trials vs. cross-sectional studies likely contribute to the different PA recommendations, the use of different methods to measure PA may also play a role in these differences.

Physical activity-induced EE (PAEE) can be classified into two components: exercise-induced EE and non-exercise activity thermogenesis (NEAT) [9]. NEAT, a large component of daily PA, is the energy expended for everything that is not sleeping, eating, or sports-like exercise [10]. It includes the energy expended walking to work, performing yard work, undertaking agricultural tasks, and household activities such as typing, vacuuming, dishwashing, and fidgeting. Many of these activities can also be defined as non-locomotive activities. However, NEAT, especially NEAT due to non-locomotive activity, is difficult to measure under free-living conditions. In fact, only supervised exercise was counted towards PAEE in clinical trials that supported the WHO Global Recommendations for body weight management [4-6]. In contrast, in the IOM report, walking distance modeled for each activity level was estimated by a factorial approach to approximate TEE measured by the DLW method; any additional EE for achieving at the "active" level from the "sedentary" level was explained by brisk walking. We hypothesized that if non-locomotive activity was counted towards total PAEE, it could explain the discrepancy between the data used for the WHO Global Recommendations and that for the recommendations in the 2005 Dietary Guidelines for Americans. Moreover, this may also explain the discrepancy between walking equivalence as indicated in the IOM report and the average steps observed under free-living conditions. Therefore, the purpose of this study was to determine the contribution of locomotive activity to total PAEE based on the relationship between total step counts and PAL under free-living conditions and using a human calorimeter. This study results should also indicate a role of non-locomotive activity to increase PAL in a daily living.

Methods

Subjects

Subjects in the two protocols were recruited separately. The study protocols were approved by the Ethics Committee of the National Institute of Health & Nutrition, and signed informed consent was obtained from all subjects. Protocol 1: 11 adult men participated in a human calorimeter study. Age, height, weight, and body mass index (BMI) for subjects in Protocol 1 were 24.7 ± 5.8 year (mean, SD), 168.1 ± 3.9 cm, 64.5 ± 7.9 kg, and 22.8 ± 2.8 kg/m^2, respectively. Protocol 2: Subjects were recruited through health care centers or at workplaces from various prefectures of the Kanto area (central Japan). 41 adults (12 males and 29 females) participated in a DLW study. Age, height, weight, and BMI for the subjects in Protocol 2 were 31.6 ± 9.1 year, 163.1 ± 8.9 cm, 57.8 ± 11.1 kg, and 21.6 ± 2.5 kg/m^2, respectively. They were college students, housewives, or desk workers. They did not report care for aging parents but three of them engaged in care for their children. All subjects were free of chronic diseases that could affect metabolism or daily physical activity.

Study concept

In Protocol 1 using a human calorimeter, each subject completed 24 h human calorimeter measurements under each of 3 different conditions. The concept of this study protocol was that subjects basically obtained PAEE from only prescribed locomotive activities since they were only permitted to carry out light activity in a sitting position during the rest of daytime. In Protocol 2 using DLW, subjects were measured total EE in a free-living condition. Obtained total EE should include PAEE induced by both of locomotive and non-locomotive activities. Thus, results from Protocol1 provide amount of locomotive activity for an active level of PAL if individuals extend PAEE from only locomotive activity. Furthermore, the gap of total step counts between Protocol 1 and 2 at same level of PAL may indicate the contribution of non-locomotive activity for maintaining an active level of PAL in daily-living condition.

Human calorimeter (study 1 protocol)

In Protocol 1 using a human calorimeter, body weight and height were measured while subjects were in a fasting state. Each subject completed 24 h human calorimeter measurements under each of 3 different conditions: a low-activity day (L-day) targeted at a low active level of PAL (1.45), and a high-frequency moderate activity day (M-day) or a high-frequency vigorous activity day (V-day) targeted at an active level of PAL (1.75). The subjects went to bed at 2400 and were gently awakened at 0700 (7 h). After getting up, subjects were permitted to use the toilet and were required to return to bed immediately. Then, the subjects remained in a supine position without movement until 0800. Basal metabolic rate (BMR) was determined as the mean metabolic rate between 0715 and 0800. Coefficient of variation (CV) for BMR over 3 days was 1.7% as previously reported [11]. Prescribed physical activity in L-day consisted of 30 min of walking at 3.2 km/h, 30 min of walking at 5.6 km/h, and 15 min of jogging at 8.0 km/h. On the basis of the L-day, we modeled M-day and V-day targeted at 1.75 of PAL with additional walking or jogging time (Table 1). Except for prescribed activity including BMR measurement and eating, and use of the toilet, the subjects were only permitted to carry out light activity in a sitting position, such as

Table 1 Amount of prescribed physical activity during 24-h calorimeter stays in Protocol 1 [a]

	L-day	M-day	V-day
Normal walking (3.2 km/h)	30 min × 1	30 min × 1	30 min × 1
Brisk walking (5.6 km/h)	30 min × 1	30 min × 1	30 min × 1
		15 min × 11	15 min × 4
Jogging (8.0 km/h)	15 min × 1	15 min × 1	15 min × 4
Total	75 min	240 min	180 min

[a]L-day: low activity day, M-day: a day with high-frequency moderate physical activity, V-day: a day with high-frequency vigorous physical activity

reading, writing, and viewing television. Sleeping was not permitted during daytime. The order of the days was randomly determined for each subject. The experimental protocol was previously described in detail elsewhere [11].

An open-circuit indirect human calorimeter was used to measure 24-h EE and BMR [12,13]. Briefly, the respiratory chamber was an airtight room (20,000 L) equipped with a bed, desk, chair, TV with video deck, CD player, telephone, toilet, sink, and treadmill. The temperature and relative humidity in the room were controlled at 25°C and 55%, respectively. The oxygen and carbon dioxide concentrations of the air supply and exhaust were measured by mass spectrometry. For each experiment, the gas analyzer (ARCO-1000A-CH, Arco System, Kashiwa, Japan) was initially calibrated using a certified gas mixture and atmospheric air. The flow rate exhausted from the calorimeter was measured by pneumotachography (FLB1; Arco System, Kashiwa, Japan). The flow meter was calibrated before each measurement, and the flow rate was maintained at 90 L/min (ATP). *V˙* O2 and carbon dioxide production (*V˙* CO2) were determined by the flow rate of exhaust from the chamber, and the concentrations of the inlet and outlet air of the chamber, respectively [12]. EE was estimated from *V˙* O2 and *V˙* CO2 using Weir's equation [14]. The accuracy and precision of our human calorimeter for measurement of EE as determined by the alcohol combustion test was 99.8 ± 0.5% over 6 h and 99.4 ± 3.1% over 30 min. The subjects entered the chamber at 1750 and stayed until 1805 the next day. Sampling data were collected between 1800 and 1800 (24 h).

Doubly-labeled water method (study 2 protocol)

Urine samples were collected early in the morning on the first study day at the study site, and body height and weight were also measured at that time. Then, a single dose of approximately 0.06 g/kg body weight of ^2H_2O (99.8 atom%, Cambridge Isotope Laboratories, MA, USA) and 1.4 g/kg body weight of $H_2{}^{18}O$ (10.0 atom%, Taiyo Nippon Sanso, Tokyo, Japan) was administered orally to each subject. After isotope administration, participants were asked to collect urine samples on day 1 (the next day after the DLW dose) and on other 7 additional days (days 2, 3, 7, 8, 13, 14, and 15) during the study period at the same time of day in their home. On the last day, body weight was measured in the fasting state. Over the entire study days, the subjects were instructed to maintain their normal daily activities and eating patterns,

Gas samples for isotope ratio mass spectrometry (IRMS) were prepared by equilibration of urine samples with a gas. The gas used for equilibration of ^{18}O was CO_2, and H_2 was used to equilibrate ^2H. A Pt catalyst was used for equilibration of ^2H. Urine was analyzed by IRMS using a DELTA Plus spectrometer (Thermo Electron Corporation, Bremen, Germany). ^2H and ^{18}O zero-time intercepts and elimination rates (k_H and k_O) were calculated using least-squares linear regression on the natural logarithm of the isotope concentration as a function of the time elapsed since dose administration. The zero-time intercepts were used to determine the isotope pool sizes. The TEE (kcal/day) calculation was performed using a modification of Weir's formula [14] based on the CO_2 production rate (rCO_2) and respiratory quotient (RQ). rCO_2 was calculated as follows: $rCO_2 = 0.4554 \times TBW \times (1.007ko\text{-}1.041k_H)$. The ratios of ^{18}O and ^2H dilution spaces were 1.030 ± 0.013 (Range; 1.001-1.056) and the coefficient of determination (R^2) for multi-point regression equations was ≥ 0.99 for both ^{18}O and ^2H. These values were within recommended ranges by the International Atomic Energy Agency [15]. Food quotient (FQ) calculated by the equation of Black et al. was used instead of RQ [16]. The dietary survey for calculating FQ was conducted using a self-administered diet history questionnaire (DHQ) [17,18] which was reported on the validity of energy intakes [19]. In the present study, estimated average of FQ values were adopted in the groups of college students (FQ: 0.864), housewives (FQ: 0.872) and others (FQ: 0.880), respectively. This assumes that under conditions of perfect nutrient balance the FQ must equal the RQ [16,20].

Basal metabolic rate and physical activity level

In Protocol 1, BMR was measured during human calorimeter stays, as further described in the "Human calorimeter" section. In Protocol 2, BMR was measured in the supine position in the early morning, 12 h or longer after the last meal, on the morning of the first or second visit to the study sites. The measurement was performed using a Douglas bag for 10 min × 2 with a 1 min break between measurements. After expired air was sampled, the O_2 and CO_2 concentrations were measured using a mass spectrometer (ARCO-1000, Arco System, Kashiwa, Japan) and the volume of expired air was measured with a certified dry gas meter (DC-5, Shinagawa, Tokyo, Japan). BMR was estimated from O_2 consumption and CO_2 production using Weir's equation [14]. CV for BMR over 3 days was 2.2% in this protocol. PAL was estimated by dividing TEE by BMR in both protocols.

Anthropometry

A digital scale was used to measure body weight to the nearest 0.1 kg while subjects were dressed in light clothing. Barefoot standing height was measured to the nearest 0.1 cm using a wall-mounted stadiometer. Body mass index was calculated as body weight (kg) divided by height squared (m^2).

Step counts and physical activity energy expenditure

Step counts were measured using a uniaxial accelerometer (Lifecorder or Lifecorder EX, Suzuken Co. Ltd., Nagoya, Japan) in both protocols. Based on the previous study [21], PAEE in light, moderate, or vigorous intensity was also calculated in the DLW study. This accelerometer has been widely used in many countries due to its reasonable cost and reliable validity which could estimate EE for locomotive activity accurately [21-23]. The accelerometer was attached to the left side of the waist at the midline of the left thigh.

Statistical analysis

All values are presented as means ± SDs. Differences were considered to be statistically significant if the *P* value was less than 0.05. In Protocol 1, the 24-h EE, BMR, PAL, and step count values obtained from the 3 conditions were compared by one-way analysis of variance with repeated measurements, and significant differences were analyzed using Scheffé's post-hoc test. In Protocol 2, correlations between step counts per day and PAL were assessed using Pearson's correlation coefficients (*r*). All statistical analyses were performed using SPSS version 14.0 J for WINDOWS (SPSS Inc, Chicago, IL).

Results

The results of Protocol 1 using a human calorimeter are shown in Table 2. There was no significant difference between BMRs on the L-day, M-day, or V-day. PALs on the M-day and V-day were significantly higher than on the L-day. According to the system of PAL categorization described in the IOM report [8], mean PAL values on the M-day and V-day would be classified as "active" and mean PAL on the L-day would be classified as "low activity". Figure 1 shows how many steps subjects would need to walk or jog throughout a day under controlled laboratory settings to increase PAEE from the "low activity" level to the "active" level. An additional 14,782 ± 650 steps/d corresponded to increase 0.32 ± 0.12 of PAL value calculated by subtracting L-day activity from V-day activity and an additional 20,615 ± 741 steps/d corresponded to a difference of 0.40 ± 0.13 PAL value between M-day and L-day activity.

Results from Protocol 2 using the DLW method are shown in Figure 2. Mean steps/d and PAL under free-living conditions were 10,022 ± 2,605 and 1.73 ± 0.15, respectively, among all subjects. The ranges of steps/d and PAL were 5,092-13,619 and 1.57-1.97, respectively, in male subjects (n = 12) and 5,288-15,242 and 1.41-2.00, respectively, in female subjects (n = 29). No

Table 2 Energy expenditure, physical activity levels, and step counts during 24-h calorimeter stays in Protocol 1 [a]

	L-day	M-day	V-day
24-h EE (kcal/day)	2228 ± 143	2816 ± 197[c]	2813 ± 163[c]
BMR (kcal/day)	1577 ± 129	1553 ± 114	1627 ± 157
Physical activity level [b]	1.42 ± 0.10	1.82 ± 0.14[c]	1.74 ± 0.15[c]
Steps (counts/day)	8973 ± 543	29588 ± 1126[c]	23755 ± 1038[c d]

[a]Values are means ± SDs, L-day: low activity day, M-day: a day with high-frequency moderate physical activity, V-day: a day with high-frequency vigorous physical activity, 24-h EE: 24-hour total energy expenditure, BMR: basal metabolic rate

[b]Physical activity level was calculated as 24-h EE divided by BMR

[c]Significant differences compared with values for L-day in each variable (*P* < 0.05)

[d]Significant differences compared with values for M-day in each variable (*P* < 0.05)

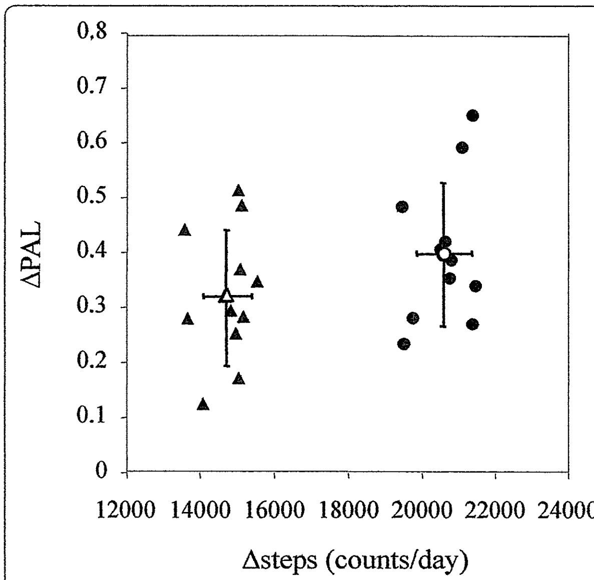

Figure 1 Relationships between delta PAL and delta step counts calculated as M-day or V-day minus L-day in Protocol 1 using a human calorimeter. Filled circles: values for a day with high-frequency moderate physical activity (M-day) minus values for a low active day (L-day), Filled triangles: values for a day with high-frequency vigorous physical activity (V-day) minus values for an L-day. Open circles or triangles and black lines are means ± SDs.

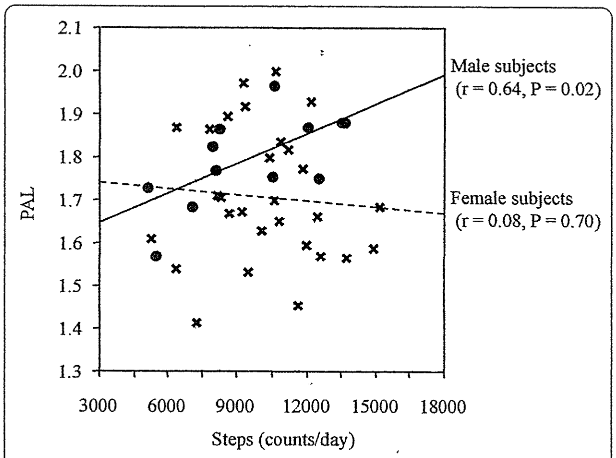

Figure 2 Relationships between physical activity level (PAL) and step counts per day under free-living conditions in Protocol 2 using doubly labeled water. Filled circles: male subjects, Crosses: female subjects.

significant relationship was observed between steps/d and PAL among all subjects (r = 0.06, P = 0.70) or in female subjects (r = 0.08, P = 0.70) although there was a significant relationship between these variables among male subjects (r = 0.64, P = 0.02). Furthermore, there was no significant relationship between PAEE in light, moderate, or vigorous intensity and PAL in either sex. Note that the step/d and PAL values in Protocol 2 are not necessarily representative values for healthy Japanese adults.

Discussion

To clarify how much locomotive activity is needed for an active physical activity level, we examined the relationship between total step counts and PAL both under free-living conditions and in a human calorimeter. In the human calorimeter study, more than an additional 10,000 steps were needed to increase PAL from the "low activity" level (1.4-1.59 of PAL) to the "active" level (1.6-1.89 of PAL) as defined in an IOM report if PAEE was primarily due to walking or jogging (Table 3). On the other hand, in DLW study, average PAL and step counts under free-living conditions were 1.73 ± 0.15 and 10,022 ± 2,605 steps/d in 41 healthy adults. Thus, the gap of total step counts between these two study protocols was large even at a similar level of PAL. These results deduce that both of locomotive activity as well as non-locomotive activity such as typing, vacuuming, and dish-washing may be significant contributor to total PAEE in daily life.

Even in human calorimeter studies, it is difficult to determine the relationship between PAEE from walking or jogging and step counts throughout a 24-hour protocol since subjects are typically permitted to engage *ad libitum* in light physical activity in addition to the prescribed exercises. de Jonge et al. [24] examined how much treadmill time is required to achieve 1.4 or 1.8 level of PAL in total 24-hour EE. The goal of that study was to develop a method for predicting an individual's 24-hour EE in a human calorimeter at these levels of PA. Average treadmill walking time was 177 ± 22 min on high-activity days (PAL: 1.78 ± 0.03) and 39 ± 9 min on low-activity days (PAL: 1.37 ± 0.02). These results indicate that 140 min of walking roughly corresponds to increase 0.40 of PAL. Note that subjects in that study conducted treadmill walking at 4.8 km per hour and at a 3% incline, and step counts were not reported in that study [24]. Subjects in the present study conducted all of their walking or jogging on a flat surface. Surprisingly, more than 120 min of extra walking time is needed to increase PAL from the "low activity" level to the "active" level, even if this PA consisted of combined

Table 3 Physical activity level (PAL) categories and walking equivalence in the IOM report

PAL Category	PAL Range	PAL	Walking Equivalence (km per day at 4.8-6.4 km per hour) [a]		
			Lightweight Individuals (44 kg)	Medium-Weight Individuals (70 kg)	Heavy Individuals (120 kg)
Sedentary	1.0-1.39	1.25	0	0 (0 min)	0
Low activity	1.4-1.59				
Mean		1.5	4.6	3.5 (35 min)	2.4
Active	1.6-1.89				
Minimum		1.6	9.3	7.0	4.8
Mean		1.75	15.8	11.7 (125 min)	8.5
Very active	1.9-2.49				
Minimum		1.9	22.4	16.5	12.0
Mean		2.2	36.0	26.7 (285 min)	19.7
Maximum		2.	49.6	36.8	27.2

[a]In addition to energy spent for general activities in normal daily life

This table was modified from the table cited on page 161, chapter 5 in the 2005 Institute of Medicine (IOM) report brisk walking (5.6 km/h) and jogging (8.0 km/h) or walking at 4.8 km/h at a 3% incline. Furthermore, if we express PA in terms of step counts based on data from the present study, approximately 24,000 steps correspond to average 1.74 of PAL on a high-frequency vigorous-activity day and approximately 30,000 steps correspond to average 1.82 of PAL on a high-frequency moderate-activity day. The results of our DLW study found a maximum step count per day of approximately 15,000 steps, but the maximum PAL value was 2.00, classified as "very active" in the IOM report. Westerterp et al. [25] reported that the proportion of PAEE induced by standing, standing-active, and cycling was relatively large in 24-hour EE if subjects spent a normal day at 1.75 of PAL. Another study by Johannsen et al. [26] examined differences in posture allocation in daily living between lean and obese women using the Intelligent Device for Energy Expenditure and Activity (IDEEA) (MiniSun LLC, Fresno, CA), which analyzes the type, onset, duration and intensity of fundamental movements such as lying, sitting, standing, and locomotion. This study found that obese women spent significantly less time standing than lean women (163 ± 58 vs. 284 ± 134 min/day), although there was no significant difference in locomotive time between the two groups (lean: 60 ± 29 min/day, obese: 48 ± 16 min/day). Activities classified in the "standing" category included all non-locomotive activity. Thus, we can speculate that some people expend a large part of their PAEE due to non-locomotive activity.

A few previous studies have analyzed the relationship between step counts per day and PAL as measured by DLW under free-living conditions [27,28]. Fogelholm et al. [27] compared four different field measures of average daily EE with criterion data obtained by the DLW method in 20 overweight premenopausal women. In that study, the field measures (24-h activity measured by an accelerometer, reported vigorous activity, monitored vigorous activity as determined by heart rate, and daily steps) did not show a significant relationship with TEE adjusted for resting metabolic rate ($r = -0.07-0.26$; $P > 0.20$). In contrast, Colbert et al. [28] reported that in 56 older adults, a significant relationship was observed between daily step counts and PAEE adjusted for body weight determined using DLW (Spearman correlation coefficient = 0.585, $P < 0.001$). In the present study, a significant relationship between steps/d and PAL was observed only in male subjects. Thus, we speculate that women expend more energy through non-locomotive activity. Therefore, significant variability may be seen in the relationship between step counts per day and PAL in female subjects. However, variability was also observed in male subjects. This variability is likely due to several factors, such as culture, occupation, place of residence, age, etc.

Physical activity recommendations for body weight maintenance as well as chronic disease prevention have proposed conducting more than moderate intensity of physical activity [1-3]. On the other hand, the increase of PAL is strongly associated with body weight maintenance [7]. Our study results showed that there was a not significant relationship between total step counts and PAL in female subjects and the number of total step counts was relatively small in some subjects even though their PAL levels were around 1.75. Thus, light activities such as household activity may also contribute to obtain PAEE to reach at the recommended level. The acceptance of light activity for counting into total PA amount in the recommendations gives individuals some options of PA performance.

The strength point of this study was the use of human calorimeter and DLW method to measure 24-h energy expenditure accurately. However, there were some limitations in the present study: PA intensity such as light, moderate, or vigorous intensity should be considered for clarifying relationships between PAL and amount of PA. Additionally, we could not directly measure non-locomotive activity under free-living conditions. These were due to technical limitations. Furthermore, Only 11 males and 29 females participated in the DLW study, thus, future studies using a larger number of subjects are needed to further investigate the relationship between step count or PA amount in each intensity and PAL in both sexes, and to determine what factors are related to this variability.

Conclusions

Our human calorimeter study showed that to increase PAEE from "low" to "active" levels through brisk walking, an additional 165 min of walking time at 5.6 km per hour (more than an additional 25,000 steps/d) was needed in subjects with a 65 kg body weight. These walking times and step counts were different from those determined under free-living conditions in our DLW study. These findings suggest that an enormous number of steps are needed for an active level of PAL if individuals extend physical activity-induced energy expenditure by only locomotive activity. Therefore, non-locomotive activity, a component of NEAT, may also play a significant role in increasing PAL under free-living conditions. Future studies are needed to clarify the contribution of non-locomotive activity to total PAEE using accurate measurement methods.

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Authors' contributions
KO, ST, and KI designed the study; KO, ST, KI, JP, and IT performed the experiments; KO, ST, and KI analyzed the data; KO, ST, and KI wrote a draft of the manuscript; JP and IT reviewed and edited the manuscript. All authors read and approved the final manuscript.

Competing interests
The authors declare that they have no competing interests.

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References

1. Pate RR, Pratt M, Blair SN, Haskell WL, Macera CA, Bouchard C, Buchner D, Ettinger W, Heath GW, King AC, *et al*: **Physical activity and public health. A recommendation from the Centers for Disease Control and Prevention and the American College of Sports Medicine.** *JAMA* 1995, 273:402-407.
2. World Health Organization: **Global recommendations on physical activity for health.** 2010.
3. Office of Disease Prevention & Health P, US Department of Health and Human Services: *2008 Physical Activity Guidelines for Americans* 2008.
4. Irwin ML, Yasui Y, Ulrich CM, Bowen D, Rudolph RE, Schwartz RS, Yukawa M, Aiello E, Potter JD, McTiernan A: **Effect of exercise on total and intra-abdominal body fat in postmenopausal women: a randomized controlled trial.** *JAMA* 2003, 289:323-330.
5. McTiernan A, Sorensen B, Irwin ML, Morgan A, Yasui Y, Rudolph RE, Surawicz C, Lampe JW, Lampe PD, Ayub K, Potter JD: **Exercise effect on weight and body fat in men and women.** *Obesity (Silver Spring)* 2007, 15:1496-1512.
6. Slentz CA, Aiken LB, Houmard JA, Bales CW, Johnson JL, Tanner CJ, Duscha BD, Kraus WE: **Inactivity, exercise, and visceral fat. STRRIDE: a randomized, controlled study of exercise intensity and amount.** *J Appl Physiol* 2005, 99:1613-1618.
7. United States Dept. of Health and Human Services: **United States. Dietary Guidelines Advisory Committee: Dietary guidelines for Americans 2005.** 2005.
8. Institute of Medicine: **Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty, Acids, Cholesterol, Protein and Amino Acids.** Washington, D.C.: The National Academies Press; 2005.
9. Levine JA, Eberhardt NL, Jensen MD: **Role of nonexercise activity thermogenesis in resistance to fat gain in humans.** *Science* 1999, 283:212-214.
10. Levine JA: **Nonexercise activity thermogenesis (NEAT): environment and biology.** *Am J Physiol Endocrinol Metab* 2004, 286:E675-685.
11. Ohkawara K, Tanaka S, Ishikawa-Takata K, Tabata I: **Twenty-four-hour analysis of elevated energy expenditure after physical activity in a metabolic chamber: models of daily total energy expenditure.** *Am J Clin Nutr* 2008, 87:1268-1276.
12. Futami J, Tanaka S, Yamamura C, Oka J, Ishikawa-Takata K, Kashiwazaki H: **Measurement of energy expenditure by whole-body indirect human calorimeter–evaluation of validity and error factors.** *J Jpn Soc Nutr Food Sci* 2003, 56:229-236.
13. Yamamura C, Tanaka S, Futami J, Oka J, Ishikawa-Takata K, Kashiwazaki H: **Activity diary method for predicting energy expenditure as evaluated by a whole-body indirect human calorimeter.** *J Nutr Sci Vitaminol* 2003, 49:262-269.
14. Weir JB: **New methods for calculating metabolic rate with special reference to protein metabolism.** *J Physiol* 1949, 109:1-9.
15. Interneational Atomic Energy Agency: **Assessment of body composition and total energy expenditure in humans using stable isotope techniques.** 2009.
16. Black AE, Prentice AM, Coward WA: **Use of food quotients to predict respiratory quotients for the doubly-labelled water method of measuring energy expenditure.** *Hum Nutr Clin Nutr* 1986, 40:381-391.
17. Sasaki S, Yanagibori R, Amano K: **Self-administered diet history questionnaire developed for health education: a relative validation of the test-version by comparison with 3-day diet record in women.** *J Epidemiol* 1998, 8:203-215.
18. Sasaki S, Ushio F, Amano K, Morihara M, Todoriki O, Uehara Y, Toyooka E: **Serum biomarker-based validation of a self-administered diet history questionnaire for Japanese subjects.** *J Nutr Sci Vitaminol* 2000, 46:285-296.
19. Okubo H, Sasaki S, Rafamantanantsoa HH, Ishikawa-Takata K, Okazaki H, Tabata I: **Validation of self-reported energy intake by a self-administered diet history questionnaire using the doubly labeled water method in 140 Japanese adults.** *Eur J Clin Nutr* 2008, 62:1343-1350.
20. Jones PJ, Leitch CA: **Validation of doubly labeled water for measurement of caloric expenditure in collegiate swimmers.** *J Appl Physiol* 1993, 74:2909-2914.
21. Kumahara H, Schutz Y, Ayabe M, Yoshioka M, Yoshitake Y, Shindo M, Ishii K, Tanaka H: **The use of uniaxial accelerometry for the assessment of physical-activity-related energy expenditure: a validation study against whole-body indirect calorimetry.** *Br J Nutr* 2004, 91:235-243.
22. McClain JJ, Craig CL, Sisson SB, Tudor-Locke C: **Comparison of Lifecorder EX and ActiGraph accelerometers under free-living conditions.** *Appl Physiol Nutr Metab* 2007, 32:753-761.
23. Schneider PL, Crouter SE, Bassett DR: **Pedometer measures of free-living physical activity: comparison of 13 models.** *Med Sci Sports Exerc* 2004, 36:331-335.
24. de Jonge L, Nguyen T, Smith SR, Zachwieja JJ, Roy HJ, Bray GA: **Prediction of energy expenditure in a whole body indirect calorimeter at both low and high levels of physical activity.** *Int J Obes Relat Metab Disord* 2001, 25:929-934.
25. Westerterp KR: **Assessment of physical activity: a critical appraisal.** *Eur J Appl Physiol* 2009, 105:823-828.
26. Johannsen DL, Welk GJ, Sharp RL, Flakoll PJ: **Differences in daily energy expenditure in lean and obese women: the role of posture allocation.** *Obesity (Silver Spring)* 2008, 16:34-39.
27. Fogelholm M, Hiilloskorpi H, Laukkanen R, Oja P, Van Marken Lichtenbelt W, Westerterp K: **Assessment of energy expenditure in overweight women.** *Med Sci Sports Exerc* 1998, 30:1191-1197.
28. Colbert LH, Matthews CE, Havighurst TC, Kim K, Schoeller DA: **Comparative Validity of Physical Activity Measures in Older Adults.** *Med Sci Sports Exerc* 2010, 43:867-876.

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日本人の代謝基準値の再評価

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特集 エネルギー代謝と体温

日本人の代謝基準値の再評価

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日本では，古くから基礎代謝および活動時のエネルギー代謝に関する研究が行なわれ，それらを土台として，日本人の栄養所要量や食事摂取基準におけるエネルギーの必要量の基準値が策定されてきた．本稿では，まず，エネルギーの必要量の歴史についてふれた後，最近の見直しの中でヒューマンカロリメーターがどのように関与してきたかを述べる．

1．総エネルギー消費量の内訳

体重変化のない成人の場合，1日当たりの総エネルギー消費量（total energy expenditure：TEE）がそのまま，エネルギーの“必要量”（かつては，エネルギーについても“所要量”と呼ばれていた）となる．TEEは，一般に以下のように大別される．

TEE＝基礎代謝量（basal metabolic rate：BMR）＋食事誘発性体熱産生（diet-induced thermogenesis：DIT）＋身体活動量

他にも，場合によっては，寒冷刺激による熱産生，運動後の代謝亢進などが加わる．このうち，DITはTEEの約10%といわれており，その絶対量や個人間差は，BMRや身体活動量と比べて，相対的に小さい．そのため，「第五次改定日本人の栄養所要量」[1]までは，BMRと身体活動量を求め，それらの和を0.9で除すことによってTEEを推定し，それをエネルギー必要量の推定値としていた．

「第六次改定日本人の栄養所要量―食事摂取基準―」[2]以降は，

TEE＝BMR×身体活動レベル（physical activity level：PAL）

としており，DITは身体活動量とともにPALの中に含まれている．

このように，以前より現在に至るまで，“BMR”と“身体活動量”がTEE推定の二大要素である．ただし，それ以外の要素（DITや寒冷刺激による熱産生，運動後の代謝亢進など）についてどのように考えるかによって，TEEの推定法が異なってくる．

2．BMRの推定

1）基礎代謝基準値の確立

1919年にHarris-BenedictによるBMR推定式が公表され[3]，1920年，内務省に栄養研究所が設立された直後に，日本におけるBMRの測定がはじまったようである[4]．1941年には，主として栄養研究所で測定されたデータに基づいた日本人の基礎代謝の標準値を利用して，栄養研究所と公衆衛生院が合併してできた厚生科学研究所国民栄養部が「日本人栄養要求量標準」を報告している．その後，昭和34（1959）年の栄養所要量改定に

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おいて，戦前・戦後にわたって男女それぞれ900名程度を対象に測定された値をもとにして，大幅な見直しがされている．

しかし，昭和44（1969）年改定の栄養所要量でさらに本格的に見直しがなされ，そこで決められた基礎代謝基準値が，現在まで最も重要な位置を占めている．長崎大学の藤本らによる文部省総合研究「日本人発育期の基礎代謝研究」は，Benedictらの方法に準じて，測定条件を厳格に規定した[4,5]．それに従って，主に長崎大学，徳島大学および昭和医科大学で，約6,500人の測定を実施し，1951年から1966年の16年間において，約60の文献で結果が報告された．それをもとにして，性・年齢階級別基礎代謝基準値が設定された．

ちなみに，健常人に対して国際的に最も用いられているのは，Schofieldの式[6]やWHO/FAO/UNUの式[7]である．これらは1930～1950年頃に発表された世界各国からの114の文献（英文で発表された日本人の結果を含む）中の値から作成されており，対象者数は7,000人強であるが，軍人・警察官を中心としたイタリア人が半数近くを占めている．日本の基礎代謝基準値も，それに近い人数の日本人での測定に基づいており，対象者の偏りのなさや条件の均一性も考えると，国際的に優れたものであるといえる．

その後，昭和50（1975）年の改定で，それまで体表面積当たりで表されていた基礎代謝基準値（kcal/m²/時）が，体重当たり（kcal/kg/日）で表されるようになった．その算出方法は，

体表面積当たりの基礎代謝基準値×基準体位における体表面積÷基準体重×24

である．この方法は，その後も採用され続けた．第六次改定まで，少しずつ基礎代謝基準値の値が変わっていたのは，基準体位が毎回変更されるのに伴って，上記の換算がなされていたためである．

体重当たりの基礎代謝基準値に変わったことにより，計算は簡単になったものの，個人における推定誤差は大きくなってしまった．そこで，昭和50年改定では，「体重当たりの基準値からの推定では，体重が大きい者のBMRを過大評価，小さい者のBMRを過小評価する」という問題を指摘した上で，体重から算出される“加算値”を用いた補正法を提案した．

2）エネルギー代謝率（relative metabolic rate：R.M.R.）

R.M.R.は，労働科学の立場から，各種作業のエネルギー消費量，ひいては1日のエネルギー必要量を推定するために考えられた指標である[8]．作業環境における安静状態からのエネルギーの増加分をBMRで除することによって，体格等の影響を除いている．

R.M.R.＝（労作時のエネルギー消費量ー座位安静時代謝量）÷BMR

ここでの座位安静時代謝量は，労作強度を測定する前あるいは後に，同じ被験者について，その現場と同じ環境条件下で測定するものであるため，DITや環境温度などの影響も受ける．ただし，快適な温度環境であれば，BMRと比べ，およそ＋20％になっているものと考えられている[8,9]．

R.M.R.の測定は，さまざまな労働作業や日常生活活動，運動を対象として，主に1924年から1940年にかけて実施された．最終的に値の得られた活動の種類は，600を優に超えている．欧米では知られていないものの，国際的にみても，質・量とも優れたデータベースである．

座位安静時代謝量＝BMR×1.2

と仮定すれば，R.M.R.から

Activity factor（Af）＝当該活動のエネルギー消費量÷BMR

を算出し，要因加算法（生活時間調査）により，身体活動の強度が推定できる．これに，基礎代謝基準値から推定されたBMRを乗じ，食事による産熱効果を考慮してTEE，ひいてはエネルギー必要量を推定する方法が，第六次改定（1999年）まで続いた．

3）R.M.R.を利用したTEE推定の問題点

基礎代謝基準値およびエネルギー代謝率（R.

M.R.）は，かなり厳格な条件のもとで測定された莫大なデータベースに基づいている．しかし，これらを利用した要因加算法による推定には，記録の正確性に加え，DIT や Excess of Post-exercise Oxygen Consumption（EPOC）の推定，寒冷時における代謝亢進など，さまざまな誤差要因が伴うため，TEE 推定の妥当性については確信がもてない状態であった．実際，第五次改定（1994）までは，R.M.R. の中に DIT が含まれているにもかかわらず，BMR と身体活動量の和をさらに 0.9 で除していたため，実際には DIT が二重に計算されていた．TEE 推定時の仮定が多くなればなるほど，TEE の推定の正確さは保証しにくくなる．

3.「日本人の食事摂取基準（2005 年版）」以降

1）二重標識水（doubly labeled water：DLW）法

1980 年頃以降，日常生活におけるエネルギー消費量を最も正確かつ非侵襲的に評価できるとして，少しずつ利用されるようになってきたのは，DLW 法であった[10]．DLW 法とは，^{2}H と ^{18}O という 2 つの安定同位体を含む水（= DLW）を摂取し，それらの減少率の差から二酸化炭素産生量を推定する方法である[10,11]．一般に 2 週間程度にわたる比較的長期間のエネルギー消費量を得るのに，被験者は数回の採尿だけで済む．非常に高価で，分析も難しく機器が少ないが，1～2％程度の誤差が確認されているヒューマンカロリメーター法を基準として比較すると，約 5％程度の誤差と報告されている[10]．日本では，ヒューマンカロリメーターと同じく 2000 年に，国立健康・栄養研究所に分析システムが導入された．

2）身体活動レベル（PAL）

第六次改定から，エネルギーの必要量は，BMR に PAL の推定値を乗じることによって求めるようになった．しかし，それ以前に用いられていた生活活動強度の指数を PAL に換算することは可能である．それらを比較すると，第六次では，実質上 4 段階のうちの 1 段階ずつ引き下げられていた（表 1）．その理由は，十分に記述されているとはいえない．しかし，本文中の記述および，各活動における Af の値が，第五次改定までと比較して 0.2 ずつ小さくなっていることからすると，主に，「R.M.R. における座位安静時代謝量と BMR が等しい」と仮定してしまったことによるものと考えられる．その結果，DIT を二重に加えていた第五次までとは逆に，第六次では DIT がまったく考慮されていないことになる．さらに，座位と立位の差の 10％も無視されている．

「日本人の食事摂取基準（2005 年版）」[12] においては，（独）国立健康・栄養研究所が DLW 法を用いて全国 4 カ所で行なった，DLW 法としては比較的大規模な調査結果[13] に基づいて，PAL の値を決定した．その結果，PAL を 4 分類することは難しいため 3 分類にし，標準の値を第六次改定の 1.5 から 1.75 へと変更した（表 1）．

その後，日本を含め新たに得られた PAL のデータをより厳密に吟味した．その結果，「日本人の食事摂取基準（2010 年版）」[14] では，成人以外の多くの性・年齢階級で，PAL の値が若干変更され，表 2 のようになった．PAL の推定法は，現在でも大きな課題である[13,15~19]．

ちなみに，子どもの PAL については，成人とは逆に，2005 年版で値が大きくなっている．子どもにおける標準の PAL は，第六次改定で 1.7 と，活動的な成人と同じ値であった．少なくとも第六次改定で明確な根拠は示されていないが，「子どもの身体活動量は多い」という仮定があったことによるようである．2005 年版以降は，DLW 法に基づき，1 歳から成人に至るまで，年齢が上がるとともに PAL の値が大きくなるように設定されている．

一方，基礎代謝基準値についても，2010 年版において，1980 年代以降に報告された値から，測定から約 50 年が経過した現在でも通用するかどうかが検証された．その結果，18～29 歳の女性では，23.6kcal/kg/日から 22.1kcal/kg/日

表 1　最近の栄養所要量・食事摂取基準における生活活動強度・身体活動レベル（PAL）の比較

第五次改定		第六次改定		日本人の食事摂取基準（2005年版/2010年版）	
生活活動強度とPAL	日常生活の内容	生活活動強度とPAL	日常生活の内容	身体活動レベルとPAL	日常生活の内容
Ⅰ（軽い）1.50	通勤，買い物など1時間程度の歩行と軽い手作業や家事などによる立位のほかは，大部分座位で事務，勉強，談話等をしている場合	Ⅰ（低い）1.3	散歩，買い物など比較的ゆっくりした1時間程度の歩行のほか，大部分は座位での読書，勉強，談話，また座位や横になってのテレビ，音楽鑑賞などをしている場合	Ⅰ（低い）1.50（1.40〜1.60）	生活の大部分が座位で，静的な活動が中心の場合
Ⅱ（中等度）1.67	通勤，買い物のほか仕事などで2時間程度の歩行と事務，読書，談話による座位のほか，機械操作，接客，家事等による立位時間の多い場合	Ⅱ（やや低い）1.5	通勤，仕事などで2時間程度の歩行や乗車，接客，家事等立位での業務が比較的多いほか，大部分は座位での事務，談話などをしている場合	Ⅱ（普通）1.75（1.60〜1.90）	座位中心の仕事だが，職場内での移動や立位での作業・接客等，あるいは通勤・買物・家事，軽いスポーツ等のいずれかを含む場合．
Ⅲ（やや重い）1.94	農耕，漁業，建築などで座位，立位，歩行のほか，1日のうち1時間程度は重い筋作業に従事している場合	Ⅲ（適度）1.7	生活活動強度Ⅱの者が1日1時間程度は速歩やサイクリングなど比較的強い身体活動を行なっている場合や，大部分は立位での作業であるが1時間程度は農作業，漁業などのような強い作業に従事している場合	Ⅲ（高い）2.00（1.90〜2.20）	移動や立位の多い仕事への従事者．あるいは，スポーツなど余暇における活発な運動習慣をもっている場合
Ⅳ（重い）2.22	1日のうち2時間程度は激しいトレーニングや木材の運搬，農繁期の農耕作業などのような重い作業に従事している場合	Ⅳ（高い）1.9	1日のうち1時間程度は激しいトレーニングや木材の運搬，農繁期の農耕作業などのような強い作業に従事している場合		

第五次改定のPALは生活活動指数より換算．

表 2　日本人の食事摂取基準（2010年版）における身体活動レベル（男女共通）

身体活動レベル	レベルⅠ	レベルⅡ	レベルⅢ
1〜2　（歳）	−	1.35	−
3〜5　（歳）	−	1.45	−
6〜7　（歳）	1.35	1.55	1.75
8〜9　（歳）	1.40	1.60	1.80
10〜11（歳）	1.45	1.65	1.85
12〜14（歳）	1.45	1.65	1.85
15〜17（歳）	1.55	1.75	1.95
18〜29（歳）	1.50	1.75	2.00
30〜49（歳）	1.50	1.75	2.00
50〜69（歳）	1.50	1.75	2.00
70以上（歳）	1.45	1.70	1.95

へと引き下げられたものの，他の性・年齢階級については，そのままで問題ない，あるいは，変更するに足るだけの根拠がないと判断された（表3）．

4．食事摂取基準に対するヒューマンカロリメーターの貢献

1）PALの値の確認

国立健康・栄養研究所に国内ではじめてヒューマンカロリメーターが設置されたのは，2000年であった．先述のように，「第六次改定日本人の栄養所要量—食事摂取基準—」[2]で，PALの値，ひいては，ふつうに相当する成人のエネルギー必要量の値が引き下げられた直後のことである．そ

表3 日本人の食事摂取基準（2010年版）における基礎代謝量

年齢	女性			男性		
	基礎代謝基準値 (kcal/kg/日)	基準体重 (kg)	基礎代謝量 (kcal/日)	基礎代謝基準値 (kcal/kg/日)	基準体重 (kg)	基礎代謝量 (kcal/日)
1〜2 （歳）	59.7	11.0	660	61.0	11.7	710
3〜5 （歳）	52.2	16.2	850	54.8	16.2	890
6〜7 （歳）	41.9	22.0	920	44.3	22.0	980
8〜9 （歳）	38.3	27.2	1,040	40.8	27.5	1,120
10〜11（歳）	34.8	34.5	1,200	37.4	35.5	1,330
12〜14（歳）	29.6	46.0	1,360	31.0	48.0	1,490
15〜17（歳）	25.3	50.6	1,280	27.0	58.4	1,580
18〜29（歳）	22.1	50.6	1,120	24.0	63.0	1,510
30〜49（歳）	21.7	53.0	1,150	22.3	68.5	1,530
50〜69（歳）	20.7	53.6	1,110	21.5	65.0	1,400
70以上（歳）	20.7	49.0	1,010	21.5	59.7	1,280

こで，設置されたばかりのヒューマンカロリメーターで，DLW法と並行して測定を実施し，DLW法での結果が出る前に，第六次改定の値が妥当かどうか検討するのに利用された．その際，1時間の歩行や1時間の立位，15分の踏み台昇降を含む24時間の生活を再現した[20]．この生活内容は，生活活動強度Ⅰ（低い：PAL = 1.3）とほぼ対応すると考えられる（表1）．しかし，実際の測定値から求めたPALの平均値はおよそ1.5，運動がまったくない生活におけるPALを推定すると1.3台であった．これらのことから，第六次改定の生活活動強度に対応するPALの値は，ほぼ一段階ずれていると考えられた．これは，その後に出たDLW法の結果と整合性のあるものであり，第六次改定で最も下の生活活動強度に対応するPAL（1.3）は，室内生活に限定されない健常人の日常生活では得られにくい値と考えられた．また，第六次改定で標準と考えられていた1.5は，PALが小さい方から1/4の集団の代表値となり，「ふつう」の代表値は1.75となった[12]．

ただし，約1時間の自転車漕ぎと1時間の立位，踏み台昇降を含んでもPALは約1.5であるのに対し，日常生活の1.75に到達するまでには，およそ300kcal/日程度の身体活動が必要である．それが何かは，今もって明確になっているとは言い難い．

2）身体活動量推定法の妥当性

先に述べたように，生活活動記録に基づく要因加算法は，TEE，ひいてはエネルギー必要量の推定にとって最も活用されてきた方法である．しかし，身体活動量の評価や各種熱産生に関する仮定については不安が残る．そこで，要因加算法の妥当性について，ヒューマンカロリメーターで検討した[21]．その結果，Afあるいはメッツなどを用いた要因加算法で，推定値と実測値の平均値は一致すること，ただし，BMRの実測値を用いても±300kcal/日以上の誤差を生じることが明らかとなった．

食事摂取基準に直結するものではないが，当研究所では，加速度計を用いた身体活動量の推定法にもヒューマンカロリメーターを利用している[22]．その成果を土台にして，新たな加速度計による身体活動評価法の開発にもつながっている[23,24]．

3）睡眠時代謝量およびBMRの推定

かつて日本の栄養所要量では，睡眠時代謝量はBMRより10%低いとされていたが，これは短時間の計測によるものであった．一方，第六次改定

では，睡眠時代謝量はBMRと等しいと解釈されていた．しかし，日本人について，睡眠時間全体のエネルギー消費量を計測したデータはかつてなかった．その点について，当研究所のヒューマンカロリメーターで検討したところ，8時間の睡眠時間におけるエネルギー消費量（kcal/日）は，実測BMRの1.03 ± 0.08倍であった[20]．一方，Kumaharaら[25]は，ローザンヌ在住の日本人を対象に，0.95 ± 0.08倍という値を報告している．その後，Ganpuleら[26]も，8時間の睡眠時間全体および最小の3時間に分けて報告している（それぞれ，1.01 ± 0.09と0.94 ± 0.07）．報告によって値に若干の差がみられるのは，睡眠中のエネルギー消費量は変化するのに対し[27]，どの時間帯を利用して睡眠時代謝量を計算しているか（特に，相対的に値の大きい，就寝直後の値が含まれているかどうか）によるところが大きいと考えられる．

Ganpuleら[26]は，睡眠時代謝量およびBMRの個人間差が，これまで報告されているより小さいことを報告するとともに，それらの推定式も求めた．そのうちBMRの推定式については，2010年版[14]で，日本人におけるBMR推定式としてとりあげられ，その後，妥当性が優れていることを報告している[28]．

4）身体活動によるエネルギー代謝の亢進

運動習慣やこれといった身体活動がみられなくても，DLW法に基づくPALを求めると，1.8から2.0以上の高い値が得られることがしばしばある．その原因のひとつとして，日常生活においてそれほど高強度ではないものの頻繁に行なわれる身体活動によって，安静時代謝が高くなっている可能性を否定できないと考えた．実際，米国の食事摂取基準[29]では，ベースとなる最低限の身体活動（約30分の歩行や着替えなどの身の回りのこと）を想定し，それを上回る身体活動については，たとえ低強度でも，身体活動中のエネルギーに15%を付加してTEEに加算することとしている．そこで，15分/回×11回/日の速歩といった頻回の身体活動による，速歩の時間以外におけるエネルギー消費量の亢進について，ヒューマンカロリメーターで検討した[30]．その結果，速歩中心の場合でも，あるいはそれと同程度のエネルギーに相当するジョギングを中心に付加した場合でも，30kcal/日程度の亢進しかみられなかった．この値は，少なくともTEEの推定にとっては無視できる量である．そのため，「日本人の食事摂取基準（2010年版）」[14]では，米国の食事摂取基準のように身体活動による代謝亢進を加算することはしないこととなった．

5）その他

ヒューマンカロリメーターは，あくまで室内生活でのエネルギー代謝に限定され，日常生活とは異なる．一方で，エネルギー消費量測定の正確性に加え，何らかの要因（食事，運動，生活習慣…）がエネルギー代謝にどの程度寄与するか実験的に検討するには適している．TEE，ひいてはエネルギー必要量の変動要因を丁寧に検討するにあたっては，今後も有用なツールではないかと考えられる．

［文　献］

1）厚生省保健医療局健康増進栄養課監修：第五次改定日本人の栄養所要量．第一出版，1994.
2）健康栄養情報研究会編：第六次改定日本人の栄養所要量―食事摂取基準―．第一出版，1999.
3）Harris JA, et al.: A biometric study of basal metabolism in man. Carnegie Institute of Washington, 1919.
4）柏崎　浩：エネルギー所要量の歴史と現状．小林修平編著，栄養所要量・基準量と食生活ガイドライン，pp61―125，建帛社，1997.
5）山本茂ほか：日本人の基礎代謝資料の評価．栄養学雑誌，59：51―59，2001.
6）Schofield WN: Predicting basal metabolic rate, new standards and review of previous work. Hum Nutr Clin Nutr, 39C: 5―41, 1985.
7）FAO/WHO/UNU: Energy and protein requirements, report of a joint FAO/WHO/UNU expert consultation. Technical Report Series 724, WHO, 1985.
8）沼尻幸吉：活動のエネルギー代謝 増補第2版．労

働科学研究所出版部, 1979.

9) 田中茂穂：メッツと基礎代謝. 体育の科学, 59：657—663, 2009.

10) Speakman JR: The history and theory of the doubly labeled water technique. Am J Clin Nutr, 68: 932S—938S, 1998.

11) 髙田和子：二重標識水法を用いたエネルギー摂取量評価への応用. 臨床スポーツ医学, 26：1097—1102, 2009.

12) 厚生労働省：日本人の食事摂取基準（2005年版）. 2004.

13) Ishikawa-Takata K, et al.: Physical activity level in healthy free-living Japanese estimated by doubly-labelled water method and International Physical Activity Questionnaire. Eur J Clin Nutr, 62: 885—891, 2008.

14) 厚生労働省：日本人の食事摂取基準（2010年版）. 2009.

15) 海老根直之ほか：二重標識水法を用いた簡易エネルギー消費量推定法の評価—生活時間調査法, 心拍数法, 加速度計法について—. 体力科学, 51：151—163, 2002.

16) Rafamantanantsoa HH, et al.: Validation of three alternative methods to measure total energy expenditure against the doubly labeled water method for older Japanese men. J Nutr Sci Vitaminol, 48: 517—523, 2002.

17) 彭雪英ほか：中年女性における簡易エネルギー消費量推定法の検討—二重標識水法との比較—. 肥満研究, 10：163—172, 2004.

18) Yamada Y, et al.: Light-intensity activities are important for estimating physical activity energy expenditure using uniaxial and triaxial accelerometers. Eur J Appl Physiol, 105: 141—152, 2009.

19) Ishikawa-Takata K, et al.: Use of doubly labeled water to validate a physical activity questionnaire developed for the Japanese population. J Epidemiol, 21: 114—121, 2011.

20) 田中茂穂ほか：ヒューマンカロリメーターを用いて測定した座位中心の生活における１日あたりのエネルギー消費量. 日本栄養・食糧学会誌, 56：291—296, 2003.

21) Yamamura C, et al.: Activity diary method for predicting energy expenditure as evaluated by a whole-body indirect human calorimeter. J Nutr Sci Vitaminol, 49: 262—269, 2003.

22) Midorikawa T, et al.: Evaluation of low-intensity physical activity by triaxial accelerometry. Obesity, 15: 3031—3038, 2007.

23) Oshima Y, et al.: Classifying household and locomotive activities using a triaxial accelerometer. Gait Posture, 31: 370—374, 2010.

24) Ohkawara K, et al.: Real-time estimation of daily physical activity intensity by triaxial accelerometer and a gravity-removal classification algorithm. Br J Nutr, 105: 1681—1691, 2011.

25) Kumahara H, et al.: The difference between the basal metabolic rate and the sleeping metabolic rate in Japanese. J Nutr Sci Vitaminol, 50: 441—445, 2004.

26) Ganpule AA, et al.: Interindividual variability in sleeping metabolic rate in Japanese subjects. Eur J Clin Nutr, 61: 1256—1261, 2007.

27) Katayose Y, et al.: Metabolic rate and fuel utilization during sleep assessed by whole body indirect calorimetry. Metabolism, 38: 920—926, 2009.

28) Miyake R, et al.: Validity of predictive equations for basal metabolic rate in Japanese adults. J Nutr Sci Vitaminol, 57: 224—232, 2011.

29) Food and Nutrition Board, Institute of Medicine: Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids. pp107—264, National Academies Press, 2005.

30) Ohkawara K, et al.: Twenty-four-hour analysis of elevated energy expenditure after physical activity in a metabolic chamber: models of daily total energy expenditure. Am J Clin Nutr, 87: 1268—1276, 2008.

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Original Article

Television Viewing Time is Associated with Overweight/Obesity Among Older Adults, Independent of Meeting Physical Activity and Health Guidelines

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ABSTRACT

Background: Previous studies have shown associations of sedentary behavior with cardiovascular risk, independent of moderate-to-vigorous physical activity (MVPA). However, few studies have focused on older adults. This study examined the joint associations of television (TV) viewing time and MVPA with overweight/obesity among Japanese older adults.
Methods: A population-based, cross-sectional mail survey was used to collect self-reported height, weight, time spent in TV viewing, and MVPA from 1806 older adults (age: 65–74 years, men: 51.1%). Participants were classified into 4 categories according to TV viewing time (dichotomized into high and low around the median) and MVPA level (dichotomized into sufficient and insufficient by the physical activity guideline level of ≥150 minutes/week). Odds ratios (ORs) for overweight/obesity (body mass index ≥25 kg/m^2) were calculated according to the 4 TV/MVPA categories, adjusting for potential confounders.
Results: Of all participants, 20.1% were overweight/obese. The median TV viewing time (25th, 75th percentile) was 840 (420, 1400) minutes/week. As compared with the reference category (high TV/insufficient MVPA), the adjusted ORs (95% CI) of overweight/obesity were 0.93 (0.65, 1.34) for high TV/sufficient MVPA, 0.58 (0.37, 0.90) for low TV/insufficient MVPA, and 0.67 (0.47, 0.97) for low TV/sufficient MVPA.
Conclusions: In this sample of older adults, spending less time watching TV, a predominant sedentary behavior, was associated with lower risk of being overweight or obese, independent of meeting physical activity guidelines. Further studies using prospective and/or intervention designs are warranted to confirm the presently observed effects of sedentary behavior, independent of physical activity, on the health of older adults.

Key words: sedentary behavior; cardiovascular risk factor; obesity

INTRODUCTION

Sedentary behavior (too much sitting, as distinct from too little exercise) is related to adverse cardiometabolic risk profiles and premature mortality.[1–10] Several studies have examined television (TV) viewing time as a predominant sedentary behavior and have shown associations with obesity and other cardiovascular risk factors.[1–3,7,8,10] Furthermore, these associations between sedentary behaviors and cardiovascular risk factors were observed regardless at all levels of moderate-to-vigorous physical activity (MVPA), defined by an intensity of 3 metabolic equivalents (METs) or greater. Sugiyama et al[4] reported that adults who met current physical activity guidelines (MVPA of ≥30 min/day for 5 days/week)[11,12] but had high levels of sedentary time were about 1.5 times more likely to be overweight or obese, relative to those who met physical activity guidelines and had lower levels of sedentary time. These findings suggest that prolonged sedentary behavior elevates health risk, independent of MVPA participation.

However, few studies of the associations of sedentary behavior and physical activity with health risk have focused on older adults.[10] Older adults tend to have lower levels of physical activity[13,14] and to spend more time in sedentary behavior.[15] They also begin to lose fitness levels, and some of

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them find it difficult to adopt and maintain MVPA.[16] Because of these changes in the behavior patterns of older adults, it is important to assess how different combinations of sedentary behavior and physical activity might influence their cardiovascular health. It is important to examine if older adults could improve their health by reducing sedentary behavior, that is, by avoiding prolonged sedentary behavior and increasing light-intensity physical activity, regardless of their level of MVPA. Thus, the purpose of this study was to examine the joint associations of TV viewing time and MVPA with overweight/obesity among older adults in Japan.

METHODS

Participants and data collection

This cross-sectional study was part of a project to investigate the association between neighborhood environment and physical activity among older adults.[17] Data were collected from February to March 2010. A total of 2700 residents who were aged 65 to 74 years and living in 3 Japanese cities (Bunkyo Ward in Tokyo, Fuchu in Tokyo, Oyama in Shizuoka prefecture) were randomly selected from registries of residential addresses and stratified by sex, age (65–69 years/70–74 years), and city of residence. In total, 2700 older adults were identified, and they received invitation letters that described the content of the study. Three cities were chosen—one each from a metropolitan urban area, a suburban area, and a rural area—because this survey was originally designed to investigate the relationship of neighborhood environment with physical activity. Bunkyo is in central Tokyo. Fuchu is a suburban city located about 20 km east of the center of Tokyo. It is in the Tokyo Metropolitan Area and within commuting distance of central Tokyo. Oyama is a small regional city located about 80 km west of Tokyo.

Two weeks after the invitation, the 2700 older adults received a questionnaire and consent form. To encourage participation, a 500-yen (about 6 US dollars in 2011) book voucher was offered to respondents. During the survey, a call center was set up to answer participants' inquiries. Reminders to return the survey were mailed twice to nonresponding participants. Those who returned an incomplete survey were asked to complete the survey again. Of 2700 older adults initially identified, 2046 returned the survey. After data cleaning, 1806 participants had valid data for the analyses of this study (response rate: 66.9%). This study received prior approval from the Tokyo Medical University Ethics Committee.

Measures

Outcome variable

Body mass index (BMI) was the outcome measure of this study and was calculated from self-reported weight and height. Participants were categorized as normal weight (BMI $<25\,kg/m^2$) and overweight or obese (BMI $\geq 25\,kg/m^2$) for regression analyses.

TV viewing time and physical activity

TV viewing time was determined by asking participants to report frequency of TV viewing (days/week) and average viewing time in each day (minutes/day) over the past 7 days. This questionnaire item was a Japanese translation of an Australian questionnaire on leisure-time sedentary behaviors.[18] TV viewing time was dichotomized using median to high TV viewing (>840 min/week) and low TV viewing (≤840 min/week).

The Short Version of the International Physical Activity Questionnaire (IPAQ-S)[19,20] was used to assess moderate-to-vigorous physical activity (MVPA). Among Japanese adults, the test-retest reliability of IPAQ-S (intraclass correlation coefficient: ICC) was 0.87 and its validity as compared with accelerometry (Spearman's correlation coefficient: ρ) was 0.39.[20] Among elderly adults, reliability and validity as compared with pedometry (partial correlation coefficient adjusted for sex, age, and education: r) were reported only in a Chinese study (ICC = 0.84; $r = 0.33$).[21] Participants were asked to report the frequency and duration of 3 types of physical activity: vigorous intensity, moderate intensity (excluding walking), and walking. Total time spent in MVPA, including walking, was calculated as the sum of these 3 activities, which was then classified as insufficient MVPA (<150 min/week) and sufficient MVPA (≥150 min/week), using physical activity guidelines for health benefits.[12,22]

Sociodemographic, lifestyle, and health variables

In addition to age and sex, which were obtained from the registry of residential addresses of each city, educational attainment (years of education), working status (working hours per week), smoking habits (currently smoking or not), alcohol consumption (days/week), and physical functioning were assessed by questionnaire. Questions on smoking and alcohol were from the National Health and Nutrition Survey of Japan.[23] Physical functioning was assessed by using an item in the 8-Item Short-Form Health Survey (SF8).[24] Participants chose the most suitable response from a 5-point scale to the statement, "During the past 4 weeks, how much did physical health problems limit your usual physical activities (such as walking or climbing stairs)?". The choices were "not at all", "very little", "somewhat", "quite a lot", and "could not do physical activity".

Statistical analyses

Participants were classified into 4 groups by combinations of TV viewing time and MVPA: high TV/insufficient MVPA, high TV/sufficient MVPA, low TV/insufficient MVPA, and low TV/sufficient MVPA. Logistic regression analyses were used to calculate the odds ratios (ORs) and 95% CIs for being overweight/obese (BMI $\geq 25\,kg/m^2$) by the 4 categories (the reference category was high TV/insufficient MVPA). Two models were examined. Model 1 adjusted for sex and age. Model 2 adjusted for sex, age, education (>12 years; ≤12 years), working status (working for ≥35 hours/week; working for 1–34 hours/week; not working), city of residence (Bunkyo; Fuchu; Oyama), smoking (current smoker; not current smoker), drinking (≥1 day/week; <1 day/week), and physical functioning (5-point scale mentioned above). Analyses were conducted first for the overall sample, then separately for men and women, and for persons who were working (>0 hour/week) and not working, because the time available for leisure activities is likely to differ between these groups. In addition, 2 subsample analyses were conducted to examine potential confounding. First, extremely low physical functioning was a potential confounder. Thus, 40 participants who answered "could not do physical activity" to the question on physical functioning[24] were excluded from analyses ($n = 1766$). Second, 127 underweight participants (BMI <18.5 kg/m^2), who were included in the normal reference category in the main analyses, were excluded from the second subsample analyses ($n = 1679$). Significance was considered to be $P < 0.05$. Analyses were conducted with SPSS Version 17.0 for Windows (SPSS Inc., Tokyo, Japan).

RESULTS

Table 1 shows the characteristics of the study sample. The mean age (SD) was 69.2 (2.9). The prevalence of being overweight/obese was 20.1% among the overall sample. The prevalence of each of the combined categories of TV viewing and MVPA was 24.6% for high TV/insufficient MVPA, 22.1% for high TV/sufficient MVPA, 17.6% for low TV/insufficient MVPA, and 18.0% for low TV/sufficient MVPA. The median (25th, 75th percentile) TV viewing time and MVPA were 840 (420, 1400) min/week and 300 (120, 630) min/week, respectively.

Table 2 shows the ORs for being overweight/obese, according to the 4 TV viewing/MVPA categories. For the overall sample, those who belonged to the most active category (low TV/sufficient MVPA) were significantly less likely to be overweight/obese, in comparison with the reference group (high TV/insufficient MVPA), after adjusting for sex and age (Model 1). After further adjustment for other potential confounders (Model 2), the 2 low-TV categories had significantly lower odds ratios of overweight/obesity: the ORs (95% CI) were 0.58 (0.37, 0.90) for low TV/insufficient MVPA and 0.67 (0.47, 0.97) for low TV/sufficient MVPA. No significant association was observed for the high TV/sufficient MVPA category (OR: 0.93 [0.65, 1.34]).

When men and women were examined separately, a significant association between TV/MVPA category and overweight was observed in the low TV/sufficient MVPA among women in Model 1, and borderline significant associations in the low TV/insufficient PA category among men and women were observed in Model 2. In the stratified analyses by working status, a significant association between TV/MVPA category and overweight was observed only among nonworking older adults. The ORs of being overweight, after adjusting for all covariates, were 0.89 (0.59, 1.36) for high TV/sufficient MVPA, 0.55 (0.33, 0.94) for low TV/insufficient MVPA, and 0.54 (0.34, 0.84) for low TV/sufficient MVPA.

The findings from 2 subsample analyses (a sample excluding those with poor physical function and one without underweight participants) showed a similar pattern: a significantly lower odds of being overweight was observed in the low TV/insufficient MVPA and low TV/sufficient MVPA categories (data not shown).

In addition, because the prevalence of meeting physical activity guidelines was high (71.3%), we conducted analyses using a different cut point for MVPA (median: 300 min/wk; data not shown in the tables) to examine the potential influence of overestimation. However, this did not substantially change the overall pattern of findings. Those in the category of "low TV viewing/insufficient PA (≤300 min/wk)" and "low TV viewing/sufficient PA (>300 min/wk)" had lower risk of overweight/obesity (OR: 0.66 [0.48–0.92], 0.67 [0.48–0.93], respectively), while no significant association between the risk of overweight/obesity and the category of "high TV viewing/sufficient PA (>300 min/wk)" was observed.

DISCUSSION

This study found that older adults who spent less time watching TV, a predominant leisure-time sedentary behavior, were less likely to be overweight or obese, regardless of their levels of MVPA. This suggests that prolonged TV viewing elevates the risk of overweight/obesity among the elderly population. Analyses also suggested that in the presence of prolonged TV viewing, a sufficient amount of MVPA, as defined by current physical activity guidelines, was not protective against overweight/obesity in this study sample. These findings could be interpreted as suggesting the importance of light-intensity activity to reduce obesity risk. A previous study showed that light-intensity activity, which is negatively correlated with sedentary time, had beneficial associations with cardiometabolic biomarkers.[25] Because some older people have difficulty in adopting and maintaining MVPA,[16] reducing sedentary behavior and increasing light-intensity activity may be an effective and practical strategy to achieve health benefits in this age group.

Associations of sedentary behavior, including TV viewing time, with obesity measures, independent of MVPA, have been consistently reported for adult samples.[2–7,9] Our study found that this was also the case with older adults. However, our study was slightly different from previous studies in that the association of MVPA with overweight/obesity seemed weaker than that of TV viewing time. A previous study on adults reported that those who spent more time in sedentary behaviors (but were sufficiently physically active) and those who were insufficiently active (but spent less time in

Table 1. Characteristics of participants by combined categories of TV viewing time and physical activity

	Overall *N* = 1806		High TV viewing/ Insufficient PA[b] *N* = 256		High TV viewing/ Sufficient PA[b] *N* = 544		Low TV viewing/ Insufficient PA[b] *N* = 262		Low TV viewing/ Sufficient PA[b] *N* = 744		*P* value[c]
	n	%	*n*	%	*n*	%	*n*	%	*n*	%	
Sex											
Male	925	51.2	125	48.8	275	50.6	127	48.5	398	53.5	0.389
Female	881	48.8	131	51.2	269	49.4	135	51.5	346	46.5	
Age, years											
Mean (SD)	69.6 (2.9)		70.0 (3.0)		69.4 (2.9)		70.1 (3.0)		69.4 (2.9)		<0.001
City of residence											
Bunkyo	571	31.6	50	19.5	174	32.0	76	29.0	271	36.4	<0.001
Fuchu	626	34.7	74	28.9	188	34.6	77	29.4	287	38.6	
Oyama	609	33.7	132	51.6	182	33.5	109	41.6	186	25.0	
Education, years											
<13	1158	64.1	198	77.3	349	64.2	193	73.7	418	56.2	<0.001
13+	648	35.9	58	22.7	195	35.8	69	26.3	326	43.8	
Working status											
Not working	1110	61.5	200	78.1	363	66.7	163	62.2	384	51.6	<0.001
1–34 hours/wk	409	22.6	26	10.2	119	21.9	53	20.2	211	28.4	
35+ hours/wk	287	15.9	30	11.7	62	11.4	46	17.6	149	20.0	
Current smoking											
Yes	273	15.1	55	21.5	88	16.2	34	13.0	96	12.9	0.006
No	1533	84.9	201	78.5	456	83.8	228	87.0	648	87.1	
Drinking, days/week											
1+	725	40.1	88	34.4	216	39.7	87	33.2	334	44.9	0.001
<1	1081	59.9	168	65.6	328	60.3	175	66.8	410	55.1	
Limitation of physical functioning											
Not at all	1086	60.1	122	47.7	348	64.0	119	45.4	497	66.8	<0.001
Very little	337	18.7	49	19.1	99	18.2	55	21.0	134	18.0	
Somewhat	258	14.3	48	18.8	80	14.7	46	17.6	84	11.3	
Quite a lot	85	4.7	22	8.6	14	2.6	25	9.5	24	3.2	
Could not do physical activity	40	2.2	15	5.9	3	0.6	17	6.5	5	0.7	
BMI, kg/m^2											
<25	1443	79.9	193	75.4	424	77.9	216	82.4	610	82.0	0.055
25+	363	20.1	63	24.6	120	22.1	46	17.6	134	18.0	
TV viewing, min/week											
Short, ≤840	1006	55.7	0	0.0	0	0.0	262	100.0	744	100.0	<0.001
Long, 840+	800	44.3	256	100.0	544	100.0	0	0.0	0	0.0	
Median (25%tile, 75%tile)	840 (420, 1400)		1680 (1260, 2520)		1500 (1260, 2100)		420 (150, 840)		480 (255, 840)		
MVPA[a], min/week											
Insufficient, <150	518	28.7	256	100.0	0	0.0	262	100.0	0	0.0	<0.001
Sufficient, 150+	1288	71.3	0	0.0	544	100.0	0	0.0	744	100.0	
Median (25%tile, 75%tile)	300 (120, 630)		20 (0, 90)		420 (272.5, 750)		20 (0, 80)		480 (300, 840)		

[a]MVPA: moderate-to-vigorous physical activity.
[b]TV viewing time was dichotomized by the median (840 min/wk); physical activity (PA) was dichotomized by MVPA of 150 min/wk.
[c]Differences between groups were examined by chi-square tests for categorical variables and 1-way analysis of variance for age.

sedentary behavior) had similar risks of overweight.[4] In youth studies, insufficient physical activity was more strongly associated than prolonged sedentary behavior with overweight.[26,27] In light of these previous studies, it is possible to argue that the impact of sedentary behavior and MVPA on obesity risk differs with age and that prolonged sedentary behavior might be a stronger risk factor for elderly adults. The association between sedentary behavior and cardiovascular risk will be influenced by non-exercise activity thermogenesis (NEAT), which is generally a much greater component of total energy expenditure than MVPA, and by the significant role of brief yet frequent muscle contractions throughout the day, which may short-circuit unhealthy molecular signals that cause metabolic dysfunction.[28] These effects might be more pronounced among older adults, who are generally less physically active than younger adults.

The fact that significant associations of TV viewing time with overweight were found in nonworkers but not in workers suggests that light-intensity and intermittent activities during work are protective against overweight/obesity in the presence of prolonged TV viewing time. However, in nonworkers, some TV viewing may accompany other leisure-time sedentary behaviors, due to the greater amount of time available for them. An Australian study found that TV viewing time was a good marker of overall sedentary time.[29] Our findings suggest that retired older adults are at risk of overweight. Thus, retirement might be a window of opportunity for interventions that prevent and reduce sedentary time.

Table 2. Odds ratios for overweight/obesity by the combined categories of TV viewing time and physical activity

TV/PA categories[a]	Sample	Overweight /obesity, %	Model 1[b]		Model 2[c]	
			OR (95% CI)	*P* value	OR (95% CI)	*P* value
Overall						
High TV/ Insufficient PA	256	24.6	1.00		1.00	
High TV/ Sufficient PA	544	22.1	0.85 (0.60, 1.21)	0.370	0.93 (0.65, 1.34)	0.693
Low TV/ Insufficient PA	262	17.6	0.65 (0.43, 1.00)	0.052	0.58 (0.37, 0.90)	0.014
Low TV/ Sufficient PA	744	18.0	0.65 (0.46, 0.92)	0.015	0.67 (0.47, 0.97)	0.033
Men						
High TV/ Insufficient PA	125	24.8	1.00		1.00	
High TV/ Sufficient PA	275	26.2	1.05 (0.64, 1.71)	0.845	1.05 (0.63, 1.75)	0.846
Low TV/ Insufficient PA	127	18.1	0.68 (0.37, 1.25)	0.215	0.54 (0.29, 1.02)	0.057
Low TV/ Sufficient PA	398	20.9	0.77 (0.48, 1.24)	0.281	0.69 (0.42, 1.15)	0.154
Women						
High TV/ Insufficient PA	131	24.4	1.00		1.00	
High TV/ Sufficient PA	269	17.8	0.68 (0.41, 1.13)	0.136	0.83 (0.49, 1.40)	0.484
Low TV/ Insufficient PA	135	17.0	0.63 (0.35, 1.16)	0.138	0.59 (0.32, 1.10)	0.099
Low TV/ Sufficient PA	346	14.7	0.54 (0.33, 0.89)	0.015	0.66 (0.39, 1.11)	0.120
Working						
High TV/ Insufficient PA	56	23.2	1.00		1.00	
High TV/ Sufficient PA	181	24.3	1.05 (0.52, 2.14)	0.891	1.17 (0.56, 2.45)	0.681
Low TV/ Insufficient PA	99	20.2	0.87 (0.39, 1.92)	0.722	0.73 (0.32, 1.67)	0.452
Low TV/ Sufficient PA	360	22.8	0.95 (0.49, 1.86)	0.883	1.04 (0.51, 2.12)	0.906
Not working						
High TV/ Insufficient PA	200	25.0				
High TV/ Sufficient PA	363	20.9	0.79 (0.53, 1.20)	0.269	0.89 (0.59, 1.36)	0.601
Low TV/ Insufficient PA	163	16.0	0.57 (0.34, 0.97)	0.038	0.55 (0.33, 0.94)	0.030
Low TV/ Sufficient PA	384	13.5	0.47 (0.31, 0.73)	<0.001	0.54 (0.34, 0.84)	0.007

[a]TV viewing time was dichotomized by the median (840 min/wk); physical activity (PA) was dichotomized by MVPA of 150 min/wk.
[b]Model 1: adjusted for sex and age.
[c]Model 2: adjusted for sex, age, education, employment status, city of residence, smoking, drinking, and physical functioning, excluding stratified variables.

There are some limitations that need to be considered in interpreting the findings of this study. First, both the dependent and independent variables were measured by self-report, which is susceptible to response bias. In particular, the percentage of participants who met physical activity guidelines was high. Overestimation of physical activity may have contributed to the weaker association of MVPA and overweight observed in this study. Although an additional analysis using a different cut point (median, 300 min/wk) produced a similar pattern of findings, reporting error and bias may have masked associations of MVPA with overweight. In addition, we used BMI calculated from self-reported weight and height. Although self-reported measurement generally has a high correlation with direct measurement,[30–35] some studies have suggested that obese and elderly persons tend to underreport their weight.[30–35] If participants tend to report their behavior and weight biased to the optimal direction, this may have reduce response variability and lead to lower statistical power and underestimation of associations.[33] Future studies should use objective measures of behaviors and overweight/obesity, to more accurately assess the health effects of sedentary behaviors among older adults. The cross-sectional design of this study is another limitation, and the possibility of reverse causality (ie, overweight and obesity could discourage activity and lead to prolongation of TV viewing time) should be considered. Longitudinal studies are needed to examine causality. Finally, the analyses could not include information on diet, which may confound the relationship between sedentary time and overweight risk.

In spite of these limitations, the current study adds new findings on the associations between TV viewing time and overweight/obesity independent of MVPA among older adults, especially among those not working. As people get older, they typically become less active and spend more time in sedentary behaviors. Further research examining the relative importance of sedentary behavior and physical activity on health outcomes is thus warranted to inform the development of public health initiatives and guidelines for older people.

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REFERENCES

1. Jakes RW, Day NE, Khaw KT, Luben R, Oakes S, Welch A, et al. Television viewing and low participation in vigorous recreation are independently associated with obesity and markers of cardiovascular disease risk: EPIC-Norfolk population-based study. Eur J Clin Nutr. 2003;57(9):1089–96.
2. Dunstan DW, Salmon J, Owen N, Armstrong T, Zimmet PZ, Welborn TA, et al. Physical activity and television viewing in relation to risk of undiagnosed abnormal glucose metabolism in adults. Diabetes Care. 2004;27(11):2603–9.
3. Bertrais S, Beyeme-Ondoua JP, Czernichow S, Galan P, Hercberg S, Oppert JM. Sedentary behaviors, physical activity, and metabolic syndrome in middle-aged French subjects. Obes Res. 2005;13(5):936–44.
4. Sugiyama T, Healy GN, Dunstan DW, Salmon J, Owen N. Joint associations of multiple leisure-time sedentary behaviours and physical activity with obesity in Australian adults. Int J Behav Nutr Phys Act. 2008;5:35.
5. Healy GN, Wijndaele K, Dunstan DW, Shaw JE, Salmon J, Zimmet PZ, et al. Objectively measured sedentary time, physical activity, and metabolic risk: the Australian Diabetes, Obesity and Lifestyle Study (AusDiab). Diabetes Care. 2008;31(2):369–71.
6. Katzmarzyk PT, Church TS, Craig CL, Bouchard C. Sitting time and mortality from all causes, cardiovascular disease, and cancer. Med Sci Sports Exerc. 2009;41(5):998–1005.
7. Dunstan DW, Barr EL, Healy GN, Salmon J, Shaw JE, Balkau B, et al. Television viewing time and mortality: the Australian Diabetes, Obesity and Lifestyle Study (AusDiab). Circulation. 2010;121(3):384–91.
8. Thorp AA, Healy GN, Owen N, Salmon J, Ball K, Shaw JE, et al. Deleterious associations of sitting time and television viewing time with cardiometabolic risk biomarkers: Australian Diabetes, Obesity and Lifestyle (AusDiab) study 2004–2005. Diabetes Care. 2010;33(2):327–34.
9. Wijndaele K, Brage S, Besson H, Khaw KT, Sharp SJ, Luben R, et al. Television viewing time independently predicts all-cause and cardiovascular mortality: the EPIC Norfolk study. Int J Epidemiol. 2011;40(1):150–9.
10. Bankoski A, Harris TB, McClain JJ, Brychta RJ, Caserotti P, Chen KY, et al. Sedentary activity associated with metabolic syndrome independent of physical activity. Diabetes Care. 2011;34(2):497–503.
11. Haskell WL, Lee IM, Pate RR, Powell KE, Blair SN, Franklin BA, et al. Physical activity and public health: updated recommendation for adults from the American College of Sports Medicine and the American Heart Association. Circulation. 2007 Aug 28;116(9):1081–93.
12. U.S. Department of Health and Human Services. 2008 Physical Activity Guidelines for Americans, Be Active, Healthy, and Happy! [http://www.health.gov/paguidelines/].
13. Carlson SA, Densmore D, Fulton JE, Yore MM, Kohl HW 3rd. Differences in physical activity prevalence and trends from 3 U.S. surveillance systems: NHIS, NHANES, and BRFSS. J Phys Act Health. 2009;6 Suppl 1:S18–27.
14. Hawkins MS, Storti KL, Richardson CR, King WC, Strath SJ, Holleman RG, et al. Objectively measured physical activity of USA adults by sex, age, and racial/ethnic groups: a cross-sectional study. Int J Behav Nutr Phys Act. 2009;6:31.
15. Clark BK, Sugiyama T, Healy GN, Salmon J, Dunstan DW, Shaw JE, et al. Socio-demographic correlates of prolonged television viewing time in Australian men and women: the AusDiab study. J Phys Act Health. 2010;7(5):595–601.
16. Brawley LR, Rejeski WJ, King AC. Promoting physical activity for older adults: the challenges for changing behavior. Am J Prev Med. 2003;25(3 Suppl 2):172–83.
17. Inoue S, Ohya Y, Odagiri Y, Takamiya T, Kamada M, Okada S, et al. Perceived neighborhood environment and walking for specific purposes among elderly Japanese. J Epidemiol. 2011; 21(6):481–90.
18. Salmon J, Owen N, Crawford D, Bauman A, Sallis JF. Physical activity and sedentary behavior: a population-based study of barriers, enjoyment, and preference. Health Psychol. 2003;22(2): 178–88.
19. Craig CL, Marshall AL, Sjöström M, Bauman AE, Booth ML,