Validity of Physical Activity Indices for Adjusting Energy Expenditure for Body Size: Do the Indices Depend on Body Size?

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Abstract To express intensity of physical activity, energy expenditure is often divided by either body weight, resting metabolic rate, or fat-free mass. These calculations are used widely as the physical activity index. However, it is unclear how body size influences the valid estimation of intensity of various kinds of activities. In the present study, we investigated whether these indices are able to adjust for body size when calculating energy expenditure in various kinds of activities. In addition, we examined to what extent the error of index is introduced by differences in body size. Resting metabolic rates and energy expenditure during sitting light work, 4 lifestyle and 7 ambulant activities were measured in the postabsorptive state using indirect calorimetry in 71 healthy Japanese adults. We regarded an index as an inappropriate adjustment for body size when there was a significant correlation between it and body weight. Energy expenditure normalized by body weight correlated with body weight in all sedentary states; when normalized by lying resting metabolic rate it correlated with body weight in 3 ambulant activities; when normalized by sitting resting metabolic rate it correlated with body weight in 2 lifestyle and 5 ambulant activities; and when normalized by fat-free mass it correlated with only 1 ambulant activity. The indices caused errors in estimates of activity intensity of less than $\pm 10\%$ when body weight was more than 10 kg above average. In conclusion, the body weight-normalized index was inappropriate for sedentary activities and the other three indices were inappropriate for ambulant activities. However, the use of any of these indices introduces an error in the estimate of total energy expenditure of considerably less than $\pm 10\%$ for body weights within the normal range. *J Physiol Anthropol* 29(3): 109–117, 2010 <http://www.jstage.jst.go.jp/browse/jpa2>
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Introduction

Measurements of energy expenditure (EE) and determination of intensity of physical activity are important for the assessment of human health and nutrition. Human daily life consists of various kinds of activities, with the pattern of daily activity not being constant even in the same individual. It is however possible to compare or evaluate different types of movement activities if each physical activity is expressed as intensity. It is important to note that EE becomes higher with increasing body size even if the same intensity of activity is performed. Therefore, it is necessary to adjust EE for body size in order to appropriately compare the intensity of activity. This makes it possible to compare different styles of physical activity with different body size, which is helpful for understanding the physiological polymorphisms that occur in humans.

There are several alternative approaches for determining the intensity of activity using physical activity indices (PAIs), defined as EE divided by either body weight (BW: EE/BW), resting metabolic rate (RMR) in the lying position (L-RMR: EE/L-RMR), RMR in the sitting position (S-RMR: EE/S-RMR), or fat-free mass (FFM: EE/FFM). These PAIs are used routinely throughout the world to normalize data. Adjustment for body size as multiples of the PAIs assumes that the relationship between EEs and the normalizing factors are linear and pass through the origin. However, it is uncertain to what degree these PAIs provide appropriate adjustment for body size in various kinds of activities.

Previous studies found that EE/BW overcorrected for body size (Prentice et al., 1996; Lawrence, 1988; Davies and Cole, 2003). EE/BW was greater for underweight than for overweight subjects despite their performing the same activity. In other words, if the same PAI value is used in these activities, EE is underestimated for underweight subjects and overestimated for overweight subjects. The authors suggested that the quantity $EE/BW^{0.5}$ was more appropriate for sedentary

lifestyles. The basal metabolic rate (BMR) was roughly proportional to weight raised to the 0.5 power. Therefore the EE of common daily activities was more proportional to BMR than to BW (Lawrence, 1988). However, other studies found that EE/BMR was not constant for different BWs when used for lifestyle and ambulant activities (Kuriyan et al., 2006; Spadano et al., 2003; Haggarty et al., 1997). In these activities, EE/BMR was greater in overweight subjects than in underweight subjects. In some cases, BMR was substituted for RMRs (L-RMR and S-RMR). However, differences in the relationships between body size and L-RMR and S-RMR were not clarified sufficiently. There is an alternative way to adjust EE for body size, namely, EE/FFM, with previous studies in children and adolescents suggesting that FFM may be the most appropriate variable for normalization of EE during physical activities (Ekelund et al., 2004; Vermorel et al., 2005).

Intensity of daily total activity can be estimated by dividing total energy expenditure (TEE) by BW (TEE/BW) or by RMRs (TEE/L-RMR and TEE/S-RMR). These indices were shown to also be sensitive to body size even for the same physical activity (Prentice et al., 1996; Goran, 1995; Carpenter et al., 1995). As a result, it was not possible to compare intensity of daily activity between groups with different body sizes.

Unfortunately, as previous studies investigated only one of these PAIs for particular activities, it is impossible to compare the PAIs for different activities (Ferro-Luzzi, 2005). As described above, daily life consists of various kinds of activities, with these activities being classified roughly into weight-dependent, non-weight dependent and intermediate activities. In order to understand the biomechanical and physiological variability of these activities, it is necessary to adequately adjust for body size or RMR. The objectives of the present study were therefore to examine the validity of the four PAIs to characterize each daily activity in the Japanese population and to determine how body size influences the reliable estimation of activity intensity during various kinds of activities.

Materials and Methods

Subjects

Seventy-eight healthy Japanese subjects in the age range of 20–69 years (41 males and 37 females) were recruited for the study. They were recruited from various types of occupations so that the distribution of body mass index (BMI) was comparable to that in the Japanese population. All subjects were free of chronic diseases that could affect metabolism or daily physical activity. Informed consent was signed by all subjects. The study protocol was approved by the Ethical Committee of the National Institute of Health & Nutrition.

Experimental protocol

The experiments were conducted after 12 or more hours of an overnight fast and sufficient sleep. The subjects visited the laboratory between 8:00 and 9:00 am on the day of the

experiment and anthropometric measurements were obtained. L-RMR and S-RMR were then determined, followed by measurement of the EEs of various physical activities. The three PAIs were calculated for each activity.

Anthropometric measurements

The anthropometric measurements included height, BW, and percentage body fat (BF, %). A digital scale (YK-150D; Yagami, Nagoya, Japan) was used to measure BW to the nearest 0.1 kg with the subjects dressed in light clothing. The weight of clothing was then subtracted. Barefoot standing height was measured to the nearest 0.1 cm using a wall-mounted stadiometer (YL-65; Yagami). The BMI was calculated as BW (kg) divided by height squared (m^2). BF was measured by a bioelectrical impedance technique (HBF-362; Omron Healthcare, Kyoto, Japan). FFM (kg) was calculated by subtracting the amount of BF (kg) from BW.

Measurement of L-RMR, S-RMR, and EE of the activities

The subjects were instructed to lie quietly for 30 minutes before the measurement of L-RMR ($\text{kcal} \cdot \text{min}^{-1}$). During the L-RMR measurement, the subject was awakened quietly and instructed not to move. The ambient room temperature was maintained at approximately 25°C. The L-RMR measurement was recorded for 2 periods of 10 minutes. Following the L-RMR measurement, the subject sat quietly in a chair and S-RMR ($\text{kcal} \cdot \text{min}^{-1}$) was then measured for a period of 10 minutes.

Based on the preliminary study using 3-day activity records of 93 subjects living in the Tokyo metropolitan area under free-living conditions, the following activities were chosen as representative activities of daily life and classified into 3 categories. Sedentary activities were lying quietly, sitting quietly, and working at the computer. Lifestyle activities were vacuuming, hanging laundry, washing dishes, and lifting and carrying a small load (loading, unloading, and carrying a 5-kg package). Ambulant activities were walking up stairs, walking down stairs, walking (55 m/min, 70 m/min, 100 m/min), walking at 70 m/min with a 3-kg load, and jogging (140 m/min). The order of these measurements was from light activities to vigorous activities. The participants performed each activity for 3 to 6 minutes to achieve steady state before the expired gas was collected, with a break of a few minutes between each activity and the next to obtain the samples.

The expired gasses were collected in a 100 L Douglas bag (Fukuda Sangyo, Chiba, Japan), and the volume measured using a dry gas meter (DC-5; Shinagawa, Tokyo, Japan). The O_2 and CO_2 concentrations were measured with a mass spectrometer (ARCO-1000; Arco System, Kashiwa, Japan). The analyzer was calibrated with room air containing 20.93% O_2 and 0.04% CO_2 , and a calibration-grade standard gas containing 15.27% O_2 and 5.12% CO_2 (Takachiho Chemical Industrial, Tokyo, Japan).

Calculation of the PAIs

We consider the PAIs to be a convenient and practical index. The PAIs were calculated for each subject and activity by dividing EE by either BW (EE/BW; kcal·min⁻¹/kg), L-RMR (EE/L-RMR; kcal·min⁻¹/kcal·min⁻¹), S-RMR (EE/S-RMR; kcal·min⁻¹/kcal·min⁻¹), or FFM (EE/FFM; kcal·min⁻¹/kg). Therefore, the EE/L-RMR for lying and the EE/S-RMR for sitting quietly were equal to 1.00.

Statistical analysis

The data are presented as means±SD, unless otherwise stated. Differences were considered to be statistically significant if the P value was less than 0.05. We regarded a PAI as an appropriate adjustment for body size when there was no significant correlation between the PAI and BW. The independent associations between the PAIs and BW were tested using a general linear model (GLM) that examined the effects of age, sex, and sex–BW interaction, given that men have a greater body weight than women. In addition, the activity styles may also be related to age and sex, although the L-RMR, S-RMR, and FFM measured in the present study already reflected the effects of age and sex. Therefore, the effects of age and sex were considered in the relationship between all the PAIs and BW. If the sex–BW interaction term was not statistically significant in the GLM, the interaction term was excluded in the subsequent analyses, and the errors in the PAIs caused by size were estimated from the regression models using the average age and a fixed value for sex (0.5). If the interaction term was significant, the errors were estimated in a similar way, but for each sex. The errors were calculated as percentages of the predicted PAIs for an average BW (PAIs_(ave.)). For example, error (%) = $B \times x / \text{PAIs}_{(ave.)} \times 100$, where B is the regression coefficient of the relationship between PAI and BW from GLM adjusted for age and sex and x is the difference from average BW. All the statistical analyses were performed using SPSS Version 15.0J for Windows (SPSS, Inc., Chicago, IL, USA).

Results

The majority of the 78 subjects weighed between 40–80 kg, although 2 subjects weighed more than 100 kg and were

outside the 98th percentile BMI for the Japanese population. As L-RMR or S-RMR data for five subjects were not obtained, these subjects were excluded from all the analyses. The physical characteristics of the remaining 71 subjects are summarized in Table 1.

The means, SDs, and coefficients of variations of PAI for all activities are presented in Table 2. Several data are missing due to difficulties in adequately collecting expired gas in the steady state or performing the activity following the prescribed speed and duration. We confirmed in respective activities there was no bias with respect to age, BW, or BMI. S-RMR/L-RMR was 1.09 ± 0.05 in males and 1.12 ± 0.08 in females. Although mean PAI was different between the sexes in some activities, the sex–BW interaction term was not statistically significant for any activity except EE/FFM–walking at 70 m/min with a 3-kg load. Therefore, all the analyses included all data from both sexes. The relationships between the PAIs and BW are summarized in Table 3 and the percentage differences in PAIs caused by a 10 kg deviation from average BW are summarized in Table 4. EE/BW correlated significantly with BW in all sedentary activities. For these activities, there were –5% to –6% (5% to 6%) differences in EE/BW values when the BW was more than 10 kg above or below average (60 kg). EE/L-RMR correlated significantly with BW for walking up stairs, walking at 70 m/min, and walking at 100 m/min. For these activities, there were +3% to 5% (–3% to –5%) differences in EE/L-RMR values when the BW exceeded or was below the average by 10 kg. EE/S-RMR correlated significantly with BW for vacuuming, lifting and carrying a small load, and for the majority of the ambulant activities. For these activities, there were +3% to 6% (–3 to –6%) differences in EE/S-RMR values when BW exceeded or was below the average by 10 kg. EE/FFM correlated significantly with BW for walking up stairs only. For this activity, there was +3.7% (–3.7%) differences in EE/FFM values when BW exceeded or was below the average by 10 kg.

Discussion

In the present study, the mean values of PAIs were significantly different between the sexes for some activities.

Table 1 Characteristics of the subjects

	All (N=71)		Male (N=34)	Female (N=37)	p-value
	Means±SD	Range	Means±SD	Means±SD	
Age (years)	43±13	21–66	43±14	43±13	0.850
Height (cm)	163.7±8.1	149.8–183.9	169.6±6.1	158.2±5.5	<0.001*
Body weight (kg)	60.0±10.5	40.3–86.1	65.3±9.6	55.2±9.0	<0.001*
BMI (kg/m ²)	22.3±3.0	16.7–32.3	22.6±2.4	22.1±3.4	0.450
Fat-free mass	45.2±8.5	32.2–62.0	51.9±6.3	38.9±4.7	<0.001*
Body fat (%)	24.7±6.7	11.0–37.8	20.0±4.5	28.9±5.4	<0.001*

BMI: (body mass index)

* Significant difference between sexes (Student's *t*-test)

Table 2 The means of respective physical activity indexes for all activities**2-a.** The means of EE/BW for all activities

	EE/BW (kcal·min ⁻¹ /kg)						
	All			Male		Female	
	N	Mean±SD	CV	N	Mean±SD	N	Mean±SD
Sedentary activities							
lying quietly	71	0.0148±0.0016	10.8	34	0.0154±0.0015*	37	0.0143±0.0015
sitting quietly	71	0.0164±0.0017	10.3	34	0.0168±0.0016*	37	0.0160±0.0017
working at the computer	69	0.0181±0.0019	10.8	32	0.0187±0.0020*	37	0.0175±0.0017
Lifestyle activities							
vacuuming	69	0.0481±0.0096	19.9	34	0.0492±0.0099	35	0.0470±0.0092
hanging laundry	71	0.0367±0.0053	14.3	34	0.0378±0.0055	37	0.0358±0.0049
washing dishes	69	0.0293±0.0046	15.8	34	0.0301±0.0047	35	0.0285±0.0045
carrying a small load	71	0.0715±0.0108	15.1	34	0.0744±0.0106*	37	0.0688±0.0104
Ambulant activities							
walking up stairs	68	0.1228±0.0093	7.6	32	0.1262±0.0090*	36	0.1197±0.0086
downstairs	71	0.0512±0.0082	16.1	34	0.0534±0.0090*	37	0.0492±0.0071
walking (55 m/s)	69	0.0502±0.0064	12.7	32	0.0516±0.0070	37	0.0489±0.0056
walking (70 m/s)	69	0.0590±0.0071	12.0	33	0.0598±0.0079	36	0.0583±0.0062
walking (100 m/s)	71	0.0759±0.0115	15.1	34	0.0771±0.0129	37	0.0748±0.0100
walking (70 m/s) with a 3 kg load	71	0.0689±0.0090	13.1	34	0.0688±0.0105	37	0.0690±0.0076
jogging (140 m/s)	62	0.1557±0.0188	12.1	34	0.1624±0.0196*	28	0.1475±0.0143

2-b. The means of EE/L-RMR for all activities

	EE/L-RMR (kcal·min ⁻¹ /kcal·min ⁻¹)						
	All			Male		Female	
	N	Mean±SD	CV	N	Mean±SD	N	Mean±SD
Sedentary activities							
lying quietly	—	—	—	—	—	—	—
sitting quietly	71	1.11±0.07	6.3	34	1.09±0.05*	37	1.12±0.08
working at the computer	69	1.23±0.11	8.6	32	1.22±0.10	37	1.23±0.11
Lifestyle activities							
vacuuming	69	3.28±0.72	21.9	34	3.21±0.71	35	3.35±0.72
hanging laundry	71	2.50±0.40	16.0	34	2.47±0.40	37	2.52±0.40
washing dishes	69	2.00±0.35	17.4	34	1.95±0.30	35	2.04±0.39
carrying a small load	71	4.85±0.79	16.2	34	4.86±0.83	37	4.85±0.75
Ambulant activities							
walking up stairs	68	8.40±0.82	9.8	32	8.29±0.81	36	8.50±0.83
downstairs	71	3.46±0.50	14.4	34	3.46±0.49	37	3.46±0.51
walking (55 m/s)	69	3.40±0.46	13.4	32	3.35±0.44	37	3.45±0.47
walking (70 m/s)	69	4.00±0.54	13.6	33	3.88±0.55	36	4.11±0.52
walking (100 m/s)	71	5.15±0.82	15.8	34	5.02±0.85	37	5.27±0.78
walking (70 m/s) with a 3 kg load	71	4.68±0.68	14.6	34	4.47±0.68*	37	4.87±0.64
jogging (140 m/s)	62	10.51±1.26	12.0	34	10.58±1.38	28	10.42±1.11

Table 2 Continued**2-c.** The means of EE/S-RMR for all activities

	EE/S-RMR (kcal·min ⁻¹ /kcal·min ⁻¹)						
	All			Male		Female	
	N	Mean±SD	CV	N	Mean±SD	N	Mean±SD
Sedentary activities							
lying quietly	71	0.91±0.06	6.1	34	0.92±0.05	37	0.89±0.06
sitting quietly		—			—		—
working at the computer	69	1.11±0.08	7.1	32	1.12±0.07	37	1.10±0.09
Lifestyle activities							
vacuuming	69	2.96±0.63	21.4	34	2.95±0.68	35	2.97±0.59
hanging laundry	71	2.26±0.37	16.2	34	2.26±0.37	37	2.25±0.37
washing dishes	69	1.80±0.32	17.6	34	1.79±0.27	35	1.81±0.36
carrying a small load	71	4.39±0.69	15.7	34	4.46±0.74	37	4.32±0.64
Ambulant activities							
walking up stairs	68	7.60±0.74	9.8	32	7.60±0.73	36	7.59±0.76
downstairs	71	3.13±0.47	14.9	34	3.18±0.48	37	3.09±0.46
walking (55 m/s)	69	3.08±0.43	14.0	32	3.08±0.43	37	3.08±0.44
walking (70 m/s)	69	3.62±0.50	13.9	33	3.57±0.52	36	3.67±0.48
walking (100 m/s)	71	4.66±0.76	16.3	34	4.61±0.80	37	4.71±0.73
walking (70 m/s)	71	4.23±0.62	14.7	34	4.11±0.64	37	4.34±0.59
with a 3 kg load							
jogging (140 m/s)	62	9.50±1.10	11.6	34	9.72±1.29	28	9.23±0.77

2-d. The means of EE/FFM for all activities

	EE/FFM (kcal·min ⁻¹ /kg)						
	All			Male		Female	
	N	Mean±SD	CV	N	Mean±SD	N	Mean±SD
Sedentary activities							
lying quietly	71	0.0197±0.0018	9.2	34	0.0193±0.0017	37	0.0201±0.0019
sitting quietly	71	0.0218±0.0019	8.6	34	0.0210±0.0017*	37	0.0225±0.0018
working at the computer	69	0.0242±0.0026	10.6	32	0.0236±0.0026	37	0.0247±0.0025
Lifestyle activities							
vacuuming	69	0.0643±0.0140	21.7	34	0.0617±0.0135	35	0.0669±0.0141
hanging laundry	71	0.0491±0.0081	16.6	34	0.0474±0.0074	37	0.0507±0.0086
washing dishes	69	0.0391±0.0071	18.0	34	0.0376±0.0061	35	0.0406±0.0077
carrying a small load	71	0.0954±0.0153	16.0	34	0.0935±0.0153	37	0.0972±0.0153
Ambulant activities							
walking up stairs	68	0.1646±0.0161	9.8	32	0.159±0.0143*	36	0.1698±0.0159
downstairs	71	0.0684±0.0118	17.2	34	0.0669±0.0117	37	0.0698±0.0119
walking (55 m/s)	69	0.0671±0.0100	14.9	32	0.0645±0.0092*	37	0.0693±0.0103
walking (70 m/s)	69	0.0789±0.0116	14.7	33	0.0750±0.0104*	36	0.0824±0.0116
walking (100 m/s)	71	0.1016±0.0180	17.7	34	0.0966±0.0171*	37	0.1061±0.0178
walking (70 m/s)	71	0.0923±0.0154	16.7	34	0.0862±0.0139*	37	0.0979±0.0148
with a 3 kg load							
jogging (140 m/s)	62	0.2040±0.0223	10.9	34	0.2035±0.0265	28	0.2045±0.0162

EE: energy expenditure, BW: body weight, L-RMR: lying resting metabolic rate, S-RMR: sitting resting metabolic rate, FFM: fat-free mass, CV: coefficient of variation.

* $p < 0.05$ vs. male group (Student's t -test)

Table 3 Results from the general linear model with physical activity index as the dependent variable and body weight, age, and sex as the independent variables

	EE/BW (kcal · min ⁻¹ /kg)			EE/L-RMR (kcal · min ⁻¹ /kcal · min ⁻¹)			EE/S-RMR (kcal · min ⁻¹ /kcal · min ⁻¹)			EE/FFM (kcal · min ⁻¹ /kg)		
	Regression coefficient ¹ (Estimate±SE)	Age, sex ²	Average EE/BW ³	Regression coefficient ¹ (Estimate±SE)	Age, sex ²	Average EE/BMR ³	Regression coefficient ¹ (Estimate±SE)	Age, sex ²	Average EE/BMR ³	Regression coefficient ¹ (Estimate±SE)	Age, sex ²	Average EE/FFM ³
Sedentary activities												
lying quietly	-0.000079±0.000016**	age, sex	0.0149	—	—	—	0.000±0.001	0.91	—	-0.000020±0.000024	—	0.0197
sitting quietly	-0.000094±0.000017**	age, sex	0.0164	-0.001±0.001	—	1.11	—	—	—	-0.000032±0.000022	sex	0.0218
working at the computer	-0.000091±0.000022**	sex	0.0181	0.000±0.001	age	1.22	0.001±0.001	age	1.11	-0.000018±0.000029	age	0.0241
Lifestyle activities												
vacuuming	-0.000016±0.000123	age	0.0480	0.015±0.009	age	3.26	0.016±0.008*	age	2.95	0.000252±0.000173	age, sex	0.0636
hanging laundry	-0.000099±0.000062	age, sex	0.0368	0.006±0.004	age	2.49	0.007±0.004	age	2.26	0.000088±0.000089	age, sex	0.0491
washing dishes	-0.000075±0.000057	age	0.0293	0.005±0.004	age	1.99	0.006±0.004	age	1.79	0.000068±0.000084	age	0.0394
carrying a small load	-0.000139±0.000132	age, sex	0.0717	0.016±0.009	age	4.85	0.017±0.008*	age	4.39	0.000233±0.000175	age	0.0953
Ambulant activities												
walking up stairs	-0.000070±0.000119	sex	0.1230	0.035±0.010**	sex	8.37	0.035±0.009**	—	7.58	0.000598±0.000178*	age, sex	0.1637
downstairs	-0.000189±0.000103	sex	0.0513	0.006±0.006	age	3.46	0.007±0.006	age	3.13	0.000050±0.000147	age	0.0683
walking (55 m/s)	-0.000119±0.000083	sex	0.0503	0.011±0.006	age	3.40	0.011±0.005*	age	3.08	0.000146±0.000123	age, sex	0.0670
walking (70 m/s)	-0.000121±0.000091	—	0.0590	0.013±0.006*	age, sex	3.99	0.035±0.009**	—	7.58	0.000213±0.000135	age, sex	0.0785
walking (100 m/s)	-0.000096±0.000149	—	0.0760	0.021±0.010*	age, sex	5.14	0.021±0.009*	age	4.66	0.000335±0.000210	age, sex	0.1012
walking (70 m/s) with a 3 kg load	-0.000186±0.000113	age	0.0689	0.012±0.007	age, sex	4.67	0.013±0.007	age, sex	4.22	0.000159±0.000168	age, sex	0.0920
jogging (140 m/s)	-0.000339±0.000242	sex	0.1547	0.031±0.018	—	10.51	0.031±0.015*	—	9.47	0.000343±0.000308	—	0.2038

EE: energy expenditure, BW: body weight, L-RMR: lying resting metabolic rate, S-RMR: sitting resting metabolic rate, FFM: fat-free mass, SE: standard error.

¹ Regression coefficient: Relationship between physical activity indices and body weight from general linear models (GLM) adjusted for age and sex.² Age, sex: Significance of age and sex in the GLM. ($P<0.05$)³ Average physical activity indices: Physical activity index of average body weight (60.0 kg) from GLM adjusted for age (43 y) and sex (0.5).* $P<0.05$, ** $P<0.001$: There was a significant correlation between the index and body weight.

Table 4 The errors (%) in physical activity indices caused by a 10 kg above average body weight (60.0 kg)¹.

Activities	EE/BW (kcal · min ⁻¹ /kg)	EE/L-RMR (kcal · min ⁻¹ /kcal · min ⁻¹)	EE/S-RMR (kcal · min ⁻¹ /kcal · min ⁻¹)	EE/FFM (kcal · min ⁻¹ /kg)
Sedentary activities				
lying quietly	−5.3	—	—	
sitting quietly	−5.7			
working at the computer	−5.0			
Lifestyle activities				
vacuuming			5.3	
hanging laundry				
washing dishes				
carrying a small load			3.9	
Ambulant activities				
walking up stairs		4.2	4.6	3.7
downstairs				
walking (55 m/s)			3.6	
walking (70 m/s)		3.3	4.6	
walking (100 m/s)		4.1	4.6	
walking (70 m/s) with a 3 kg load				
jogging (140 m/s)			3.2	

EE: energy expenditure, BW: body weight, L-RMR: lying resting metabolic rate, S-RMR: sitting resting metabolic rate, FFM: fat-free mass.

¹ The discrepancies were calculated as follows;

The error (%) = $B \times x / \text{PAIs(ave.)} \times 100$

B is the regression coefficient of the relationship between physical activity index and body weight from general linear models (GLM) adjusted for age and sex.

x is the difference from average body weight (60.0 kg).

PAI_(ave.): Physical activity index for average body weight (60.0 kg) from GLM adjusted for age and sex.

Data are presented only for the significant relationship between physical activity index and body weight.

This table shows when x is +10 kg (70 kg). If x is 10 kg below average, the values of the discrepancies change from plus to minus or from minus to plus.

However, gender did not influence the correlation between PAI and BW in any activity except for EE/FFM-walking at 70 m/min with a 3-kg load. Therefore, we were able to combine the data for both sexes in most of the analyses.

Our results showed that the EE/BW was not appropriate for adjusting for body size in sedentary activities. In contrast, EE/L-RMR and EE/S-RMR were appropriate for sedentary activities, but inappropriate for the other activities. The EEs of sedentary activities were not weight-dependent and increased less than body weight. In contrast, the EEs of other activities were weight-dependent as they increased with increasing BW, whereas the observed L-RMR and S-RMR increased less with increasing BW. Therefore, EE/BW values in non-weight-dependent activities decreased and EE/L-RMR and EE/S-RMR values in weight-dependent activities increased with increasing BW. When we used EE/BW to evaluate the intensity of non-weight-dependent activities, this caused about a 20% higher estimate for 40 kg than for 80 kg BWs for the same activity. When we used EE/L-RMR or EE/S-RMR values to estimate the intensity of weight-dependent activities, this caused a 12% to 20% lower estimate for 40 kg than 80 kg BWs.

It has been reported that EE/RMR (including EE/BMR) was inappropriate for evaluation of intensity of some activities in girls and adults (Kriyan et al., 2006; Spadano et al., 2003; Haggarty et al., 1997). These researchers suggested it was necessary to take BW into consideration when using the BMR-

multiple approach to estimate EE. Kuriyan et al., (2006) considered the relationship between EE/BMR, BW, and BMI. They found in three walking activities that BMI caused a 3% to 16% overestimation of EE/BMR in underweight men (BMI 16.0–18.3 kg/m², BW 42.3–49.8 kg) and a 3% to 11% underestimation of EE/BMR in overweight men (BMI 25.2–33.0 kg/m², BW 51.0–92.3 kg) when EE was estimated using the EE/BMR value for normal weight (BMI 19.1–24.3 kg/m², BW 46.6–66.5 kg) men. A similar tendency was observed by Haggarty et al., (1997) who showed that EE/BMR increased in a hyperbolic manner as weight increased, and that the rate of increase in EE/BMR became larger as intensity of activity rose. However, in our study the error in EE/BMR caused by BW for jogging was smaller than the difference for walking activities. This could be due to the fact that the EE of high intensity activities such as jogging was influenced not only by body size, but also by physical fitness (Margaria et al., 1963).

Our study indicated that S-RMR is undifferentiated from L-RMR in some cases. While the relationship between EE/L-RMR and BW was similar to the relationship between EE/S-RMR and BW, the errors caused by BW were more likely to be observed and be larger in EE/S-RMR than in EE/L-RMR. This discrepancy was probably caused by differences in the relationship between L-RMR, RMR, and BW. The difference in relationship was not statistically significant, although RMR

increased less with BW compared to L-RMR.

On the other hand, EE/FFM was appropriate except for the ambulant activity of walking up stairs. We found that size-independent comparisons could be made using FFM. Moreover, previous studies succeeded in comparing physical activity using EE/FFM even between obese and nonobese adult subjects (Meijer et al., 1992) and between children and adolescents (Ekelund et al., 2004; Vermorel et al., 2005). On the basis of these results it appears that FFM has characteristics of both BW and RMRs.

Daily life consists of various kinds of activities. The average intensity of daily activity is evaluated as TEE/BW, TEE/L-RMR, or TEE/S-RMR. Some previous papers have suggested that TEE/BW (Lawrence, 1988; Margaria et al., 1963) and TEE/BMR (Goran, 1995; Carpenter et al., 1995; Goran, 2005) produced spurious differences when subjects of different size were compared across the range of TEE levels. We consider that the maximum difference from average BW was no more than $\pm 10\%$ for a daily lifestyle in the normal BW group. For example, for an 80-kg person sitting quietly for 24 hours, the intensity of daily activity calculated using TEE/BW is about a 10% underestimation of the true intensity of daily activity. As daily activities consisted of various activities, including weight-dependent activities, the estimation errors caused by BW for particular activities become smaller than 10%. It seems unimportant that a 10% estimation error (at a maximum) can be caused by using PAIs, as intra-individual variation in TEE is approximately $\pm 10\%$ in free-living activities for some weeks (Goran et al., 1993). In addition, there are unavoidable differences in methodology when using a physical activity record and physical activity recall. Comparing the unavoidable differences reported in a previous study (Conway et al., 2002) to the differences in our data, our maximum estimation error of 10% was about 1/3 that of the TEE estimated from the physical activity record and only 1/10 that of the TEE estimated from physical activity recall. Thus, our estimation errors in TEE appear to be considerably smaller than the other error factors. Moreover, use of PAIs may reduce errors when the intensity of daily activity is estimated using TEE/L-RMR and TEE/S-RMR to calculate physical activity levels.

It is important to note that a two-step procedure is required to predict physical activity level in general situations (Goran, 2005). In many cases, RMRs are predicted from an equation that often is based on BW. For example, the basal metabolism per unit body weight (BMR/BW) was included in the Dietary Reference Intakes for Japanese, 2010 (Ministry of Health, Labour, and Welfare, Japan, 2009). However, BMR/BW correlated negatively with BW (Takahashi et al., 2007). As BMR corresponded to L-RMR in the present study, there will be an estimation error when BMR/BW is used in the estimate of BMR. According to our study, -5% to 6% errors may occur in BMR values when the BW is more than 10 kg above average. In addition, it is also necessary to consider the effect of the errors in estimations of RMRs. As the measurement

error of body weight is considerably smaller than the prediction error of BMR or RMR, different effects of the errors would occur when using the predicted values.

This study had several limitations. The coefficient of variation tended to be large, especially for lifestyle activities. This was attributed to the fact that we prescribed only the duration of the activities and did not strictly prescribe the motion of activities. In addition, we did not obtain information on the motion for each activity of each subject, and accordingly could not examine the effects of inter-individual differences. Other limitations included the fact that the methodology for determining body composition in our study was not sophisticated, as we estimated FFM using bioelectrical impedance analysis. Therefore, the results for EE/FFM would include the predictive error associated with the measurement method (Korth et al., 2007). Another limitation is that we did not take into account aerobic fitness, although we considered the influence of this factor was small, as subjects who were not athletes performed each activity for only several minutes.

In conclusion, although BW influenced EE/BW in sedentary activities and also the three alternative indices in other activities, the error in the estimate of total EE using any of these indices should be considerably less than $\pm 10\%$ for body weights within the normal range. The PAIs are simple calculations and make it easy to compare the intensities of activity and to estimate EEs using activity diaries, recall, and direct observation data. It is most important in future studies to consider the size of the error effects of the indices. It will then be possible to properly compare physical activity among different body sizes.

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