Table 2. Total and physical activity energy expenditure of junior high school students who did and did not exercise
(Mean values and standard deviations; medians and 25th–75th percentiles)

	Percentage of body fat		TEE_{DLW} (MJ/d)		RMR_m (MJ/d)		$PAEE_{DLWm}$ (MJ/d)		PAL_{DLWm}		TEE_{ACCp} (MJ/d)		Walking (steps
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean
Boys													
Ex (*n* 27)†	17·3	8·1	12·7	2·4	6·3	0·8	5·2	1·7	2·03	0·30	12·1	2·0	15 920
Median			12·9		6·4		5·5		2·03		12·0		16 5
25th–75th percentile			10·9–14·1		5·8–6·7		3·8–6·7		1·78–2·21		10·8–13·7		13 563–
Non-Ex (*n* 5)‡	21·6	4·7	11·0	2·4	6·5	1·0	3·4	1·4	1·69	0·20	10·8	1·2	11 170
Median			11·1		6·8		3·5		1·71		11·2		10 8
25th–75th percentile			8·9–13·0		5·6–7·1		2·1–4·7		1·51–1·86		9·2–12·3		8378–1
Total (*n* 32)	18·0	7·7	12·4	2·4	6·3	0·8	4·9	1·8	1·97	0·31	11·9	2·0	15 178
Median			12·6		6·5		5·1		1·97		11·9		15 2
25th–75th percentile			10·7–14·0		5·8–6·8		3·2–6·4		1·73–2·16		10·6–13·4		13 046–
Girls													
Ex (*n* 18)†	22·8	2·5	9·7	1·7	5·1	0·4	3·6	1·4	1·90	0·30	9·3	1·1	13 289
Median			9·0		5·1		3·1		1·80		9·1		13 3
25th–75th percentile			8·4–11·4		4·8–5·4		2·7–4·7		1·73–2·06		8·6–9·8		12 047–
Non-Ex (*n* 10)‡	26·7	6·0	8·7	1·2	5·0	0·4	2·9	1·0	1·75	0·21	9·4	1·6	12 303
Median			8·3		4·8		2·5		1·69		9·4		12 5
25th–75th percentile			7·9–9·3		4·7–5·5		2·0–3·5		1·57–1·91		8·3–10·1		10 869–
Total (*n* 28)	24·2	4·4	9·3	1·6	5·1	0·4	3·3	1·3	1·85	0·27	9·3	1·3	12 937
Median			8·8		5·0		3·0		1·79		9·2		12 8
25th–75th percentile			8·2–10·3		4·8–5·5		2·5–3·8		1·67–1·94		8·6–9·8		11 974–
P													
Exercise	0·041		0·041		0·812		0·010		0·006		0·304		0·0
Sex	0·009		<0·001		<0·001		0·030		0·715		<0·001		0·44
Exercise × sex	0·913		0·540		0·503		0·294		0·288		0·184		0·05

TEE_{DLW}, total energy expenditure measured by the doubly labelled water method; RMR_m, measured RMR; $PAEE_{DLWm}$, physical activity energy expenditure (TEE_{DLW} × 0·9 − RM
the doubly labelled water method using RMR_m (TEE_{DLW}/RMR_m); TEE_{ACCp}, total energy expenditure measured by the accelerometer using predicted RMR.
* Non-wear time: duration of the time that subjects did not wear the accelerometer.
† Ex: subjects who exercised except for the physical education class.
‡ Non-Ex: subjects who did not exercise except for the physical education class.

Statistical analysis

All the analyses were performed using SPSS 16.0 J for Windows (IBM Japan). The characteristics of the subjects are expressed as means and standard deviations. As the PA data were not normally distributed, they were expressed as both means and standard deviations and medians with ranges. Differences between grades and sexes were analysed by two-way ANOVA. The linear relationships between PAL and light PA, moderate PA, vigorous PA and MVPA were assessed using Pearson's correlation coefficients. Student's paired *t* test, Spearman's rank correlation coefficients, intraclass correlation coefficient and Bland–Altman plot analysis[22] were used to compare data obtained from the DLW method and accelerometry.

Results

The physical characteristics of the subjects are shown in Table 1. Height and weight were significantly lower in girls than in boys (both $P<0{\cdot}001$). The percentage of body fat was higher in girls than in boys ($P<0{\cdot}001$). TEE_{DLW} and RMR_m were significantly lower in girls than in boys. PAL_{DLWm} ranged from 1·48 to 2·54 in individual subjects, with a mean of 1·91. PAL_{DLWm} was not different between sexes or grades. All subjects included in the analysis wore the accelerometers for more than four weekdays and more than one weekend day. Of the subjects, 82 % wore the accelerometer for five weekdays, and 90·2 % wore it for two weekend days. TEE_{DLW} and PAL_{DLWm} were not different between the subjects included in the analysis and subjects excluded due to insufficient accelerometer use (TEE_{DLW} 11·0 (SD 2·6) *v.* 11·0 (SD 2·5) MJ/d; RMR_m 5·7 (SD 0·9) *v.* 5·9 (SD 1·1) MJ/d; PAL_{DLWm} 1·91 (SD 0·30) *v.* 1·85 (SD 0·26), respectively).

Of the present subjects, 75 % (twenty-seven boys and ten girls) participated in exercise other than the physical education class. The frequency and duration of exercise were 3·6 (SD 1·8) times/week and 523 (SD 291) min/week for boys, and 2·1 (SD 1·1) times/week and 318 (SD 219) min/week for girls, respectively. Major sports activities included kendo (*n* 5), soccer (*n* 4), tennis (*n* 4), basketball (*n* 4), track and field (*n* 4) and baseball (*n* 3) for boys, and badminton (*n* 6), track and field (*n* 5) and tennis (*n* 3) for girls. The percentage of body fat was significantly lower in subjects who exercised; however, RMR_m did not differ with exercise activity (Table 2). Non-wear time, including bathing, periods of PA preventing accelerometer use and times when participants forgot to wear the accelerometer, also did not differ with exercise activity. TEE_{DLW}, TEE_{ACCm} and TEE_{ACCp} were 11·0 (SD 2·0), 10·3 (SD 1·9) and 10·7 (SD 2·1) MJ/d for all subjects, respectively. All three indices were significantly greater in subjects who exercised compared with subjects who did not exercise. Walking step counts were greater in subjects who exercised; however, TEE_{ACCp} did not differ with exercise activity.

RMR_m and RMR_p correlated strongly in all subjects and in subjects who exercised, although RMR_p was significantly greater than RMR_m in all subjects and subjects who did not exercise (Fig. 1; Table 3). The percentage difference between

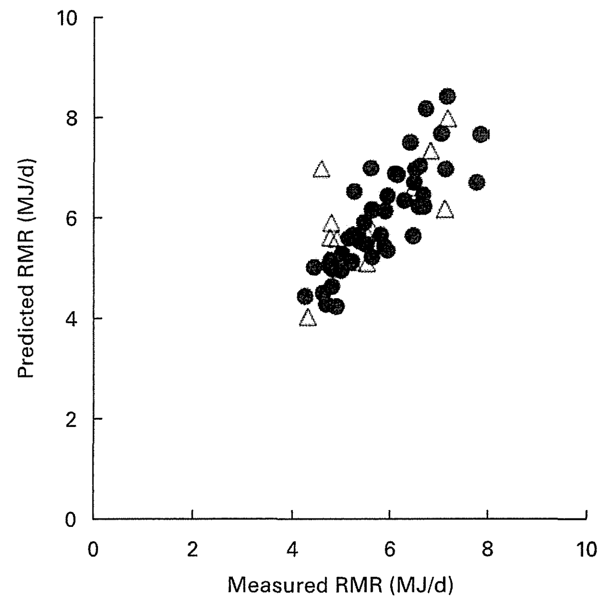

Fig. 1. Correlation between measured and predicted RMR. ●, Subjects who exercised; Δ, subjects who did not exercise. The Spearman's correlation coefficients were 0·732 ($P<0{\cdot}001$) for all subjects, 0·800 ($P<0{\cdot}001$) for subjects who exercised, and 0·436 ($P=0{\cdot}020$) for subjects who did not exercise.

RMR_m and RMR_p correlated with body weight (*r* 0·401, $P=0{\cdot}002$) and the percentage of body fat (*r* 0·524, $P<0{\cdot}001$), but not with sex, age or height. TEE_{DLW} correlated significantly with both TEE_{ACCm} and TEE_{ACCp}, although TEE_{ACCp} was significantly smaller than TEE_{DLW} in all the subjects. In subjects who exercised, accelerometry underestimated TEE significantly using either RMR_m or RMR_p. Spearman's rank correlation coefficients and intraclass correlation coefficient were lower for PAEE than for TEE in all subjects and in the exercising and non-exercising subjects. Accelerometry underestimated PAEE significantly in comparisons between $PAEE_{DLWm}$ *v.* $PAEE_{ACCm}$, and $PAEE_{DLWm}$ *v.* $PAEE_{ACCp}$ in all subjects and in subjects who exercised. Subjects who did not exercise showed a weaker correlation between PAEE assessed by the DLW method and accelerometry. In comparison with PAL, Spearman's rank correlation coefficient and intraclass correlation coefficient were lower than those for PAEE and TEE. Accelerometry underestimated PAL only when PAL_{ACCp} was compared with PAL_{DLWm} in all subjects and in exercising and non-exercising subjects. The percentage of body fat correlated significantly with the percentage difference in TEE, PAEE and PAL assessed by the DLW method and accelerometry using RMR_p (*r* 0·304, $P=0{\cdot}018$ for TEE and PAL; *r* 0·349, $P=0{\cdot}006$ for PAEE), and PAL using RMR_m (*r* 0·304, $P=0{\cdot}018$). Sex, age, body weight and height did not correlate significantly with the percentage difference between TEE, PAEE and PAL. The Bland–Altman agreement plots showed a moderate negative correlation between PAL assessed by either the DLW method or accelerometry, even when measured or RMR_p was used (Fig. 2).

When the subjects were divided into tertile subgroups for PAL, 47, 45 and 52 % of the subjects were stratified into the same tertiles of PAL_{DLWm} *v.* PAL_{ACCm}, PAL_{DLWp} *v.* PAL_{ACCp}

Table 3. Comparison of energy expenditure measured by the doubly labelled water method and triaxial accelerometry

	All subjects (*n* 60)							Subjects who exercised (*n* 45)							Subjects who did not exercise (*n* 15)						
	%Δ*	SD	P_t†	Cor‡	P_c§	ICC	95 % CI	%Δ*	SD	P_t†	Cor‡	P_c§	ICC	95 % CI	%Δ*	SD	P_t†	Cor‡	P_c§	ICC	95 % CI
RMR_m *v.* RMR_p	4·5	11·4	0·005	0·792	<0·001	0·770	0·622, 0·861	2·4	9·1	0·174	0·800	<0·001	0·782	0·603, 0·887	6·9	13·3	0·001	0·436	0·020	0·318	−0·018, 0·602
TEE_{DLW} *v.* TEE_{ACCm}	−4·0	13·3	0·003	0·783	<0·001	0·730	0·556, 0·837	−5·6	13·5	0·034	0·778	<0·001	0·751	0·581, 0·856	6·7	20·1	0·386	0·512	0·051	0·513	0·028, 0·804
TEE_{DLW} *v.* TEE_{ACCp}	−0·7	15·8	0·193	0·741	<0·001	0·730	0·587, 0·829	−3·1	13·5	0·002	0·758	<0·001	0·681	0·431, 0·824	0·5	12·0	0·887	0·826	<0·001	0·832	0·567, 0·941
$PAEE_{DLWm}$ *v.* $PAEE_{ACCm}$	−4·3	33·1	0·003	0·551	<0·001	0·452	0·218, 0·636	−5·1	32·5	0·013	0·522	0·002	0·394	0·074, 0·645	−3·3	34·4	0·098	0·196	0·318	0·041	−0·300, 0·388
$PAEE_{DLWp}$ *v.* $PAEE_{ACCp}$	−11·8	61·3	0·193	0·507	<0·001	0·467	0·247, 0·643	0	38·8	0·071	0·500	0·004	0·487	0·183, 0·709	26·3	78·3	0·997	−0·089	0·654	−0·147	−0·510, 0·245
$PAEE_{DLWm}$ *v.* $PAEE_{ACCp}$	−2·8	34·1	0·008	0·557	<0·001	0·508	0·289, 0·676	−6·2	29·4	0·011	0·585	<0·001	0·545	0·234, 0·752	1·1	38·9	0·249	0·121	0·540	−0·033	−0·390, 0·335
PAL_{DLWm} *v.* PAL_{ACCm}	−0·7	15·8	0·298	0·426	0·001	0·361	0·121, 0·562	−3·1	13·6	0·077	0·594	0·001	0·545	0·255, 0·747	2·0	18·4	0·931	0·218	0·265	0·105	−0·289, 0·461
PAL_{DLWp} *v.* PAL_{ACCp}	−0·7	15·8	0·163	0·412	0·001	0·351	0·113, 0·553	−3·1	13·0	0·054	0·514	0·003	0·488	0·183, 0·710	2·0	18·4	0·878	0·082	0·678	−0·021	−0·405, 0·357
PAL_{DLWm} *v.* PAL_{ACCp}	−4·6	13·4	0·002	0·391	0·002	0·275	0·039, 0·486	−5·0	11·9	0·009	0·551	0·001	0·445	0·121, 0·683	−4·2	15·1	0·077	0·028	0·888	−0·095	−0·411, 0·262

ICC, interclass correlation coefficient; RMR_m, measured RMR; RMR_p, predicted RMR; TEE_{DLW}, total energy expenditure measured by the doubly labelled method; TEE_{ACCm}, total energy expenditure measured by accelerometry using RMR_m; TEE_{ACCp}, total energy expenditure measured by accelerometry using RMR_p; $PAEE_{DLWm}$, physical activity energy expenditure using TEE_{DLW} and RMR_m ($TEE_{DLW} \times 0{\cdot}9 - RMR_m$); $PAEE_{ACCm}$, physical activity energy expenditure using TEE_{ACCm} and RMR_m ($TEE_{ACCm} \times 0{\cdot}9 - RMR_m$); $PAEE_{DLWp}$, physical activity energy expenditure using TEE_{DLW} and RMR_p ($TEE_{DLW} \times 0{\cdot}9 - RMR_p$); $PAEE_{ACCp}$, physical activity energy expenditure using TEE_{ACCp} and RMR_p ($TEE_{DLW} \times 0{\cdot}9 - RMR_p$); PAL_{DLWm}, physical activity level using TEE_{DLW} and RMR_m (TEE_{DLW}/RMR_m); PAL_{ACCm}, physical activity level using TEE_{ACCm} and RMR_m (TEE_{ACCm}/RMR_m); PAL_{DLWp}, physical activity level using TEE_{DLW} and RMR_p (TEE_{DLW}/RMR_p); PAL_{ACCp}, physical activity level using TEE_{ACCp} and RMR_p (TEE_{DLW}/RMR_p).

* %Δ: (data measured by accelerometry − data measured by the doubly labelled method)/(data measured by the doubly labelled method) × 100 or ($RMR_p - RMR_m$)/RMR_m × 100.

† P_t: *P* value for the paired *t* test.

‡ Cor: Spearman's rank correlation coefficient.

§ P_c: *P* value for Spearman's rank correlation coefficient.

and PAL_{DLWm} *v.* PAL_{ACCp}. However, 27, 30 and 25 % of the subjects were divided into the lower PAL subgroups according to PAL_{DLWm} *v.* PAL_{ACCm}, PAL_{DLWp} *v.* PAL_{ACCp} and PAL_{DLWm} *v.* PAL_{ACCp}.

The average number of walking steps and the duration of light PA, moderate PA, vigorous PA and MVPA assessed by accelerometry were 14 132 (SD 3469) steps/d, and 894 (SD 66), 89 (SD 29), 13 (SD 14) and 103 (SD 39) min/d, respectively. MVPA in subjects who did or did not exercise was 113 (SD 38) and 72 (SD 22) min/week, respectively. MVPA in weekends was significantly shorter ($P < 0{\cdot}001$) than in weekdays (81 (SD 47) *v.* 111 (SD 42) min/d). Walking step counts were also significantly lower ($P < 0{\cdot}001$) in weekends (10 630 (SD 5622) steps/d) compared with weekdays (15 652 (SD 3632) steps/d). MVPA correlated significantly with PAL_{DLWm} (r 0·341, $P = 0{\cdot}008$). The linear relationship between MVPA and PAL_{DLWm} ($PAL_{DLWm} = MVPA \times 0{\cdot}003 + 1{\cdot}65$) showed that 30 min of MVPA per d was equivalent to 1·74 of PAL_{DLW}.

Discussion

This is the first study to assess PA among Japanese junior high school students using the DLW method and triaxial accelerometry. TEE assessed by accelerometry was found to have good accuracy as determined by comparison with TEE_{DLW}, whereas the accuracy of PAEE and PAL was lower compared with that of TEE. The errors caused by accelerometry were considered to be attributable to the error in the prediction of RMR and the assessment of exercise intensity.

The average height of the subjects in the present study was slightly higher, and the girls' height slightly lower than that in data collected in 2010 by the Ministry of Education, Culture, Sports, Science, and Technology, Japan[1]. In the present study, only three students weighed more than 120 % of the standard body weight for sex, age and height in Japanese students[1].

The average PAL_{DLWm} of 1·91 (SD 0·30) in the present study was greater than that in previous studies conducted in Western countries (PAL 1·48–1·89)[23–33]. The proportion of the present subjects performing exercise, with the exception of the physical education class, was higher than that in a previous report on the entire student population at this school (in the previous study, boys 70 % and girls 46 %)[34]. As the subjects who exercised participated in MVPA about 2 h each week and had a smaller percentage of body fat than non-exercising subjects, they were well trained and had higher energy expenditure.

The average number of walking steps in the present study was also greater than that in previous studies that used uniaxial accelerometry. The accuracy of step counts in the present accelerometry had already been examined in an adult population only, and it is possible that there may be differences in accuracy between adult and children[35]. The accelerometer used in the present study underestimated step counts by 18 % when subjects walked 55 m/min with a normal step frequency. However, this accelerometry did not show significant differences in step count compared with visually counted step

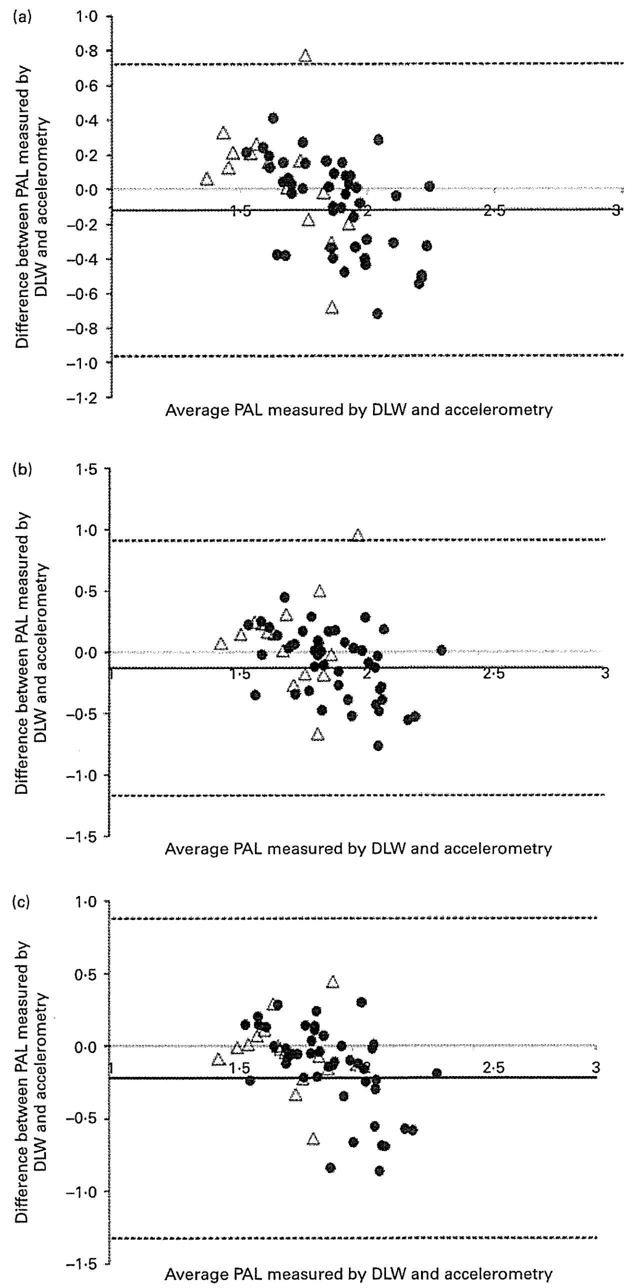

Fig. 2. Bland–Altman plots of physical activity level (PAL) assessed by either the doubly labelled water (DLW) method or an accelerometer. ●, Subjects who exercised; Δ, subjects who did not exercise. —, Mean PAL measured by the DLW method and accelerometry; ----, mean (2 SD) of PAL measured by the DLW method and accelerometry. Comparison of (a) PAL measured by the DLW method and accelerometry with predicted RMR (r −0·564, $P<0·001$), (b) PAL measured by the DLW method and accelerometry with the measured RMR (r −0·381, $P=0·003$) and (c) PAL measured by the DLW method with the measured RMR and accelerometry with the predicted RMR (r −0·508, $P<0·001$).

counts at walking speeds of 75 and 95 m/min. Although we could not examine the accuracy of assessing MVPA by accelerometry, the relationship between MVPA and the number of walking steps was similar to that reported in previous studies. Tudor-Locke *et al*[36] recommended 10 000–11 700 steps/d for adolescents to satisfy 60 min of MVPA. In the present study, 60 min of MVPA was equivalent to an average of 11 006 steps/d.

The present study shows that TEE measured by EW4800P triaxial accelerometry had good accuracy. The percentage difference between TEE_{DLW} and TEE_{ACCp} was −0·7 (SD 15·8) %. Although the commercially available software uses RMR_p, in the present study, we also used RMR_m to calculate energy expenditure. TEE_{ACCp} showed less difference than TEE_{ACCm} in comparison with TEE_{DLW}. The difference between TEE_{DLW} and TEE_{ACCp} was very close to the results of a previous study that used the same accelerometer in elderly subjects, and showed a 1·6 % difference[9]. These results suggest that this accelerometer can evaluate TEE with a similar level of accuracy in both elderly and junior high school students, at least at the group level. In addition, this accelerometer has very good accuracy compared with other accelerometers. A study using triaxial accelerometry in an age group similar to that in the present study and the most accurate estimation equation[37] showed that the root mean square error was 40·72 % for boys and 59·72 % for girls. We examined the effects of sex, age, body weight, height and percentage of body fat on the difference between TEE_{DLW} and TEE_{ACCp} or TEE_{ACCm}, and found only the percentage of body fat to be correlated significantly with the percentage difference between TEE_{DLW} and TEE_{ACCp}. As the percentage of body fat also correlated with the difference between RMR_m and RMR_p, the prediction error in RMR for subjects with higher body fat deposition affected the estimation error of TEE using RMR_p.

Although TEE_{ACCp} and TEE_{ACCm} showed good accuracy as established by comparison with TEE_{DLW}, RMR accounted for a large portion of TEE in the study subjects. To lessen the contribution of RMR, we compared PAEE and PAL measurements obtained using the two methods. The accuracy for PAEE and PAL was lower than that for TEE. For PAEE, the difference between the two methods was most apparent when RMR_p was used in both the DLW method and accelerometry. In particular, the mean difference in PAEE and PAL was overestimated by accelerometry in subjects who did not exercise. The reasons for this finding were that one subject who did not exercise showed a large overestimation of PAEE by accelerometry, while the estimation error of PAEE by accelerometry was relatively small in the other non-exercising subjects. In comparison with PAL, PAL_{DLWm} and PAL_{ACCm} showed the strongest correlation. One reason for these results is the prediction error of RMR. RMR_p is based on a standard value of RMR for Japanese in the dietary reference intake for Japan. The dietary reference intake for Japan is revised every 5 years, although the standard RMR value for children was calculated using the data collected in the 1950s. When the dietary reference intake was revised in 2010 based on data measured in the 2000s, the standard value of RMR in females aged 18–29 years decreased from 98·7 to 92·5 kJ/d. It is therefore possible that RMR_p may also be overestimated in adolescents. Another possible reason for the overestimation of RMR_p was the systematic error of the measurement. Cooper *et al.*[38] suggested that there was a systematic error in calorimetry systems. The system used in the present study has been tested previously[21]. As the standard value was based on data collected more than 50 years ago, we could not examine the systematic error between the present system and systems that were used to decide the standard value of RMR. Given that RMR can vary with age, maturation, body weight and the level of PA, we considered that a better estimation of PAEE may be obtained using a more accurate measurement of RMR[39].

In the present study, subjects who exercised tended to have a greater underestimation of PAL by accelerometry than other subjects who did not exercise. RMR and non-wear time of accelerometry were not different between the exercising and non-exercising subjects, while walking step counts were greater in subjects who exercised. As most accelerometers are more sensitive for accelerations in the vertical place and less sensitive for a more complex movement[40], the intensity of exercise may be estimated less accurately. In addition, although the prediction model of EW4800P was constructed using data from adults, the models are population specific[41]. It is therefore possible that PA in some adolescents may not have been estimated correctly.

The most significant limitation of the present study was that all the subjects were recruited from one school. Most of the students in the present study used trains to go to school, and had to walk approximately 15 min each way from the nearest station to the school. In Japan, most public school students go to school on foot or by a bicycle. It is therefore necessary to collect data from other schools to generalise the present results to other Japanese junior high school students.

Second, although we sent an information letter to all the students, the participation rate was quite low. We are therefore not sure whether the subjects in the study were representative of the students in this school.

Third, some subjects had issues with improper wearing of the accelerometer. According to our criteria, approximately 25 % of the subjects were excluded from the analysis because of inappropriate accelerometer use. Of the seventeen subjects excluded from the analysis, fifteen did not wear the accelerometer on any weekend days. All the subjects included in the analysis wore the accelerometer more than 12 h/d and for more than 5 d. This exclusion rate was not greater than that in the International Children's Accelerometry Database, which found that only 62·2 % of boys and 59·3 % of girls in their study wore an accelerometer more than 12 h/d over periods longer than 4 d[42]. On weekdays, members of the research team met with the subjects every morning to remind them to wear their accelerometers. However, TEE_{DLW} and PAL_{DLW} were not different between the subjects included in the analysis and those who were excluded.

Fourth, we used a triaxial accelerometer made by a Japanese company. This made it difficult to compare the present results with those from Western countries, which have most often used Actigraph accelerometers. Actigraph accelerometers are not used widely in Japan, and Japanese people tend to be more familiar with pedometers and accelerometers made by Japanese companies. The present study examined the accuracy of the EW4800P accelerometer, and showed that it can estimate the total PA with a high degree of accuracy.

In conclusion, based on a comparison with the DLW method, the present study showed that EW4800P triaxial accelerometry can estimate daily TEE with good accuracy and precision. However, the accuracy of PAEE and PAL estimations was not high in Japanese adolescents. Prediction of RMR in Japanese adolescents and the prediction model of accelerometry for adolescents therefore need to be improved.

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The relationship of body composition to daily physical activity in free-living Japanese adult men

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Abstract

The objective of the present study was to investigate whether a previously reported apparent negative relationship between fat mass and daily physical activity in Japanese adult women would also be observed in Japanese adult men. The subjects were grouped into quartiles of BMI and body fat percentage (%BF). The number of steps walked each day and the duration of light- to vigorous-intensity physical activity were assessed by an accelerometer over the same period of time as for the doubly labelled water experiment. The results showed that BMI negatively correlated with the number of steps and time spent in moderate-intensity physical activity, whereas %BF showed a negative relationship with physical activity-related energy expenditure (PAEE)/body weight (BW) and physical activity level. The analysis of data using %BF quartiles revealed that PAEE/BW decreased from the second quartile in which the BMI was $<25\,kg/m^2$. These observations are similar to those reported in our previous study in Japanese adult women. These cross-sectional studies cannot prove causality, and that obesity causes physical inactivity may be the case. However, the results of the present study provide information regarding which physical activity variables should be used in longitudinal studies.

Key words: **Body composition: Physical activity: Doubly labelled water: Accelerometry: Japanese adult men**

The prevalence of obesity is rising rapidly in most Asian countries, especially in Japan with an increase of 46 % from 1976–80 to 2000[1]. Specifically, the overall prevalence of overweight and obese adult men in Japan has increased gradually over the past 20 years, whereas the prevalence of overweight and obese adult women has not changed[2]. Obesity is commonly caused by an energy imbalance, with low total energy expenditure (TEE) possibly being a contributing factor in this process. While a negative relationship between obesity and daily physical activity has been reported[3,4], the majority of studies have not observed this relationship[5,6]. Therefore, the relationship between BMI (body weight (BW, kg) divided by height squared (m^2)) and daily physical activity still remains unclear.

In studies using the doubly labelled water (DLW) method, the most accurate method for measuring TEE in free-living conditions[7,8], the majority of Western adult populations showed no relationship between BMI and physical activity level (PAL, the ratio of TEE:RMR)[9–11].

On the other hand, we have recently reported that Japanese adult women with higher fat deposition had higher body fat percentage (%BF) with an apparent lower PAL compared with those with lower fat deposition[12]. However, this association was not observed when women were categorised using BMI. In addition,

Abbreviations: %BF, body fat percentage; BW, body weight; DLW, doubly labelled water; FM, fat mass; FFM, fat-free mass; PAEE, physical activity-related energy expenditure; PAL, physical activity level; TEE, total energy expenditure.

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step counts or time spent in moderate- or vigorous-intensity physical activity assessed by an accelerometer (i.e. the part composed of PAL) was also found to be lower in women with higher fat deposition[12].

However, Westerterp & Goran[13] using a meta-analysis of data of 290 adults from twenty-two DLW studies reported that a higher PAL was related to a lower fat mass (FM) only in men but not in women. This indicates that the relationship between physical activity and fat deposition may be different between the sexes. However, this relationship was not observed if data were stratified according to BMI.

The main aim of the present study was to examine whether the negative relationship that we observed between %BF and daily physical activity in our previous cross-sectional study in Japanese adult women[12] was also apparent in Japanese adult men. Information from the present study will help to understand the role of daily physical activity in the increased prevalence of obesity in adult males.

Methods

Subjects

Participants were recruited through health-care centres or at workplaces in three urban districts in central and western Japan, as described previously[12]. In each location, subjects were included for the study according to the following criteria: (1) in good health; (2) not involved in hard physical labour such as farming or athletics; (3) BMI $>18{\cdot}5\,kg/m^2$; (4) living in their home prefecture 2 weeks before and during the study; (5) not on a weight-loss or treatment diet; (6) alcohol consumption $<40\,g/d$. The occupations of the participants were mainly salesmen, teachers, clerks and desk jobs, and some were unemployed. Overall, eighty-five male subjects aged 30–69 years were selected for the study. Over the entire assessment period, subjects were instructed to carefully maintain their normal daily activities and eating patterns and to make no conscious effort to lose or gain weight. The present study was conducted according to the guidelines laid down in the Declaration of Helsinki, and all procedures involving human subjects were approved by the Ethical Committee of the National Institute of Health and Nutrition in Japan. Written informed consent was obtained from all subjects.

Experimental procedures

The experimental design has been described in detail in our previous study[12]. Briefly, urine samples were collected and BW and height measured on the day before the assessment of physical activity (day 0). RMR was measured in the supine position using a Douglas bag in the early morning 12 h or longer after the last meal. A single dose of DLW was then given orally to each subject. After administration of this dose, the participants were instructed to collect urine samples on the following day and at eight additional times at the same time of the day during the 2-week study period. On day 15, BW and height were measured again to examine changes in BW during the study period. The subjects were then provided with an accelerometer and a self-administered diet history questionnaire. Daily physical activity was estimated over the same 2-week study period under free-living conditions using the DLW method and accelerometer.

Measurement of energy expenditure and body composition

We measured TEE using the DLW method, as described previously[12]. Briefly, the single dose of DLW consisted of approximately 0·06 g/kg BW of ^2H_2O (99·8 atom%; Cambridge Isotope Laboratories) and 1·4 g/kg BW of $H_2\,^{18}O$ (10·0 atom%; Taiyo Nippon Sanso). Isotopic enrichment of urine samples was measured using an isotope ratio mass spectrometer (model DELTA Plus; Thermo Electron Corporation). The ^2H and ^{18}O zero-time intercepts and elimination rates (k_H and k_O) were calculated using least-squares linear regression of the natural logarithm of the isotope concentration as a function of the elapsed time from dose administration. The zero-time intercepts were used to determine isotope pool sizes. Total body water was calculated as the mean value of the isotope pool size of ^2H divided by 1·041 and that of ^{18}O divided by 1·007. Fat-free mass (FFM) was calculated by assuming a hydration of 0·732[14]. FM was calculated as BW minus FFM, while %BF was computed from BW and FFM. Calculation of TEE (kJ/d) was performed using the modified Weir formula[15] based on the CO_2 production rate and respiratory quotient. Food quotient calculated from the diet history questionnaire was used instead of the respiratory quotient. This assumes that under conditions of perfect nutrient balance, the food quotient must equal the respiratory quotient[16,17]. PAL was estimated by dividing TEE by RMR. Physical activity-related energy expenditure (PAEE) was calculated as $0{\cdot}9 \times TEE - RMR$, assuming that the thermic effect of food was 10 % of TEE[18].

Other measurements

Measurements of anthropometry, accelerometry and the diet history questionnaire have been described in detail in our previous study[12]. Briefly, a uniaxial accelerometer (Lifecorder EX; Suzuken Company Limited) was used for measuring the intensity of physical activity and step counts. The intensity of physical activity every 2 min was classified as either light (<3 metabolic equivalents), moderate (3 to <6 metabolic equivalents) or vigorous (≥6 metabolic equivalents)[16]. The validation and methodology of the diet history questionnaire have been described in detail elsewhere[17].

Statistical analysis

Data are presented as means and standard deviations. BMI was calculated as BW (measured before the DLW dose) divided by height squared (kg/m^2). The associations between physical activity and BMI or %BF, expressed as continuous variables, were examined by the linear regression analysis with or without adjustment for covariates. Subjects were then grouped according to quartiles of BMI and %BF. A one-way ANOVA or ANCOVA was used to compare the variables in the quartiles, with Fisher's least-square difference used as

Table 1. Participants' characteristics, energy expenditure components and physical activity variables, grouped according to BMI||
(Mean values and standard deviations)

BMI quartiles...	First (18·7–22·5 kg/m²)		Second (22·6–24·5 kg/m²)		Third (24·6–27·5 kg/m²)		Fourth (27·6–39·1 kg/m²)			
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	P (ANOVA)	r¶
Energy expenditure										
TEE (kJ/d)||||	11 070	1290	11 663	2055	12 188	1949	13 396††‡‡§	2172	0·009	0·458**
RMR (kJ/d)	5629	769	5792	774	6039	809	7165††‡‡§§	861	<0·001	0·658**
PAL	1·99	0·23	2·02	0·29	2·03	0·29	1·87	0·19	0·227	−0·168
PAEE (kJ/d)	4335	957	4705	1521	4930	1454	4891	1390	0·830	0·169
PAEE/BW (kJ/d per kg)¶¶	71·7	16·9	69·0	21·8	67·4	18·9	52·9††‡§	12·2	0·008	−0·343**||||||
Accelerometer										
Step counts (per d)	10 296	2699	10 085	2891	9848	3001	7992†‡§	3222	0·027	−0·259*
Light, <3 MET (min/d)	56·6	12·5	55·1	16·2	57·6	20·2	54·9	21·4	0·695	−0·017
Moderate, 3 to <6 MET (min/d)	39·8	17·9	37·5	12·9	35·8	19·6	24·2††‡‡§	14·3	0·009	−0·298**
Vigorous, 6 MET (min/d)	3·6	3·0	4·7	6·6	3·2	4·0	2·2	4·6	0·397	−0·154

TEE, total energy expenditure; PAL, physical activity level (TEE/RMR); PAEE, physical activity-related energy expenditure (0·9 × TEE − RMR); BW, body weight; MET, metabolic equivalents.
There was a significant correlation with BMI: * $P<0·05$, ** $P<0·01$.
Mean values were significantly different from those of the first quartile: † $P<0·05$, †† $P<0·01$.
Mean values were significantly different from those of the second quartile: ‡ $P<0·05$.
Mean values were significantly different from those of the third quartile: § $P<0·05$.
|| The subjects were categorised by quartile. The number of subjects in each quartile was twenty-five. In the nine intensity levels (1–9) of physical activity assessed by using an accelerometer, 1–3 indicates light intensity, 4–6 moderate intensity and 7–9 vigorous intensity.
¶ The associations between BMI and physical activity variables and energy expenditure components, expressed as continuous variables, were examined by the linear regression analysis.
|||| A statistical significance in TEE among the quartiles was still found even after adjustment for BW using ANCOVA ($P=0·026$).
¶¶ There was no significant difference in PAEE among the quartiles after adjustment for BW using ANCOVA ($P=0·155$).
|||||| There was no significant difference between BMI and PAEE after adjustment for BW (partial r −0·046, $P=0·677$).

a *post hoc* test for multiple comparisons. Differences were considered statistically significant when the P value was <0.05. All statistical analyses were carried out using SPSS for Windows (version 16.0 J; SPSS, Inc.).

Results

Of the total eighty-five men studied, the proportion of normal-weight (BMI 18·5 to $<25\,kg/m^2$), overweight (BMI ≥ 25 to $<30\,kg/m^2$) and obese participants (BMI $\geq 30\,kg/m^2$) was 54·1, 35·3 and 10·6 %, respectively. The mean age of the subjects was 47·5 (SD 11·0, range 30–69) years. The mean BW, height and BMI were 73·5 (SD 14·0, range 51·1–116·3) kg, 1·70 (SD 0·07, range, 1·51–1·88) m and 25·3 (SD 3·9, range 18·7–39·1) kg/m^2, respectively. BW did not change during the study (change in BW: −0·13 (SD 0·04) kg, P=0·987). The range of PAL was 1·46–2·51 with a mean value of 1·98.

The relationships between BMI and energy expenditure or physical activity variables are shown in Table 1 and Fig. 1. Both FM (r 0·824) and FFM (r 0·714) showed a linear correlation with BMI. TEE increased linearly with BMI, whereas PAEE/BW, step counts and moderate-intensity physical activity showed a negative correlation. PAL and PAEE adjusted for BW did not correlate with BMI (Fig. 1).

Energy expenditure and physical activity variables were also compared between the BMI quartiles. Age and height were not significantly different between the quartiles. TEE, step counts and moderate-intensity physical activity were significantly different between the quartiles. The fourth quartile had significantly smaller PAEE/BW, step counts and moderate-intensity PAL compared with the other three quartiles. A statistically significant decrease in TEE between the BMI quartiles was still observed after adjustment for BW using ANCOVA (P = 0·026). However, PAEE did not show any significant difference between the BMI quartiles after adjustment for BW using ANCOVA (P=0·155).

PAL, PAEE/BW and moderate-intensity physical activity negatively correlated with %BF (Table 2; Fig. 1). FM increased with %BF (r 0·876), whereas FFM did not (r 0·008). As shown in Fig. 1, after PAEE was adjusted for BW, a negative correlation was still observed between PAEE and %BF. A statistically significant difference was found between the %BF quartiles for PAL, PAEE/BW, step counts and moderate- and vigorous-intensity physical activities. A significant difference in TEE and PAEE was still found between the %BF quartiles after adjustment for BW using ANCOVA (P = 0·001 and 0·002). PAEE was lower in the second and fourth quartiles than in the first quartile when it was adjusted for BW using ANCOVA. PAL was lower in the second and fourth quartiles than in the first quartile, whereas there was no significant difference between the second and fourth quartiles.

Discussion

The present study aimed at comparing the relationship of BMI and %BF with various aspects of daily physical activity between Japanese adult men investigated in the present study and Japanese adult women that we have reported

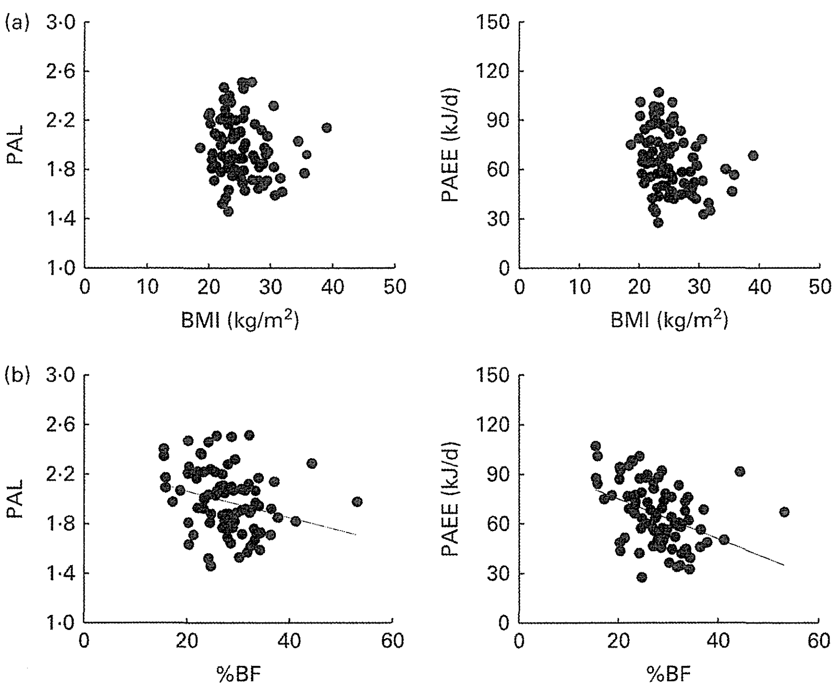

Fig. 1. Relationships between (a) BMI and physical activity level (PAL) or physical activity-related energy expenditure (PAEE) and (b) between body fat percentage (%BF) and PAL or PAEE. PAL = TEE/RMR, where TEE is the total energy expenditure; PAEE = 0·9 × TEE − RMR. %BF was negatively associated with PAL or PAEE, after adjustment for body weight, although this relationship was not observed between BMI and PAL or PAEE even after adjustment for body weight. (a) PAL: r −0·17; PAEE: partial r −0·05 (adjusted for body weight). (b) PAL: r −0·26, $P<0.05$; PAEE: partial r −0·27 (adjusted for body weight), $P<0.05$.

Table 2. Participants' characteristics, energy expenditure components and physical activity variables grouped according to body fat percentage (%BF)‖

(Mean values and standard deviations)

%BF quartiles...	First (15·4–23·4)		Second (23·4–27·6)		Third (27·8–32·0)		Fourth (32·1–53·1)		*P* (ANOVA)	*r*¶
	Mean	SD	Mean	SD	Mean	SD	Mean	SD		
Energy expenditure										
TEE (kJ/d)‖‖	12 166	1745	11 925	2137	11 687	1933	12 486	2288	0·632	0·123
RMR (kJ/d)	5736	687	6196	1081	5981	931	6707††§	988	0·009	0·329**
PAL	2·13	0·23	1·94†	0·26	1·97†	0·25	1·86††	0·23	0·005	−0·263*
PAEE (kJ/d)	5214	1234	4536	1383	4537	1275	4531	1445	0·245	−0·075
PAEE/BW (kJ/d per kg)¶¶	80·7	17·9	64·3††	17·7	60·8††	15·4	54·7††	16·2	<0·001	−0·407**‖‖‖
Accelerometer										
Step counts (per d)	10 524	3067	9838	2876	9867	3181	7982††‡§	2731	0·038	−0·202
Light, < 3 MET (min/d)	54·8	12·3	54·5	18·1	62·6	19·8	52·3	19·4	0·254	0·083
Moderate, 3 to < 6 MET (min/d)	39·9	14·7	37·8	19·2	34·5	16·8	25·1††‡	14·8	0·024	−0·299**
Vigorous, 6 MET (min/d)	6·0	6·7	3·3	3·4	1·9	3·4	2·4	4·5	0·018	−0·138

TEE, total energy expenditure; PAL, physical activity level (TEE/RMR); PAEE, physical activity-related energy expenditure (0·9 × TEE − RMR); BW, body weight; MET, metabolic equivalents.
There was a significant correlation with BMI: * $P<0·05$, ** $P<0·01$.
Mean values were significantly different from those of the first quartile: † $P<0·05$, †† $P<0·01$.
Mean values were significantly different from those of second quartile: ‡ $P<0·05$.
Mean values were significantly different from those of the third quartile: § $P<0·05$.
‖ Subjects were categorised by quartile. The number of subjects in each quartile was twenty-five. In the nine intensity levels (1–9) of physical activity assessed by an accelerometer, 1–3 indicates light intensity, 4–6 moderate intensity and 7–9 vigorous intensity.
¶ The associations between BMI and physical activity variables and energy expenditure components, expressed as continuous variables, were examined by the linear regression analysis.
‖‖ A statistical significance in TEE among the quartiles was still found even after adjustment for BW using ANCOVA ($P=0·001$).
¶¶ A statistical significance in PAEE among the quartiles was still found even after adjustment for BW using ANCOVA ($P=0·002$).
‖‖‖ A statistical significance between %BF and PAEE was still found even after controlling for BW (partial r −0·266, $P=0·015$).

previously[12]. The common finding in both studies was that BMI was negatively related to the number of steps and time spent in moderate-intensity physical activity, whereas %BF was negatively related to PAEE/BW and PAL.

No significant correlation was observed between BMI and PAL in Japanese adult men, a finding consistent with previous studies in Japanese women[12] and Western populations[9–11]. On the other hand, Tooze *et al.*[19] reported that normal (BMI $<25\,kg/m^2$) and overweight (BMI 25 to $<30\,kg/m^2$) women had a higher PAL compared with obese women (BMI $\geq 30\,kg/m^2$). This relationship was not observed in adult men in their study.

However, grossly obese subjects often showed a lower PAL. Prentice *et al.*[9] reported that grossly obese men (BMI $\geq 35\,kg/m^2$) tended to have a lower PAL (mean 1·52) compared with normal-weight and obese men (BMI 18·5 to $<35\,kg/m^2$) whose mean PAL values ranged between 1·80 and 1·86. In the present study, the number of grossly obese men was three and their PAL values were 1·77, 1·94 and 2·14, respectively. Therefore, the lower mean PAL value of 1·52 reported by Prentice *et al.*[9] was not observed in grossly obese men in the present study. Similarly, Das *et al.*[11] reported that PAL did not differ in grossly obese women within the BMI range of $37·5–77\,kg/m^2$.

In contrast to the lack of the relationship between BMI and PAL, we showed that PAEE/BW was significantly lower in the highest quartile of BMI in Japanese adult men, a result similar to that observed in Japanese women[12]. This result is also in agreement with the study by Schoeller[20], which reported that obese Western populations had a lower PAEE/BW compared with non-obese populations. However, the present study revealed that there was no significant relationship between BMI and PAEE, following adjustment for BW as a covariate. Despite the convenience of correcting for body size, dividing PAEE by BW should be interpreted with caution, as this may be subject to artifacts due to problems with a zero intercept or the requirement of proportionality.

Although no significant relationship was observed between BMI and PAEE after correction for body size, %BF negatively correlated with both PAL and PAEE/BW. In particular, a significant relationship was still found between %BF and PAEE even after adjustment for BW as a covariate. The present study also showed a similar relationship between PAEE/BW and %BF to that observed in women[12], Chinese adults[21] and Western men[22]. Therefore, it is not necessary to consider ethnic differences in this relationship. Moreover, when the data were analysed using the %BF quartiles (Table 2), PAEE/BW decreased from the second quartile in which BMI was $<25\,kg/m^2$. These results are similar to those observed in Japanese women[12], and suggested that daily physical activity differed according to the level of fat deposition, even in the normal-weight adult population. However, it is also important to note that PAEE corrected for BW has the limitation of assuming that all physical activities are weight-dependent.

The present study showed the negative relationship between BMI and step counts or moderate-intensity physical activity, which is likely to that observed in Japanese women. However, Mitsui *et al.*[23] reported that there was a significant relationship between step counts and BMI in Japanese adult women, but not in men. This discrepancy in the relationship between BMI and step counts in Japanese subjects may be attributable to lower BW, BMI and step counts in the study by Mitsui *et al.*[23]. Thus, physical activity variables assessed by an accelerometer may be useful for understanding daily physical activity in obese adult populations in large epidemiological studies.

On the other hand, time spent in moderate-intensity physical activity was significantly related to %BF in men, although this relationship was not observed in women[12]. Conversely, the number of steps was related to %BF not in men but in women. The reason for this discrepancy between the sexes was not clear, although it is possible that %BF may be related to the total energy expended in daily physical activity rather than to the part composed of PAEE or PAL that included the number of steps and exercise intensity.

The present study is limited by the cross-sectional study design, which makes it difficult to clarify the causality between obesity and physical inactivity. Therefore, we cannot exclude the possibility of reverse causality that obesity may cause physical inactivity. For example, obese subjects fatigue after taking a few steps because they have to propel a larger mass; as a result, the lowered physical activity may cause obesity[24]. In line with this, men in the fourth quartile, almost obese, may have had less volitional movement during physical activity due to their excess weight. The possibility of reversal causality is in agreement with the longitudinal study by Luke *et al.*[25] demonstrating that physical inactivity on the basis of energy expenditure does not predict weight change.

The present study also has the following limitations. First, FFM hydration was assumed to be equal in all participants at a value of 0·732[14]; therefore, some errors in estimating FM obtained from FFM may have resulted from differences in the levels of obesity and sex. Second, PAL in the study was higher than 1·75, the value reported in the general population of Eastern and Western countries[21,26–28]. The average daily number of steps of about 9564 observed in the participants of the present study was also higher than that reported for Japanese adult men in another study, who generally walk an average of 7893 steps/d[29]. This indicates that the individuals included in the present study may have been more physically active than adult men in the general Japanese population. However, the ranges of PAL were similar between men and women (1·46–2·51 and 1·36-2·52, respectively)[12], which were within the PAL of the general population[30].

In conclusion, the present cross-sectional study in Japanese adult men showed a negative relationship between BMI and the number of steps and time spent in moderate-intensity physical activity. It also showed that men with higher fat deposition were less active on the basis of PAEE adjusted for BW and PAL. These observations are very similar to those reported in our previous study in adult Japanese women[12]. These cross-sectional studies cannot prove causality, and that obesity causes physical inactivity may be the case. Despite these limitations, the present study did provide information regarding which physical activity variables are appropriate for use in a longitudinal study. Additional research using a longitudinal study design is required to examine the cause–effect relationships between obesity and physical inactivity including factors of dietary intake.

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Resting Energy Expenditure (REE) in Six- to Seventeen-Year-Old Japanese Children and Adolescents

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Summary Accurate estimation of resting energy expenditure (REE) in children and adolescents is important to establish estimated energy requirements for the Japanese population. Our objectives were 1) to determine the REE of 6- to 17-y-old Japanese children and adolescents by indirect calorimetry in order to estimate energy expenditure for this group, 2) to compare measured REE with predicted REE to determine the accuracy of predictive equations of REE for Japanese children and adolescents, and 3) to derive new predictive equations for REE for Japanese children and adolescents based on measured REE. REE was measured in 221 Japanese children and adolescents, aged 6 to 17 y old (113 boys and 108 girls) using a ventilated indirect calorimeter. Anthropometric and body composition measurements were also performed. REE expressed as absolute values increased with age in both genders, and there was a significant difference between genders in the 12–17 y age group. REE was strongly correlated with body weight (BW) and fat-free mass (FFM). REE adjusted for BW or FFM decreased with age in both genders, and a gender difference was still observed in the 12–17 y age group after this adjustment. The highest accuracy of prediction was achieved using the Dietary Reference Intake for Japanese (1969) for boys and the Molnar equation for girls. Step-down multiple regression analysis was carried out using either a combination of age, gender, BW, and height, or a combination of age, gender, FFM, and fat mass (FM). The predictive equation accounted for 75% (R^2) and 76% of the variance, respectively. In conclusion, absolute REE increased and REE adjusted for BW or FFM decreased with age. The major determinant of REE was FFM, but significant gender differences were observed in the 12–17 y range for both absolute REE and adjusted REE.

Key Words resting energy expenditure, body composition, fat-free mass, children, adolescents

The current Japanese recommendations for average daily energy requirements in children are based on resting energy expenditure (REE), physical activity level (PAL), and the energy need associated with normal growth (*1*). As REE is the main component, comprising an average of 60% of daily energy expenditure (*2*), an underestimation or overestimation of REE may lead to large errors in planning energy requirements for a population and in calculating the energy needs of an individual. The current formulas for the prediction of REE of Japanese children and adolescents are based on measurements from studies carried out before 1969. The Recommended Dietary Allowances for Japanese (Japan-DRI) (1969) (*3*) predicted Basal Metabolic Rate (BMR) according to body surface area. The Japan-DRI (1975) (*4*) provided BMR standards per unit weight according to sex and age category; the data used for these standards were from the BMR database for Japanese (*1*). However, the validity of these predictive equations has not been examined in Japanese children. In view of the scarcity of information regarding REE in Japanese children and adolescents, we measured REE in a group of free-living, healthy boys and girls by indirect calorimetry.

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Several equations have been developed to predict REE from simple variables such as weight, height, gender, and age in children and adolescents (*2, 5–8*). Many investigators have suggested that REE in children and adolescents is influenced by body composition, pubertal stage, and ethnicity (*9–11*), and recently, validated predictive equations for REE in children and adolescents have been proposed or derived (*12–16*). Some studies have suggested that it is necessary to use ethnicity-specific REE equations for some ethnic populations (*5, 14–16*). However, the validity of REE predictive equations in Japanese children and adolescents was not previously known.

The goals of this study were 1) to investigate REE in children and adolescents by indirect calorimetry in order to assess the recommendations for energy intake for 6- to 17-y-old Japanese children and adolescents, 2) to compare measured and predicted REE to determine the accuracy of predicted REE equations for Japanese children and adolescents, and 3) to derive REE predictive equations for Japanese children and adolescents based on measured REE.

METHODS

Subjects. A total of 226 16- to 17-y-old Japanese children (118 boys and 108 girls) living in the Kanagawa Prefecture area volunteered for the study after receiving an invitation through their schools. All the children were in apparent good health, without any anamnesis of conditions affecting energy expenditure, such as abnormal thyroid gland function. Informed consent was obtained from the children and their parents after both the nature and the purpose of the study were explained. Data were collected from 221 subjects (113 boys and 108 girls) and utilized for the analysis with the exception of data from five boys who were unable to lie motionless during REE measurement. Measurements were taken between September 2006 and September 2008. The experimental protocol was in compliance with the Code of Ethics of the World Medical Association (Declaration of Helsinki), and had previously been approved by the Ethical Committee of Yokohama National University.

Protocol. All subjects traveled from their homes by car or public transportation, arriving at the laboratory at 8 AM after at least 12 h of fasting. Anthropometric and body composition measurements were performed before REE measurement. The child's weight was determined to the nearest 0.1 kg with a digital balance while he or she was wearing light clothes (shorts and T-shirts). Body height and sitting height were measured to the nearest 0.1 cm. Circumferences of the waist, hip, thigh, and arm and skinfold measurements of the triceps, biceps, midthigh, subscapular, suprailiac and abdominal regions were measured by a single observer using calipers in the standard manner (*17*). Body mass index (BMI) was calculated dividing weight (kg) by height squared (m^2). Percent body fat (BF) was determined by two methods. BF-1 was determined by bioelectrical impedance (BI) using a model TBF-300 body fat analyzer (Tanita Co., Tokyo); BF-2 was determined from skinfold measurements. Body density was calculated using the predictive equations of Nagamine (*18*) for Japanese adolescents from the sum of the triceps and subscapular skinfolds, and calculation of body fat was based on the equation of Tobe et al. (*19*). Fat-free mass (FFM) was calculated by subtracting body fat mass (FM, percent body fat×body weight (BW)) from body weight. Relative weight was calculated as [(measured weight −standard weight)/standard weight (*20*)×100], and body surface area (SA) was calculated using BW and body height according to a formula from the Dietary Reference Intake for Japanese (*3*). Girls were asked if they had undergone menarche.

Resting energy expenditure. After the subject had been lying supine for 30 min, measurement of REE was initiated using a ventilated hood system (Model AR-1, ARCO System Co., Chiba) at an environmental temperature between 22 and 25°C. We have already reported that a steady state is established 3 min after starting respiration and that the accuracy of REE measured by this system is ±0.02% (*21*). Subjects were placed under a transparent plastic hood that covered their heads and that was connected to the system. After the child had adapted to the hood for 5 min REE was measured for 20 min. Oxygen consumption and carbon dioxide production were measured at 1-min intervals and averaged over 6 to 20 min during 20 min of measurement. Energy expenditure was calculated using Weir's equation (*22*) (results expressed as kilocalories per day). REE is known to be difficult to measure in young children because children are often reluctant to stay still for a prolonged period. All children were carefully instructed of the test procedure.

Predicted REE was calculated by a formula derived using REE standards based on body surface area for Japanese (*3*), using REE standards based on body weight (*1*, *4*) and using the following equations:

(1) FAO/WHO/UNU (*2*) (kJ/d)

6–10 y Boys: 95×BW (kg)+2,070
Girls: 94×BW (kg)+2,090

11–17 y Boys: 73×BW (kg)+2,720
Girls: 51×BW (kg)+3,120

(2) Schofield (*5*) (kJ/d)

6–10 y Boys: (0.082×BW (kg)+0.545×ht (m) +1.736)×1,000
Girls: (0.071×BW (kg)+0.677×ht (m) +1.553)×1,000

11–17 y Boys: (0.068×BW (kg)+0.574×ht (m) +2.157)×1,000
Girls: (0.035×BW (kg)+1.948×ht (m) +0.837)×1,000

(3) Maffeis et al. (*6*) (kJ/d), 6–10 y

Boys: 28.6×BW (kg)+23.6×ht (cm) −69.1×Age (y)+1,287
Girls: 35.8×BW (kg)+15.6×ht (cm) −36.3×Age (y)+1,552

(4) Molnár et al. (*7*) (kJ/d), 10–16 y

Boys: 50.9×BW (kg)+25.3×ht (cm) −50.3×Age (y)+26.9
Girls: 51.2×BW (kg)+24.5×ht (cm) −207.5×Age (y)+1,629.8

Statistical analysis. All results are shown as means±SD. Two-factor analysis of variance (ANOVA) was employed to establish the effects of age and gender, as well as the interaction of these factors. Where a main effect was observed, post-hoc testing using Dunnett's T3 test was performed for multiple comparisons. Student's *t*-test was carried out to assess the influence of gender. A p value of less than 0.05 was considered statistically significant. The relationship between the two variables was evaluated using Pearson's correlation and a linear regression model. The statistical significance of differ-

Table 1. Characteristics of the subjects.[a]

	Boys					Girls				
	6–7 (y)	8–9 (y)	10–11 (y)	12–14 (y)	15–17 (y)	6–7 (y)	8–9 (y)	10–11 (y)	12–14 (y)	15–17 (y)
n	6	11	20	41	35	7	14	12	39	36
Height (cm)	119.6±4.3	131.0±5.7	142.3±6.6	163.1±8.9	170.0±5.1	121.4±2.6	131.0±7.0	144.8±7.6	156.5±5.5	157.9±5.9
Body weight (kg)	22.6±3.8	28.0±5.1	36.3±9.0	52.3±9.7	59.7±8.3	23.7±2.7	25.7±3.7	32.8±6.9	44.0±5.3	51.2±6.7
Sitting height (cm)	69.1±7.2	71.9±3.2	76.9±3.8	86.9±5.2	91.7±2.8	67.9±2.3	71.8±3.6	78.2±4.3	84.0±3.4	83.8±5.7
Circumferences										
Waist (cm)	52.5±3.4	56.2±5.9	60.9±8.1	65.9±7.5	71.3±6.8	54.7±5.5	53.1±3.3	55.2±5.2	59.9±4.2	65.3±4.2
Hip (cm)	63.3±5.5	69.9±5.8	76.5±6.9	86.6±6.1	92.6±4.9	66.0±3.7	67.2±4.7	74.3±6.7	84.8±4.4	92.2±4.5
Arm (cm)	18.5±2.7	19.7±2.0	22.1±3.6	24.7±2.9	27.1±3.2	19.3±1.9	18.8±1.8	19.8±2.1	22.3±2.0	25.8±2.4
Thigh (cm)	33.7±4.5	36.8±3.9	40.5±4.6	47.5±4.7	48.9±3.9	35.2±2.8	34.7±2.7	38.5±4.0	45.1±3.4	49.8±3.8
Skin folds										
Triceps (mm)	8.7±3.3	9.5±5.3	12.2±6.1	10.2±4.3	10.3±5.3	10.6±3.8	9.2±2.6	9.9±3.4	11.8±3.7	17.6±4.5
Biceps (mm)	4.4±1.4	5.3±3.2	6.3±4.2	4.6±2.2	4.6±2.3	4.9±1.9	4.3±1.3	4.3±1.7	4.8±1.5	7.6±2.6
Midthigh (mm)	12.7±4.8	12.9±5.7	14.0±5.2	13.0±4.2	11.7±3.9	14.7±4.7	13.8±3.8	12.7±4.1	17.0±5.0	23.1±5.7
Subscapular (mm)	6.9±3.8	7.0±3.9	9.4±7.5	8.4±3.3	10.2±5.0	7.6±2.7	6.7±2.2	7.3±3.8	9.0±3.3	15.3±4.9
Suprailiac (mm)	8.2±5.5	9.9±8.4	12.5±8.6	12.5±8.4	13.8±7.6	10.3±6.8	7.9±3.0	9.1±3.5	12.0±5.2	17.6±5.7
Abdominal (mm)	7.9±5.2	9.6±7.9	12.5±9.2	10.9±7.7	12.1±6.8	9.1±5.2	8.4±4.0	9.7±4.4	10.7±4.7	19.0±4.6
BMI[b]	15.7±1.9	16.3±2.4	17.7±3.1	19.6±2.9	20.7±3.0	16.0±1.7	15.0±1.5	15.5±2.1	18.0±1.9	20.5±2.1
Rohrer Index	131.4±14.0	124.5±18.9	124.4±18.3	121.2±19.0	122.1±19.3	132.2±13.9	114.4±13.3	106.9±12.2	114.5±14.1	130.0±13.7
Relative weight[c] (%)	1.4±11.5	1.2±15.2	2.8±15.0	−4.3±15.9	−5.1±16.1	3.6±10.8	−8.2±10.3	−13.8±9.8	−8.2±10.9	3.1±11.2
Surface area[d] (m^2)	0.84±0.08	0.99±0.10	1.17±0.15	1.50±0.16	1.64±0.11	0.87±0.05	0.95±0.09	1.13±0.14	1.36±0.09	1.46±0.11
FFM-1[e] (kg)	18.6±2.4	23.0±3.3	28.5±4.4	43.3±7.3	47.6±5.4	20.0±1.6	22.3±2.7	27.8±4.4	35.0±2.9	37.8±3.6
FFM-2[f] (kg)	20.1±3.5	24.9±3.5	30.4±4.2	45.6±7.1	52.5±4.3	21.4±2.5	22.6±3.0	27.5±4.7	36.4±3.3	37.9±3.7
BF-1[g] (%)	17.3±3.7	17.6±4.4	19.9±7.6	17.0±3.8	19.9±5.6	15.4±3.6	13.0±4.0	14.2±4.8	20.0±4.3	25.7±4.7
BF-2[h] (%)	11.1±1.3	10.4±6.2	14.0±9.8	12.3±4.4	11.4±6.8	9.6±0.5	12.0±3.1	15.4±4.9	16.8±4.8	25.4±6.4

[a] Means±SD.
[b] Body mass index.
[c] Calculated as [(measured weight−standard weight)/standard weight×100].
[d] Surface area calculated by the fomula of the Ministry of Health and Welfare (Japan) (1969).
[e] Fat-free mass measured by bioelectrical impedance.
[f] Fat-free mass measured by skinfold measurements.
[g] Percent body fat calculated by bioelectrical impedance.
[h] Percent body fat calculated by skinfold measurements.

Table 2. Resting energy expenditure (REE) of absolute values adjusted for body size according to age and gender.[a]

	6–7 (y)	8–9 (y)	10–11 (y)	12–14 (y)	15–17 (y)
Boys					
RQ	0.82±0.03	0.79±0.04	0.86±0.12	0.85±0.07	0.78±0.05
REE					
(kcal/d)	1,043±102^{1}	1,229±167^{2}	1,296±184^{1,3}	1,539±207^{c,1,2,3}	1,546±196^{c,1,2,3}
(kcal/m^2 SA/h)^{b}	51.5±3.0^{1}	51.8±3.4^{2}	46.5±4.1^{2}	42.6±2.5^{c,1,2}	39.2±4.0^{c,1,2}
(kcal/kg BW/d)	46.6±3.9^{1}	44.2±3.4	36.6±5.0^{1}	29.5±2.5^{c,1}	26.1±3.0^{c,1}
(kcal/kg FFM-1/d)	56.4±3.1^{1}	53.6±3.8^{2}	45.9±4.5^{1,2,3}	35.9±2.6^{c,1,2,3,4}	32.7±3.9^{1,2,3,4}
(kcal/kg FFM-2/d)	52.5±4.8^{1}	49.4±3.0^{2}	42.8±4.0^{2,3}	34.0±2.5^{1,2,3,4}	29.5±3.1^{c,1,2,3,4}
Girls					
RQ	0.84±0.08	0.85±0.08	0.81±0.07	0.86±0.09	0.75±0.05
REE					
(kcal/d)	1,025±68^{1}	1,122±132	1,182±115^{1}	1,203±99^{c,1}	1,214±136^{c,1}
(kcal/m^2 SA/h)^{b}	49.1±4.0^{1}	49.2±3.3^{2}	43.9±3.8^{2}	37.0±3.0^{c,1,2}	34.8±3.1^{c,1,2}
(kcal/kg BW/d)	43.7±5.5^{1}	43.9±3.8^{2}	37.1±6.0^{2,3}	27.3±3.3^{c,1,2,3}	23.9±2.6^{c,1,2,3}
(kcal/kg FFM-1/d)	51.6±4.7^{1}	50.4±3.8^{2}	43.0±4.9^{2,3}	34.5±2.9^{c,1,2,3}	32.2±3.2^{1,2,3}
(kcal/kg FFM-2/d)	48.4±5.9^{1}	49.9±3.6^{2}	43.7±6.0^{3}	33.2±2.7^{1,2,3}	32.2±3.1^{c,1,2,3}

[a] Means±SD.
[b] SA means surface area calculated using BW and body height according to the formula for Japanese (*3*).
[c] Significantly different between boys and girls, $p<0.05$ (Student's *t*-test).
[1,2,3,4] Means within a row with the same number letters are significantly different, $p<0.05$ (Dunnet T3 test after repeated-measures ANOVA).

ences between measured and predicted REE values was determined by one-way analysis of variance (ANOVA) and Dunnett's post-hoc test. Accuracy of the REE predictive equations was assessed by percent bias, the root mean squared prediction error (RMSPE), and Bland-Altman analysis.

$$\text{RMSPE}=\sqrt{(\Sigma(\text{Predicted REE}-\text{Measured REE})^2/\text{N})}$$

The relationship between measured REE and weight, height, age, pubertal status (for girls only), and gender, or measured REE and FFM, FM, height, age, pubertal status (for girls only), and gender were assessed by the use of simple and step-down multiple regression analysis. In this analysis, gender and pubertal status in girls were entered as a dummy variable, with girls assigned a value of 0 and boys a value of 1, or with those who had not achieved menarche assigned a value of 0 and others a value of 1. Statistical analysis was carried out using SPSS version 10.0J for Windows (SPSS Inc. Japan, Tokyo).

RESULTS

Physical characteristics of the subjects are shown in Table 1. Average weights and heights of age-by-gender subgroups were within 90% to 110% of the reference values for Japanese children and adolescents as determined by the Ministry of Health, Labour and Welfare (*1*). According to standard body weight criteria (*20*) and using relative weight, overweight was defined as being at least 10% above average, and underweight was defined as being at least 10% below average. One hundred nineteen subjects (53.8%) were classified as normal weight, 28 (12.7%) as overweight, and 74 (33.5%) as underweight.

Table 2 shows measured REE. REE expressed in absolute values increased with age in both genders. There was no significant difference between genders in the 6–7 y, 8–9 y, or 10–11 y age groups. REE adjusted for BW, FFM-1, FFM-2, and body surface area decreased with age in both genders, and a significant gender difference remained in the 12–14 y and 15–17 y age groups.

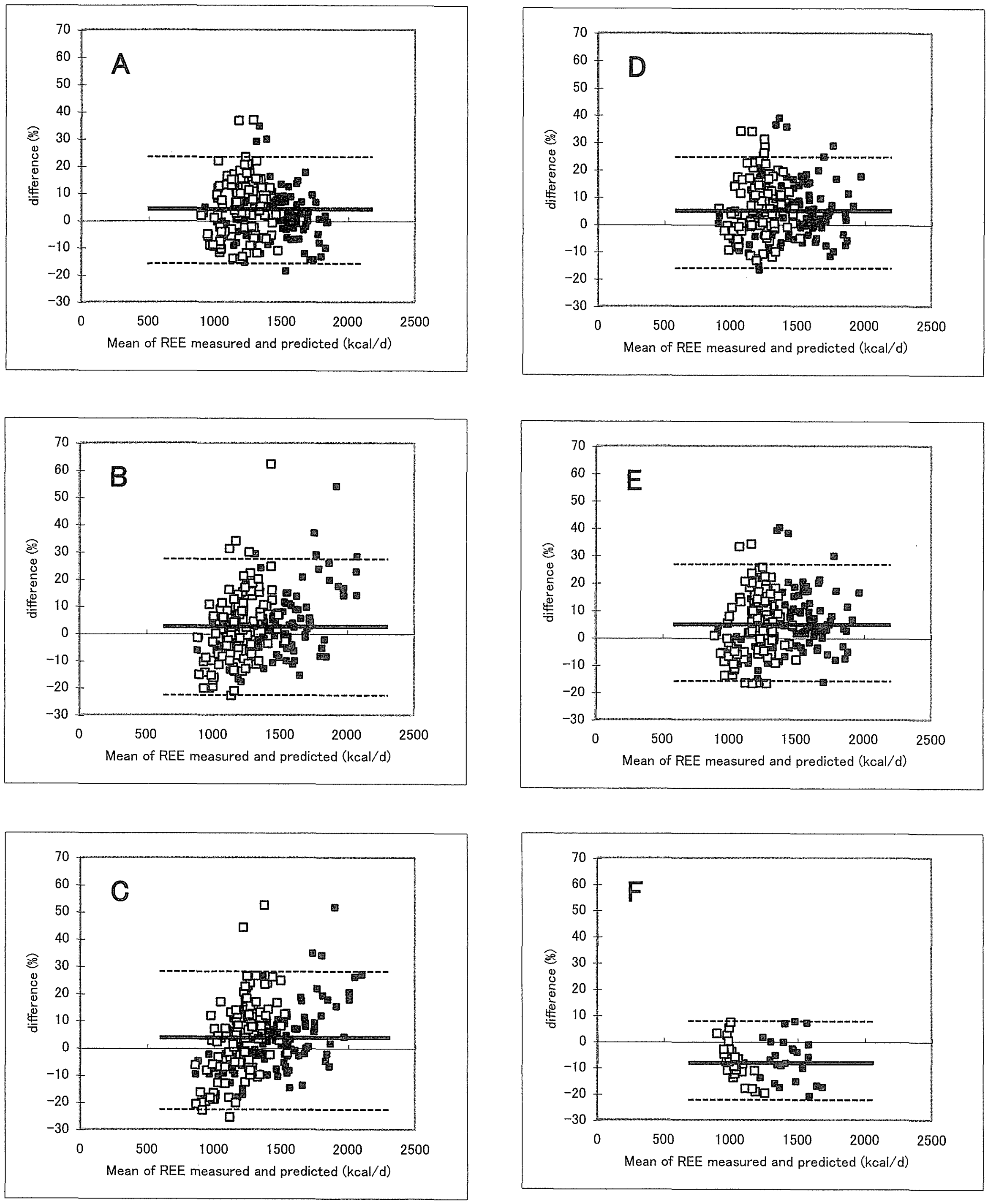
Correlation analysis showed that age, height, BW, FFM, body surface area, and relative weight were significantly correlated with REE in boys, girls, and in the combined group (Table 3). The strongest correlation for the combined group (boys and girls, 6–17 y) was between REE and FFM-2 ($r=0.797$), explaining 64% (R^2) of the variability in REE.

Figure 1 shows a Bland-Altman plot of the differences between measured and predicted REE using the seven formulas. The numbers of subjects included in the data plotted are 51 (24 boys and 27 girls), 155 (81 boys and 74 girls), and 221 (113 boys and 108 girls), using the Maffeis equation, Molnár equation, and other equations, respectively. Table 4 shows the average of measured or predicted REE (in kcal/d), percent bias, RMSPE (in kcal/d), and percent frequency of accurate estimation (when the difference between predicted and measured REE was within ±10%), underestimation (the difference between predicted and measured REE was $<-10\%$), and overestimation (the difference between predicted and measured REE was $>10\%$). The means of REE predicted by all formulas except the WHO equation and Maffeis equation in girls, and Maffeis equation in boys were not significantly different from measured REE. The bias for the seven formulas varied from −7.1% to 4.6% in boys and from −8.0 to 6.5% in girls. The Japan-DRI (1969) formula had the smallest bias (1.2%) in boys and the Japan-DRI (1975) for-

Table 3. Correlation between REE (kcal/d) and age, height, body weight (BW), fat-free mass (FFM), body surface area (SA) or relative weight.

Subject	y	n	Age		Height		BW		FFM-1[a]		FFM-2[b]		SA[c]		Relative weight[d]	
			r	*p*	*r*	*p*	*r*	*p*	*r*	*p*	*r*	*p*	*r*	*p*	*r*	*p*
Boys and girls	6–7	13	−0.257	0.396	0.420	0.153	0.548	0.053	0.589	0.034	0.520	0.069	0.589	0.034	0.454	0.119
	8–9	25	0.236	0.166	0.593	0.002	0.863	0.000	0.828	0.000	0.878	0.000	0.848	0.000	0.486	0.014
	10–11	32	0.028	0.878	0.552	0.001	0.752	0.000	0.759	0.000	0.761	0.000	0.746	0.000	0.558	0.001
	12–14	80	0.181	0.108	0.686	0.000	0.822	0.000	0.897	0.000	0.901	0.000	0.839	0.000	0.251	0.025
	15–17	71	0.180	0.134	0.642	0.000	0.732	0.000	0.770	0.000	0.818	0.000	0.777	0.000	0.061	0.615
	6–17	221	0.425	0.000	0.657	0.000	0.742	0.000	0.780	0.000	0.797	0.000	0.728	0.000	0.178	0.004
Boys	6–7	6	−0.505	0.307	0.538	0.271	0.831	0.040	0.883	0.020	0.802	0.055	0.806	0.053	0.836	0.038
	8–9	11	0.578	0.063	0.640	0.034	0.894	0.000	0.889	0.000	0.877	0.000	0.899	0.000	0.611	0.046
	10–11	20	−0.165	0.486	0.662	0.001	0.752	0.000	0.822	0.000	0.801	0.000	0.772	0.000	0.523	0.018
	12–14	41	0.321	0.041	0.690	0.000	0.897	0.000	0.907	0.000	0.881	0.000	0.910	0.000	0.272	0.085
	15–17	35	0.163	0.348	0.199	0.252	0.597	0.000	0.501	0.002	0.587	0.000	0.592	0.000	0.598	0.018
	6–17	113	0.603	0.000	0.737	0.000	0.841	0.000	0.829	0.000	0.808	0.000	0.828	0.000	0.179	0.029
Girls	6–7	7	−0.004	0.994	0.338	0.458	0.155	0.740	0.296	0.520	0.152	0.745	0.225	0.627	0.006	0.989
	8–9	14	0.009	0.977	0.659	0.010	0.800	0.001	0.795	0.001	0.844	0.000	0.801	0.001	0.127	0.665
	10–11	12	0.429	0.164	0.732	0.007	0.709	0.010	0.734	0.007	0.654	0.021	0.735	0.006	0.284	0.371
	12–14	39	0.131	0.425	0.366	0.022	0.345	0.032	0.475	0.002	0.571	0.000	0.403	0.011	−0.009	0.958
	15–17	36	0.168	0.329	0.385	0.021	0.656	0.000	0.584	0.000	0.618	0.000	0.626	0.000	0.346	0.038
	6–17	108	0.538	0.000	0.392	0.000	0.566	0.000	0.578	0.000	0.588	0.000	0.570	0.000	0.148	0.063

[a] Fat-free mass measured by bioelectrical impedance.
[b] Fat-free mass measured by skinfold measurements.
[c] Body surface area (m^2) calculated using BW and body height according to the formula for Japanese (*3*).
[d] Calculated as [(measured weight−standard weight)/standard weight×100].



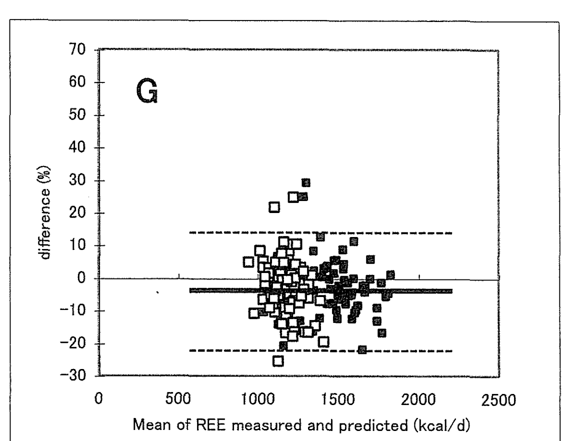


Fig. 1. Bland-Altman comparisons for the total sample (A–E), or within age groups (F and G). Differences between measured REE and predicted REE plotted against average measured REE and predicted REE. (A) Japan-DRI (1969) (*3*), (B) Japan-DRI (1975) (*4*), (C) Japan-DRI (2009) (*1*), (D) FAO/WHO/UNU (*2*), (E) Schofield (*5*), (F) Maffeis et al. (*6*), and (G) Molnár et al. (*7*). Filled squares: boys, *open squares*: girls, thick straight line: mean, dashed line: means±2SD of the total sample.

Table 4. Evaluation of resting energy expenditure (REE) predictive equation in 221 children and adolescents based on bias, root mean squared prediction error (RMSPE), and percentage of accurate estimation.

	Age	n	REE (kcal/d) Mean±SD	Bias (%) (Min–Max)Mean±SD	RMSPE (kcal/d)	Accurate estimation[a] (%)	Under estimation[b] (%)	Over estimation[c] (%)
Boys								
REE measured	6–17	113	1,442±244					
	6–10	24	1,208±176					
	10–16	81	1,472±220					
REE predicted								
Japan-DRI (1969)	6–17	113	1,451±231	1.2±9.2 (−18.9–34.2)	129.3	77.0	9.7	13.3
Japan-DRI (1975)	6–17	113	1,491±324	3.2±12.2 (−20.9–53.7)	188.1	67.3	10.6	22.1
Japan-DRI (2009)	6–17	113	1,492±333	3.1±12.0 (−18.5–51.3)	184.4	68.1	8.8	23.0
WHO (1985)	6–17	113	1,488±267	3.5±10.6 (−17.7–38.4)	153.1	70.8	6.2	23.0
Schofield (1985)	6–17	113	1,504±269	4.6±10.6 (−16.7–39.8)	159.4	69.0	4.4	26.5
Maffeis (1993)	6–10	24	1,111±103**	−7.1±8.3 (−21.2–7.32)	144.2	25.0	75.0	0.0
Molnár (1995)	10–16	81	1,419±202	−3.2±8.7 (−22.2–28.9)	134.2	74.1	21.0	4.9
Girls								
REE measured	6–17	108	1,184±128					
	6–10	27	1,098±121					
	10–16	74	1,205±122					
REE predicted								
Japan-DRI (1969)	6–17	108	1,234±144	4.7±10.5 (−14.6–36.5)	130.6	61.1	8.3	30.6
Japan-DRI (1975)	6–17	108	1,200±185	1.6±13.2 (−23.2–61.8)	151.6	57.4	19.4	23.1
Japan-DRI (2009)	6–17	108	1,220±207	3.1±13.9 (−25.8–52.1)	164.0	52.8	17.6	29.6
WHO (1985)	6–17	108	1,256±136**	6.5±10.5 (−13.5–33.6)	138.6	56.5	4.6	38.9
Schofield (1985)	6–17	108	1,244±153	5.6±11.4 (−17.2–33.8)	144.2	53.7	7.4	38.9
Maffeis (1993)	6–10	27	1,004±52**	−8.0±7.2 (−20.1–6.84)	129.5	63.0	37.0	0.0
Molnár (1995)	10–16	74	1,158±96	−3.3±8.9 (−25.8–24.5)	111.8	74.3	18.9	6.8

** Significantly defferent from measured REE corresponding to the same age group ($p<0.05$).
[a] Percentage of the subjects predicted by equation within ±10% of measured REE.
[b] Percentage of the subjects predicted by equation <90% of measured REE.
[c] Percentage of the subjects predicted by equation >110% of measured REE.

mula had the smallest bias (1.6%) in girls. The smallest RMSPEs were obtained using the Japan-DRI (1969) formula (129.3 kcal/d) in boys and the Molnár equation (111.8 kcal/d) in girls. The highest percentage of accurate REE predictions was obtained using the Japan-DRI (1969) formula (77.0%) in boys and the Molnár equation (74.3%) in girls.

Step-down multiple regression analysis was carried out using either body size measurements (age, gender, BW, and height), or body composition measurements (age, gender, FFM, and FM) (Table 5). The predictive equation for boys and girls comprising these four parameters accounted for 75% (R^2) and 76%, respectively, of REE variance. When the predictive equation for girls was used taking pubertal status into account, the variance of the equation was slightly higher. Then, simple regression sets of equations used variables easily obtained in clinical as well as epidemiological studies: age, BW, and height were obtained. For boys, the equation used was: 14.4×BW (kg)+5.09×ht (cm)−34.0×Age (y)+403, for girls: 7.64×BW (kg)+4.22×ht (cm)−22.5×Age (y)+526. These models accounted for 74.2% of the variance in boys and 39.5% of the variance in girls. Standard errors of the estimates (SE) were 125.4 kcal/d in boys and 100.9 kcal/d in girls.

DISCUSSION

REE increased significantly with age, and REE adjusted for BW, FFM, or SA decreased with age in both genders. The results support the association between REE and body size or body composition (FFM and FM) previously reported in both adults (*2*, *23*, *24*) and children (*2*, *6*, *9*, *10*, *25*).

REE adjusted for FFM decreased with age in both genders. The difference between genders was not significant from age 6–11 y, but was significant between the ages of 12 and 17 y. Our results suggest that the metabolic activity of FFM decreases with age, and that the gender-specific change in body composition that occurs during puberty directly influences REE. FFM includes both relatively low-metabolic-rate fat-free adipose tissue, skeletal muscle (SM), and bone, and high-metabolic-rate residual mass (*26*). Midorikawa examined body composition in Japanese children using dual-energy X-ray absorptiometry (DXA) and ultrasound to measure total and regional fat mass, and found that whole-body SM mass dramatically increases from the prepubertal to the adolescent stage, which is similar to body composition in