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

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

Subjects and methods

Subjects

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

Study protocol

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

DLW energy measurement

After providing a baseline urine sample, a single dose of approximately 0.06 g/kg body weight of ^2H_2O (99.8 atom%, Cambridge Isotope Laboratories, Andover, MA, USA) and 0.14 g/kg body weight of $H_2^{18}O$ (10.0 atom%, Cambridge Isotope Laboratories) were given orally to each subject using a straw. Next, the container was rinsed twice with 50 ml of tap water provided from the same place where the subject lived. After dose administration, the subject refrained from eating and drinking over a 4-h equilibration period (4 h sampling) for measurement of total body water (TBW). Then, the second voided urine on the mornings of day 1 (the next day of DLW dose) and day 14 (at the same time as the void of day 1) was collected for the isotopic (^2H and ^{18}O) elimination rate. All urine samples except for baseline were collected by the participant, and the time of sampling was recorded. All samples were first stored by freezing at −40°C in airtight parafilm-wrapped containers, and then transported to the analytical facility for isotopic abundance analyses.

Gas samples for the Isotopes Ratio Mass Spectrometer (IRMS) were prepared by equilibration of urine sample with a gas. The gas for equilibration of ^{18}O was CO_2 and that for ^2H was H_2. Pt catalyst was used for equilibration of ^2H. The isotopic analyses were conducted using machines of IRMS of DELTA Plus (Thermo Electron Corporation, Bremen, Germany) calibrated using Vienna Standard Mean Ocean

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

Analytical calculations of isotopic abundance and TEE

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

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

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

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

rCO_2 were determined from the next equation.

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

where rCO_2 (mol/day) is the CO_2 production rate, TBW (mol) is the total body water, and k_O (per day) and k_H (per day) are the elimination rates of ^{18}O and ^{2}H, respectively (Wolfe, 1992; Racette *et al.*, 1994).

Each elimination rate (k) was calculated as follows:

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

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

Finally, TEE (kcal/day) calculation was performed using a modified Weir's formula (Weir, 1949) based on rCO_2 (mol/day) and FQ. FQ is calculated from DHQ, and average value of all present subjects (0.867±0.03) was used in this calculation. This assumes that under conditions of perfect nutrient balance, the FQ must equal the respiratory quotient (RQ) (Black *et al.*, 1986; Jones and Leitch, 1993; Surrao *et al.*, 1998).

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

PAL was calculated to be TEE/BMR. BMR was estimated according to the sixth Recommended Dietary Allowances for Japanese (Ministry of Health, Labour and Welfare, Japan, 1999).

Statistics

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

Results

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

Physical characteristics of all present subjects are shown in Table 1. Changes in body weight during the study period were −0.5 to 0.1 kg in each sex and age group. Males in their 30s and 40s decreased significantly body weight during the study period; however, their changes were within 3% of body weight at pre-examination. Of all the subjects, 6.8% of males and 13.2% of females were classified as lean (BMI less than 18.5 kg/m^2) and 36.5% of males and 14.5% of females were classified as obese (BMI more than 25 kg/m^2) according to the criteria for Japanese (Japan Society for the Study of Obesity, 2006). The average TBW was 36.9±4.8 kg for males and 27.2±35 kg for females. If we used 73.2% for the proportion of water in fat mass (Heyward and Wagner, 2004), the percent of fat mass was 24.7±6.0% for males and 31.4±5.7% for females.

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

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

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

Table 1 Physical characteristics of all subjects

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

Abbreviations: BMI, body mass index; TBW, total body water by doubly labelled method.
Values are means±s.d.
[a]*P*-value for paired *t*-test for body weight at pre- and post-examination.

Table 2 TEE and PAL by sex and age group

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

Abbreviations: PAL, physical activity level; TEE, total energy expenditure.
Sex difference: $P=0.799$.
Age group difference: $P=0.196$.
Area group difference: $P=0.336$.

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

Discussion

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

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

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

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

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

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

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

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

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

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

There were no significant differences in PAL between light and moderate categories in DRI, or between insufficient active and sufficient active categories in IPAQ. There was a clear overlap of measured PAL in these lower two categories. The lower categories both by IPAQ and DRI are divided mainly by the duration of light to moderate physical activity. The duration of these activities is thought to pose more difficulty than vigorous activity in terms of response, and this made it difficult to categorize the less active population. However, the duration of these activities had much impact on PAL among subjects with the normal PAL range, because they spent an average 9% of their active time engaging in high-intensity activity, and the distribution of time spent in activities of low and moderate intensity determines the activity level (Westerterp, 2001).

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

One of the most important limitations of the present study is that BMR was predicted, not measured. Calculation of PAL using predicted BMR could lead to some error for individuals. This may have caused a wide variation in PAL among each category divided by sex and age groups or the questionnaire on physical activity. However, we thought the use of prediction equations for BMR would generate the present result. Many prediction equations are available for estimating BMR, but their applicability to other ethnic groups is uncertain (Hayter and Henry, 1993; Frankenfield *et al.*, 2005). Ganpule *et al.* (2007) suggested recently that the use of FAO/WHO/UNU equations overestimated BMR among Japanese when compared with measured BMR. The predictive equations used in the present study were established based on the large database obtained under strictly controlled protocol, and have been reported to be accurate for Japanese (Taguchi *et al.*, 2001; Rafamantanantsoa *et al.*, 2003; Yamamura et al., 2003). Therefore, the error from using predicted BMR seems to be modest.

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

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

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ORIGINAL ARTICLE

Validation of self-reported energy intake by a self-administered diet history questionnaire using the doubly labeled water method in 140 Japanese adults

H Okubo[1,2], S Sasaki[2], HH Rafamantanantsoa[3], K Ishikawa-Takata[4], H Okazaki[4] and I Tabata[4]

[1]*Department of Nutrition Science, Kagawa Nutrition University, Saitama, Japan;* [2]*Nutritional Epidemiology Program, National Institute of Health and Nutrition, Tokyo, Japan;* [3]*Department of Exercise and Sport Sciences, Shanghai Institute of Physical Education, Shanghai, PR China and* [4]*Health Promotion and Exercise Program, National Institute of Health and Nutrition, Tokyo, Japan*

Objective: To validate reported energy intake (rEI) with a self-administered diet history questionnaire (DHQ) against total energy expenditure (TEE) by the doubly labeled water (DLW) method.
Subjects: A total of 140 healthy Japanese adults (67 men and 73 women) aged 20–59 years living in four areas in Japan.
Methods: Energy intake was assessed twice with DHQ over a 1-month period before and after TEE measurement (rEI_{DHQ1} and rEI_{DHQ2}, respectively). TEE was measured by DLW during 2 weeks (TEE_{DLW}).
Results: Mean rEI_{DHQ1} was lower than those of TEE_{DLW} by 1.9±2.4 MJ/day (16.4%, $P<0.001$) for men and 0.6±1.9 MJ/day (6.0%, $P<0.01$) for women. In men and women together, 62 subjects (44%) were defined as underreporters (rEI_{DHQ1}/TEE_{DLW} <0.84), 58 (41%) as acceptable reporters (0.84–1.16) and 20 (14%) as over-reporters (>1.16). Pearson correlation coefficient was 0.34 for men and 0.22 for women. After adjustment for the dietary and non-dietary factors related to rEI_{DHQ1}/TEE_{DLW}, the correlation coefficient improved to 0.42 and 0.37, respectively.
Conclusion: The energy intake assessed with DHQ correlated low to modestly with TEE measured by DLW. In addition, DHQ underestimated energy intake at a group level. Caution is needed when energy intake was evaluated by DHQ at both individual and group levels.
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Keywords: doubly labeled water; energy intake; self-administered diet history questionnaire; validation; Japanese adults

Introduction

Dietary intake estimates from self-administered dietary assessment methods such as questionnaires are commonly used in large-scale nutritional epidemiologic studies. Dietary assessment questionnaires have been developed for assessing habitual dietary intake and for ranking subjects according to their dietary intake. However, they cannot entirely avoid reporting errors (Barrett-Connor, 1991), including not only random but also systematic errors (Black and Cole, 2001; Livingstone and Black, 2003), due to the fact that they are self-reported.

In validation studies, data from dietary assessment questionnaires have often been compared with data from reference methods such as weighed diet records or 24 h recall (Willett and Lenart, 1998). However, all these dietary assessment methods were based on self-reporting. Therefore, the errors of both the new and reference methods might be correlated each other. The doubly labeled water (DLW) method, which measures the total energy expenditure (TEE) of subjects in free-living situations, has made it possible to validate reported energy intake (rEI) with an external biomarker (Hill and Davies, 2001; Trabulsi and Schoeller, 2001). The error of the DLW method is independent of self-rEI error (Livingstone and Black, 2003). However,

Correspondence: Dr S Sasaki, Nutritional Epidemiology Program, National Institute of Health and Nutrition, 1-23-1 Toyama, Shinjuku-ku, Tokyo 162-8636, Japan.
E-mail: stssasak@nih.go.jp
Guarantor: S Sasaki.
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relatively few validation studies of food frequency questionnaires against the DLW method have appeared (Sawaya et al., 1996; Andersen et al., 2003; Subar et al., 2003). Furthermore, no such studies have been reported in non-Western countries.

The purpose of the present study was to examine the validity of energy intake assessed with a self-administered diet history questionnaire (DHQ) (Sasaki et al., 1998) in comparison with TEE, as measured by the DLW method in a Japanese population.

Subjects and methods

Study population

This study was conducted in four districts of Japan from May to August 2003. We invited 40 healthy subjects (20 men and 20 women) aged 20–59 years from each of the four areas to participate, and distributed five subjects equally in each sex and age class of 20–29, 30–39, 40–49 and 50–59 years. Details of study recruitment and enrollment were described previously (Ishikawa-Takata et al., 2007). All subjects providing written informed consent were finally considered eligible for the study. The total number of participants was 157 (78 men and 79 women).

Procedures

The study protocol was approved by the Ethics Committee of the National Institute of Health and Nutrition in Japan. The participants completed three visits over the study period and all participants completed the study. After recruitment, the participants were mailed an introductory letter and two dietary questionnaires including a DHQ, four physical activity questionnaires, and a supplemental questionnaire on lifestyle variables, and asked to fill them out and mail them back before the first visit (visit 1).

At visit 1, the participants had their questionnaires reviewed, their body weight and height measured and provided a baseline urine sample. At visit 2, on the morning following visit 1, they received a dose of DLW after an overnight fast. At visit 3, 14 days after visit 2, the participants brought urine samples and had their body weight and height measured.

After visit 3, the participants were mailed two dietary questionnaires including the DHQ, four physical activity questionnaires, supplemental questionnaire on lifestyle variables and diary about lifestyle during the period of TEE measurement.

All the collected questionnaires were checked by trained dietitians in each local center and again then in the study center. When missing answers, errors or both were found, the subjects were requested to answer the questions again.

Dietary assessment methods

Self-administered DHQ. The DHQ is a validated 16-page structured questionnaire, which assesses dietary habits in the preceding 1-month period (Sasaki et al., 1998, 2000). Details of the questionnaire, methods of calculating nutrients and validity are given elsewhere (Sasaki et al., 1998, 2000). Briefly, the DHQ consists of seven sections; (1) general dietary behavior, (2) major cooking methods, (3) consumption frequency and amount of six alcoholic beverages, (4) consumption frequency and semiquantitative portion size of 121 selected food and nonalcoholic beverage items, (5) dietary supplements, (6) consumption frequency and amount of 19 staple foods (rice, bread, noodles and other wheat foods) and miso soup (fermented soybean paste soup), and (7) open-ended items for foods consumed regularly (=once/week), which are not listed in the question. The food and beverage items and portion sizes in the DHQ were derived primarily from the data in the National Nutrition Survey of Japan (Sasaki et al., 1998) and several recipe books for Japanese dishes. Measures of energy and dietary intakes for food and beverage items and dietary supplements with energy (148 food items in total) were calculated using an ad hoc computer algorithm for the DHQ, which was based on the Standard Tables of Food Composition in Japan (Science and Technology Agency, 2000). Information on dietary supplements, such as tablet, powder and liquid, which contained few energy and on data from the open-ended questionnaire items were not used in the calculation of dietary intake.

Anthropometric measures

Anthropometric measures were obtained at visits 1 and 3 by a single-trained study member. Body weight and height were measured to the nearest 0.1 kg and 0.1 cm, respectively, in subjects wearing light clothing and no shoes. body mass index (BMI) was calculated as body weight (kg) divided by the square of body height (m^2).

Measurement of TEE with the DLW method

At visit 2, after a baseline urine sample was obtained, a single dose of approximately 0.06 g/kg body weight of ^2H_2O (99.8 atom%, Cambridge Isotope Laboratories, MA, USA) and 0.14 g/kg body weight of $H_2^{18}O$ (10.0 atom%, Cambridge Isotope Laboratories, MA, USA) was orally given to each subject via a drinking straw. After the dose administration, the subjects refrained from eating and drinking over a 4-h equilibration period (4 h sampling) for measurement of total body water. The second voided urine in the morning of day 1 (the day after the DLW dose) and day 14 (at the same time as the voiding on day 1) were collected for measurement of the isotopic (^2H and ^{18}O) elimination rate.

The procedure for specimen analysis and for subsequent data analyses was described previously (Ishikawa-Takata et al., 2007). Briefly, the isotopic analyses were conducted using the Isotope Ratio Mass Spectrometry (IRMS) *DELTA Plus* equipment (Thermo Electron Corporation, Bremen, Germany) and calibrated using Vienna Standard Mean Ocean Water (V-SMOW), 302B, and the Greenland Ice Sheet Precipitation (GISP) standard provided by the International Atomic Energy Agency. Each measurement of samples and the corresponding references was performed in duplicate. The average s.d. through the analyses were 0.5‰ for ^2H and 0.03‰ for ^{18}O.

TEE (kcal/day) calculation was performed using a modified Weir's formula Weir, 1949 based on rCO_2 (mol/day) and food quotient (FQ):

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

FQ was derived from the dietary assessment data (g/day) of DHQ using an equation of Black *et al.* (1986). The average value of all subjects (0.867) was used for all subjects to estimate TEE.

Assessment of other variables possibly related to the rEI

Lifestyle, behavioral and psychological variables possibly related to the rEI were obtained from the four-page questionnaire as follows: educational attainment, alcohol drinking, history of diet experiences, desire for body weight change, and difference between ideal and measured body weight.

A physical activity level was calculated as TEE divided by basal metabolic rate (BMR). BMR was estimated according to the 6th Recommended Dietary Allowances for Japanese Ministry of Health Welfare (1999).

Statistical analysis

We excluded 17 subjects who was non-Japanese ($n = 1$), who was obese ($n = 1$), who did not complete at least first or second DHQ ($n = 2$), who had left more than 40 items blank in the questions regarding frequency for 121 selected food and beverage items in DHQ ($n = 4$), who rEI outside the range of 3.0–16.0 MJ/day ($n = 2$), or who did not provide sufficient urine sample volume ($n = 7$). Thus, 140 subjects (67 men and 73 women) were included in the present analysis.

As we monitored the body weight change during the assessment period of rEI by second DHQ (rEI_{DHQ2}), we estimated EI (eEI) from TEE_{DLW} with a correction for change in body energy store during the survey period (Bathalon *et al.*, 2000):

$$eEI = TEE + (\Delta wt \times 0.03)$$

where TEE is measured as MJ/day, Δwt is measured as g/day between visits 1 and 3, and 0.03 MJ/day (7 kcal/day) is the energy cost of weight change (Saltzman and Roberts, 1995). The eEI was used for the validation of rEI_{DHQ2}. In contrast, this correction of change in body energy store was not considered for the validation of rEI_{DHQ1} because of the lack of the monitoring.

The results were expressed as the mean and s.d. Mean differences between sexes and among methods were tested by the non-paired *t*-test and paired *t*-test, respectively. The Pearson and Spearman correlation coefficient was used to examine correlations between the test and the reference methods. Furthermore, the study participants were classified into tertiles of energy intake according to the distribution of

Table 1 Characteristics of 140 Japanese men and women aged 20–59 years included in the analyses[a]

	Men (n = 67)	*Women (n = 73)*
Age (years)	39.4±11.1	38.5±10.4
Body height (cm)	169.3±6.3	157.9±6.1[e]
Body weight (kg)	67.3±9.7	53.9±7.3[e]
BMI (kg/m^2)[b]	23.3±2.9	21.6±2.7[e]
<18.5	5 (7)	10 (14)[i]
18.5–24.9	39 (58)	55 (75)
⩾25.0	23 (34)	8 (11)
Educational attainment		
High school or less	28 (42)	23 (32)[h]
Technical or professional school	5 (7)	28 (38)
University or more	34 (51)	22 (30)
History of diet experience[c]		
No	58 (87)	57 (78)
Yes	9 (13)	16 (22)
Desire for weight change		
Reduction	37 (55)	50 (68)
No change	20 (30)	20 (27)
Increase	10 (15)	3 (4)
Difference between ideal and measured body weight (kg)[d]	−4.2±6.7	−4.5±4.3
Frequency of alcohol intake (times/week)	2.6±2.7	1.0±1.9[e]
Physical activity level	1.70±0.21	1.69±0.27
Body weight change during survey (g/day)	−23±55[j]	−2±45[g]
TEE_{DLW} (MJ/day)	10.7±1.7	8.3±1.2[e]
eEI_{DLW} (MJ/day)	10.0±2.1	8.2±2.0[e]
rEI_{DHQ1} (MJ/day)	8.8±2.4	7.7±1.7[f]
rEI_{DHQ2} (MJ/day)	8.9±2.5	7.4±1.5[e]

Abbreviations: BMI, body mass index; DHQ, diet history questionnaire; DHQ1, first measurement of DHQ before dose of DLW; DHQ2, second measurement of DHQ 2 weeks after dose of DLW; DLW, doubly labeled water method; eEI, estimated energy intake = TEE_{DLW} + (body weight change during survey × 0.03); rEI_{DHQ}, reported energy intake assessed with self-administered DHQ; TEE_{DLW}, total energy expenditure measured by DLW.

[a]Mean ± s.d. or *n* (%).

[b]The categorization was based on the Japan Society for the Study of Obesity (Matsuzawa *et al.*, 2000).

[c]Dieting was defined as at least 2 kg intentional reduction of body weight within 1 month.

[d]Ideal body weight was evaluated by the following question: how many kilograms is your ideal body weight? Difference between ideal and measured body weight was calculated, as ideal body weight (kg)—measured body weight (kg), to evaluate the degree of desire for body weight change.

[e–g]Difference between sexes by non-paired *t*-test: [e]$P<0.001$, [f]$P<0.01$, [g]$P<0.05$.

[h,i]Significant difference between sexes in all categories by χ^2 test: [h]$P<0.001$, [i]$P<0.01$

[j]Difference within sexes from 0 by paired *t*-test: $P<0.01$.

the test and the reference methods, and the proportions of subjects classified into the same, adjacent or opposite tertiles were determined.

To evaluate the prevalence of under- or over-reporters, we calculated 95% confidence limits of rEI_{DHQ1}/TEE_{DLW} and rEI_{DHQ2}/eEI_{DLW} as a cutoff value proposed by Livingstone and Black (2003). Then, subjects with rEI_{DHQ1}/TEE_{DLW} and rEI_{DHQ2}/eEI_{DLW} smaller than 0.84 or larger than 1.16 were considered as under- or over-reporters, respectively.

A stepwise multiple regression analysis was performed to evaluate the influence of sociodemographic, lifestyle, behavioral and psychological factors on rEI_{DHQ1}/TEE_{DLW} and rEI_{DHQ2}/eEI_{DLW}, simultaneously. The following potential factors were entered into the model as the independent variables: age, BMI, body height, residential area, educational attainment, physical activity level, frequency of alcohol drinking, desire for body weight change, difference between ideal and measured body weight, and history of diet experience.

To examine the reproducibility, we compared mean rEIs between first and second DHQs (DHQ1 and DHQ2, respectively). Furthermore, the Pearson correlation coefficients were used to compare the rEIs assessed with DHQ1 and DHQ2.

All statistical analyses were performed using version 8.2 of the SAS software package (SAS Institute Inc., Cary, NC, USA). The test was considered significant at a P-value of <0.05.

Results

Basic characteristics of the study subjects, the mean TEE_{DLW}, eEI, first and second measurements of rEI by the DHQ (rEI_{DHQ1} and rEI_{DHQ2}) are shown in Table 1. Men had the higher BMI than women (23.3 versus 21.6 kg/m^2, $P<0.001$). Twenty-three of 67 men and eight of 73 women were overweight (BMI $\geqslant 25$ kg/m^2). This table also shows body weight change during the TEE measurement, between visits 1 and 3. Mean body weight in men, although not in women, significantly changed by -23 ± 55 g/day ($P<0.01$ by paired t-test). Mean rEI_{DHQ1} was significantly lower than mean TEE_{DLW} by 1.9 ± 2.4 MJ/day (16.4%, $P<0.001$) for men and 0.6 ± 1.9 MJ/day (6.0%, $P<0.01$) for women. Mean rEI_{DHQ2} was also significantly lower than mean eEI_{DLW} by 1.1 ± 2.7 MJ/day (9.1%, $P<0.001$) for men and 0.8 ± 2.4 MJ/day (4.6%, $P<0.01$) for women.

Table 2 shows reporting accuracy of energy intake assessed with DHQ expressed as rEI_{DHQ1}/TEE_{DLW} and rEI_{DHQ2}/eEI_{DLW}. The rEI_{DHQ1}/TEE_{DLW} and rEI_{DHQ2}/eEI_{DLW} was 0.84 and 0.91 for men and 0.94 and 0.95 for women, respectively, resulting in a significantly lower rEI_{DHQ1}/TEE_{DLW} ratio for men than for women ($P<0.05$). There was a wide range in reporting accuracy of DHQ1; 31 and 51% were identified as acceptable, and 58 and 32% as under-, and 10 and 18% as over-reporters for men and women, respectively.

The rEI_{DHQ1} and TEE_{DLW} were significantly correlated only for men (Pearson correlation coefficient = 0.34, Spearman correlation coefficient = 0.33), but not for women (0.22 and 0.16, respectively). Forty-one, 45 and 14% of the subjects were cross-classified into the same, the adjacent and the opposite tertiles of the respective distributions of rEI_{DHQ1} and TEE_{DLW}, respectively (Figure 1a). The results of the correlation between rEI_{DHQ2} and eEI_{DLW} were similar (Figure 1b).

Table 3 shows the results of multiple regression analysis with rEI_{DHQ1}/TEE_{DLW} and rEI_{DHQ2}/eEI_{DLW}, as the dependent variables to examine the prediction of accuracy of reporting energy intake. For men, frequency of drinking alcohol, the difference between ideal and measured body weight, and history of diet experience correlated significantly and

Table 2 Reporting accuracy of energy intake determined by the self-administered diet history questionnaire[a]

	DHQ1			DHQ2		
	All (n = *140*)	*Men* (n = *67*)	*Women* (n = *73*)	*All* (n = *140*)	*Men* (n = *67*)	*Women* (n = *73*)
Reporting accuracy[b]	0.89±0.22	0.84±0.21	0.94±0.22[c]	0.93±0.30	0.91±0.26	0.95±0.33
Underreporters (*n* (%))	62 (44)	39 (58)	23 (32)[d]	64 (46)	30 (45)	34 (47)
Acceptable reporters (*n* (%))	58 (41)	21 (31)	37(51)	48 (34)	27 (40)	21 (29)
Overreporters (*n* (%))	20 (14)	7 (10)	13 (18)	28 (20)	10 (15)	18 (25)
Pearson's correlation coefficient	0.40[e]	0.34[f]	0.22	0.36[e]	0.35[f]	0.11
Spearman correlation coefficient	0.35[e]	0.33[f]	0.16	0.36[e]	0.41[e]	0.07

Abbreviations: DHQ1, first measurement of DHQ before dose of DLW; DHQ2, second measurement of DHQ 2 weeks after dose of DLW; DLW, doubly labeled water; eEI, estimated EI.
[a]Mean ± s.d. or *n* (%).
[b]Reporting accuracy was assessed as the ratio of energy intake to total energy expenditure (rEI_{DHQ1}/TEE_{DLW}) and the ratio of energy intake to estimated energy intake (rEI_{DHQ2}/eEI_{DLW}), respectively. eEI was determined by using a correction for change in body energy during the measurement period, as TEE ± (body weight change during survey × 0.03). Under-, acceptable, and over-reporters were defined as the ratio rEI_{DHQ}/TEE_{DLW} and rEI_{DHQ}/eEI_{DLW} <0.84, 0.84–1.16 and >1.16, respectively.
[c]Difference between sex by non-paired t-test: $P<0.01$.
[d]Significant difference between sexes in all categories by χ^2 test: $P<0.01$.
[e,f]Correlation coefficients between two methods: [e]$P<0.001$, [f]$P<0.01$.

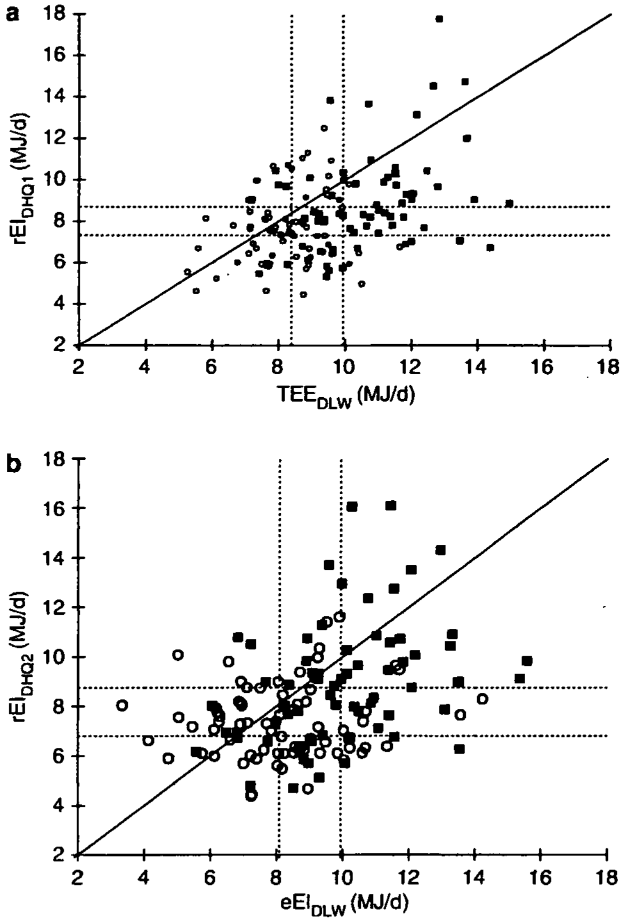

Figure 1 (**a**) Comparison of the first measurement of energy intake determined by the self-administered diet history questionnaire (rEI_{DHQ1}) with total energy expenditure measured by the doubly labeled water method (TEE_{DLW}) (■ = 67 men, O = 73 women). The dotted lines divide intake according to the tertiles of distribution. A straight line is $y = x$. Pearson and Spearman correlation coefficient was 0.40 and 0.35, respectively (both $P<0.001$). (**b**) Comparison of the second measurement of energy intake determined by the self-administered diet history questionnaire (rEI_{DHQ2}) with estimated energy intake (eEI_{DLW}) determined by a correction of body weight change during survey period, as TEE + (Δwt × 0.03), (■ = 67 men, O = 73 women). The dotted lines divide intake according to the tertiles of distribution. A straight line is $y = x$. Pearson and Spearman correlation coefficient was both 0.36 ($P<0.001$).

positively, and physical activity level negatively with rEI_{DHQ1}/TEE_{DLW}. For women, age and educational attainment correlated significantly and positively, and BMI negatively with rEI_{DHQ1}/TEE_{DLW}. We also conducted the same analysis with rEI_{DHQ2}/eEI_{DLW}. Body height, BMI and physical activity level significantly and negatively correlated with rEI_{DHQ2}/eEI_{DLW} for women. On the other hand, no factors attained the significance level for men.

The Pearson correlation coefficients between rEI_{DHQ1} and TEE_{DLW} slightly improved in both sexes after adjustment for the above-mentioned related factors (0.42 for men and 0.37 for women).

We also examined reproducibility of energy intake between DHQ1 and DHQ2. The rEI_{DHQ2} was significantly lower than rEI_{DHQ1} for women (the difference was -0.3 ± 1.1 MJ/day, $P = 0.03$), but not for men. The Pearson correlation coefficient between rEI_{DHQ1} and rEI_{DHQ2} was 0.79 for men and 0.76 for women.

Discussion

To our knowledge, this is the first report in a non-Western country to validate energy intake estimated with a dietary assessment questionnaire against TEE measured by DLW method. Moreover, the sample size was relatively large compared to the previous studies with the same purpose and method (Sawaya *et al.*, 1996; Kroke *et al.*, 1999; Andersen *et al.*, 2003).

The mean rEI_{DHQ1} was 11.0% less (16.4% for men and 6.0% for women) than the mean TEE_{DLW}. Several validation studies have shown that dietary assessment instruments underestimated daily energy intake (Livingstone *et al.*, 1990; Hill and Davis, 2001). The degree of such error, under- or overestimation, has also been examined using TEE measured by the DLW method (Sawaya *et al.*, 1996; Kroke *et al.*, 1999; Andersen *et al.*, 2003; Livingstone and Black, 2003). Average underreporting in the previous studies between EI from dietary assessment questionnaires and TEE measured by DLW ranged from 10 to 38% (Sawaya *et al.*, 1996; Subar *et al.*, 2003), which depends on sample size and subjects (Trabulsi and Schoeller, 2001).

For the individual ranking, the rEI_{DHQ1} significantly and positively correlated with TEE_{DLW} ($r = 0.40$, $P<0.001$), showing a correlation similar to or relatively higher than those observed in the previous studies ($r = 0.06$–0.48) (Kroke *et al.*, 1999; Bathalon *et al.*, 2000). Acceptable reporting was observed in 41% of the subjects, whereas 44% underreported and 14% over-reported. Underreporting of energy intake therefore seems to be a more serious problem than over-reporting.

In this study, the mean rEI_{DHQ1}/TEE_{DLW} ratio was significantly lower in men than in women. Further, the rate of underreporting was higher in men than in women. In a previous analysis of individual data from 21 studies, in contrast, the proportion of underreporters did not statistically differ between sexes (Black, 2000). In our previous study using semi-weighed diet records in 4 days × 4 seasons, the mean value of the ratio of rEI to BMR estimated from sex, age and body weight was not statistically different between sexes (Okubo *et al.*, 2006). In the DHQ, the portion sizes of food items are standardized regardless of sex, for example as 'one small cup'. The subjects then select the relative portion size from the five categories given except for rice, bread, noodles, other wheat foods and miso soup. This structure

Table 3 Result of multiple regression analysis by stepwise procedure with the ratio of energy intake to total energy expenditure ($rEID_{HQ1}/TEE_{DLW}$ and rEI_{DHQ2}/eEI_{DLW}) as dependent variables[a]

Independent variable[b]	*Men (n = 67)*						*Women (n = 73)*					
	DHQ1			*DHQ2*			*DHQ1*			*DHQ2*		
	Partial regression coefficient[c]	*s.e.*[d]	*P-value*	*Partial regression coefficient*[c]	*s.e.*[d]	*P-value*	*Partial regression coefficient*[c]	*s.e.*[d]	*P-value*	*Partial regression coefficient*[c]	*s.e.*[d]	*P-value*
Age (years)	—	—	—	—	—	—	0.005	0.002	0.04	—	—	—
BMI (kg/m^2)	—	—	—	—	—	—	−0.036	0.009	<0.001	−0.049	0.015	<0.01
Body height (cm)	—	—	—	—	—	—	—	—	—	−0.016	0.006	0.02
Residential area	—	—	—	—	—	—	—	—	—	—	—	—
Educational attainment, (more than University versus high school or less as reference)	—	—	—	—	—	—	0.145	0.053	<0.01	—	—	—
Physical activity level	−0.356	0.120	<0.01	—	—	—	—	—	—	−0.480	0.154	<0.01
Frequency of drinking alcohol (times/week)	0.026	0.009	<0.01	—	—	—	—	—	—	—	—	—
Desire for body weight change	—	—	—	—	—	—	—	—	—	—	—	—
Difference between ideal and measured body weight (kg)	0.013	0.003	<0.01	—	—	—	—	—	—	—	—	—
History of diet experience (yes versus no as reference)	0.170	0.071	0.02	—	—	—	—	—	—	—	—	—

[a] TEE_{DLW}, total energy expenditure measured by doubly labeled water method (DLW); rEI_{DHQ}, reported energy intake assessed with self-administered diet history questionnaire (DHQ); DHQ1, first measurement of DHQ before dose of DLW; DHQ2, second measurement of DHQ 2 weeks after dose of DLW. Reporting accuracy were assessed as the ratio of energy intake to total energy expenditure (rEI_{DHQ1}/TEE_{DLW}) and the ratio of energy intake to estimated energy intake (rEI_{DHQ2}/eEI_{DLW}), respectively. Estimated EI (eEI) was determined by using a correction for change in body energy during the measurement period, as TEE + (body weight change during survey × 0.03).

[b] See table 1 for the definition of each independent variable. Age (as a continuous variable), BMI (as a continuous variable), body height (as a continuous variable), residential area (Hokuriku, Shikoku, North Kyushu, and South Kyushu), educational attainment (high school or less, technical or professional school, or university or more), physical activity level (as a continuous variable), frequency of alcohol drinking (as a continuous variable), desire for body weight change (reduction, no change or increase), difference between ideal and measured body weight (as a continuous variable), history of diet experience (yes or no).

[c] Partial regression coefficient; change in dependent variable related to a 1-U change in independent variable.

[d] Standard error (s.e.) of the regression coefficient.

might have led to relative over- and underreporting of energy in women and men, respectively.

The rEI_{DHQ1}/TEE_{DLW} was significantly and independently correlated with several anthropometric and behavioral factors (Table 3). Several previous studies have already examined non-dietary factors, such as physiological (Zhang *et al.*, 2000; Livingstone and Black, 2003) and psychological (Johansson *et al.*, 1998; Bathalon *et al.*, 2000; Tooze *et al.*, 2004) factors associated with reporting accuracy of energy intake. After adjusting for these variables, the validity slightly improved (Pearson correlation coefficient was 0.42 for men and 0.37 for women). Therefore, these non-dietary factors are needed to consider when evaluating rEI.

This study has several limitations. First, FQ was derived from dietary assessment data by DHQ. Therefore, TEE was not theoretically independent of EI. Second, the surveyed period for the first measurement of EI by DHQ (DHQ1) was ahead of, and not overlapping with, TEE measurement by the DLW method. Third, we used the TEE as gold standard for the validation of DHQ1 without any consideration for a possible body weight change during the assessment period because of lack of the data. Fourth, we used the TEE with a correction for change in body weight during the survey period as gold standard for the validation of DHQ2, because the body weight has significantly changed in men. Fifth, the change in body composition, such as change in fat mass and fat-free mass, is probably the better indicator than the change in body weight for the correction of energy content for the study purpose. Sixth, the rEI_{DHQ1} was significantly lower than the rEI_{DHQ2} for women. Intentional or non-intentional intervention effect might have influenced dietary behaviors between the first and the second measurement. As shown in Table 3, the factors affecting reporting accuracy of energy intake were different between the two measurements. This may be one of the reasons. Seventh, we applied a two-point rather than multipoint method for the measurement of TEE_{DLW}. Eighth, the subjects were not randomly sampled from the general Japanese population. Moreover, the survey areas were not equally distributed over the country but were rather selected mostly from the Western parts of Japan.

In summary, the energy intake assessed with DHQ correlated low to modestly with TEE measured by DLW. In addition, DHQ underestimated energy intake at a group level. Caution is needed when energy intake was evaluated by DHQ at both individual and group levels.

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一軸加速度計を用いた幼児の身体活動量の評価精度

田中千晶[1]　田中茂穂[2]　河原純子[3]　緑川泰史[4]

UNIAXIAL ACCELEROMETER FOR ASSESSING PHYSICAL ACTIVITY IN 5- TO 6-YEAR-OLD CHILDREN

CHIAKI TANAKA, SHIGEHO TANAKA, JUNKO KAWAHARA and TAISHI MIDORIKAWA

Abstract

The accuracy of a uniaxial accelerometer for assessing physical activity in preschool-aged children was assessed by using an indirect calorimeter which provides the physical activity ratio (PAR) for free living activities. Subjects were 5- to 6-yr-old Japanese girls and boys (n=24, 6.1±0.3 years). PAR was assessed for nine activities (lying down, watching a video while sitting and standing, line drawing for coloring-in, playing with blocks, walking, stair climbing, ball toss, and running) using the Douglas bag method. "Exercise intensities" were recorded with the uniaxial accelerometer (Lifecorder EX ; Suzuken Co. Ltd, Nagoya, Japan). PARs were also predicted by using the equations presented by Higuchi et al. (2003) and Kumahara et al. (2004). Significant correlation was observed between "exercise intensities" as measured by the uniaxial accelerometer and PAR for all activities (r=0.827). Predicted PAR values for walking and running were overestimated according to the equations. On the other hand, PAR values for stair climbing and ball toss were underestimated. These findings indicate that although the uniaxial accelerometer may help in evaluating daily physical activity in preschool-aged children, its use as a proxy measure of PAR based on the above equations may be limited.

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key word : physical activity, preschool children, accelerometer

I．はじめに

わが国では，最近約20年間の比較において，幼児期に肥満傾向の者が増えていることが報告されている[1]．幼児期の肥満は，成人期の肥満や糖代謝異常にもつながるため，幼児期の肥満対策は重要である[2]．幼児期の肥満の主要な要因のひとつは，身体活動(Physical Activity : PA)量の減少であると考えられている[3,4]．運動(Exercise)とは「身体活動の一種であり，特に体力を維持・増進させるために行う計画的・組織的で継続性のあるもの」と定義されるが[5]，幼児期は，一定の運動を長時間連続的に行うことが少ないため，運動以外の身体活動を評価することが重要となる．

日常生活におけるあらゆるPA評価の妥当性を検討する上で，最も正確な基準(Gold standard)は，二重標識水法である[6]．しかし，測定器を設置している施設が世界的にみても少なく，高額な費用がかかる．さらに，測定期間中，数回にわたり採尿を行う必要があることから，幼児では実施が難しい．また，活動強度の内訳などに関する情報は得られない．より簡便な方法として質問紙や加速度計を用いた方法があるが，幼児を対象とする場合，質問紙では，妥当性の検討が十分に行われておらず[7]，またPAの自己申告は困難である．一方，加速度計を用いた評価は，客観的にエネルギー消費量の推定や低強度

[1]桜美林大学 健康福祉学群 健康科学専修
〒194-0294 東京都町田市常盤町3758
J. F. Oberlin University, 3758 Tokiwamachi, Machida, Tokyo 194-0294, JAPAN

[2](独)国立健康・栄養研究所 健康増進プログラム
〒162-8636 東京都新宿区戸山1-23-1
National Institute of Health and Nutrition

[3](独)国立環境研究所 環境リスク研究センター
〒305-8506 茨城県つくば市小野川16-2
National Institute for Environmental Studies

[4]早稲田大学 スポーツ科学 学術院
〒359-1192 埼玉県所沢市三ヶ島2-579-15
Waseda University

から高強度の活動強度を分類して評価することができる[8～11]．学童期以降の子どもや成人における加速度計の妥当性の研究はいくつかなされてきているものの，幼児を対象とした研究は最近始まったばかりである[12～14]．そのため，わが国におけるこれまでの幼児の PA に関する研究では，主に歩数計を用いた歩数の検討が中心である[15～17]．しかし，PA は，「筋活動によって安静時よりエネルギー消費量の増大がもたらされる全ての営み」と定義されている[5,18]ことから，歩行・走行以外の活動を含む，日常生活全般を捉えることが重要である．

2006年に策定された成人を対象とした運動基準[19]では，MET(metabolic equivalent)を指標として目標とする日常生活の PA の量が示されている．国際的には，成人に限らず子どもにおいても，活動レベル毎に PA の量(時間)を評価する方法が注目されている[8,11,20]．我が国で広く用いられている一軸加速度計(ライフコーダ)は，歩数に加え，11段階に区分された“運動強度”と微小運動を計測できる．樋口ら[21]と Kumahara et al.[22]は，この一軸加速度計の妥当性について，成人を対象に，トレッドミルでの歩行・走行時の間接カロリメトリーを用いて実測した METs との関係を検討し，非常に高い相関を得た．しかし，幼児には，成人の METs を当てはめることができない[23]．また，これまで各種加速度計の妥当性について，トレッドミルでの歩行・走行によって検討した研究では[20,24]，日常の活動について検討した研究と比べて[8,25～27]エネルギー消費量と加速度信号との間により良好な相関が得られている．しかし，トレッドミルでの歩行・走行は，必ずしも全ての日常生活を反映していないことが指摘されている[20]．Kumahara et al.[22]は，ヒューマンカロリメーターを用いて，座位中心の生活時における24時間のエネルギー消費量と一軸加速度計からの推定値との関係を検討している．しかし，幼児の日常生活は成人とは異なる活動を含み，かつ一定の運動を長時間連続的に行うことが少ない．例えば，ボール遊びやブロック遊び・砂遊びなどは，必ずしも連続的な歩行を伴わず，姿勢も直立位のみではない．また，規則的な歩行・走行とは異なり，静止状態を含む様々な種類の動作・姿勢の組み合わせであるが，そうした複合的な動作全体の活動強度もとらえる必要がある．こうしたタイプの活動に対する評価精度は，主に欧米で利用されている ActiGraph などの一部の機種を除いては[11]，成人の場合を含め，ほとんど評価されていない．

そこで，本研究では，幼児を対象に，歩行・走行を含む日常生活にみられる活動時の PA に関する，一軸加速度計を用いた推定精度について検討した．さらに，成人の歩行・走行を用いて作成された活動強度の推定式を用いて，幼児を対象とした活動強度評価について検討した．

Ⅱ．方　　　法

A．対象者

対象者は，本研究の実施に保護者が同意した東京都の郊外在住の女児11名と男児13名(6.1＋/－0.3歳)であった．保護者への問診により，甲状腺機能の異常などエネルギー代謝や通常の PA に影響を与えると考えられる疾病についての既往歴がある者は対象から除いた．対象者数は，これまで報告されている同様の研究の結果に基づき決定した．本研究は桜美林大学の倫理委員会の許可を得て実施した．測定にあたって，保護者に測定の目的，利益，不利益，危険性，データの公表について説明を行い，書面にて同意を得た．

B．測定項目

本研究で用いたライフコーダ EX(株式会社スズケン製，名古屋，72.5×41.5×27.5 mm，60 g)は垂直方向への加速度を検出する一軸加速度計である．この装置は，加速度信号を 32 Hz で検出し，0.06 G から 1.94 G の範囲の値を評価する[22]．4秒間の最大電圧と歩数により，9 段階の“運動強度”(1-9)を決定する．なお，加速度変化量が0.06G未満の場合の“運動強度”は 0 とする．さらに，1-9 の“運動強度”には当てはまらないものの，0.06 G 以上の加速度変化量を検出した場合，微小運動ありとして認識し，“運動強度”として0.5という値が与えられる．以上のように，4 秒毎にそれぞれの活動は11段階の“運動強度”のいずれかに分類される．ただし，初めの 1 歩を認識後1.5秒以内に 2 歩目を認識しない時は，初めの 1 歩を取り消す．

身長と体重は，各々，0.1 cm と 0.1 kg 単位で計測した．対象者は，以下の 9 つの活動中，一軸加速度計を右腰に装着し，同時にダグラスバックを用い

た実測によるエネルギー消費量を算出するために，マスクを装着して呼気ガスを採取した．測定は，食事誘発性体熱産生の影響を考慮し，朝食後約2時間以上経過した後に開始した．対象者は，測定中，水のみを摂取した．

測定に用いた活動は，自由歩行と自由走行および日常にみられる仰臥安静，座位でのビデオ視聴，立位でのビデオ視聴，色塗り，ブロック遊び，階段昇降およびボール投げの9種類の身体活動であった．これらの活動は，あらかじめ保育所での4～6歳の幼児における観察法による活動記録を用いた結果に基づき，日常生活で代表的な活動，かつ5～6歳の幼児がダグラスバックを装着して行うことができるか否かを考慮して選択した．

対象者は，ダグラスバックに繋がったマスクを装着し，仰臥位安静を行い，安静を開始してから30～40分後に呼気ガスの測定を行った．次に，座位および立位でのビデオ鑑賞，色塗り，ブロック遊びを行った．これらの動作は，定常状態を保った状態で，各々終了前5分間に採気した．自由歩行は，日常歩いている速度を一定に保ったまま，あらかじめ設定されたコースを4分間歩かせ，終了前2分間の採気を行った．ボール投げは，対象者の正面あるいは左右へランダムに一定の時間間隔で検者が転がしたボールを拾い，片手あるいは両手で検者へ投げ返した．4分間行い，終了前2分間の採気を行った．階段の昇降は，片道32歩の階段を3往復行い，2～3往復目に採気した．自由走行は，220 m の距離の走行を2回行い，後半1回の間，採気した．インターバルは約5秒とした．なお，これら各活動の測定時間は，これまで報告されている子どもの結果に基づき，定常状態に達してから測定を行うことになるよう決定した．

加速度計の結果（4秒毎の“運動強度”および1分毎の歩数）は，全ての測定が終了した後，コンピュータに取り込んだ.呼気量は乾式ガスメーター（株式会社シナガワ製，DC-5，東京）を用いて測定した．採集した呼気は，ガス分析器（ミナト医科学株式会社製，AE-300S，東京）を用いて酸素濃度と二酸化炭素濃度を測定した．エネルギー消費量は，Weir の式[28]を用いて，酸素消費量と二酸化炭素産生量から算出した．ガス分析器の校正は，各測定前に，室内大気と校正ガスを用いて行った．そして，各活動のエネルギー消費量を推定基礎代謝量（食事誘発性体熱産生を10%と仮定し，仰臥安静時のエネルギー消費量を用いて推定した：推定基礎代謝量＝(仰臥安静時のエネルギー消費量/1.1)）で除することにより，身体活動強度（Physical Activity Ratio：PAR）を算出した[28～30]．METは，成人の場合 1MET＝3.5 ml/kg/min と仮定して求めることが多いが，子どもでは 1MET が 3.5 ml/kg/min より大きくなるため，使用されないことが多い[30,31]．本研究と同様の一軸加速度計の“運動強度”を用いて，成人を対象とした METs を求める推定式が報告されている．そこで，本研究では，これら2つの推定式（樋口ら[21]：$y=0.091x^2+0.022x+1.887$，Kumahara et al.[22]：$y=0.043x^2+0.379x+1.361$）に，本研究で得られた一軸加速度計の”運動強度”を当てはめ，活動強度の推定値を1.2倍することにより[32]，PAR の推定値を算出した．この比率（1.2倍）は，成人における複数の先行研究に基づいて得られた値であり[32]，日本でエネルギー代謝率を利用する場合に広く用いられてきた．

C．統計処理

統計処理は，SPSS package15.0J for Windows (SPSS Inc, Japan, Tokyo) を用いて行った．全ての結果は，平均値±標準偏差で示した．2変量間の関係は，Pearson の相関係数を用いて評価した．これまで報告されている成人の歩行・走行のデータを用いて作成した活動強度の推定式[21,22]から算出した PAR の推定値と実測値の一致度は，Bland and Altman[33]の方法を用いて評価した．これは，推定値と実測値の差を両者の平均値に対してプロットし，推定値と実測値の差の平均値±2 SD（95%限界）を推定精度の指標として評価するものである．Percent difference は，((推定値－実測値)/実測値)×100として算出した．有意水準は5%未満とした．

Ⅲ．結　　果

対象者の身体的特徴と推定基礎代謝量を Table 1 に示した．各活動の PAR，加速度計の“運動強度”および樋口ら[21]と Kumahara et al.[22]の推定式から算出した，PAR の推定値と Percent difference を Table 2 に示した．一軸加速度計による“運動強度”と PAR との関係を Figure 1 に示した（r＝0.827）．

Table 1. Physical characteristics of subjects.

(n=24)

Variable	Mean±SD	Range
Age (yr)	6.1 ± 0.3	5.6 - 6.5
Height (cm)	113.4 ± 4.5	104.4 - 122.6
Weight (kg)	20.7 ± 3.7	15.9 - 31.9
BMI ($kg \cdot m^{-2}$)	16.1 ± 2.1	14.1 - 22.8
Predicted basal metabolic rate (MJ・day-1)*	3.75 ± 0.59	2.75 - 4.99

*Predicted from observed resting energy expenditure in the supine position.

Table 2. Observed and predicted physical activity ratio, accelerometer counts and percent difference with observed and predicted physical activity ratio for each activity.

Activity	n	Observed PAR	Accelerometer ("Exercise Intensity")	Predicted PAR Higuchi et al.	Predicted PAR Kumahara et al.	Higuchi et al. (predicted %dif)	Kumahara et al. (predicted %dif)
Resting while lying down	24		0.0 ± 0.0	2.27 ± 0.00	1.64 ± 0.01	105.9 ± 0.1	49.4 ± 1.2
Watching a video while sitting	22	1.14 ± 0.09	0.0 ± 0.0	2.26 ± 0.00	1.64 ± 0.00	100.2 ± 14.7	44.7 ± 10.5
Watching a video while standing	21	1.16 ± 0.12	0.0 ± 0.0	2.27 ± 0.00	1.66 ± 0.02	96.6 ± 18.7	43.5 ± 12.8
Line drawing for coloring-in	21	1.39 ± 0.14	0.1 ± 0.1	2.27 ± 0.01	1.68 ± 0.04	64.6 ± 15.1	22.1 ± 11.0
Playing with blocks	23	1.51 ± 0.17	0.2 ± 0.1	2.28 ± 0.01	1.74 ± 0.04	52.2 ± 16.0	16.2 ± 11.4
Walking	24	2.60 ± 0.47	4.8 ± 1.1	5.08 ± 1.13	5.11 ± 1.00	96.4 ± 33.0	98.2 ± 30.8
Stair climbing (up and down)	24	4.10 ± 0.63	3.5 ± 0.9	3.79 ± 0.80	3.90 ± 0.79	-6.8 ± 17.0	-3.9 ± 17.2
Performing a ball toss	24	3.64 ± 0.82	1.5 ± 0.6	2.59 ± 0.26	2.45 ± 0.38	-25.8 ± 18.5	-30.0 ± 18.9
Running	23	5.58 ± 1.27	8.5 ± 0.4	10.33 ± 0.71	9.19 ± 0.50	94.9 ± 48.7	73.5 ± 43.1

PAR : physical activity ratio=observed energy expenditure/predicted basal metabolic rate (from observed resting energy expenditure while lying down), Percent difference : ((predicted physical activity ratio/observed physical activity ratio)/observed physical activity ratio) *100.

また, 1)歩行と走行および 2)日常生活にみられる歩行・走行以外の 7 活動, の活動別に区分した場合についても, 何れも有意な正の相関関係が見られた(r＝0.840, 0.886). 前述したように, 本研究で用いた一軸加速度計の”運動強度”は, 1-9 と 0 あるいは0.5に認識される際, その基準が異なる. そこで, “運動強度” が 1 未満の 5 活動について PAR との関連を検討した結果, 両者の間には有意な関係が見られた(r＝0.740). 樋口ら[21]の推定式から推定した PAR の推定値と実測値の相関を Figure 2 に, 一致度を Figure 3 に示した. 全活動時の推定値と実測値の差は, 樋口ら[21]が1.20±2.40(2 SD), Kumahara et al.[22]が0.75±3.00(2 SD)であった. Figure 4 には, 活動別の PAR について樋口ら[21]の推定式からの推定値と実測値の差を示した. 推定式は, 仰臥安静, 座位および立位でのビデオ視聴, 色塗り, ブロック, 通常歩行, および走行は過大評価, 階段昇降とボール投げは過小評価した. Kumahara et al.[22]の推定式でも同様の傾向がみられた.

歩行および走行時の速度は, 57.4±9.4 m/分と118.2±16.2 m/分であった. また, その際の歩行率(1 分間当たりの歩数)は, 122.7±13.4歩/分と188.1±9.7歩/分であった. なお, ライフコーダによる歩数は, 1 分間毎の値のみ得られる. そのため, 走行

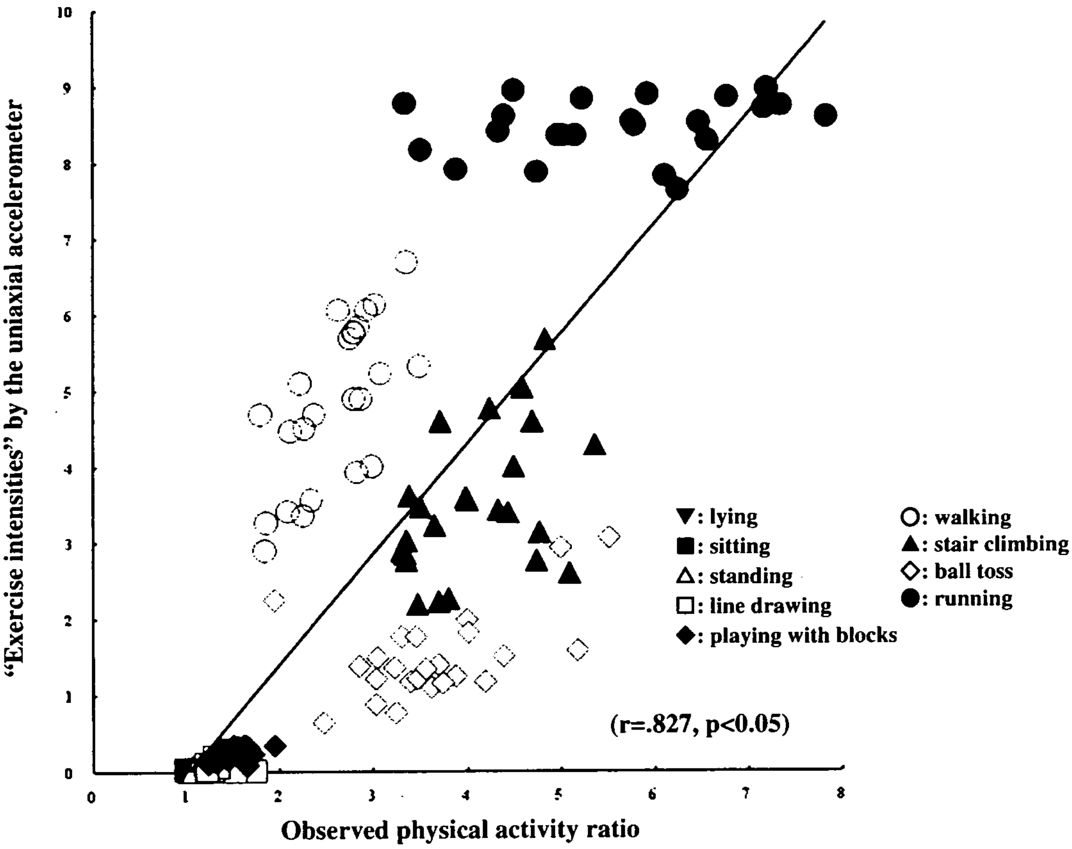

Figure 1. Relationship between "exercise intensities" by the uniaxial accelerometer and observed physical activity ratio for all activities.

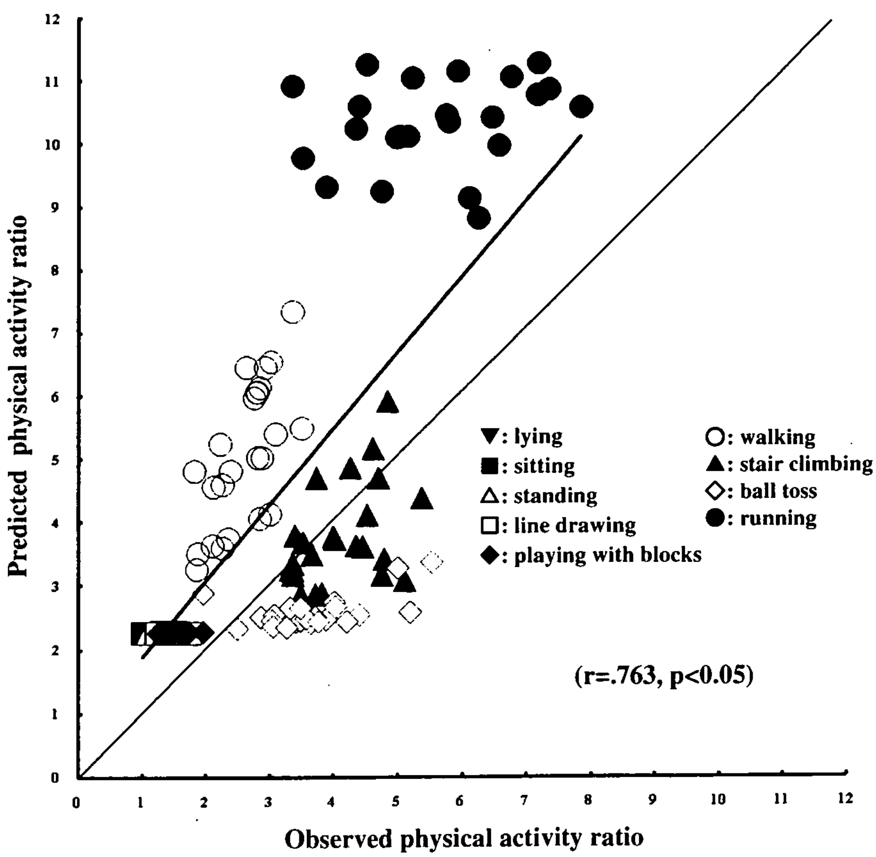

Figure 2. Relationship between observed and predicted physical activity ratio for all activities.

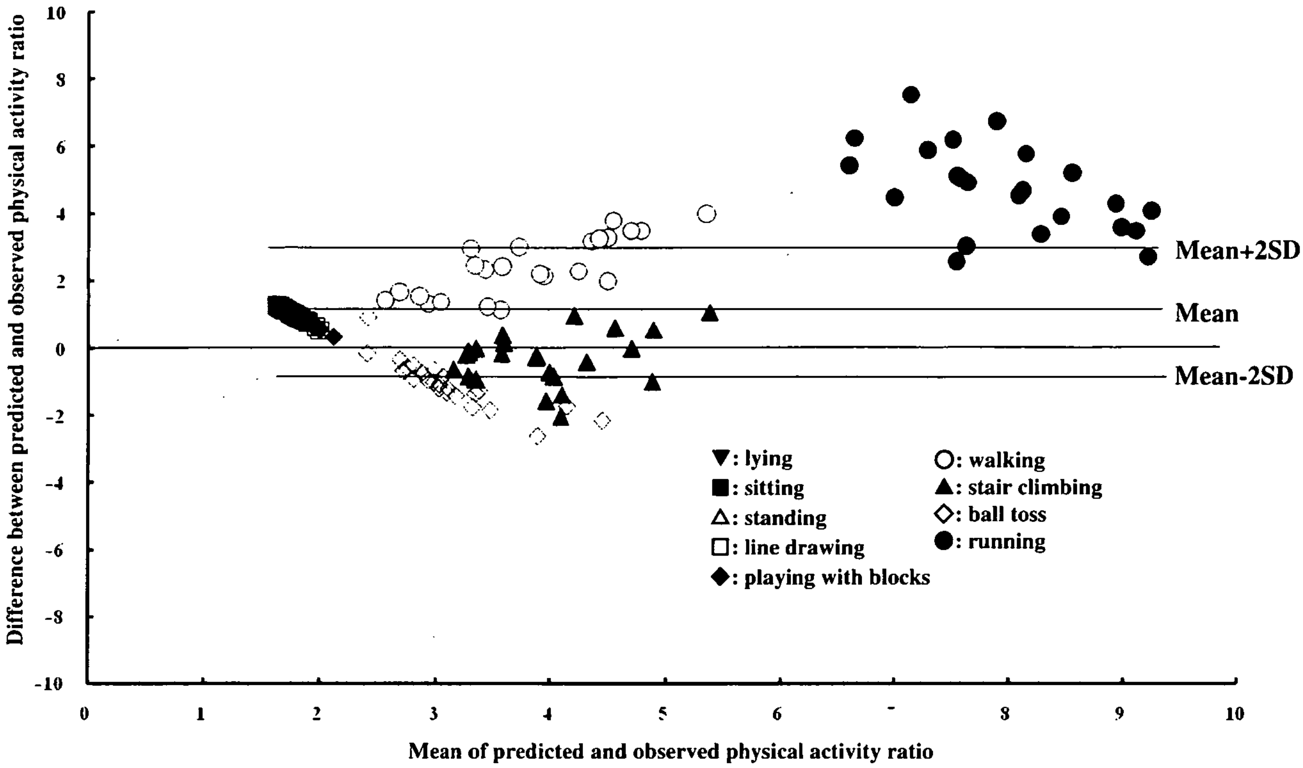

Figure 3. Limits of agreement between observed and predicted physical activity ratio for all activities.

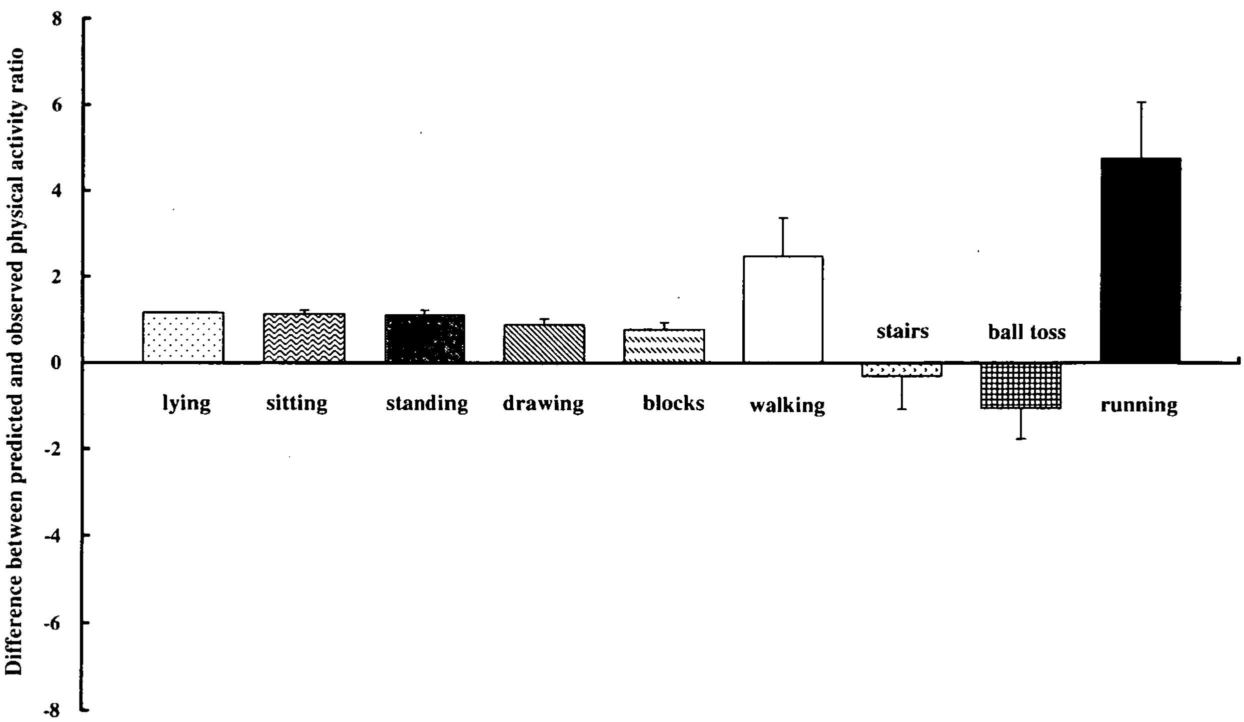

Figure 4. Comparisons of difference between observed and predicted physical activity ratio for each activities.

中の歩数は，走行時のみによる1分間の歩数が得られたことを確認できた19名の対象者の結果を示した．