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Validation and Comparison of 3 Accelerometers for Measuring Physical Activity Intensity During Nonlocomotive Activities and Locomotive Movements

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Background: The current study evaluated the validity of 3 commercially-available accelerometers to assess metabolic equivalent values (METs) during 12 activities. ***Methods:*** Thirty-three men and thirty-two women were enrolled in this study. The subjects performed 5 nonlocomotive activities and 7 locomotive movements. The Douglas bag method was used to gather expired air. The subjects also wore 3 hip accelerometers, a Lifecorder uniaxial accelerometer (LC), and 2 triaxial accelerometers (ActivTracer, AT; Actimarker, AM). ***Results:*** For nonlocomotive activities, the LC largely underestimated METs for all activities (20.3%–55.6%) except for desk work. The AT overestimated METs for desk work (11.3%) and hanging clothes (11.7%), but underestimated for vacuuming (2.3%). The AM underestimated METs for all nonlocomotive activities (8.0%–19.4%) except for hanging clothes (overestimated by 16.7%). The AT and AM errors were significant, but much smaller than the LC errors (23.2% for desk work and –22.3 to –55.6% for the other activities). For locomotive movements, the 3 accelerometers significantly underestimated METs for all activities except for climbing down stairs. ***Conclusions:*** We conclude that there were significant differences for most activities in 3 accelerometers. However, the AT, which uses separate equations for nonlocomotive and locomotive activities, was more accurate for nonlocomotive activities than the LC.

Keywords: algorithm, metabolic equivalents, daily activity

It is well known that physical fitness and activity confer numerous health benefits in the prevention of lifestyle-related diseases.[1,2] Physical activity energy expenditure (PAEE) can be divided into exercise-related activity thermogenesis and nonexercise activity thermogenesis (NEAT), with the latter consisting mainly of energy expenditure (EE) of low-to-moderate intensity during lifestyle activities.[3] Levine et al suggested that the EE due to NEAT, including nonlocomotive activity, is much larger than EE due to exercise throughout the day and may be an important factor in the prevention of obesity.[4] Therefore, it is important to estimate EE of daily activities, including locomotive movements and nonlocomotive activities such as household tasks and occupational activities. As Westerterp indicates, PAEE of nonlocomotive activities accounts for more than 50% of total PAEE.[5]

Recently, various types of small and lightweight accelerometers have become available for assessing the amount and intensity of physical activity (PA). However, these devices use different algorithms, which depend on the number of axes (uni- or triaxial) and predictive equations for PAEE and intensity.[6] The usefulness of the Kenz Lifecorder EX (LC; SUZUKEN Co., Ltd., Nagoya, Japan), a uniaxial accelerometer widely used in Japan, for assessing PA intensity and PAEE during locomotive movements such as walking and jogging has been reported.[7,8] However, total energy expenditure (TEE) calculated from the LC data significantly underestimated by 20%–35% the TEE measured by the doubly labeled water method in Japanese men.[9,10] We speculate that the most important reason for this underestimation is related to the algorithm of the LC accelerometer, which was designed to assess PA intensity during ambulation. The LC device determines PA intensity from the frequency of steps and the degree of vertical acceleration.[11] However, if some PA such as household work does not involve a sufficient number of steps, the LC instrument may not be able to accurately assess PA intensity.

Triaxial accelerometers have also become popular devices for assessing PA intensity.[12–14] Nevertheless,

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Hendelman et al indicated that the regression equation used to predict metabolic equivalent (MET) values based on locomotive movements had a different slope and intercept compared with regression equation based on nonlocomotive activities.[12] Thus, when an equation based on locomotive movements is used to predict MET values for nonlocomotive activities and ambulation, there could be large prediction errors. Midorikawa et al tried to resolve this discrepancy by separating nonlocomotive activities from locomotive movements using the ratio of vertical to horizontal acceleration.[13] That approach contributed to a small difference between predicted EE for 10.5 h and EE measured with a metabolic chamber. As observed above, accelerometers are gradually being developed with new specific algorithms. To date, numerous epidemiological studies on physical activity have been performed. Some studies used several different types of accelerometers to assess PA.[15,16] Since each accelerometer has a specific algorithm for estimating PA, it is difficult to compare the results obtained from different accelerometers.[17]

The current study examined the validity of 3 commercially-available accelerometers to predict MET values focusing specifically on nonlocomotive activities in field conditions. The accelerometers included the LC device, a triaxial accelerometer that uses 2 separate regression equations for nonlocomotive and locomotive activities, and a triaxial accelerometer that uses a single regression equation for all activities. We believe that these discussions might help us understand data of various accelerometers accumulated in epidemiology.

Methods

Subjects

All subjects were recruited through public applications and had no physical impairments that could affect household and locomotion activities. All subjects were fully informed of the purpose of the study and written informed consent was obtained from all subjects before the beginning of the study. This study was conducted according to the guidelines of the Declaration of Helsinki, and all procedures involving human subjects were approved by the Ethical Committee of the National Institutes of Health and Nutrition.

Anthropometry

Body weight was measured to the nearest 0.1 kg using a digital balance, and height was measured on a stadiometer to the nearest 0.1 cm. Body mass index (kg/m^2) was calculated as body weight divided by the square of body height.

Instruments

Lifecorder EX (LC). The LC (size: 72.5 × 41.5 × 27.5 mm; mass: 60 g, including a battery) was worn on the hip with an attached belt. This device was a uniaxial accelerometer with a sampling interval of 32 Hz. The LC output was a PA intensity score that consisted of a scale from 0–9 (level 0: rest; level 0.5: micro activity; level 1–9: movement). The intensity of PA (level 1–9) was determined from the frequency of steps and the magnitude of vertical acceleration that was categorized into 4 parts with 4 thresholds [threshold 1 (TH1): 0.06 g, TH2: manufacturer's fixed values, TH3: manufacturer's fixed values, TH4: 1.96 g]. The LC device registered steps when the vertical acceleration signal exceeded the second threshold or when the gap between the pulses was ≤ 1.5 s.[7,11] An activity eliciting 3 acceleration signals during a 4-s sampling interval was recognized as PA, which caused the grade (level 1–9) to be computed. If this condition was not satisfied and vertical acceleration did not exceed TH2, activities were considered by the LC to be micro activities (level 0.5). The LC intensity data output (level 1–9) were entered into a previously published equation to predict the MET value.[7] The equation was as follows:

$$\text{MET} = 0.043 \times a^2 + 0.379 \times a + 1.361$$

where a is the LC intensity.

ActivTracer (AT). This device (AC-210; size: 48 × 67 × 16 mm; mass: 57 g; GMS Co., Ltd., Tokyo, Japan) is a triaxial accelerometer for detecting movement in 3 dimensions. It was able to obtain 3-dimensional accelerations every 4 s with a sensitivity of 2 mG and using a band-pass filter of 0.3–100 Hz. We calculated the synthetic accelerations from the following equation:

$$\text{Synthetic acceleration} = (x^2 + y^2 + z^2)^{0.5}$$

where x is anteroposterior acceleration, y is mediolateral acceleration and z is vertical acceleration. The synthetic acceleration was inserted into the formula reported by Midorikawa et al to calculate the physical activity ratio (PAR).[13] The PAR was then divided by 1.1 to convert it to a MET value because resting metabolic rate (RMR) in the sitting position without a meal was 1.1 times the basal metabolic rate (BMR) (RMR: 0.99 ± 0.177 kcal/min; BMR: 0.89 ± 0.19 kcal/min) in the current study. Although Midorikawa et al adapted their formula for sleeping metabolic rate (SMR; ie, average metabolic rate over an 8-h sleeping period),[13] we confirmed that SMR for adults was approximately equal to BMR.[18] The equations of Midorikawa et al were as follows[13]:

$$\text{PAR} = 0.0123 \times b + 1.7208 \text{ (House work)}$$

$$\text{PAR} = 0.0081 \times b + 0.9234 \text{ (Walk)}$$

$$\text{MET} = \text{PAR} / 1.1$$

where b is the synthetic acceleration in mG detected by the AT. Midorikawa et al reported that this device could differentiate the activity level from "housework" to "walk" based on the ratio of vertical to horizontal acceleration (housework < 0.750; walk > 0.751). Therefore, we followed this procedure and predicted MET values from these equations.[13]

Actimarker (AM). The AM (test model; size: 60 × 35 × 13 mm; mass: 24 g; Matsushita Electric Works, Ltd., Osaka, Japan) was another triaxial accelerometer. It obtained 3-dimensional acceleration every 12 s with a sensitivity of 40 mG at a sampling rate of 20 Hz. We calculated the synthetic acceleration from the following equation:

$$\text{Synthetic acceleration} = (X^2 + Y^2 + Z^2)^{0.5}$$

where X is anteroposterior acceleration, Y is vertical acceleration, and Z is mediolateral acceleration. A predictive equation was obtained from the relationship between 3-dimensional synthetic acceleration and oxygen uptake during sedentary to vigorous PA, including nonlocomotive activities and locomotive movements.[19–21] The following equations were used to convert 3-dimensional synthetic acceleration to EE:

$$\text{Kcal (min)} = c \times d \times \text{BMR (kcal/day)} + \text{RMR (kcal/min)}$$

$$\text{MET} = \text{kcal (min) /RMR (kcal/min)}$$

where c is the coefficient and d is synthetic acceleration. BMR was estimated using predicted body surface area (cm^2). BMR was calculated from body weight (kg), height (cm), sex, and age using a formula for the Japanese population standardized by multiplying by a standard value ($kcal/m^2/h$) corresponding to age (5th edition of Recommended Allowances Dietary Reference Intake in Japan).[22] Moreover, BMR (kcal/day) was multiplied by 1.2, which is the ratio of sitting RMR to BMR in AM and includes diet-induced thermogenesis, and then divided by 1440 min to estimate RMR per minute in the sitting position several hours after a meal.

Procedures

The subjects visited the laboratory early in the morning in a fasted state. After the study protocol was explained, anthropometric measurements were done. Next, they were asked to rest in the supine position for 30 min, and then BMR was measured in the supine position and RMR in the sitting position. The subjects performed 12 physical activities that included nonlocomotive activities such as desk work, vacuuming, hanging clothes, washing dishes, and moving a small load (5 kg), and locomotive activities such as climbing down stairs, climbing up stairs, slow walk (55 m/min), normal walk (70 m/min), brisk walk (100 m/min), walk with 3-kg baggage (70 m/min), and jogging [male (140 m/min), female (120 m/min)]. These activities were chosen as representative activities of daily life and were based on our preliminary 3-day observations in free-living conditions. The preliminary study was performed using the activity records of 93 subjects who lived in the Tokyo metropolitan area. MET values were measured during all activities. All subjects wore the AM on the right waist and the AT on the left waist symmetrically. Furthermore, the LC was placed diagonally forward right of the waist according to the instructions of the manufacturer. These accelerometers were tightly attached with a belt during each activity. According to our unpublished data, such a small difference in the position of placement does not systematically affect the results. Before the experiment started, the accelerometers were synchronized using a wave clock for reference.

Measurement of BMR and RMR

After we verified that the subjects had fasted, each subject was fitted with a facemask and breathed into a Douglas bag twice for 10 min; the bag concentrations of oxygen and carbon dioxide were analyzed by a mass spectrometer (ARCO-1000; Arco System Inc., Kashiwa, Japan). Oxygen consumption (VO_2) and carbon dioxide production (VCO_2) at rest and during activity were measured using the Douglas-bag method. Expired gas volume was measured using a certified dry gas meter (DC-5; Shinagawa Co., Ltd., Tokyo, Japan). EE was calculated from VO_2 and VCO_2 using Weir's equation[23]:

$$\text{EE (kcal)} = 3.9 \times VO_2 + 1.1 \times VCO_2 .$$

Measurement of PA intensity

Measurement of each activity began after a preliminary period that was needed for subjects to reach a steady-state condition. The times needed to collect expired gas, which differed between activities, are shown in Table 1. The method for calculating the EE of each activity was the same as the method used for BMR and RMR. To calculate the MET value, EE during each activity was divided by the measured value of RMR.

Statistics

Statistical analysis was performed using JMP version 6.0 for Windows (SAS Institute, Tokyo, Japan). All results are shown as mean ± standard deviation (SD). Pearson's correlation coefficient was used to evaluate the relationships between variables. One-way analysis of variance (ANOVA) was used to compare measured and predicted MET values, and Tukey's HSD test was used for post hoc comparisons when the ANOVA was significant. Midorikawa's discriminative method was used to discriminate data produced by nonlocomotive activities from that produced by locomotive movements.[13] $P < .05$ was considered statistically significant.

Results

The participants were 33 men (age: 41.8 ± 14.0 years, height: 169.9 ± 6.2 cm, weight: 67.3 ± 14.1 kg, body mass index (BMI): 23.2 ± 3.9 kg/m^2) and 32 women (age: 43.1 ± 12.8 years, height: 158.0 ± 5.2 cm, weight: 55.6 ± 9.6 kg, BMI: 22.2 ± 3.5 kg/m^2).

We examined the effects of sex and age on measured MET values using a general linear model before statistical analysis because of the large age range of the subjects. As a result, there was no effect ($R^2 = .003$, $P = 0.23$) of age (F value = 2.35, $P = .13$) or sex (F value = 0.55, $P = .46$) on the measured MET values. Therefore, the relationships between measured and predicted PA intensities were examined without adjustment for age and sex.

Table 1 Duration for Measurement of Physical Activity Intensity

	Content of activity	Steady state (min)	Measurement of expired gas (min)
Desk work	Typewriting using personal computer with sitting in a chair	3.0	7.0
Vacuuming	Vacuuming clean in a room (about 17m^2) while moving	3.0	3.0
Hanging clothes	Hanging out washing then and there	3.0	3.0
Washing dishes	Washing dishes with standing position	3.0	3.0
Moving a small load	Moving a small load (5kg) from one place to the other place (between about 3 meters), repeatedly	3.0	2.0
Climbing down stairs	Climbing down stairs according to the leader	2.0	1.0
Climbing up stairs	Climbing up stairs according to the leader	1.0*	0.8
Slow walk	Walk according to pace leader machine (55m/min) on ground	3.0	3.0
Normal walk	Walk according to pace leader machine (70m/min)on ground	3.0	2.0
Brisk walk	Walk according to pace leader machine (100m/min) on ground	3.0	2.0
Walk with a baggage	Walk with a baggage (3kg)according to pace leader machine (70m/min) on ground	3.0	2.0
Jogging	Jogging according to pace leader machine (male: 140m/min, female: 120m/min) on ground	3.0	1.0

* Average time; the measurement for climbing up stairs was performed with a very short interval after climbing down stairs.

The differences between predicted and measured MET values are shown in Figure 1 (nonlocomotive) and Figure 2 (locomotive). Predicted MET values of nonlocomotive activities estimated by the AT and AM moderately agreed with measured MET values, whereas the LC systematically underestimated measured MET values. In contrast to nonlocomotive activities, the 3 accelerometers tended to have similar validity for locomotive movements.

The percentage difference between predicted and measured MET values is shown in Table 2. In all nonlocomotive activities except desk work, MET values were significantly underestimated by 20.3%–55.6% using the LC data. Using the AT data, MET values were significantly underestimated by 11.0% for moving a small load and by 2.3% for vacuuming, whereas MET values were overestimated by 11.3% for desk work and 11.7% for hanging clothes. Using the AM data, the MET values during all activities except for hanging clothes (overestimated by 16.7%) were significantly underestimated by 8.0%–20.0%. Although MET values during locomotive movements except for climbing down stairs were significantly underestimated by all 3 accelerometers, there were no differences among the 3 devices with the exception that high-intensity PA such as jogging was underestimated more by the LC (25.7%) than by the 2 other devices.

We described the relationship between LC intensity and MET values in Figure 3. For nonlocomotive activities, the LC intensities were within a narrow range (0.5 to 1.5), in spite of the finding that the MET values during each activity were significantly different.

Table 3 indicates that the rate of walking evaluated by the LC device, which was calculated from dividing the total number of steps during each activity by the length of that activity period, was considerably less during nonlocomotive activities than during locomotive movements.

Discussion

The purpose of this study was to compare the validity of 3 accelerometers equipped with specific algorithms to measure PA intensity during nonlocomotive activities and locomotive movements.

Figure 1 and Figure 2 show the differences between predicted MET values and measured MET values. We found that the LC instrument had difficulty evaluating PA intensity during nonlocomotive activities (Figure 1, Table 2). One of the reasons for this is that the equations for the LC device were specific for walking and running on a treadmill in the laboratory.[7] In addition, although the LC intensity (output data) was determined from the number of steps and vertical acceleration, the steps per minute were considerably less in nonlocomotive activities than in locomotive movements (Table 3). The LC device registered movement when the vertical acceleration signal exceeded the second threshold or when the gap between pulses was ≤ 1.5 s.[7,11] Therefore, it is possible that most steps taken during nonlocomotive activities were not detected by the LC device because the acceleration signals were not regular but rather intermittent. For example, during vacuuming, the LC accelerometer could not detect movements because the interval between them was often > 1.5 s (Table 3). We confirmed that nonlocomotive activities such as vacuuming and moving a small load corresponded to LC intensities "0.5–1.5,"

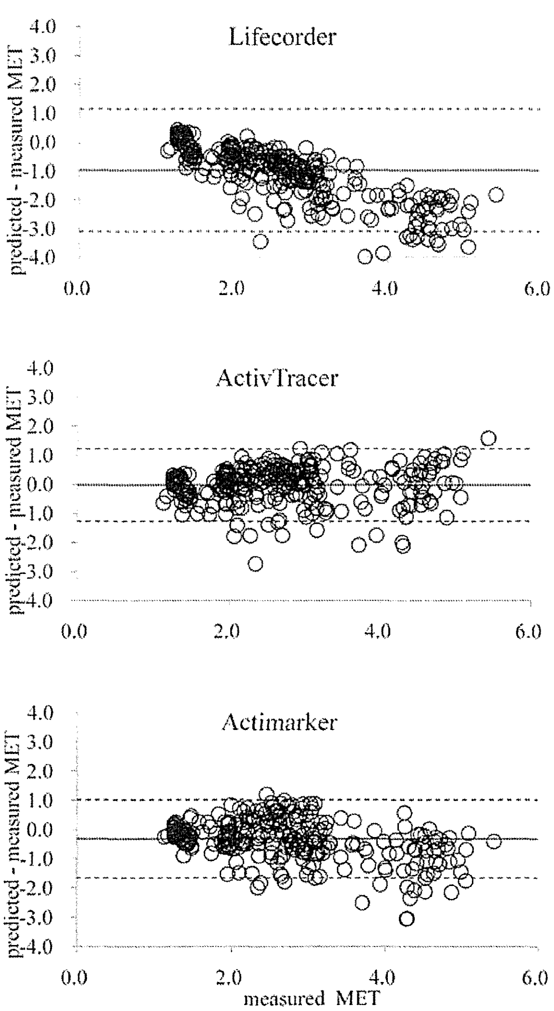

Figure 1 — Mean differences of each accelerometer between predicted and measured METs for nonlocomotive activities using Bland and Altman plots.

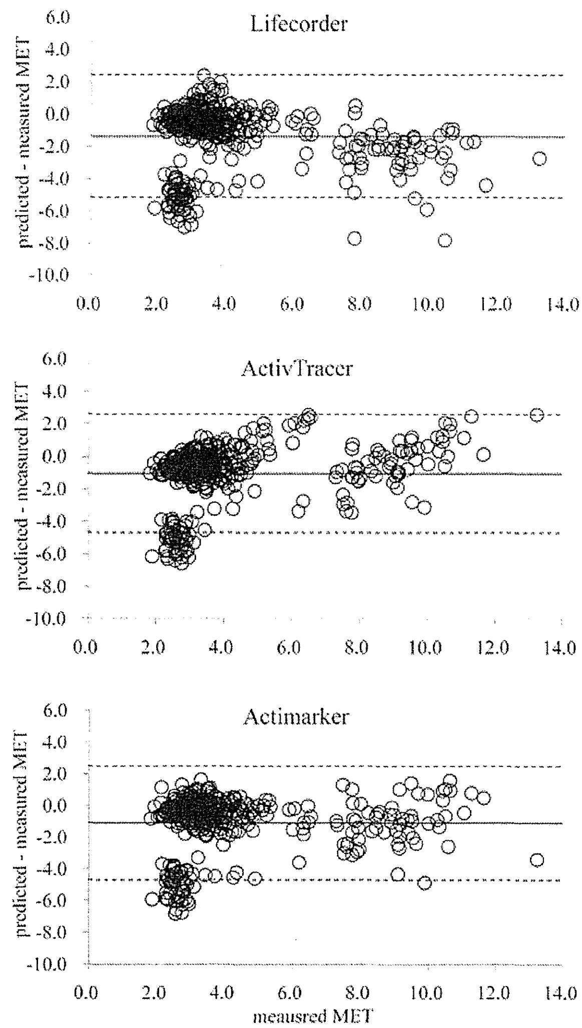

Figure 2 — Mean differences of each accelerometer between predicted and measured METs for locomotive movements using Bland and Altman plots.

even when these MET values were comparable to slow walk and normal walk (Figure 3).

In contrast, the differences between measured and predicted MET values obtained using AT and AM data were less than those obtained using LC data, although there were also significant differences between MET values by triaxial accelerometers and measure MET values for several nonlocomotive activities (Table 2). The predictive equations for the AT and AM devices were obtained for both locomotive movements and nonlocomotive activities.[13,21] This might explain why the differences between predicted and measured MET values were better with the AT and AM accelerometers compared with the LC accelerometer. Moreover, the AT equations tended to have better predictive ability than the AM equations because the suggested discrimination method of Midorikawa et al was applied for discriminating between the MET values of nonlocomotive activities and locomotive movements.[13] An advantage of the AT over other devices is that it can evaluate complex motions such as moving a small load, which consist of both types of activity like ambulatory movement, bending forward (unloading) and standing up (catching up load). However, since the AT as well as the other accelerometers could not detect the weight that an individual was carrying, it is not surprising that the MET values predicted by the AT underestimated the actual values by 11.0%.

Meanwhile, we confirmed that the accuracy of 3 accelerometers in locomotive movements was similar (Figure 2, Table 2). However, the underestimation of MET values for jogging was greater with the LC device than with the 2 other devices. Based on the original

Table 2 Percent of Differences Between Measured and Predicted METs

	Measured METs		Predicted METs						Percent of difference						Statistics	
			Lifecorder		ActivTracer		Actimarker		Lifecorder		ActivTracer		Actimarker			
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	*P*	Post hoc test
Desk work	1.1	0.1	1.4	0.0	1.3	0.0	1.0	0.1	23.2	7.9	11.3	7.9	–8.0	7.6	<0.0001	LC > AT > ME > AM
Vacuuming	2.9	0.7	1.6	0.0	2.7	0.4	2.3	0.3	–44.0	11.1	–2.3	24.9	–20.0	14.1	<0.0001	ME > AT > AM > LC
Hanging clothes	2.3	0.4	1.5	0.0	2.5	0.4	2.6	0.4	–32.6	10.6	11.7	21.8	16.7	20.4	<0.0001	AM,AT > ME > LC
Washing dishes	1.8	0.4	1.4	0.1	1.8	0.3	1.6	0.3	–20.3	13.5	0.2	23.6	–12.0	19.5	<0.0001	ME,AT > AM > LC
Moving a small load	4.4	0.7	1.9	0.1	4.2	0.6	3.5	0.3	–55.6	7.3	–11.0	7.3	–19.4	13.8	<0.0001	ME,AT > AM > LC
Climbing down stairs	3.2	0.5	3.4	0.8	3.0	0.4	3.3	0.4	9.6	30.3	–3.2	20.1	8.6	22.4	0.0003	LC,AM > AT
Climbing up stairs	7.6	0.8	2.5	0.3	2.8	0.5	2.7	0.3	–66.4	5.1	–63.8	8.0	–64.5	5.6	<0.0001	ME > AM,AT,LC
Slow walk	3.1	0.4	2.7	0.3	2.8	0.7	2.8	0.3	–12.7	13.2	–11.3	19.7	–9.0	12.8	<0.0001	ME > AT,AM,LC
Normal walk	3.6	0.5	3.2	0.4	3.3	0.7	3.3	0.3	–10.5	12.8	–7.3	20.4	–8.0	13.1	<0.0001	ME > AT,AM,LC
Brisk walk	4.6	0.7	4.0	0.5	4.2	0.7	4.0	0.6	–12.9	12.6	–9.1	18.3	–11.7	13.8	<0.0001	ME > AT,AM,LC
Walk with a baggage	4.2	0.6	3.5	0.5	3.7	0.8	3.6	0.4	–16.1	12.3	–12.8	20.3	–14.5	12.6	<0.0001	ME > AT,AM,LC
Jogging	9.5	1.1	6.8	1.5	9.0	1.3	8.1	1.8	–25.7	14.6	–4.0	14.8	–10.7	14.6	<0.0001	ME > AT < AM < LC

Abbreviations: ME; measured, LC; Lifecorder, AT; ActivTracer, AM; Actimarker.

Note. Post hoc test was adapted by Tukey's HSD test.

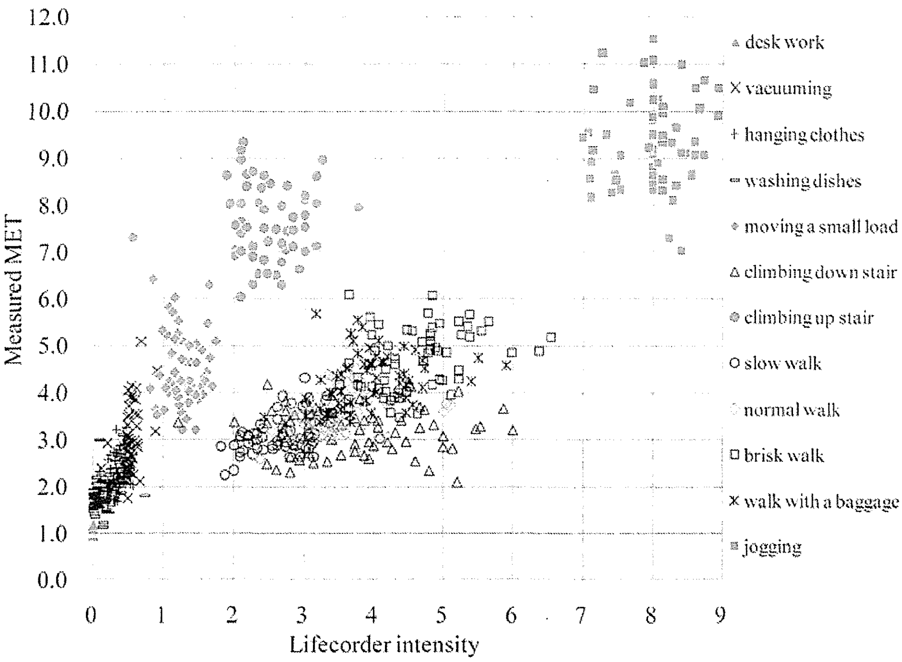

Figure 3 — Relationship between output data from Lifecorder and measured MET values.

Table 3 Rate of Steps for Each Activity*

	Rate of steps	
	Mean	**SD**
Desk work	0.0	0.0
Vacuuming	6.8	8.0
Hanging clothes	1.6	2.6
Washing dishes	0.3	1.6
Moving a small load	44.4	9.4
Climbing down stairs	104.1	14.6
Climbing up stairs	90.9	13.9
Slow walk	100.0	6.8
Normal walk	111.1	6.2
Brisk walk	121.0	6.8
Walk with a baggage	115.5	6.0
Jogging	161.0	25.5

* Rate of steps (frequency/minute) was calculated from dividing total steps during each activity by action time (minutes).

algorithm and equation, the LC can detect PA up to 8.3 MET values corresponding to a maximum LC intensity of "9".[7] Therefore, it would be difficult to evaluate jogging over 120–140 m/min using the LC, because jogging in this study corresponded to 9.5 MET values.

An important aspect of MET prediction by the 3 accelerometers is the measurement of RMR, and the error in RMR can affect the predicted MET values. The equation for the AT device predicts the physical activity ratio (PAR), which is the energy expenditure divided by the BMR. Therefore, the PAR was divided by 1.1 to convert it to a MET value in this study according to the Dietary Reference Intake in the US.[24] Actually, since the ratio of RMR to BMR in this study was 1.11 (see the Methods section), there was little effect of the RMR on the MET values predicted by the AT device. Furthermore, the LC equation depends on MET values calculated using 3.5 ml/kg/min as the RMR according to a previous report.[7] With the AM device, the estimated RMR was used (see the Methods section). We found that 3.5 ml/kg/min (LC) and the predicted RMR (AM) were about 8% higher than the actual RMR. Considering the difference of RMRs, it may raise the validity of this study by up to approximately 7% positively. However, even if the RMR differences slightly affected the predictive accuracies of the LC and AM accelerometers, we still found that there was a larger error for nonlocomotive activities than for locomotive movements.

An important issue that must be considered is whether the AT accelerometer evaluated in the current study is valid in obese individuals. With respect to this point, we previously reported the effect of body weight on MET values in the same subjects and during the same physical activities as in the current study.[25] Our previous report indicated that when the BW is more than 10 kg above average body weight (60.0 kg), there is about a +5% error for nonlocomotive activities (vacuuming) and +3% to 5% error for locomotive movements. Thus, MET values are associated with body weight to some degree. Therefore, when the results of this study are applied to obese individuals, the effect of body weight on MET values should be considered. However, significant correlations were not obtained between the predictive errors and body weight in this study except for climbing up stairs.

There are 2 limitations in this study. The primary limitation is whether the errors in predictive accuracy in the current study affect TEE in an entire day. To address this issue, it will be necessary to examine the validity using the doubly labeled water method under free-living conditions in a future study. However, Westerterp indicated that in a subject with an average physical activity level of 1.75, PAEE of nonlocomotive activities, which consist of sitting and standing without movement and standing active (ie, washing dishes), accounts for more than 50% of total PAEE.[5] Therefore, it may be possible that the difference in predictive ability among the AT, AM and LC devices in the current study affects the prediction of TEE. Furthermore, Leenders et al indicated that the predictive equations based on the relationship between acceleration and energy expenditure during locomotive movements led to underestimation of TEE by more than 10%, but the predictive equations based on both nonlocomotive activities and locomotive movements did not necessarily lead to TEE underestimation.[26] Considering these viewpoints, to improve the predictive ability for TEE, the predictive equation should be based on both nonlocomotive activities and locomotive movements.

Another limitation is that it is not easy to make generalizations regarding the currently used other accelerometers, because the aim of this study was to examine the validity of 3 commercially-available accelerometers that employ specific algorithms. However, few previous studies have attempted to validate PA intensity from commercially-available accelerometers data for both nonlocomotive activities and locomotive movements obtained under field conditions. Based on our results, we suggest that triaxial accelerometers based on nonlocomotive activities and locomotive movements have better accuracy than uniaxial accelerometer. In particular, triaxial accelerometer with equations that distinguish between nonlocomotive and locomotive movements might be more accurate. Meanwhile, the algorithm of LC could not evaluate nonlocomotive activities, which probably attributes to underestimation of PA in a whole day. We also believe that it gives full recognition to the significance of nonlocomotive activities (or NEAT). In addition, our results may help both researchers and general users understand how to use accelerometers to evaluate PA.

In conclusion, we didn't find a difference in predictive ability of 3 accelerometers for locomotive movements except for jogging. Meanwhile, we found that the MET values obtained during nonlocomotive activities by the LC device consistently underestimated the measured MET values. In contrast, the AT and AM devices more accurately assessed MET values during nonlocomotive activities, although there were still significant deviations from measured MET values. In particular, the reason why the AT device has better predictive ability for nonlocomotive activities is probably due to the use of separate predictive equations for both nonlocomotive activities and locomotive movements.

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DIETARY SURVEYS AND NUTRITIONAL EPIDEMIOLOGY

Association between dietary intake of micronutrients and cardiorespiratory fitness in Japanese men

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Abstract

Previous studies have demonstrated that meeting the dietary recommendations for macronutrients was significantly associated with higher cardiorespiratory fitness (CRF) levels in adults. However, the relation between the status of micronutrient intake and CRF still remains unclear. This study examined the association between micronutrient intake status (based on adherence to the dietary reference intakes (DRI)) and CRF in Japanese men. The study comprised 373 Japanese men aged 30–69 years. Dietary intake was assessed with a self-administered diet history questionnaire. Overall micronutrient intake status was quantified using an overall nutrient adequacy score (ONAS) for thirteen selected micronutrients. ONAS was calculated based on adherence to the DRI for Japanese. CRF was defined as $\dot{V}O_{2max}$ during a maximal incremental test on a bicycle ergometer. Physical activity was measured using accelerometer-based activity monitors for seven consecutive days. We observed a significant inverse trend for the prevalence of inadequacy for the intake of vitamin A and Ca across incremental CRF categories ($P < 0·05$). In a multivariate model, the ONAS was positively associated with absolute ($\beta = 0·10$, $P = 0·02$) and relative $\dot{V}O_{2max}$ ($\beta = 0·09$, $P = 0·04$), independent of physical activity. The OR for being unfit (the lowest 25 % of the age-specific distribution of $\dot{V}O_{2max}$) in the third ONAS tertile compared with the first ONAS tertile was 0·52 (95 % CI 0·28, 0·96). These results demonstrated that the intake of several individual micronutrients and overall micronutrient intake status are independently and positively associated with CRF in Japanese men.

Key words: **$\dot{V}O_{2max}$: Nutrient inadequacy: Diet: Physical activity**

It is well established that high levels of cardiorespiratory fitness (CRF) are associated with a favourable metabolic risk profile and an independent predictor of overall risk of illness and all-cause mortality[1–4]. CRF is influenced by several factors, including age, sex, heredity, body composition and the individual's lifestyle factors[5,6]. Among those factors, lifestyle factors including physical activity, dietary habits and smoking status are thought to be modifiable contributors to variation in CRF.

Considerable evidence exists to demonstrate that both self-reported physical activity[4,6–9] and objectively measured physical activity[10–13] are clearly related to CRF. Compared with physical activity, fewer reports are available on the association

Abbreviations: BDHQ, brief self-administered diet history questionnaire; CRF, cardiorespiratory fitness; DRI, dietary reference intake; ONAS, overall nutrient adequacy score.

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between nutrition status and CRF[6,14–17]. Existing studies usually focused on macronutrient intake. CRF has been frequently assessed using estimated $\dot{V}O_{2max}$, and few studies have properly controlled for the confounding effects of physical activity. Previous studies have demonstrated that meeting the dietary recommendations for macronutrients is significantly associated with higher CRF levels in adults[14]. However, there is a paucity of data on the relation between the status of micronutrient intake and CRF. In the present study, we examined the relationship between micronutrient intake status (based on adherence to the dietary reference intakes (DRI)) and directly measured CRF in Japanese men. As positive associations have been observed between physical activity and healthy nutritional intake[8,18], we also investigated whether these associations are independent of physical activity, quantified by step counts per d.

Experimental methods

Subjects

The sample comprised 373 men aged 30–69 years (mean 48·8 (SD 11·5) years) who participated in the Physical Activity and Fitness for Health Promotion Study, which was designed to investigate Japanese physical activity and fitness as well as their association with other risk factors for lifestyle-related diseases. None of the subjects had any chronic diseases or were taking any medications that could affect the study variables. This study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving human participants were approved by the Ethical Committee of the National Institute of Health and Nutrition. Written informed consent was obtained from all participants.

Dietary assessment

Dietary habits during the previous month were assessed with a brief self-administered diet history questionnaire (BDHQ) for Japanese adults[19]. The BDHQ is a four-page structured questionnaire that enquires about the consumption frequency of a total of fifty-six food and beverage items, with specified serving sizes described in terms of the natural portion or the standard weight and volume measurement of servings commonly consumed in general Japanese populations. The BDHQ for adults was developed based on a comprehensive (sixteen-page) version of a validated self-administered diet history questionnaire[20–22]. Estimates of dietary intake for the fifty-six food and beverage items, energy and selected nutrients were calculated using an *ad hoc* computer algorithm for the BDHQ, which was based on the Standard Tables of Food Composition in Japan[23,24]. The validity of the BDHQ using 16-d weighed dietary records as the 'gold standard' is described elsewhere[19,25,26]. Nutrient variables were energy adjusted using the nutrient density method (amount of nutrient intake per 4184 kJ (1000 kcal)), to reduce the measurement error common with dietary assessment questionnaires and to avoid biased grouping due to variation in body size and energy requirement[27]. Adequacy of nutrient intake was examined using the reference values given in the DRI for Japanese people as a temporal 'gold standard'[28]. Of the eighteen micronutrients with estimated average requirement presented in the DRI, five nutrients (Cr, Mo, Se, iodine and Na) were excluded from this study because the intake of these nutrients (Cr, Mo, Se and iodine) cannot be reliably assessed by the BDHQ or because for Na, a tentative dietary goal for the prevention of lifestyle-related diseases is more important than the estimated average requirement in the DRI. The thirteen selected micronutrients were vitamin A, thiamin, riboflavin, niacin, vitamin B_6, vitamin B_{12}, vitamin C, folate, Ca, Mg, Fe, Zn and Cu. For each of these nutrients, a nutrient adequacy score of 1 was allocated if the nutrient (amount of nutrient intake per 4184 kJ) met or exceeded the estimated average requirement (amount of nutrient intake per 4184 kJ) given in the DRI, and a '0' if it did not meet the estimated average requirement. As a measure of overall micronutrient adequacy, an overall nutrient adequacy score (ONAS) was constructed by summing the scores of all nutrients. Overall micronutrient adequacy was defined as low ($ONAS < 10$), moderate ($ONAS = 10$ or 11), or high ($ONAS = 12$ or 13) according to the tertile of ONAS.

Cardiorespiratory fitness

CRF was defined as $\dot{V}O_{2max}$ during a maximal graded exercise test with bicycle ergometers (Lode Excalibur, Lode BV; Monark Ergomedic 828E). The methodology and equipment used in taking this measurement have been described in detail elsewhere[11]. Achievement of $\dot{V}O_{2max}$ was accepted if at least two of three criteria were met: (1) a plateau in $\dot{V}O$ despite increasing the work rate; (2) maximal $RER \geq 1·10$; and (3) maximal heart rate was not less than 95 % of the age-predicted maximum (220 – age). Low (unfit), moderate and high CRF were defined according to the lowest 25 %, the middle 50 % and the upper 25 %, respectively, of the age-specific distribution of $\dot{V}O_{2max}$ in all participants.

Physical activity

We measured physical activity using the activity monitor (Kenz Lifecorder; Suzuken Co. Ltd). An activity monitor attached to a waist belt on the left side of the body was used to collect step count data for seven consecutive days in all participants. The mean total step counts per d were used for further analyses. Additional details have been published elsewhere[12].

Anthropometrics and smoking status

Height, without shoes, was measured to the nearest millimetre using a stadiometer. Body mass was measured using an electronic scale with the subjects wearing light clothing and no shoes and was determined to the nearest 0·1 kg. BMI was calculated by dividing the body mass in kilograms by the square of height in metres (kg/m^2). Cigarette smoking status was assessed by self-report on a lifestyle and health history questionnaire. Smoking status was classified as never smoked, former smoker, or current smoker.

Statistical analysis

Subject characteristics (reported as mean values and standard deviations, or percentages) were contrasted between $\dot{V}O_{2max}$ tertiles using a one-way ANOVA for age, height, body mass, BMI, $\dot{V}O_{2max}$ and step counts and for smoking status using the χ^2 test (Table 1). The χ^2 test was also used to identify significant differences in the prevalence of participants with inadequate micronutrient intake across levels of CRF. ANCOVA was used to identify significant differences in the micronutrient intake across levels of CRF after adjustment for the important confounding factors. The relationship of overall micronutrient intake adequacy with CRF was examined by multiple regression models. Model 1 adjusted for age, BMI and smoking status. Model 2 additionally adjusted for physical activity. Logistic regression analysis was used to determine the OR of being unfit (the lowest 25 % of the age-specific distribution of $\dot{V}O_{2max}$) associated with each tertile of ONAS adjusted for age, BMI, smoking status (model 1) and further adjusted for physical activity (model 2). All statistical analyses were performed using SPSS statistical software version 19 (IBM Japan Ltd). Statistical significance was set at $P < 0{\cdot}05$ (two-sided).

Results

Descriptive characteristics across incremental categories of CRF are shown in Table 1. Significant inverse trends were observed for body mass (P value for trend = 0·001), BMI (P value for trend = 0·004), and smoking status (P value for trend = 0·004) across incremental CRF categories. Significant positive trends across incremental CRF categories were observed for step counts (low fitness group 7458, medium fitness group 8763 and high fitness group 10313 steps per d, respectively).

We examined the prevalence of inadequacy for micronutrient intake in our participants. As shown in Table 2, the average prevalence of adequacy calculated across all thirteen micronutrients was 78·9 % for Japanese men. Overall, the subjects reported diets with reasonable adequacy of intakes for niacin, vitamin B_{12}, folate, Fe and Cu (96·5–100 %). However, the prevalence of potentially inadequate intakes was 25–35 % for Mg, Ca and Zn, and may also be relatively high for vitamin A (61·1 %) and thiamin (81·0 %).

We assessed differences of individual micronutrient intake and overall micronutrient intake status across levels of CRF by ANCOVA (Table 2). Participants in the high CRF category had the highest vitamin A, riboflavin and Ca intake and the highest ONAS compared with those in participants in the lower CRF categories (P value for ANCOVA <0·05, after adjustment for age, BMI and smoking status). These differences remain after further adjustment for step counts (vitamin A, $P = 0{\cdot}02$; riboflavin, $P = 0{\cdot}08$; Ca, $P = 0{\cdot}06$). There were no significant differences in other nutrient intakes among CRF categories. We also observed a significant inverse trend for the prevalence of inadequacy for the intake of vitamin A (P value for trend = 0·006) and Ca (P value for trend = 0·005) across incremental CRF categories (Table 2).

In a multiple regression analysis with age, BMI, smoking status and ONAS as independent variables and CRF as the dependent variable, ONAS was the significant determinant of the variance in CRF in terms of absolute ($\beta = 0{\cdot}11$, $P < 0{\cdot}05$) and relative $\dot{V}O_{2max}$ ($\beta = 0{\cdot}10$, $P < 0{\cdot}05$) (Table 3). As seen in models 2 and 4, after further adjustment for step counts, ONAS remains the significant determinant of the variance in CRF in terms of absolute ($\beta = 0{\cdot}10$, $P < 0{\cdot}05$) and relative $\dot{V}O_{2max}$ ($\beta = 0{\cdot}09$, $P < 0{\cdot}05$).

We fitted logistic regression models to assess the association between ONAS (tertile) and being unfit, adjusting for age, BMI and smoking status, with the lowest tertile used as the referent (Fig. 1). Individuals in the top tertile of ONAS had 52 % decreased odds of being unfit (OR 0·48; 95 % CI 0·24, 0·97), compared with those whose ONAS were in the lowest tertile. The OR of being unfit in the intermediate tertile compared with the lowest tertile was 0·57 (95 % CI 0·31, 1.05). The OR for being unfit remained strong comparing the top tertile with the lowest tertile (OR 0·49; 95 % CI 0·24, 0·99) when we further adjusted the models for step counts. After the further adjustment, the OR for being unfit in the intermediate tertile compared with the lowest tertile was 0·56 (95 % CI 0·30, 1·04). Similar results were observed when step counts were substituted with minutes of moderate-

Table 1. Characteristics of participants
(Mean values and standard deviations, or percentages)

	All (n 373)		Low fitness (n 75)		Moderate fitness (n 208)		High fitness (n 90)		
Variables	Mean	SD	Mean	SD	Mean	SD	Mean	SD	P for trend
Age (years)	48·8	11·5	48·6	11·4	48·9	11·6	48·7	11·6	0·973
Height (cm)	170·0	6·0	170·0	5·6	170·3	6·2	169·3	5·9	0·480
Body mass (kg)	66·9	8·5	68·3	9·0	67·5	8·6	64·2	7·0	0·001
BMI (kg/m^2)	23·2	2·7	23·7	3·1	23·3	2·7	22·5	2·3	0·004
$\dot{V}O_{2max}$ (mk/kg per min)	34·8	7·7	27·0	4·8	34·0	5·2	43·1	6·5	<0·001
Step counts (steps per d)	8875	3389	7458	2675	8763	3372	10313	3435	<0·001
Smoking status (%)									0·004
Non-smoker	36·4		27·0		36·8		43·9		
Former smoker	41·0		39·2		42·0		40·2		
Current smoker	22·6		33·8		21·2		15·8		

Table 2. Micronutrient intake (unit/4184 kJ) and proportion of participants with inadequate micronutrient intakes presenting a nutrient intake below the estimated average requirement (EAR) in the low, moderate and high fitness tertiles
(Mean values, standard errors and percentages)

	All (*n* 373)			Low fitness (*n* 75)			Moderate fitness (*n* 208)			High fitness (*n* 90)				
	Mean	SE	%	Mean	SE	%	Mean	SE	%	Mean	SE	%	*P**	*P*†
Vitamin A (μg RE/4184 kJ)‡	381·9	9·71	61·1	335·9	17·83	72·0	380·0	13·20	61·5	424·3	20·86	51·1	0·03	0·01
Thiamin (mg/4184 kJ)	0·4	0·00	81·0	0·4	0·01	80·0	0·4	0·01	83·2	0·4	0·01	76·7	0·25	0·53
Riboflavin (mg/4184 kJ)	0·7	0·01	12·1	0·6	0·02	12·0	0·7	0·01	14·4	0·7	0·02	6·7	0·03	0·25
Niacin (mg NE/4184 kJ)§	9·1	0·11	1·3	9·3	0·29	1·3	9·0	0·15	1·4	8·9	0·21	1·1	0·69	0·89
Vitamin B_6 (mg/4184 kJ)	0·7	0·01	6·2	0·7	0·02	5·3	0·7	0·01	8·7	0·7	0·02	1·1	0·54	0·20
Vitamin B_{12} (μg/4184 kJ)	4·7	0·11	0·3	5·0	0·29	1·3	4·7	0·15	0·0	4·5	0·19	0·0	0·39	0·12
Folate (μg/4184 kJ)	177·6	2·88	1·6	171·9	5·84	0·0	176·3	3·87	2·4	185·4	6·17	1·1	0·27	0·64
Vitamin C (mg/4184 kJ)	57·1	1·27	13·9	57·7	3·05	16·0	56·5	1·72	16·3	58·2	2·35	6·7	0·74	0·07
Ca (mg/4184 kJ)	268·3	4·65	31·6	246·8	9·36	45·3	270·2	6·65	29·8	281·9	8·37	24·4	0·04	0·01
Mg (mg/4184 kJ)	133·0	1·27	26·8	131·3	2·68	26·7	132·5	1·72	26·9	135·6	2·61	26·7	0·39	1·00
Fe (mg/4184 kJ)	3·9	0·05	3·5	3·9	0·96	0·0	3·9	0·06	5·8	4·1	0·10	1·1	0·27	0·84
Zn (mg/4184 kJ)	4·1	0·03	34·9	4·1	0·06	36·0	4·1	0·04	35·1	4·2	0·06	33·3	0·28	0·72
Cu (mg/4184 kJ)	0·6	0·01	0·0	0·6	0·01	0·0	0·6	0·01	0·0	0·6	0·01	0·0	0·58	–
ONAS	10·3	0·10	–	10·0	0·20	–	10·1	0·15	–	10·7	0·17	–	0·03	–

ONAS, overall nutrient adequacy score; RE, retinol equivalents; NE, niacin equivalents.
* *P* value for ANCOVA adjusted for age, BMI and smoking habits.
† *P* value for trend by the χ^2 test.
‡ 1 μg RE = retinol (μg) + β-carotene (μg) × 1/12 + α-carotene (μg) × 1/24 + β-cryptoxanthin (μg) × 1/24 + other provitamin A carotenoids (μg) × 1/24[28].
§ NE were computed as niacin (mg) + protein (mg)/6000 according to the dietary reference intake for the Japanese[28].

to vigorous-intensity physical activity as the adjusted variable (data not shown).

Discussion

The main finding of the present study was that a number of dietary micronutrients and an overall micronutrient intake score representing the overall micronutrient adequacy for thirteen micronutrients were positively associated with CRF in a group of Japanese men. These associations were independent of physical activity and other potential confounding variables including age, BMI and smoking status, suggesting that physical activity does not confound the association between micronutrient intake and CRF in our population sample of Japanese men. Furthermore, these results show that participants who had a poor overall micronutrient intake status have a significantly higher risk of being unfit compared with men with a good micronutrient intake status.

Micronutrients most commonly function as essential co-enzymes and co-factors for metabolic reactions (as structural components of enzymes and mitochondrial cytochromes and as active electron and proton carriers in the ATP-generating respiratory chain) and thus help support basic cellular reactions (i.e. glycolysis, the citric acid cycle, lipid and amino acid metabolism) required to maintain energy production and life[29]. Although micronutrients probably play important roles in physical work capacity and therefore performance through different biological pathways, the relationship between dietary micronutrients and CRF is not well studied in the population sample of adults, especially in large sample sizes. Chatard *et al.*[30] examined the association between micronutrient intake (eleven nutrient density variables) and CRF in eighteen sportsmen aged 56–72 years.

Table 3. Results of the multiple regression analyses between overall micronutrient intake status (overall nutrient adequacy score; ONAS) and cardiorespiratory fitness (*n* 373)*

	$\dot{V}O_{2max}$ (litres/min)							
	Model 1				Model 2			
Independent variable	*B*	β	*P*	R^2	*B*	β	*P*	R^2
ONAS	0·03	0·11	0·01	0·33	0·03	0·10	0·02	0·38
	$\dot{V}O_{2max}$ (ml/kg per min)							
	Model 3				Model 4			
Independent variable	*B*	β	*P*	R^2	*B*	β	*P*	R^2
ONAS	0·39	0·10	0·02	0·27	0·35	0·09	0·04	0·34

B, unstandardised regression coefficients; *β*, standardised regression coefficients.
* Model 1 is adjusted for age, BMI and smoking habits. Model 2 is adjusted for all covariates in model 1 plus step counts. Model 3 is adjusted for age and smoking habits. Model 4 is adjusted for all covariates in model 3 plus step counts.

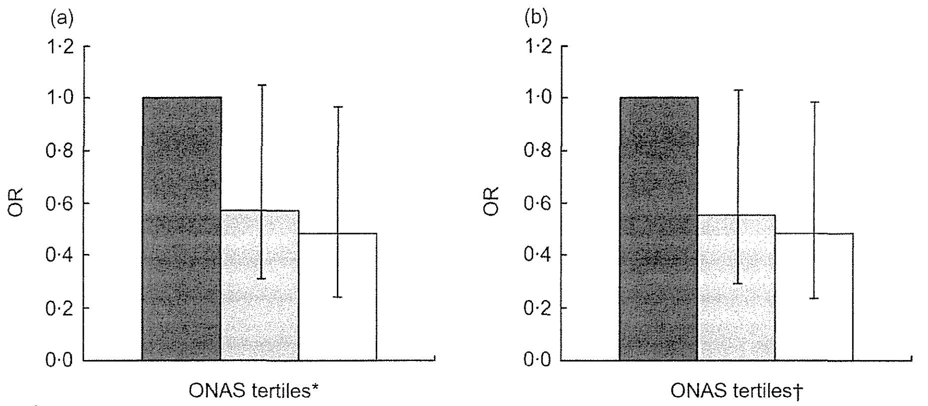

Fig. 1. Odds of being unfit (low cardiorespiratory fitness) by overall nutrient intake status categories (overall nutrient adequacy score (ONAS) tertiles). ■, Lowest tertile (reference); □, intermediate tertile; □, highest tertile. Values are OR, with 95 % CI represented by vertical bars. * Adjusted for age, BMI and smoking status. † Adjusted for age, BMI, smoking status and step counts.

Diet was assessed with a 6-d diet recall and CRF ($\dot{V}O_{2max}$) was objectively measured using a Monark cycle ergometer. Stepwise regression analyses indicated that vitamin C intake (expressed per 1000 kJ of energy intakes) was the only determinant to have a relationship with $\dot{V}O_{2max}$. By contrast, Butterworth *et al.*[31] studied a group of 20–40-year-old women (*n* 34) who varied widely in levels of physical activity and found no significant relationship between micronutrient intake (nutrient density) and $\dot{V}O_{2max}$, as assessed by a maximal graded treadmill test. However, they did not adjust for the important confounding factors. To our knowledge, only one study examined individual micronutrient intake in relation to CRF in a large sample of men and women. Brodney *et al.*[14] investigated nutrient intakes of 7959 men and 2453 women aged 20–87 years across low, moderate and high fitness categories. CRF was assessed using estimated $\dot{V}O_{2max}$ from treadmill time, and diet was assessed with a 3-d food record. The authors found that there was a significant difference across low, moderate and high fitness for both macronutrients and micronutrients (including vitamins A, B_6, B_{12}, C and E, folate and Ca), after adjusting for age, smoking status, health status and BMI in ANCOVA. However, they did not adjust micronutrient variables using the nutrient density method. Although physical activity is usually positively associated with healthy nutritional intake, the aforementioned studies do not appear to consider the independent effects of these lifestyle factors on CRF. Our results are the first to confirm that micronutrient intake is correlated with CRF independent of physical activity level (Table 2).

A unique contribution of the present study is that associations between individual and overall micronutrient adequacy and CRF were examined in a sample of Japanese men. Our results showed a significant inverse trend for prevalence of inadequacy for the intake of vitamin A and Ca across incremental CRF categories (Table 2). As *in vivo* biological activities of nutrients are interdependent, the combination of inadequate micronutrient intakes may have a greater impact on functional status than inadequate intake of individual micronutrients[32]. We therefore also examined relationships between overall micronutrient intake status (ONAS, overall micronutrient adequacy for thirteen selected micronutrients) and CRF. We found that ONAS emerged as a significant independent determinant of $\dot{V}O_{2max}$. As shown in Table 3, for each 1-score increase in ONAS, the value of $\dot{V}O_{2max}$ increased by 0·03 litres/min or 0·35 ml/kg per min after adjusting for step counts and other potential confounding variables. Individuals who had an inadequacy intake of a single micronutrient (the top tertile of ONAS) had a 51 % decreased odds of being unfit compared with those whose intake of more than four micronutrients was inadequate (the lowest tertile) even after adjusting for age, BMI, smoking status and physical activity. These results extend the findings of a previous study of males in the Netherlands[33], in which the authors carried out a double-blind intervention examination of the combined restriction of thiamin, riboflavin and vitamins B_6 and C in relation to $\dot{V}O_{2max}$ in eleven men. They found that a combined restricted intake of these micronutrients caused a 9·8 % decrease in $\dot{V}O_{2max}$ within a few weeks. The aforementioned results indicate that it is necessary to incorporate both dietary and physical activity advice into fitness promotion counselling.

Our study has some limitations. The study participants consisted of only men aged 30–69 years and are not representative of the entire Japanese population, and thus the present results may have limited generalisability. Our study was a cross-sectional study, and cannot provide causal evidence on the association between micronutrient intake status and CRF. Despite its limitations, the present study has some strengths, including the relatively large population sample of Japanese men, the objective measures of CRF and physical activity and the examination of 'the micronutrient intake status (based on adherence to DRIs)'–CRF relationship and an important confounding variable (physical activity).

Conclusion

In conclusion, both several individual micronutrients' intake and overall micronutrient intake status were found to be independently and positively associated with CRF in Japanese men.

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Comparison of coffee, tea and green tea consumption between Japanese with and without metabolic syndrome in a cross-sectional study

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ABSTRACT

There are some reports that coffee consumption improves insulin resistance. Therefore, we investigated the link between metabolic syndrome and coffee, tea and green tea consumption in Japanese. We used data of 150 men and 227 women who were not taking any medications, aged 22 - 74 years, in this cross-sectional investigation study. Habitual coffee, tea and green tea consumption was defined as drinking one or more cups of coffee, tea and green tea per day. The diagnosis of metabolic syndrome was based on the Japanese criteria. In subjects without medications, 34 men (22.7%) and 10 women (4.4%) were diagnosed with metabolic syndrome. Coffee and green tea consumption was weakly and positively correlated with age in women. Significant differences of coffee consumption between women with and without abdominal obesity, dyslipidemia and hypertension, tea consumption between men with and without dyslipidemia were noted after adjusting for age. However, there were no significant differences of other consumption between subjects with and without metabolic syndrome in both sexes. Among Japanese not taking medications, coffee, tea and green tea consumption was not clearly associated with metabolic syndrome in the Japanese population.

Keywords: Coffee Consumption; Metabolic Syndrome; Japanese

1. INTRODUCTION

Metabolic syndrome, characterized by abdominal obesity, has become public health challenge in Japan [1]. We previously reported that 30.7% of men and 3.6% of women were diagnosed as having metabolic syndrome [2]. Metabolic syndrome is closely linked to an increased risk for cardiovascular disease [3], proteinuria [4], the elevation of hepatic enzymes [5] and serum uric acid levels [6]. Therefore, the prevention and improvement of metabolic syndrome is urgently required.

Coffee, tea and green tea are common frequently consumed beverages. For example, 10.6 coffee cups per week are reported to be consumed [7] and about 50% of Japanese drinks coffee daily [8]. There some studies showed that habitual coffee consumption may improve insulin resistance and abdominal glucose metabolism [9-11]. However, the link between metabolic syndrome taking no medications and coffee, tea and green tea consumption in Japanese is still remains to be investigated.

In this study, we compared the coffee, tea and green tea consumption between Japanese with and without metabolic syndrome in a cross-sectional study.

2. SUBJECTS AND METHODS

2.1. Subjects

We used the data for 150 men and 227 women, aged 22 - 74 years, who met the following criteria, 1) they had wanted to change their lifestyle *i.e.* diet and exercise habits, and had received annual health checkups from April 2006 to December 2010 at Okayama Southern Institute of Health, Okayama Health Foundation, Japan, 2) they had received anthropometric measurements, fasting blood examination, and evaluation of coffee, tea and green tea consumption, 3) they had revived taking no medications such as diabetes, dyslipidemia, hypertension, infectious and/or neoplastic conditions, and 4) they had obtained written informed consent (**Table 1**).

The study was approved by the Ethics Committee of Okayama Health Foundation.

2.2. Anthropometric and Body Composition Measurements

The anthropometric parameters were evaluated by using

Table 1. Clinical profiles of enrolled subjects.

	Men			Women		
	Mean ± SD	Minimum	Maximum	Mean ± SD	Minimum	Maximum
Number of subjects	150			227		
Age	47.0 ± 12.3	22	74	43.5 ± 14.8	22	74
Height (cm)	170.6 ± 5.3	156.5	184.2	157.2 ± 4.9	143.1	171.5
Body weight (kg)	72.8 ± 11.2	50.0	125.5	55.9 ± 8.6	29.3	88.1
Body mass index (kg/m^2)	25.0 ± 3.5	15.9	38.4	22.6 ± 3.2	14.3	32.9
Abdominal circumference (cm)	87.0 ± 9.6	67.0	123.5	78.4 ± 9.5	58.5	111.1
Hip circumference (cm)	96.0 ± 6.5	81.0	125.5	92.8 ± 6.1	70.0	118.0
Systolic blood pressure (mmHg)	128.7 ± 12.7	94.0	183.0	116.9 ± 15.6	86.0	182.0
Diastolic blood pressure (mmHg)	78.6 ± 10.0	56.0	105.0	68.0 ± 10.2	46.0	106.0
Triglyceride (mg/dl)	137.5 ± 93.0	24.0	670.0	87.6 ± 52.3	28.0	354.0
HDL cholesterol (mg/dl)	57.2 ± 14.8	32.0	111.0	70.5 ± 16.4	22.0	144.0
Blood glucose (mg/dl)	98.0 ± 12.9	67.0	164.0	91.8 ± 10.9	68.0	159.0
Coffee consumption (cup/week)	10.1 ± 9.1	0	40	8.6 ± 9.0	0	50
Tea consumption (cup/week)	1.5 ± 4.1	0	30	2.1 ± 2.9	0	15
Green tea consumption (cup/week)	6.3 ± 6.6	0	40	7.4 ± 8.6	0	70
Number of subjects with exercise habits	49 (32.7%)			43 (18.9%)		
Number of subjects with smoking habits	43 (28.7%)			14 (6.2%)		

the following respective parameters such as height, body weight, body mass index (BMI), abdominal circumference, and hip circumference. BMI was calculated by weight/[height]^2 (kg/m^2). The abdominal circumference was measured at the umbilical level and the hip was measured at the widest circumference over the trochanter in standing subjects after normal expiration [1].

2.3. Blood Pressure Measurements

Each participant's blood pressure was measured after resting at least 15 minutes in the sitting position.

2.4. Blood Sampling and Assays

High-density lipoprotein (HDL) cholesterol, triglycerides (L Type Wako Triglyceride·H, Wako Chemical, Osaka, Japan) and blood glucose (hexokinase method) were measured at the Okayama Southern Institute of Health, Okayama Health Foundation. The accuracy of the measurements was maintained during the study period.

2.5. Definition of Metabolic Syndrome

The syndrome was defined [1], among men with an abdominal circumference in excess of 85 cm and women with an abdominal circumference in excess of 90 cm [12], as having two or more of the following components: 1) dyslipidemia: triglyceride ≥ 150 mg/dl and/or HDL cholesterol < 40 mg/dl; 2) hypertension: blood pressure ≥ 130/85 mmHg; 3) Impaired glucose tolerance: fasting blood glucose ≥ 110 mg/dl.

2.6. Coffee, Tea and Green Tea Consumption

Subjects were asked how many cups of coffee, tea and green tea per week. The way of drinking was not asked.

2.7. Exercise Habits

The data on exercise habits were obtained at interviews conducted by well-trained staff using the structured method of the National Nutrition Survey in Japan. The subjects were asked if they currently exercise (over 30 min per session, 2 times per week for duration of 3 months). When the answer was "yes", they were classified as subjects with exercise habits. When the answer was "no", they were classified as subjects without exercise habits.

2.8. Smoking Habits

The data on cigarette smoking was obtained at interviews by well-trained staff in a structured way. The subjects were asked if they currently smoked cigarettes. When the answer was "yes", they were classified as current smokers. When the answer was "no", they were classified as non-smokers.

2.9. Statistical Analysis

Data are expressed as means ± standard deviation (SD) values. It is well known that the difference of prevalence of men and women in Japanese [2]. Therefore, we analyzed separately in men and women. A comparison of parameters between the two groups was made using the unpaired *t*-test, covariance analysis and logistic regression analysis. Simple correlation analysis was performed as well to test for the significance of the linear relationship among continuous variables: $p < 0.05$ was considered statistically significant.

3. RESULTS

Clinical profiles are summarized in **Table 1**. The mean coffee consumption was 10.1 ± 9.1 cups/week/person in men and 8.6 ± 9.6 cups/week/person in women. The mean tea consumption was 1.5 ± 4.1 cups/week/person in men and 2.1 ± 2.9 cups/week/person in women. The mean green tea consumption was 6.3 ± 6.6 cups/week/person in men and 7.4 ± 8.6 cups/week/person in women, respectively.

We evaluated the relationship between coffee, tea and green tea consumption and age (**Table 2**). Coffee consumption was weakly and positively correlated with age in both sexes. Green tea consumption in women was also weakly and positively correlated with age.

A total of 34 men (22.7%) and 10 women (4.4%) were diagnosed with metabolic syndrome in subjects without medications. In subjects not taking medications, we compared coffee, tea and green tea consumption between the groups with and without each component of the Japanese definition of metabolic syndrome (**Table 3**). To avoid the influence of age, we used age as a covariate and compared coffee, tea and green tea consumption between Japanese with and those without metabolic syndrome components using covariance analysis. Tea consumption in men with dyslipidemia and coffee consumption in women with abdominal obesity and hypertension were significantly higher than those in subjects without, even after adjusting for age. Coffee consumption in women with dyslipidemia was significantly lower than that in subjects without dyslipidemia.

Finally, we evaluated the coffee, tea and green tea consumptions with and without metabolic syndrome using logistic regression analysis. There was significant difference of green tea consumption between men with and without metabolic syndrome after adjusting for age, exercise habits, smoking habits and coffee, tea consumptions. There were also significant differences of coffee, and green tea consumptions between women with and without metabolic syndrome after various parameters (**Table 4**).

Table 2. Relationship between coffee, tea and green tea consumption and age.

	r	*p*
Men		
Coffee consumption (cup/week)	0.169	**0.0392**
Tea consumption (cup/week)	−0.025	0.7613
Green tea consumption (cup/week)	0.146	0.0738
Women		
Coffee consumption (cup/week)	0.378	**<0.0001**
Tea consumption (cup/week)	0.045	0.5001
Green tea consumption (cup/week)	0.334	**<0.0001**

4. DISCUSSION

We firstly evaluated the link between metabolic syndrome using developed in Japan and coffee, tea and green tea consumption in Japanese without taking any medications. The clear differences of these consumptions were not noted between Japanese with and without metabolic components in this cross-sectional study.

Hino *et al.* reported that they examined the relationship between metabolic syndrome using Japanese criteria and the consumption of coffee or green tea in 1902 Japanese over 40. They concluded that coffee but not green tea consumption was inversely associated with metabolic syndrome [13]. In turn, Balk *et al.* showed in prospective study that coffee consumption was signifycantly associated with lower HDL cholesterol in women and coffee consumption was not associated with any of the components of the metabolic syndrome in men [14]. Driessen *et al.* also showed that coffee consumption was not associated with metabolic syndrome and its components in healthy samples in 174 men and 194 women followed up for 9 years [15]. Therefore, the link between coffee, tea and green tea consumption and metabolic syndrome was not clearly proved. In this study, we compared coffee, tea and green tea consumption between subjects with and without metabolic components. Significant differences of some consumption between subjects with and without metabolic syndrome components were noted after adjusting for age. In addition, there were also some significant differences of coffee and green tea consumption between subjects with and without metabolic syndrome after adjusting for various parameters. However, we could not also prove the clear link between metabolic syndrome and its components and coffee, tea and green tea consumption in Japanese without medications.

Potential limitations remain in this study. First, our study was a cross sectional and not a longitudinal study. Second, 150 men and 227 women, all of whom wanted to change their lifestyle, underwent measurements for this study: they were therefore more health-conscious than the average person. Third, we could not clarify the mechanism the link between metabolic syndrome and

Table 3. Comparison of coffee, tea and green tea consumption between subjects with and without metabolic components.

			p	*p* (After adjusting for age)
Men	Abdominal obesity (–)	Abdominal obesity (+)		
Number of subjects	63	87		
Age	45.0 ± 13.2	47.9 ± 11.6	0.1609	
Coffee consumption (cup/week)	10.7 ± 9.8	9.8 ± 8.5	0.5513	0.6662
Tea consumption (cup/week)	1.9 ± 5.3	1.1 ± 2.8	0.2351	0.5626
Green tea consumption (cup/week)	6.0 ± 6.0	6.5 ± 7.0	0.6713	0.2377
	Dyslipidemia (–)	Dyslipidemia (+)		
Number of subjects	98	52		
Age	45.8 ± 13.6	48.4 ± 9.5	0.2118	
Coffee consumption (cup/week)	8.9 ± 8.0	12.4 ± 10.5	**0.0244**	0.6096
Tea consumption (cup/week)	1.4 ± 3.7	1.6 ± 4.7	0.8535	**0.0238**
Green tea consumption (cup/week)	6.5 ± 6.9	5.8 ± 6.2	0.5203	0.6581
	Hypertension (–)	Hypertension (+)		
Number of subjects	80	70		
Age	45.7 ± 13.4	47.9 ± 11.0	0.2801	
Coffee consumption (cup/week)	9.7 ± 8.5	10.7 ± 9.7	0.4971	0.2058
Tea consumption (cup/week)	1.1 ± 2.7	1.9 ± 5.1	0.2620	0.9057
Green tea consumption (cup/week)	6.5 ± 6.0	6.1 ± 7.3	0.7292	0.1660
	Inpaired glucose tolerance (–)	Inpaired glucose tolerance (+)		
Number of subjects	131	19		
Age	46.0 ± 12.7	51.2 ± 8.8	0.0913	
Coffee consumption (cup/week)	10.2 ± 9.3	9.9 ± 7.1	0.9186	0.3668
Tea consumption (cup/week)	1.2 ± 3.4	3.1 ± 7.1	0.0602	0.0810
Green tea consumption (cup/week)	6.5 ± 6.8	5.1 ± 4.7	0.4069	0.8693
Women	Abdominal obesity (–)	Abdominal obesity (+)		
Number of subjects	198	29		
Age	42.6 ± 14.8	49.3 ± 13.7	**0.0243**	
Coffee consumption (cup/week)	8.5 ± 8.5	9.7 ± 11.8	0.4906	**0.0009**
Tea consumption (cup/week)	2.2 ± 3.0	1.9 ± 2.7	0.7013	0.4672
Green tea consumption (cup/week)	7.3 ± 7.7	8.0 ± 13.6	0.6877	0.5246
	Dyslipidemia (–)	Dyslipidemia (+)		
Number of subjects	199	28		
Age	43.0 ± 14.5	47.3 ± 16.9	**0.1449**	
Coffee consumption (cup/week)	8.6 ± 8.8	8.6 ± 10.6	0.9795	**0.0274**
Tea consumption (cup/week)	2.1 ± 2.9	2.1 ± 3.3	0.9686	0.2693
Green tea consumption (cup/week)	7.6 ± 8.9	6.0 ± 6.2	0.3611	0.8384
	Hypertension (–)	Hypertension (+)		
Number of subjects	185	42		
Age	40.6 ± 14.2	56.4 ± 10.1	**<0.0001**	
Coffee consumption (cup/week)	8.4 ± 9.1	9.7 ± 8.4	0.3902	**0.0163**
Tea consumption (cup/week)	2.2 ± 3.1	1.8 ± 2.2	0.4745	0.7635
Green tea consumption (cup/week)	7.3 ± 8.8	8.1 ± 7.7	0.5953	0.6948
	Inpaired glucose tolerance (–)	Inpaired glucose tolerance (+)		
Number of subjects	216	11		
Age	43.1 ± 14.6	50.9 ± 17.8	**0.0892**	
Coffee consumption (cup/week)	8.6 ± 9.0	9.1 ± 9.7	0.8568	0.8598
Tea consumption (cup/week)	2.2 ± 3.0	1.5 ± 2.2	0.4386	0.6263
Green tea consumption (cup/week)	7.4 ± 8.6	8.5 ± 8.5	0.6614	0.5721