M-day and the V-day in several subjects. One possible reason may have been interday variations in resting metabolic rate. In the present study, SMR values on M-day or V-day were lower than the SMR values on C-day in some cases, and the correlation coefficients for EPEE versus between-day SMR difference were 0.31 and 0.63 on M-day and V-day, respectively. Therefore, the negative values of EPEE may reflect interday variations in resting metabolic rate. In addition, people may compensate for an increase in EE due to activity by decreasing their nonexercise EE (37). In the present study, the total duration of prescribed physical activity was 240 min on the M-day. That is, the duration on the M-day was 60 min longer than on the V-day. Therefore, the total duration or frequency of physical activity during the day may affect the observed decrease in nonexercise EE.

In the present study, there were no significant correlations between EPEE for M-day (or V-day) and physical status (fat-free



mass, fat mass, and body mass index). Crommett and Kinzey (38) have reported similar results. Although body composition may not influence EPEE, many obese persons are untrained and have a low level of fitness. Therefore, our results suggest that obese persons with a low fitness level could expect additional EE as EPEE to assist in weight reduction, provided that they perform high-frequency, relatively vigorous physical activity in the course of daily living. Otherwise, persons with a high fitness level may not expect significant EPEE through daily physical activity, because daily activity is difficult to adjust to high intensity, like typical exercise activity.

This study had several limitations. First, we could not measure actual daily physical activity because we conducted the measurements in a metabolic chamber. Additionally, the duration of each physical activity under normal living conditions may be shorter than 15 min in many cases, whereas 15 min was the minimum duration of activity required for accurate measurement values in this study. Even though we gathered data under well-controlled conditions, our experimental protocol could not detect any EPEE on the control day. However, control day EPEE values should be added to the calculated EPEE values on M-day and V-day. Although we believe that control day EPEE values would not be large, the actual Δ PAEE in normal daily living may thus be slightly higher than our calculated results. Furthermore, future studies are needed to clarify the association between fitness and EPEE, because inclusion of a single subject in our data set, the one with the lowest fitness, strongly contributed to the significant (but modest) inverse association observed between these variables.

In conclusion, we found that EPEE has a only small effect on 24-h EE under normal living conditions. Therefore, adding 15% EE as EPOC to Δ PAEE, in accord with the Institute of Medicine recommendation for estimating TEE, would overestimate 24-h EE. However, persons with a low physical fitness level may produce additional EE as EPEE by increasing relatively vigorously intense daily living physical activity.

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REFERENCES

- World Health Organization. Diet, nutrition and the prevention of chronic diseases. *World Health Organ Tech Rep Ser* 2003;916:1-149.
- Klem ML, Wing RR, McGuire MT, Seagle HM, Hill JO. A descriptive study of individuals successful at long-term maintenance of substantial weight loss. *Am J Clin Nutr* 1997;66:239-46.
- Hill JO, Wyatt HR. Role of physical activity in preventing and treating obesity. *J Appl Physiol* 2005;99:765-70.
- LaForgia J, Withers RT, Gore CJ. Effects of exercise intensity and duration on the excess post-exercise oxygen consumption. *J Sports Sci* 2006;24:1247-64.
- Gaesser GA, Brooks GA. Metabolic bases of excess post-exercise oxygen consumption: a review. *Med Sci Sports Exerc* 1984;16:29-43.
- Borsheim E, Bahr R. Effect of exercise intensity, duration and mode on post-exercise oxygen consumption. *Sports Med* 2003;33:1037-60.
- Bahr R, Sejersted OM. Effect of intensity of exercise on excess post-exercise O_2 consumption. *Metabolism* 1991;40:836-41.
- Gore CJ, Withers RT. Effect of exercise intensity and duration on post-exercise metabolism. *J Appl Physiol* 1990;68:2362-8.
- Levine JA, Eberhardt NL, Jensen MD. Role of nonexercise activity thermogenesis in resistance to fat gain in humans. *Science* 1999;283:212-4.
- American College of Sports Medicine. ACSM's guideline for exercise testing and prescription. 7th ed. Philadelphia, PA: Lippincott Williams & Wilkins, 2006.
- Ministry of Health Labour and Welfare of Japan. Exercise and physical activity reference for health promotion 2006. Internet: <http://www.nih.go.jp/eiken/programs/pdf/epar2006.pdf> (accessed 2 June 2007).
- Levine JA, Lanningham-Foster LM, McCrady SK, et al. Interindividual variation in posture allocation: possible role in human obesity. *Science* 2005;307:584-6.
- Bahr R, Ingnes I, Vaage O, Sejersted OM, Newsholme EA. Effect of duration of exercise on excess post-exercise O_2 consumption. *J Appl Physiol* 1987;62:485-90.
- Institute of Medicine. Dietary reference intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein and amino acids. Washington, DC: National Academy Press, 2005.
- Leonard WR, Galloway VA, Ivakine E. Underestimation of daily energy expenditure with the factorial method: implications for anthropological research. *Am J Phys Anthropol* 1997;103:443-54.
- Warwick PM. Factorial estimation of daily energy expenditure using a simplified method was improved by adjustment for excess post-exercise oxygen consumption and thermic effect of food. *Eur J Clin Nutr* 2006;60:1337-40.
- Seale JL, Klein G, Friedmann J, Jensen GL, Mitchell DC, Smiciklas-Wright H. Energy expenditure measured by doubly labeled water, activity recall, and diet records in the rural elderly. *Nutrition* 2002;18:568-73.
- Walsh MC, Hunter GR, Sirikul B, Gower BA. Comparison of self-reported with objectively assessed energy expenditure in black and white women before and after weight loss. *Am J Clin Nutr* 2004;79:1013-9.
- Borg G. Borg's perceived exertion and pain scales. Champaign, IL: Human Kinetics, 1998.
- Futami J, Tanaka S, Yamamura C, Oka J, Ishikawa-Takata K, Kashiwazaki H. Measurement of energy expenditure by whole-body indirect human calorimeter—evaluation of validity and error factors. *J Jpn Soc Nutr Food Sci* 2003;56:229-36.
- Yamamura C, Tanaka S, Futami J, Oka J, Ishikawa-Takata K, Kashiwazaki H. Activity diary method for predicting energy expenditure as evaluated by a whole-body indirect human calorimeter. *J Nutr Sci Vitaminol (Tokyo)* 2003;49:262-9.
- Weir JB. New methods for calculating metabolic rate with special reference to protein metabolism. *J Physiol* 1949;109:1-9.
- Ministry of Health Labour and Welfare Japan. Dietary reference intakes for Japanese, 2005. Tokyo, Japan: Daiichi Shuppan, 2005.
- Meijer BP, Goris AH, Wouters L, Westerterp KR. Physical inactivity as a determinant of the physical activity level in the elderly. *Int J Obes Relat Metab Disord* 2001;25:935-9.
- Westerterp KR. Pattern and intensity of physical activity. *Nature* 2001;410:539.
- Ainsworth BE, Haskell WL, Whitt MC, et al. Compendium of physical activities: an update of activity codes and MET intensities. *Med Sci Sports Exerc* 2000;32:S498-504.
- Hughson RL, O'Leary DD, Betik AC, Hebestreit H. Kinetics of oxygen uptake at the onset of exercise near or above peak oxygen uptake. *J Appl Physiol* 2000;88:1812-9.
- Koga S, Poole DC, Shiojiri T, et al. Comparison of oxygen uptake kinetics during knee extension and cycle exercise. *Am J Physiol Regul Integr Comp Physiol* 2005;288:R212-20.
- Almuzaini KS, Potteiger JA, Green SB. Effects of split exercise sessions on excess post-exercise oxygen consumption and resting metabolic rate. *Can J Appl Physiol* 1998;23:433-43.
- Pate RR, Pratt M, Blair SN, et al. Physical activity and public health. A recommendation from the Centers for Disease Control and Prevention and the American College of Sports Medicine. *JAMA* 1995;273:402-7.
- Melanson EL, Sharp TA, Seagle HM, et al. Effect of exercise intensity on 24-h energy expenditure and nutrient oxidation. *J Appl Physiol* 2002;92:1045-52.



32. Saris WH, Schrauwen P. Substrate oxidation differences between high- and low-intensity exercise are compensated over 24 hours in obese men. *Int J Obes Relat Metab Disord* 2004;28:759–65.
33. Short KR, Sedlock DA. Excess postexercise oxygen consumption and recovery rate in trained and untrained subjects. *J Appl Physiol* 1997;83:153–9.
34. Hermansen L, Stensvold I. Production and removal of lactate during exercise in man. *Acta Physiol Scand* 1972;86:191–201.
35. Astrand P, Rodahl K. *Textbook of work physiology: physiological bases of exercise*. 2nd ed. New York, NY: McGraw-Hill Book Company, 1977.
36. Frey GC, Byrnes WC, Mazzeo RS. Factors influencing excess postexercise oxygen consumption in trained and untrained women. *Metabolism* 1993;42:822–8.
37. Leon AS, Casal D, Jacobs D Jr. Effects of 2,000 kcal per week of walking and stair climbing on physical fitness and risk factors for coronary heart disease. *J Cardiopulm Rehabil* 1996;16:183–92.
38. Crommett AD, Kinzey SJ. Excess postexercise oxygen consumption following acute aerobic and resistance exercise in women who are lean or obese. *J Strength Cond Res* 2004;18:410–5.





ORIGINAL ARTICLE

Physical activity level in healthy free-living Japanese estimated by doubly labelled water method and International Physical Activity Questionnaire

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Objective: To measure total energy expenditure (TEE) for normal healthy Japanese by the doubly labelled water (DLW), and to compare the physical activity level (PAL) among categories classified by the categories used in daily reference intake (DRI), Japan and the International Physical Activity Questionnaire (IPAQ).

Subjects and methods: A total of 150 healthy Japanese men and women aged 20- to 59-year-old living in four districts of Japan. TEE was measured by the DLW method, and the PAL was calculated from TEE divided by basal metabolic rate. Simultaneously with TEE measurement, the PAL was assessed employing the categories used in DRI, Japan and IPAQ.

Results: The average TEE and PAL were 10.78 ± 1.67 MJ/day and 1.72 ± 0.22 for males and 8.37 ± 1.30 MJ/day and 1.72 ± 0.27 for females, respectively. The subjects in the highly active categories assessed by both DRI and IPAQ showed significantly higher PAL compared with less active categories. However, PALs among light and moderate categories by DRI, and insufficient and sufficiently active by IPAQ were not significantly different.

Conclusions: In developed countries, highly active subjects could be assessed by a simple questionnaire. However, the questionnaire should be improved to clarify the sedentary to moderately active subjects by assessing carefully very light to moderate physical activity.

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Introduction

Assessment of total energy expenditure (TEE) is essential for establishing dietary reference intakes (DRI) and recommendations for physical activity. The doubly labelled water (DLW) method is recognized as the gold standard for measuring TEE in free-living conditions (Montoye *et al.*, 1996). Many studies using the DLW method have been performed, mainly in developed countries (Schulz *et al.*, 1994; Black *et al.*, 1996; Prentice *et al.*, 1996; Westerterp, 2003; Brooks *et al.*, 2004). However, the physical activity level (PAL) calculated as TEE divided by the basal metabolic rate (BMR) is expected to be different among populations with different lifestyles. The typical lifestyle of healthy

Japanese may have different amounts and types of physical activities compared with inhabitants of western countries. For example, many Japanese adults take trains or buses with walking to and from the stations or bus stops to work on weekdays, spending a relatively longer time commuting with a mean time of about 80 min/day on average (NHK Broadcasting Culture Research Institute, 2001). There are few people with body mass index (BMI) of 30 or more (0.8%) according to the National Nutrition Survey in Japan, 2003 (Ministry of Health, Labour and Welfare, Japan, 2006), categorized into obesity by the WHO classification (World Health Organization, 1997). The assessment of the PAL among normal healthy Japanese will serve as valuable data to consider the appropriate amount of physical activity. Then the primary purpose of the present study is to measure TEE for normal healthy Japanese living in four districts of Japan, chosen from sex and age categories.

Several indirect methods, for example, activity records, heart rate monitoring and accelerometer methods, have been used for estimating daily energy expenditure (Lamonte and Ainsworth, 2001; Vanhees *et al.*, 2005). The factorial methods and indirect measures, even if done well, provide estimates that are not sound and often inaccurate. However, a simple questionnaire to assess the PAL is required when we use DRI or provide recommendations for physical activity in the practical field of public health or epidemiological study with a larger sample. The second objective of this study is to compare the PAL among the categories classified according to the DRI in Japan (Ministry of Health, Labour and Welfare, Japan, 1999) and the International Physical Activity Questionnaire (IPAQ) (Murase *et al.*, 2002; Graig *et al.*, 2003) to develop a simple way to categorize the PAL.

Subjects and methods

Subjects

Study participants were Japanese men and women who were recruited from Kagoshima, Niigata, Fukuoka and Tokushima Prefectures in Japan. Subjects were recruited through health care centres in each prefecture or at four workplaces. In each location, five subjects from each sex and age category (20–29, 30–39, 40–49 and 50–59 years) were selected according to the following criteria: (1) in good health, (2) not pregnant or breast-feeding, (3) BMI less than 30 kg/m², (4) lived in their home prefecture 2 weeks before and during the study, (5) not on a weight-loss or treatment diet, (6) did not consume more than 40 g of alcohol per day and (7) did not engage in a physically demanding occupation. However, we could not select the subjects randomly from different levels of physical activity. One hundred and fifty-seven subjects volunteered for the present study. Data were collected from May to August 2003. Over the whole assessment period, subjects were carefully instructed to maintain their normal daily activities and eating patterns and to make no conscious effort to lose or gain weight.

Study protocol

This study was approved by the Ethical Committee of the National Institute of Health and Nutrition in Japan. All subjects gave their informed consent before the commencement of the investigations. TEE was estimated over the 14-day study period in free-living conditions using the DLW method. Body weight and height were measured in the fasting state before the dose of DLW and the last day of the study. To assess the food quotient (FQ) and their PAL, a self-administered diet history questionnaire (DHQ) and a questionnaire on physical activity were completed for all subjects before and after the study period. In this study, the questionnaire assessed before the study was used in the analysis. Diet history was asked using the DHQ (Sasaki *et al.*, 1998a, b). The DHQ is a validated 16-page questionnaire that recalls dietary habits over a 1-month period. Physical activity status was assessed using the last 7-day short version of the IPAQ Japanese version (Murase *et al.*, 2002; Graig *et al.*, 2003). Subjects were divided into three categories according to the IPAQ Scoring Protocol (Graig *et al.*, 2003). In addition, the total metabolic equivalents (total METs) were calculated as the sum of walking time multiplied by 3.3, the time of moderate activity multiplied by 4.0 and the time of vigorous activity multiplied by 8.0. The physical activity status was also assessed by the category used in the DRI, Japan sixth edition (Ministry of Health, Labour and Welfare, Japan, 1999).

DLW energy measurement

After providing a baseline urine sample, a single dose of approximately 0.06 g/kg body weight of ²H₂O (99.8 atom%, Cambridge Isotope Laboratories, Andover, MA, USA) and 0.14 g/kg body weight of H₂¹⁸O (10.0 atom%, Cambridge Isotope Laboratories) were given orally to each subject using a straw. Next, the container was rinsed twice with 50 ml of tap water provided from the same place where the subject lived. After dose administration, the subject refrained from eating and drinking over a 4-h equilibration period (4 h sampling) for measurement of total body water (TBW). Then, the second voided urine on the mornings of day 1 (the next day of DLW dose) and day 14 (at the same time as the void of day 1) was collected for the isotopic (²H and ¹⁸O) elimination rate. All urine samples except for baseline were collected by the participant, and the time of sampling was recorded. All samples were first stored by freezing at –40°C in airtight parafilm-wrapped containers, and then transported to the analytical facility for isotopic abundance analyses.

Gas samples for the Isotopes Ratio Mass Spectrometer (IRMS) were prepared by equilibration of urine sample with a gas. The gas for equilibration of ¹⁸O was CO₂ and that for ²H was H₂. Pt catalyst was used for equilibration of ²H. The isotopic analyses were conducted using machines of IRMS of DELTA Plus (Thermo Electron Corporation, Bremen, Germany) calibrated using Vienna Standard Mean Ocean

Water, 302B and Greenland Ice Sheet Precipitation standard provided from International Atomic Energy Agency. Each sample and the corresponding reference were analyzed in duplicate. The average standard deviations through the analyses were 0.5‰ for ^2H and 0.03‰ for ^{18}O . The difference in the two repeat measurements of the 10 same sets of urine samples was $1.6 \pm 3.9\%$. TEE was expressed as the mean TEE over the 13-day period of assessment.

Analytical calculations of isotopic abundance and TEE

The dilution space of each subject was obtained from urine (^2H and ^{18}O) enrichments using the following equation (Racette *et al.*, 1994).

$$N = [\text{WA}(\delta a - \delta t)] / [18.02a(\delta u - \delta b)]$$

where N (mol) is the dilution space, W (g) is the amount of tap water used to dilute the dose for analysis, A (g) is the amount of dose given to the subject, a (g) is the amount of dose diluted for analysis and δ (‰) is the isotopic abundance of the dose (a), tap water (t), urine sample at 4 h after dose (u) and baseline urine (b).

TBW (mol) was calculated as the mean of Nd (mol) divided by 1.041 for dilution space estimated by ^2H and No (mol) divided by 1.007 for dilution space estimated by ^{18}O .

$r\text{CO}_2$ were determined from the next equation.

$$r\text{CO}_2 = 0.4554 \times \text{TBW} \times (1.007 k_{\text{O}} - 1.041 k_{\text{H}})$$

where $r\text{CO}_2$ (mol/day) is the CO_2 production rate, TBW (mol) is the total body water, and k_{O} (per day) and k_{H} (per day) are the elimination rates of ^{18}O and ^2H , respectively (Wolfe, 1992; Racette *et al.*, 1994).

Each elimination rate (k) was calculated as follows:

$$k = [\ln(\delta_f - \delta_b) - \ln(\delta_i - \delta_b)] / t$$

where δ_i and δ_f are the isotopic abundance of the urine samples collected after dose administration on day 1 and the final day (day 14) of the assessment period, respectively; δ_b is the isotopic abundance of the urine sample background (baseline sample); and t represents the duration of the assessment period in days, which came to 13 in the present study.

Finally, TEE (kcal/day) calculation was performed using a modified Weir's formula (Weir, 1949) based on $r\text{CO}_2$ (mol/day) and FQ. FQ is calculated from DHQ, and average value of all present subjects (0.867 ± 0.03) was used in this calculation. This assumes that under conditions of perfect nutrient balance, the FQ must equal the respiratory quotient (RQ) (Black *et al.*, 1986; Jones and Leitch, 1993; Surrao *et al.*, 1998).

$$\text{TEE} = 3.9 \times (r\text{CO}_2 / \text{FQ}) + 1.1 \times (r\text{CO}_2)$$

PAL was calculated to be TEE/BMR. BMR was estimated according to the sixth Recommended Dietary Allowances for

Japanese (Ministry of Health, Labour and Welfare, Japan, 1999).

Statistics

Statistical analyses were performed with SPSS for Windows (version 13.0J; SPSS Inc., Chicago, IL, USA). All results are shown as mean \pm s.d. The comparison of TEE and PAL in sex, age and area was tested by three-way analysis of variance (ANOVA). The PAL in the categories of physical activity assessed by questionnaire was compared by one-way ANOVA. All statistical tests were regarded as significant when the $P < 0.05$.

Results

Of the 157 subjects who participated in this study, 150 were included in the analytic sample. Seven subjects were excluded because urine samples were not collected or kept properly.

Physical characteristics of all present subjects are shown in Table 1. Changes in body weight during the study period were -0.5 to 0.1 kg in each sex and age group. Males in their 30s and 40s decreased significantly body weight during the study period; however, their changes were within 3% of body weight at pre-examination. Of all the subjects, 6.8% of males and 13.2% of females were classified as lean (BMI less than 18.5 kg/m^2) and 36.5% of males and 14.5% of females were classified as obese (BMI more than 25 kg/m^2) according to the criteria for Japanese (Japan Society for the Study of Obesity, 2006). The average TBW was 36.9 ± 4.8 kg for males and 27.2 ± 3.5 kg for females. If we used 73.2% for the proportion of water in fat mass (Heyward and Wagner, 2004), the percent of fat mass was $24.7 \pm 6.0\%$ for males and $31.4 \pm 5.7\%$ for females.

Mean values of TEE and PAL were presented for each sex and age group in Table 2. The average TEE and PAL were 10.78 ± 1.67 MJ/day and 1.72 ± 0.22 for males, 8.33 ± 1.31 MJ/day and 1.72 ± 0.27 for females, respectively. The minimum of the average PAL values in sex and age groups was 1.58 ± 0.29 for females in their 20s and the maximum was 1.78 ± 0.20 for 30-year-old males. PAL for 20- to 29-year olds showed lower levels than the other age groups; however, there were no significant differences in TEE and PAL among age groups, sexes and areas.

Table 3 shows TEE and PAL among four categories assessed by DRI, Japan. The distribution of four categories across sex and age groups was uniform. Categories III (light heavy) and IV (heavy) had relatively higher PAL compared with categories I (light) and II (moderate). When we combined categories III and IV together ($n = 10$, $\text{PAL} = 1.87 \pm 0.29$) because of their small number, this category had significantly higher PAL compared with category I ($P = 0.036$).

Table 4 shows TEE and PAL across the three categories assessed by IPAQ. The distribution of these three categories

Table 1 Physical characteristics of all subjects

Age group	n	Age (year)	Height (cm)	Weight (kg)			P ^a	BMI (kg/m ²)	TBW (kg)
				Pre	Post	Difference			
<i>Male</i>									
20–29	19	25.1±2.7	171.2±6.1	65.0±11.3	64.8±11.0	-0.2±1.0	0.354	22.1±3.0	38.1±5.3
30–39	18	33.8±3.3	168.9±5.2	67.4±10.7	66.9±10.6	-0.5±0.7	0.012	23.6±3.7	36.0±4.9
40–49	18	43.8±2.5	170.4±7.5	70.8±8.9	70.3±8.8	-0.5±0.6	0.008	24.4±2.6	37.9±4.6
50–59	19	53.3±2.5	166.5±5.4	67.5±7.9	67.3±7.8	-0.2±0.8	0.415	24.3±2.4	35.5±3.9
Total	74	39.0±11.1	169.2±6.3	67.6±9.8	67.3±9.7	-0.3±0.8	0.001	23.6±3.0	36.9±4.8
<i>Female</i>									
20–29	17	24.9±2.7	160.6±7.2	54.1±8.9	53.9±9.0	-0.2±0.6	0.303	20.9±3.0	27.8±3.9
30–39	22	33.7±2.8	159.6±4.3	55.0±8.0	55.1±8.2	0.1±0.8	0.705	21.6±3.0	28.0±3.9
40–49	22	44.0±3.0	157.0±6.1	53.9±7.4	53.9±7.6	-0.1±0.7	0.669	21.9±2.8	27.0±3.2
50–59	15	52.7±2.0	153.9±4.5	53.9±4.9	53.9±4.7	0.1±0.5	0.712	22.7±1.5	2.55±2.2
Total	76	38.5±10.2	157.9±6.0	54.3±7.4	54.2±7.5	0.0±0.7	0.734	21.8±2.7	27.2±3.5

Abbreviations: BMI, body mass index; TBW, total body water by doubly labelled method.

Values are means ± s.d.

^aP-value for paired t-test for body weight at pre- and post-examination.

Table 2 TEE and PAL by sex and age group

Age group	N	TEE (MJ/day)	PAL
<i>Male</i>			
20–29	19	11.01±1.56	1.72±0.29
30–39	18	11.11±2.20	1.78±0.20
40–49	18	10.80±1.52	1.67±0.20
50–59	19	10.23±1.30	1.71±0.14
Total	74	10.78±1.67	1.72±0.22
<i>Female</i>			
20–29	17	8.29±1.51	1.58±0.29
30–39	22	8.53±1.65	1.76±0.29
40–49	22	8.40±0.98	1.75±0.22
50–59	15	8.17±0.92	1.77±0.22
Total	76	8.37±1.30	1.72±0.30

Abbreviations: PAL, physical activity level; TEE, total energy expenditure.

Sex difference: $P=0.799$.

Age group difference: $P=0.196$.

Area group difference: $P=0.336$.

was not significantly different across sex and age groups. The insufficiently active (category I) and the sufficiently active (category II) groups had significantly lower PAL than the highly active group (category III), though there were few in the highly active group (category III). However, PAL did not differ significantly between the insufficiently active and the sufficiently active categories. Farther, we divided the subjects equally among the three groups according to the total METs assessed by IPAQ and PAL measured by the DLW method, respectively. As the results, only 36% of the subjects were classified into the same level of groups by both IPAQ and DLW data, 31% of them were classified in the lower groups and another 33% were classified into the higher groups divided by IPAQ compared with groups divided by PAL measured by the DLW method.

Discussion

In the present study, average PAL was 1.72 for males and 1.71 for females, respectively. When we compared PAL among the physical activity categories assessed by DRI, Japan and IPAQ, highly active groups showed significantly higher PAL; however, PAL in the lowest and moderate groups did not differ significantly.

The overall average PAL in the present study was similar to the average PAL for the general population of western countries (Schulz *et al.*, 1994; Black *et al.*, 1996; Prentice *et al.*, 1996; Westerterp, 2003), but relatively higher than the sedentary Japanese in the previous studies (Ebine *et al.*, 2002; Peng *et al.*, 2005). Ebine *et al.* (2002) reported PAL of 1.63 for 10 Japanese male students (24.2±1.8 years), and Peng *et al.* (2005) reported that of 1.62 for middle-aged sedentary women (49.4±6.0 years). We measured previously TEE for simulated sedentary lifestyle according to the data on NHK's National time use survey (NHK Broadcasting Culture Research Institute, 2001) and The National Nutrition Survey (The Ministry of Health, Labour and Welfare, Japan, 2000) by indirect human calorimeter, and the PAL of this study was 1.51±0.12 (Tanaka *et al.*, 2003). The relatively higher proportion of the present subjects who participated in regular physical activity (more than twice a week and more than 30 min at a time) compared with the National Nutrition Survey (Ministry of Health, Labour and Welfare, Japan, 2006) is one of the potential reasons for higher PAL. However, the subjects with active exercise habits did not show significantly higher PAL compared with non-exercisers, though exercisers engaged in exercise 227±141 min/week on average. Schoeller *et al.* (1997) and Weinsier *et al.* (2002) suggested that a PAL of around 1.7 might be required to prevent weight regain in post-obese females. Brooks *et al.* (2004) also suggested that most adults maintaining a BMI in

Table 3 TEE and PAL among categories according to Dietary Reference Intake in Japan

		n	TEE (KJ/day)	PAL	P-value
I (light)	Mostly sedentary position doing reading, studying and talking, or sitting or lying position watching TV and listening to music with 1-h slow walk for walking and shopping	77	9.63 ± 1.90	1.68 ± 0.21	0.070
II (moderate)	Mostly sedentary position doing clerical work and housework with 2-h walk for commuting and shopping, and long hours of standing while meeting people doing housework	63	9.29 ± 1.87	1.74 ± 0.25	
III (light heavy)	In addition to moderate activity (II), 1 h of brisk walk, bicycle and other vigorous physical activity; mostly standing during farming, fishing with heavy muscular work for 1 h a day	6	9.64 ± 2.04	1.85 ± 0.31	
IV (heavy)	Engaged in heavy muscular work for about 1 h a day such as hard training, carrying lumbers, farming in the busy season and so on	4	12.31 ± 1.21	1.91 ± 0.30	

Abbreviations: PAL, physical activity level; TEE, total energy expenditure. P-values were calculated by one-way analysis of variance for PAL.

Table 4 TEE and PAL among categories of International Physical Activity Questionnaire

Group	n	TEE (KJ/day)	PAL	P-value
Category 1 (insufficiently active)	82	9.49 ± 1.90	1.70 ± 0.24*	0.016
Category 2 (sufficiently active)	61	9.48 ± 1.88	1.75 ± 0.23	
Category 3 (highly active)	7	11.13 ± 2.14	1.95 ± 0.24	

Abbreviations: PAL, physical activity level; TEE, total energy expenditure. *Significantly different from category III (highly active). P-value was estimated by one-way analysis of variance for PAL.

the healthful range had PAL values >1.6. The higher proportion of subjects with lean to normal BMI (74%) in the present study might partly explain the relatively higher PAL in the present subjects.

In the public health status and epidemiological study, a simple questionnaire to assess the PAL is required. In the present study, we used the questionnaire in the DRI, Japan sixth edition and IPAQ. Highly active groups assessed both by DRI and IPAQ showed significantly higher PAL, though there were few subjects in these groups. In IPAQ, the highly active category consisted of subjects with 1500 met-min/week by vigorous activity or by a combination of walking, moderate or vigorous activities. In DRI, heavy is categorized as persons engaging in more than 1 h a day of muscular work. Among the healthy normal subjects in developed countries, vigorous physical activity could be easily assessed by questionnaire, and subjects who participated in these activities showed higher PAL compared to those with little or no vigorous physical activity.

There were no significant differences in PAL between light and moderate categories in DRI, or between insufficient active and sufficient active categories in IPAQ. There was a clear overlap of measured PAL in these lower two categories. The lower categories both by IPAQ and DRI are divided mainly by the duration of light to moderate physical activity. The duration of these activities is thought to pose more difficulty than vigorous activity in terms of response, and this made it difficult to categorize the less active population.

However, the duration of these activities had much impact on PAL among subjects with the normal PAL range, because they spent an average 9% of their active time engaging in high-intensity activity, and the distribution of time spent in activities of low and moderate intensity determines the activity level (Westerterp, 2001).

In addition, we could not find any differences in PAL between exercisers and non-exercisers. In one study of weight reduction (Kempen *et al.*, 1995), there were no significant differences in PAL and energy expended on physical activity between diet only and diet plus exercise treatment groups. This was considered the result of partial compensation in physical activity for the addition of training to dietary treatment during the non-exercise part of the day. It also suggests the importance of assessing non-exercise physical activity. Other recent studies also point out the importance of the proportion of light to moderate activity on TEE (Westerterp, 2003; Levine, 2004; Levine *et al.*, 2005). In a future study, we should clarify the physical activity that has much effect on the TEE among sedentary to moderately active subjects, and the method of assessing accurately these physical activities.

One of the most important limitations of the present study is that BMR was predicted, not measured. Calculation of PAL using predicted BMR could lead to some error for individuals. This may have caused a wide variation in PAL among each category divided by sex and age groups or the questionnaire on physical activity. However, we thought the use of prediction equations for BMR would generate the present result. Many prediction equations are available for estimating BMR, but their applicability to other ethnic groups is uncertain (Hayter and Henry, 1993; Frankenfield *et al.*, 2005). Ganpule *et al.* (2007) suggested recently that the use of FAO/WHO/UNU equations overestimated BMR among Japanese when compared with measured BMR. The predictive equations used in the present study were established based on the large database obtained under strictly controlled protocol, and have been reported to be accurate for Japanese (Taguchi *et al.*, 2001; Rafamantanantsoa *et al.*,

2003; Yamamura *et al.*, 2003). Therefore, the error from using predicted BMR seems to be modest.

Another limitation is that subjects were not selected randomly from different activity levels. This caused unequal distribution of subjects across activity categories, which may have caused lower statistical power in comparison among activity categories.

In conclusion, the present study clarified the PAL among healthy normal Japanese and compared the PAL among the categories assessed by a simple questionnaire. In developed countries, highly active subjects seem to be easily assessed by a simple questionnaire. However, assessment of the PAL among sedentary to moderately active subjects is more complete, and must be addressed in a separate study.

References

- Black AE, Coward WA, Cole TJ, Prentice AM (1996). Human energy expenditure in affluent societies: an analysis of 574 doubly-labelled water measurements. *Eur J Clin Nutr* 50, 72–92.
- Black AE, Prentice AM, Coward WA (1986). Use of food quotients to predict respiratory quotients for the doubly labelled water method of measuring energy expenditure. *Hum Nutr Clin Nutr* 40C, 381–391.
- Brooks GA, Butte NF, Rand WM, Flatt JP, Caballero B (2004). Chronicle of the Institute of Medicine physical activity recommendation: how a physical activity recommendation came to be among dietary recommendations. *Am J Clin Nutr* 79 (Suppl), 921S–930S.
- Ebine N, Shimada M, Tanaka H, Nishimuta M, Yoshitake Y, Saitoh S *et al.* (2002). Comparative study of total energy expenditure in Japanese men using doubly labeled water method against activity record, heart rate monitoring, and accelerometer methods. *Jpn J Phys Fitness Sport Med* 51, 151–164. (in Japanese with English abstract).
- Frankenfield D, Roth-Yousey L, Compher C (2005). Comparison of predictive equations for resting metabolic rate in healthy nonobese and obese adults: a systematic review. *J Am Diet Assoc* 105, 775–789.
- Ganpule AA, Tanaka S, Ishikawa-Takata K, Tabata I (2007). Inter-individual variability in sleeping metabolic rate in Japanese subjects. *Eur J Clin Nutr* advance online publication.
- Graig CL, Marshall AL, Sjostrom M, Bauman AE, Booth ML, Ainsworth BE *et al.* (2003). International physical activity questionnaire: 12-country reliability and validity. *Med Sci Sports Exerc* 35, 1381–1395.
- Hayter JE, Henry CJ (1993). Basal metabolic rate in human subjects migrating between tropical and temperate regions: a longitudinal study and review of previous work. *Eur J Clin Nutr* 47, 724–734.
- Heyward VH, Wagner DR (2004). Body composition reference methods. In: *Applied Body Composition Assessment*. Human Kinetics. pp 27–47.
- Japan Society for the Study of Obesity (2006). Guideline for the treatment of obesity. *J Jpn Soc Study of Obes* 32, 10–15. (in Japanese).
- Jones PJH, Leitch CA (1993). Validation of doubly labeled water for measurement of calorie expenditure in collegiate swimmers. *J Appl Physiol* 74, 2909–2914.
- Kempen KPG, Saris WHM, Westerterp KR (1995). Energy balance during an 8-wk energy-restriction diet with and without exercise in obese women. *Am J Clin Nutr* 62, 722–729.
- Lamonte MJ, Ainsworth BE (2001). Quantifying energy expenditure and physical activity in the context of dose response. *Med Sci Sports Exerc* 33, S370–S378.
- Levine JA (2004). Nonexercise activity thermogenesis (NEAT): environment and biology. *Am J Physiol Endocrinol Metab* 286, E675–E685.
- Levine JA, Lanningham-Foster LM, McCrady SK, Krizan AC, Olson LR, Kane PH *et al.* (2005). Interindividual variation in posture allocation: possible role in human obesity. *Science* 307, 584–586.
- Ministry of Health, Labour and Welfare, Japan (1999). *Recommended Dietary Allowances for the Japanese* 6th edn. Ministry of Health, Labour and Welfare, Japan.
- Ministry of Health, Labour and Welfare, Japan (2000). *The National Nutrition Survey, Japan, 1998*. Ministry of Health, Labour and Welfare, Japan.
- Ministry of Health, Labour and Welfare, Japan (2006). *The National Nutrition Survey in Japan, 2003*. Ministry of Health, Labour and Welfare, Japan.
- Montoye HJ, Kemper HCG, Saris WHM, Washburn RA (1996). *Measuring Physical Activity and Energy Expenditure*. Human Kinetics, Champaign, IL.
- Murase N, Katsumura T, Ueda C, Inoue S, Shimomitsu T (2002). International standardization of physical activity. *Kosei no Shihyo* 49, 1–9. (in Japanese).
- NHK Broadcasting Culture Research Institute (2001). *National Time Use Survey 2000 Report*. NHK Service Center: Tokyo, Japan.
- Peng H, Saito S, Hikihara Y, Ebine N, Yoshitake Y (2005). Energy expenditure, body composition and maximal oxygen uptake in middle-aged Japanese women who have long-term habits of exercising. *Jpn J Phys Fitness Sports Med* 54, 237–248. (in Japanese with English abstract).
- Prentice AM, Black AE, Coward WA, Cole TJ (1996). Energy expenditure in overweight and obese adults in affluent societies: an analysis of 319 doubly-labelled water measurements. *Eur J Clin Nutr* 50, 93–97.
- Racette SB, Schoeller DA, Luke AH, Shay K, Hnilicka J, Kushner RF (1994). Relative dilution spaces of ²H- and ¹⁸O-labeled water in humans. *Am J Physiol* 267, E585–90.
- Rafamantanantsoa HH, Ebine N, Yoshioka M, Yoshitake Y, Tanaka H, Saitoh S *et al.* (2003). The role of exercise physical activity in varying the total energy expenditure in healthy Japanese men 30 to 69 years of age. *J Nutr Sci Vitaminol* 49, 120–124.
- Sasaki S, Yanagibori R, Amano K (1998a). Self-administered diet history questionnaire developed for health education: a relative validation of the test-version by comparison with 3-day diet record in women. *J Epidemiol* 8, 203–215.
- Sasaki S, Yanagibori R, Amano K (1998b). Validity of a self-administered diet history questionnaire for assessment of sodium and potassium. Comparison with single 24-h urinary excretion. *Jpn Circ J* 62, 431–433.
- Schoeller DA, Shay K, Kushner RF (1997). How much physical activity is needed to minimize weight gain in previously obese women? *Am J Clin Nutr* 66, 551–556.
- Schulz LO, Schoeller DA (1994). A compilation of total daily energy expenditures and body weights in healthy adults. *Am J Clin Nutr* 60, 676–681.
- Surrao J, Sawaya AL, Dallal GE, Tsay R, Roberts SB (1998). Use of food quotient in human doubly labeled water studies: comparable results obtained with 4 widely used food intake methods. *J Am Diet Assoc* 98, 1015–1020.
- Taguchi M, Higuchi M, Oka J, Yoshiga C, Ishida Y, Matsushita M (2001). Basal metabolic rate in Japanese female endurance athletes. *Jpn J Nutr* 59, 127–134. (in Japanese with English abstract).
- Tanaka S, Tanaka C, Futami J, Oka J, Ishikawa-Takata K, Kashiwazaki H (2003). Twenty-four-hour energy expenditure of adults in sedentary life measured using indirect human calorimeter. *J Jpn Soc Nutr Food Sci* 56, 291–296.
- Vanhees L, Lefevre J, Philippaerts R, Martens M, Huygens W, Troosters T *et al.* (2005). How to assess physical activity? How to assess physical fitness? *Eur J Cardiovasc Prev Rehabil* 1, 102–114.

- Weinsier RL, Hunter GR, Desmond RA, Byrne NM, Zuckerman PA, Darnell BE (2002). Free-living activity energy expenditure in women successful and unsuccessful at maintaining a normal body weight. *Am J Clin Nutr* 75, 499–504.
- Weir JBDV (1949). New methods for calculating metabolic rate with special reference to protein metabolism. *J Physiol* 109, 1–9.
- Westertep KR (2001). Pattern and intensity of physical activity. *Nature* 410, 539.
- Westertep KR (2003). Impacts of vigorous and non-vigorous activity on daily energy expenditure. *Proc Nutr Soc* 62, 645–650.
- Wolfe RR (1992). Measurement of total energy expenditure using the doubly-labeled water method. In: Wolfe RR (ed). *Radioactive and Stable Isotope Tracers in Biomedicine*. Wiley-Liss Inc.: New York. pp 207–233.
- World Health Organization (1997). *Obesity: Preventing and Managing the Global Epidemic*. World Health Organization: Geneva.
- Yamamura C, Tanaka S, Futami J, Oka J, Ishikawa-Takata K, Kashiwazaki H (2003). Activity diary method for predicting energy expenditure as evaluated by a whole-body indirect human calorimeter. *J Nutr Sci Vitaminol* 49, 262–269.

ボディービルダーの基礎代謝量と身体活動レベルの検討

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Basal Metabolic Rate and Physical Activity Level in Bodybuilders

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We measured the basal metabolic rate (BMR), fat-free mass (FFM) and physical activity level (PAL) of well-trained bodybuilders as typical athletes with muscular development by resistance training in order to examine the standard BMR and PAL ranges for athletes. The subjects were 14 bodybuilders (mean \pm SD age : 36.8 \pm 9.1 y.; height : 171.6 \pm 6.2 cm ; weight : 77.1 \pm 7.6 kg ; FFM : 67.6 \pm 6.8 kg) who each trained for an average of 7.5 h per week. BMR was measured by using a Douglas bag, the oxygen and carbon dioxide concentrations were analyzed by mass spectrometry, and FFM was measured by dual X-ray energy absorptiometry. PAL was measured by the doubly labeled water method for 7 subjects selected from the 14 bodybuilders. BMR/FFM was 25.4 \pm 2.1 kcal/kg of FFM/day. Total energy expenditure (TEE) was 3,432 \pm 634 kcal, and PAL calculated as TEE divided by BMR was 2.00 \pm 0.21. The FFM value needs to be considered when evaluating a standard BMR range, and both training and daily physical activity levels should be considered when evaluating a standard PAL range.

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Key words : basal metabolic rate, bodybuilder, physical activity level, fat-free mass

緒 言

「日本人の食事摂取基準 (2005年版)」¹⁾ (Dietary Recommended Intake : DRI) では推定エネルギー必要量 (Estimated Energy Requirement : EER) を、基礎代謝量 (Basal Metabolic Rate : BMR) と身体活動レベル (Physical Activity Level : PAL) を用いて算定している。DRIは健康な個人または集団を対象としており、極端にエネルギー消費量の多いスポーツ選手や高い身体活動量を有する者、傷病者等を含んでいないため、スポーツ選手のEER推定のためには、スポーツ選手の基礎代謝基準値及びPALの値の設定が必要となる。そのため、国立スポーツ科学センター (Japan Institute of Sports Science : JISS) は、日本人スポーツ選手を対象とした基準値策定に関するプロジェクトを立ち上げ、スポーツ選手を対象としたBMRとPALについて報告した^{2,3)}。

BMRについては、JISSのプロジェクトではDRIに

示されている基礎代謝基準値と日本人の一般的な体格から除脂肪量 (Fat Free Mass : FFM) あたりのBMR (BMR/FFM) を28.5% kcal/kgFFM/dayと設定した。これは、これまでの報告においてボート選手及びランナーと非運動群の間でFFMあたりのBMRに差が見られず、運動習慣や運動種目による差がなかったという研究報告⁴⁾を根拠としたものである。一方で、Weinsier, R. L.ら⁵⁾はBMRとFFMを測定した文献をレビューし、FFMの大きく異なる対象ではBMR/FFMが小さくなることを報告している。FFMが異なる対象でFFMあたりのBMRが異なる理由として、FFMに含まれる組織中の代謝率の高い組織と低い組織の割合の影響があると言われている^{5~8)}。JISSが設定したBMR/FFMの値は、一般人の値からの推定値であり、一定のBMR/FFMの値が各種スポーツ選手に適用可能かについては、各種のスポーツ選手について実測したBMRの値のデータを収集したうえで、検討する必要がある

キーワード：基礎代謝量, ボディービルダー, 身体活動レベル, 除脂肪量

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ある。そこで、本研究の第一の目的として、FFMの多い選手としてボディービルダーを対象にBMRの測定を行い、スポーツ選手における基礎代謝基準値について検討することとした。なお、BMRは、生命維持に必要な生理化学的反応を行うための覚醒安静時の最小エネルギーと定義され、実際には食後12時間以上経過した早朝空腹時に仰臥安静・覚醒状態で適正な室温において測定される^{9,10)}。しかし、食事摂取基準における基礎代謝基準値の算定根拠となったデータは、宿泊して起床後すぐに測定したデータと、測定当日に測定室に入室し30分程度の仰臥安静後、測定されたデータが混在している。そこで本研究においては、BMRを測定当日に測定場所へ来所した後移動し30分の仰臥安静後に空腹状態で測定した。また、引用する文献についても測定日の宿泊の有無を問わず、早朝空腹時に十分な安静後に測定した値をすべてBMRとして比較することとした。

PALについては、DRIでは二重標識水(Doubly Labeled Water: DLW)法を用いて測定したエネルギー消費量の測定値に基づいて、3段階に分類されている¹⁾。スポーツ選手のPALの設定にあたって、JISSのプロジェクトはスポーツ選手を対象とした先行研究におけるPALの値を基に、持久系、瞬発系、球技系、その他の種目カテゴリー別にオフトレーニング期と通常トレーニング期の期ごとにPALの値を示した^{2,3)}。瞬発系、球技系についてはスポーツ選手の値の平均値、持久系ではトレーニング時間が長いことと、体重が比較的軽い選手が多いことから既存研究のデータの上限值が採用されている。これまで測定されている選手のデータは、まだ限られた種目であり、特に日本人選手を対象としたものは少ない。そこで本研究の第二の目的として、レジスタンストレーニングを主として実施しているボディービルダーについてDLW法を使用してPALを測定し、スポーツ選手における身体活動レベルについて検討することとした。本研究で対象としたボディービルダーは、筋力の高度な発達を目的として、ほぼ毎日レジスタンストレーニングを実施している。トレーニング内容は他競技が筋力向上のために行っている内容とほぼ同じであるが、練習時間は他種目に比べ比較的短い対象である。

方 法

1. 対象

対象者は、22～55歳の健康な成人男性で、週3～5回のトレーニングを行い、定期的に大会に参加しているボディービルダー14名である。全員、日本ボディービルディング連盟において薬物の使用がないことが確

認されている。トレーニング量は週に平均 4.6 ± 0.9 回、1回のトレーニング時間は平均 99 ± 21 分で、週あたりの平均トレーニング時間は 7.5 ± 2.4 時間であった。測定期間は冬季であり、通常トレーニング期であった。調査期間中は、できるだけ体重変動のない生活をするように指示し、それ以外は、通常の食事、トレーニングをするように指示した。

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2. 測定項目

(1) 身体組成

身長及び体重は早朝空腹時に測定した。体脂肪率及びFFMはDXA法(Dual Energy X-ray Absorptiometry)(QDR-4500, Hologic, USA)により測定した。

(2) 基礎代謝量(BMR)

被験者は測定前夜の午後9時までに通常通りの夕食を済ませ、測定当日に朝食をとらずに測定場所に到着した後、9時から23～25℃の快適な室温で30分以上仰臥させた。測定場所への移動はできるだけ静かに行うように指示したが、移動による活動量は把握しなかった。その後、仰臥位のまま10分間の呼吸を1分の間隔を置いてダグラスバッグに2回採集した。呼吸は直ちに質量分析計(ARCO-1000, アルコシステム, 千葉)を用いて酸素及び二酸化炭素量の濃度を分析した。その後、乾式ガスメーター(DC-5, シナガワ, 東京)にて呼吸量を測定した。それらの測定値から酸素摂取量(VO_2)と二酸化炭素排出量(VCO_2)を算出し、Weir¹¹⁾の式により1分あたりのBMRを求めた。さらに1,440(分)に換算し、1日あたりのBMR(kcal/day)とした。BMRは体重(Body Weight: BW)あたり(kcal/kg BW/day)及びFFMあたり(kcal/kg FFM/day)でも算出した。

(3) 身体活動レベル(PAL)の測定

対象者のうち7名について、DLW法を用いて総エネルギー消費量(Total Energy Expenditure: TEE)を測定し、それをBMRで除してPALを算出した。DLW法は、現時点では自由生活下での身体活動量を最も精度が高く評価できる方法とされており、ヒューマンカロリメータとの比較により検討した正確度は約±4%とされている¹²⁾。

10% ^{18}O (太陽日酸, 東京)と99.9% 3H (Cambridge Isotope Laboratories, Inc., USA)を混合した液により、体重あたり0.14gの ^{18}O と0.06gの 3H を投与した。投与前、投与後4及び5時間後、翌日(2回)と8日後(2

Table 1 Physical characteristics and basal metabolic rate among body builders

	N	Age (yr.)	Height (cm)	BW (kg)	FFM (kg)	BMR (kcal)	BMR/BW (kcal/kg)	BMR/FFM (kcal/kg)
20-29yrs	3	24.0±3.5	172.3±7.6	80.0±11.5	70.7±11.0	1,843±264	23.0±0.4	26.1±1.2
30-39yrs	5	35.6±2.6	174.8±4.6	80.2±6.3	69.4±5.1	1,722±198	21.5±1.9	24.8±2.1
40-49yrs	5	41.8±2.5	169.5±6.4	72.6±6.4	65.0±6.0	1,590±171	21.9±1.4	24.5±1.7
50-59yrs	1	56	164.3	75.4	62.7	1,873	24.8	29.9
Total	14	36.8±9.1	171.6±6.2	77.1±7.6	67.6±6.8	1,712±209	22.2±1.6	25.4±2.1

BW : body weight, FFM : fat free mass assessed by dual energy X-ray absorptiometry, BMR : basal metabolic rate per day

回)の同時刻に採尿した。サンプルは密閉した状態で、分析まで-30℃で保存した。²HはPtを触媒としてH₂ガスで、¹⁸OはCO₂ガスで平衡法により前処理を行った後、²H、¹⁸Oの安定同位体比を質量比分析計(Finnigan Delta Plus, Thermo Fisher Scientific, USA)により分析した。分析の測定誤差は、²Hで0.5%、¹⁸Oで0.03%である。また、10名のサンプルを2回分析した際の誤差は、1.6±3.9%であった。

身体水分量(Total Body Water: TBW)は投与後4及び5時間後の尿中の安定同位体濃度から、 $N = [WA(\delta a - \delta t)] / [18.02a(\delta s - \delta b)]$ の式により求めた。ただし、Nは²H及び¹⁸Oの希釈容積(mol)、Wは同位体比分析の際にDLWを希釈するのに用いた飲料水の量(g)、Aは投与したDLWの量(g)、 δa は希釈したDLWにおける同位体比、 δt はDLWの希釈に用いた飲料水の同位体比、aは同位体比分析の際に飲料水で希釈されたDLWの量(g)、 δs は尿中の同位体比、 δb はベースラインでの尿の同位体比である。TBWは、²HのNを1.041で除したものと、¹⁸OのNを1.007で除したものの平均値とした。

測定期間中の安定同位体の減衰率を $k = [\ln(\delta f - \delta b) - \ln(\delta i - \delta b)] / t$ から求めた。 δf は8日後の尿中の同位体比、 δb はベースライン尿の同位体比、 δi は投与翌日の同位体比、tは測定期間である。二酸化炭素の排出量は、 rCO_2 (mol/day) = 0.4554TBW (1.007ko - 1.041kh)により求めた。koは¹⁸Oの減衰率、khは²Hの減衰率である。DLW法においては、全期間を通じた呼吸商(Respiratory Quotient: RQ)の直接測定が不可能なため、体重変動のないエネルギーバランスのとれた状態では食事調査より求めた食物商(Food Quotient: FQ)¹⁰⁾を使用して、TEEを求めることが最も適切とされている¹⁰⁾。そこで、TEEはDLW法による身体活動量の調査期間中の食事調査より求めたFQを用いて、Weir¹¹⁾の式により求めた。

(4) 食事調査

PALの測定を行った7名については、測定期間中に3日間の食事記録法により食事調査を行った。食事の

記録内容は、調査終了後に管理栄養士が面接により確認した。摂取栄養素量は、エクセル栄養君 ver.4.0(建帛社、東京)により計算した。補助食品については、各メーカーの資料により栄養素量を求め、追加した。

(5) 統計処理

すべてのデータは、平均値と標準偏差(mean ± SD)で表した。本研究で得られた各指標の統計処理は、SPSS13.0 J for Windows (SPSS Inc., USA)にて行った。

結 果

1. 基礎代謝量(BMR)

14名のボディービルダーの身体特性及びBMRをTable 1に示した。全対象における1日あたりのBMRは、1日あたりでは1,712 ± 209kcal/day、BW 1 kgあたりでは22.2 ± 1.6kcal/kg/day、FFMあたりでは25.4 ± 2.1kcal/kgFFM/dayであった。年代別に分けると、各年代の人数は少ないものの、身体特性、BMRとも一定した傾向は認められなかった。

2. 身体活動レベル(PAL)

ボディービルダー7名の身体特性、BMR、TEE、PAL、歩数及び1週間あたりのトレーニング時間(分)をTable 2に示した。DLW法で測定した1日のTEEは、3,432 ± 634kcal/dayであった。TEEとBMRから計算したPALは、2.00 ± 0.21であった。また、総エネルギー摂取量(Total Energy Intake: TEI)は1日あたりでは3,268 ± 663kcal/day、体重あたりでは43.3 ± 6.8kcal/kg/dayであった。タンパク質、脂質、炭水化物の摂取量は、161 ± 55g、79 ± 25g、429 ± 130g、FQは0.923であった。TEIとBMRから求めたTEI/BMRは1.93 ± 0.24であった。

考 察

本研究で、高度にトレーニングされたボディービルダー男性のBMRを測定したところ、BMR/FFMは25.4 ± 2.1kcal/kgFFM/dayであり、JISSが設定した値(28.5kcal/kgFFM/day)^{2,3)}より低いことをみとめた。また、週に約8時間のトレーニングを行っているボデ