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Twenty-four–hour analysis of elevated energy expenditure after physical activity in a metabolic chamber: models of daily total energy expenditure[1–3]

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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 (ΔPAEE) to estimate total EE. However, the magnitude of elevated post–physical activity energy expenditure (EPEE) under normal daily living conditions has not been examined.

Objective: We examined the effects of EPEE 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 (± 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 EPEEs on the M-day and the V-day did not significantly contribute to increasing 24-h EE. Relative EPEEs to ΔPAEEs were 6.2 ± 13.9% (M-day) and 5.1 ± 9.2% (V-day). However, EPEE/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 EPEE 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 EPEE 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 postexercise 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 EPEE). There are no data on the effect of EPEE 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 (ΔPAEE) 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.

TABLE 1
Physical characteristics of the subjects[1]

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

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

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 °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 ± 0.5% (mean ± SD) over 6 h and 99.4 ± 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.

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 chamber[1]

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 (ΔPAEE) in the US and Canada DRI equation, ΔPAEE 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 ΔPAEE, 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

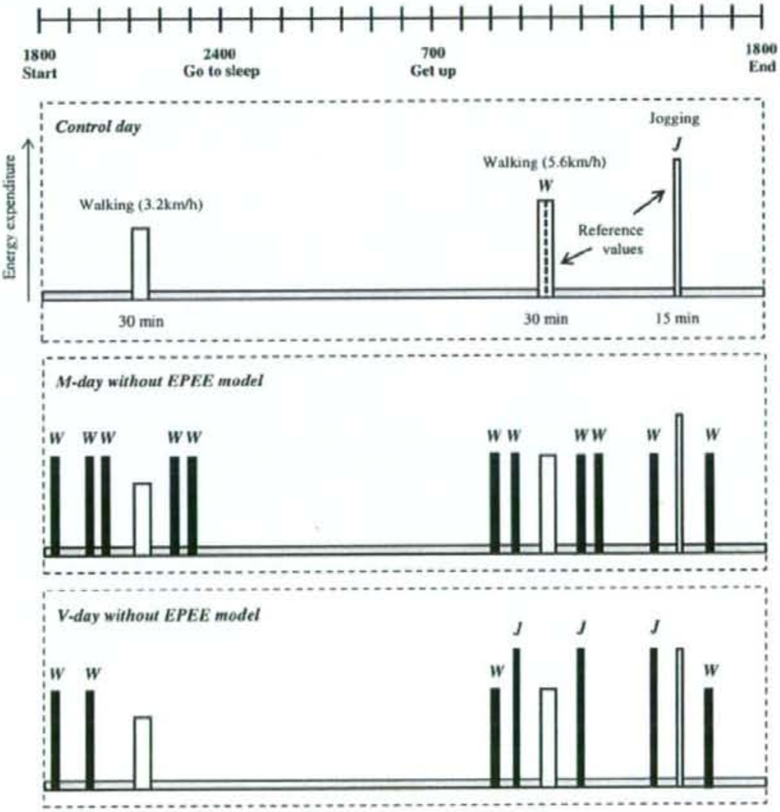

FIGURE 1. Model for predicting 24-h energy expenditure (EE) without elevated post–physical activity energy expenditure (EPEE). M-day, a day with high-frequency, moderate-intensity physical activity; V-day, a day with high-frequency, vigorous-intensity physical activity; W, reference energy expenditure 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.

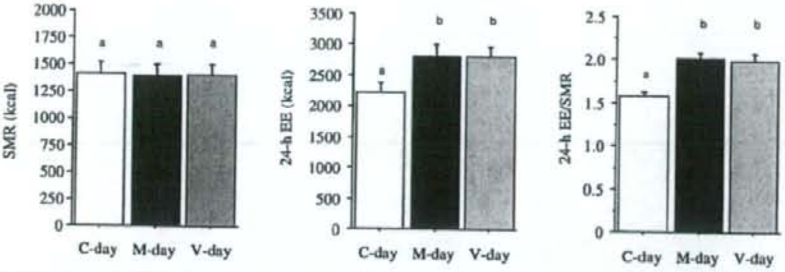

FIGURE 2. Sleeping metabolic rate (SMR), 24-h energy expenditure (24-h EE), and 24-h EE/SMR for each modeling day ($n = 11$). C-day, a control day; M-day, a day with high-frequency, moderate-intensity physical activity; V-day, a day with high-frequency vigorous-intensity physical activity. Error bars 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 ± 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 ± 5.1%, 33.3 ± 7.0%, and 65.0 ± 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 ± 2.7% and 1.0 ± 0.8%. Furthermore, relative EPEEs to ΔPAEEs were 6.2 ± 13.9% and 5.1 ± 9.2%, respectively.

Mean percentages of spontaneous physical activity during prescribed physical activity (slow walking, brisk walking, and jogging) for the 3 d were ≈100%. There were no significant differences in mean percentages of spontaneous physical activity for resting periods for the 3 d (C-day: 38.1 ± 9.0%; M-day: 43.8 ± 5.6%; V-day: 40.4 ± 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-day[1]

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

[1] All values are $\bar{x}$ ± 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.

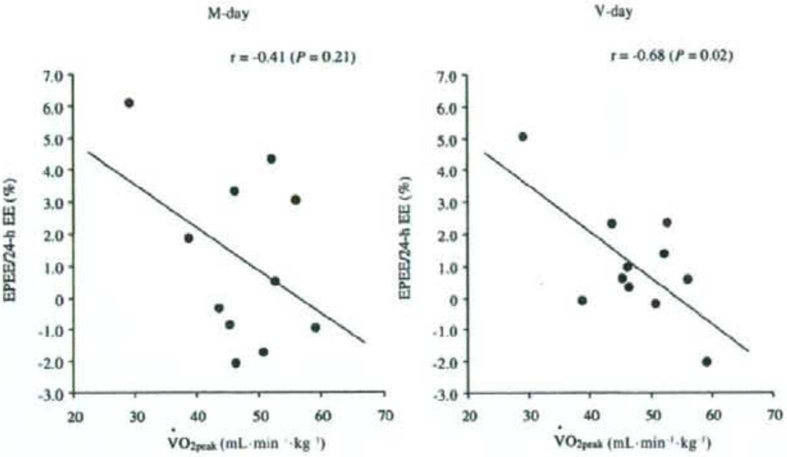

FIGURE 3. Relation between elevated post–physical activity energy expenditure (EPEE) and peak oxygen uptake ($\dot{V}O_{2peak}$) for the M-day (a day with high-frequency, moderate-intensity physical activity) and the V-day (a day with high-frequency, vigorous-intensity physical activity). 24-h EE, 24-h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

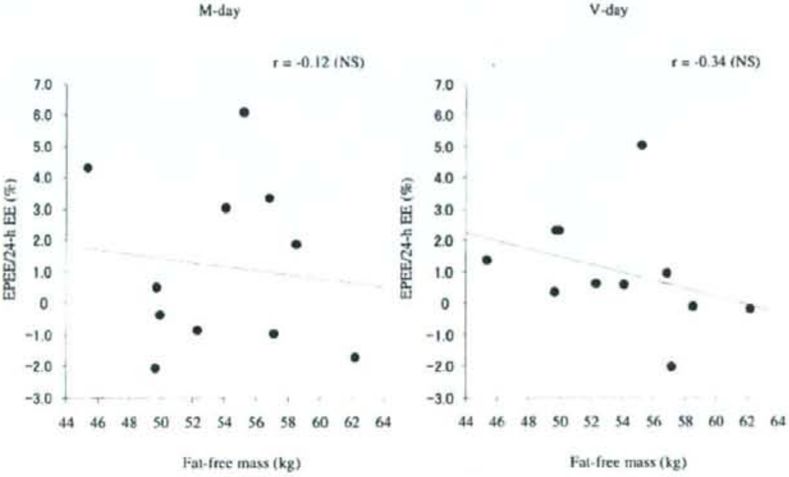

FIGURE 4. Relation between elevated post–physical activity energy expenditure (EPEE) and fat-free mass for the M-day (a day with high-frequency, moderate-intensity physical activity) and the V-day (a day with high-frequency, vigorous-intensity physical activity). 24-h EE, 24-h energy expenditure. There 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 ΔPAEE 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 ≈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 ± 13.9% (M-day) and 5.1 ± 9.2% (V-day) of ΔPAEE. Therefore, the equation estimating TEE proposed by the Institute of Medicine, which adds 15% EE as EPOC to ΔPAEE, 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 ± 7.0% and 65.0 ± 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 ΔPAEE 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 ΔPAEE 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 ΔPAEE, 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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The responsibilities of the authors were as follows—KO: study design, data acquisition, data analysis, data interpretation, and writing the manuscript; ST: study design, data acquisition, data analysis, data interpretation, and writing the manuscript; KI: study design and editing the manuscript, IT: study design and editing key aspects of the manuscript. None of the authors had a personal or financial conflict of interest.

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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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Keywords: doubly labelled water; energy expenditure; physical activity; assessment; questionnaire

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

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Contributors: KIT had the original idea, supervised IRMS analyses, analyzed the data, wrote the first draft and edited subsequent versions. IT supervised the study and edited the manuscript. SS supervised the field data collection and edited the manuscript. HHR and H Okazaki participated in the field data collection and IRMS analyses and edited the manuscript. H Okubo managed the field measurements and edited the manuscript. ST participated in the data analyses and edited the manuscript and SY, TS, KU and MM participated in field measurements and edited the manuscript.

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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/m^2, (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 ^2H_2O (99.8 atom%, Cambridge Isotope Laboratories, Andover, MA, USA) and 0.14 g/kg body weight of $H_2^{18}O$ (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 ^{18}O) 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 ^{18}O was CO_2 and that for ^2H was H_2. 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 ^{2}H and 0.03‰ for ^{18}O. The difference in the two repeat measurements of the 10 same sets of urine samples was 1.6±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 (^{2}H and ^{18}O) enrichments using the following equation (Racette *et al*., 1994).

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

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 ^{2}H and No (mol) divided by 1.007 for dilution space estimated by ^{18}O.

$\mathrm{rCO_2}$ were determined from the next equation.

$$\mathrm{rCO_2} = 0.4554 \times \mathrm{TBW} \times (1.007\,\mathrm{k_O} - 1.041\,\mathrm{k_H})$$

where $\mathrm{rCO_2}$ (mol/day) is the $\mathrm{CO_2}$ production rate, TBW (mol) is the total body water, and $\mathrm{k_O}$ (per day) and $\mathrm{k_H}$ (per day) are the elimination rates of ^{18}O and ^{2}H, 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; δb 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 $\mathrm{rCO_2}$ (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).

$$\mathrm{TEE} = 3.9 \times (\mathrm{rCO_2}/\mathrm{FQ}) + 1.1 \times (\mathrm{rCO_2})$$

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±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±35 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±6.0% for males and 31.4±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 ($n=10$, PAL$=1.87\pm0.29$) 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)*				*BMI (kg/m^2)*	*TBW (kg)*
				Pre	*Post*	*Difference*	P^a		
Male									
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
Female									
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.
^{a}*P*-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*
Male			
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
Female			
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 Instutute, 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 musculer 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.

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|||||||| 研究ノート ||||||||

栄養学雑誌 Vol. 66 No. 4 195〜200 (2008)

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 ± SD age : 36.8 ± 9.1 y. ; height : 171.6 ± 6.2 cm ; weight : 77.1 ± 7.6 kg ; FFM : 67.6 ± 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 ± 2.1 kcal/kg of FFM/day. Total energy expenditure (TEE) was 3,432 ± 634 kcal, and PAL calculated as TEE divided by BMR was 2.00 ± 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

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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