correlates of PA were observed among normal-weight and overweight men. Furthermore, significant interactions regarding PA were observed between BMI status and two environmental correlates: access to public transportation (P = 0.03) and crime safety during the day (P = 0.01). The results indicated that BMI status is a potential moderator between perceived environmental factors and PA and suggested that different environmental intervention approaches should be developed for overweight populations.

Keywords: BMI; overweight; moderator; perceived environment; walking; moderate-to-vigorous physical activity; physical activity recommendation; Japan

1. Introduction

Overweight and obesity are associated with an increased risk of morbidity from chronic diseases, as well as with higher health-care costs and lower quality of life [1-4]. An increasing prevalence of obesity has been reported in Western countries, and in those countries, the groups with higher risk of obesity varied by age, gender, and race/ethnicity [5-7]. Compared to the U.S. (where the prevalence of obesity is approximately 30%), the prevalence of obesity in Japan is much lower (approximately 3%) and has changed little during the last 40 years [8,9]. However, more recently, the prevalence of overweight adults in Japan has grown to 28.6% in men and 20.6% in women, and men aged 40–49 years had the highest percentage (35.9%) [10]. Therefore, with regard to the obesity epidemic, identifying effective, population-based strategies for preventing weight gain would be a public health priority, not only in Western countries, but also in Japan.

Numerous longitudinal and cross-sectional studies have shown that engaging in physical activity (PA) is beneficial for the prevention of obesity and overweight [11-16]. Based on these findings, the World Health Organization has recommended engaging almost daily in at least 30 minutes of moderate-intensity PA for the prevention of obesity and other chronic diseases [5,17]. Despite such a benefit, overweight and obese individuals spent less time on PA and were less likely than normal-weight individuals to meet the minimum recommended level of PA [moderate-to-vigorous PA (MVPA) at least 30 minutes per day, 5 or more days per week; ≥150 minutes per week] [12-16]. Therefore, developing effective strategies to promote PA to overweight and obese subgroups is needed to prevent further increases in the obesity rate among populations.

A better understanding of factors associated with PA is critical in designing relevant policies and effective interventions. From an ecological perspective, the manipulation of environmental attributes would be expected to provide a long-term impact on the PA of an associated population [18,19]. In this context, the association between environmental factors and PA behaviors has been reported in many countries [20]. However, many of these previous studies have been conducted in general populations [20,21]. Recent studies have suggested that environmental factors associated with PA differ between socio-demographic subgroups, such as men and women [22,23], older and younger adults [24], African-American and white adults [25], and driving and non-driving rural women [26]. In addition to these differences, BMI status has been also suggested as a potential moderator for the correlates of PA [27]. It is important to examine the factors associated with engaging in PA in the overweight subgroup to develop more tailored intervention strategies. However, to date only a Portuguese study has examined the environmental dimensions associated with meeting the PA recommendation among overweight/obese women [22], although previous studies have consistently observed gender differences in environmental correlates [22,28]. Thus, the present study examined the differences in perceived environmental factors associated with PA among normal-weight and overweight Japanese men.

2. Methods

2.1. Participants

An internet-based cross-sectional survey was conducted in January 2009 by a Japanese internet research service organization, which listed approximately 264,000 voluntarily registered subjects across Japan and their detailed socio-demographic attributes. Thus, the organization could access data from the targeted group on the basis of the requirements of each survey. In the current study, the sample size and personal attributes of the targeted group was set as follows: (1) approximately 3,000 adults aged between 30 and 59 years. (2) 500 men and 500 women in each age group (aged 30–39, 40–49, and 50–59 years). A total of 9,418 potential respondents, aged 30–59 years, were randomly selected from the database and invited to attend this internet-based survey via email (final respondents: 3,000 adults; response rate: 31.9%). The email invitations included the URL for access to this survey, and the potential respondents could log in using their own ID and password to answer the questionnaire voluntarily. The present study received prior approval from the Ethics Committee of the Faculty of Sports Sciences, Waseda University, Japan.

2.2. Measures

BMI: Self-reported height and weight were used to calculate the body mass index (BMI; body weight in kilograms divided by the square of height in meters). The participants were classified as normal-weight men (BMI < 25) and overweight men (BMI ≥ 25) in the present study.

Physical activity: Physical activity was measured by the self-administered, short version of the International Physical Activity Questionnaire (IPAQ-SV), which was recommended for the national prevalence studies [29]. IPAQ-SV, which includes seven items, was used to measure the frequency and duration of vigorous-intensity PA, moderate-intensity PA, and walking level for young and middle-aged adults (15–69 years). The test-retest reliability ($r = 0.72$–0.93) and criterion validity ($r = 0.39$) of the Japanese version of the IPAQ-SV are good and acceptable [30]. The total minutes of each PA category in a week were first computed. In the present study, two independent variables, the total minutes of walking and MVPA (excluding walking), were calculated. MVPA (excluding walking) was computed by summing the minutes per week of moderate- and vigorous-intensity PA time in the IPAQ-SV. Both walking and MVPA excluding walking were dichotomized at 150 minutes or more per week according to the public health PA recommendation [31]. In each variable, the respondents could be categorized into two groups: either meeting the recommended level or not.

Perceived environmental factors: The Japanese version of the International Physical Activity Questionnaire-Environmental Module (IPAQ-E) was utilized to measure the perceived environmental factors associated with PA. The IPAQ-E questionnaire was originally developed by the International Physical Activity Prevalence Study (IPS), has been used in several countries, and has shown good reliability [18,32-34]. This self-administered questionnaire consists of three sets of items, which include seven core items, four recommended items, and six optional items [35]. In this study, all 17 items were included using a 4-point Likert scale (strongly agree, somewhat agree, somewhat disagree, and strongly disagree), with the exception of the following two questions: (1) *What is the main type of housing in your neighborhood*? For this question, the five options were detached single-family housing; apartments with 2–3 stories; mix of single-family housing and apartments with 2–3 stories; condos with 4–12 stories; and condos with >13 stories. (2) *How many household cars or auto bikes are there at your household?* This question was open ended.

For the analyses, similar to previous studies [18,36], the 17 environmental variables were converted into binary items. Residential density was divided into "detached single-family housing" and "others", and having household car or auto bikes was classified into "0" and ">0". Other items were categorized as "agree" (strongly agree and somewhat agree) and "disagree" (somewhat disagree and strongly disagree).

Socio-demographic variables: In the present study, socio-demographic correlates included gender, age, marital status, educational level, household income, and employment status. Age was categorized as 30–39, 40–49, and 50–59 years. Marital status was classified into married and unmarried. Educational level was divided into three categories: less than high school graduate, junior college graduate or equivalent, and college graduate or higher. Household income was categorized as less than 5 million yen, 5–10 million yen, and >10 million yen. Employment status was classified into full-time job and not full-time job.

2.3. Statistical Analyses

The data were analyzed from 1,420 men who provided complete information for study variables. All analyses were stratified by BMI. Forced-entry adjusted logistic regression for gender, age, marital status, educational level, household income, and employment status was conducted to examine the association between environmental factors and meeting the PA recommendation. Adjusted odd ratios (ORs) and 95% confidence intervals (CI) were calculated for each variable. Likelihood ratio tests were used to compare models with or without interaction terms between environmental variables and BMI status. Inferential statistics were performed using SPSS 15.0, and the level of significance was set at $p < 0.05$.

3. Results

3.1. The Characteristics of the Participants

Table 1 presents the basic characteristics of the participants (mean age was 44.4 ± 8.3 years). Of all respondents, 31.1% were overweight, 70.4% were married, 64.4% had an education level of 4-year college/graduate school, 92.0% had full-time jobs, and 49.7% had a household income between 5,000,000 yen and 10,000,000 yen. The prevalence of achieving the PA recommendation (the sum of walking and other MVPA times) was 57.4% in the present study.

Table 1. Basic characteristics of all respondents stratified by normal-weight and overweight men.

	Total sample N = 1,420		Normal weight N = 979 (68.9%)		Overweight N = 441 (31.1%)			
	N	%	N	%	N	%	X^2	p
Age group							3.43	0.18
30–39	475	33.4	338	34.5	137	31.1		
40–49	474	33.4	312	31.9	162	36.7		
50–59	471	33.2	329	33.6	142	32.2		
Mean age (± SD)	44.4 ± 8.3							
Marital status							0.03	0.86
Married	1,000	70.4	688	70.3	312	70.7		
Unmarried	420	29.6	291	29.7	129	29.3		
Educational level							2.04	0.36
Junior high/high school	330	23.2	219	22.4	111	25.2		
2-year college	176	12.4	118	12.1	58	13.2		
4-year college/ graduate school	914	64.4	642	65.5	272	61.6		
Job status							0.09	0.77
full-time job	1,306	92.0	899	91.8	407	92.3		
not full-time job	114	8.0	80	8.2	34	7.7		
Household income							2.46	0.65
<5,000,000 yen	488	34.4	343	35.0	145	32.9		
<10,000,000 yen	706	49.7	481	49.1	225	51.0		
>10,000,000 yen	226	15.9	155	15.9	71	16.1		

SD = standard deviation.

3.2. Perceived Environmental Factors Associated with Walking and MVPA (Excluding Walking) among Men

Table 2 shows the results of the adjusted logistic regression analysis in walking and MVPA (excluding walking) among normal-weight and overweight men. Ten significant environmental correlates of walking in normal-weight men and three in overweight men were observed. For normal-weight men, good access to shops (OR = 1.61; 95% CI: 1.24–2.10), good access to public transport (OR = 2.30; 95% CI: 1.57–3.38), good access to recreational facilities (OR = 1.42; 95% CI: 1.09–1.84), seeing people being active (OR = 1.49; 95% CI: 1.15–1.94), aesthetics (OR = 1.74; 95% CI: 1.33–2.29), street connectivity (OR = 1.48; 95% CI: 1.11–1.98), good maintenance of sidewalks (OR = 1.49; 95% CI: 1.14–1.94), good maintenance of bike lanes (OR = 1.58; 95% CI: 1.22–2.04), and presence of destination (OR = 1.61; 95% CI: 1.24–2.10) were significantly associated with engaging in 150 minutes of walking per week. However, having household cars or auto bikes (OR = 0.60; 95% CI: 0.41–0.88) was inversely associated with walking in normal-weight men. For overweight men, environmental factors associated with engaging in 150 minutes of walking per week were good access to recreational facilities (OR = 1.75; 95% CI: 1.18–2.58) and presence of destination (OR = 1.63; 95% CI: 1.10–2.41). Furthermore, lack of safety from crime during the day (OR = 0.48; 95% CI: 0.24–0.94) was negatively related to engagement in 150 minutes of walking per week.

Forced-entry, adjusted logistic regression analyses also indicated that connectivity of streets (OR = 1.45; 95% CI: 1.04–2.03) was a positive environmental factor associated with engaging in MVPA (excluding walking) for 150 minutes or more per week for normal-weight men. On the other hand, seeing people being active (OR = 2.27; CI: 1.38–3.75) was positively associated with engaging in MVPA (excluding walking) at the recommended level for overweight men.

Table 2. Adjusted model of perceived environmental factors associated with walking and MVPA (excluding walking) among normal-weight and overweight men.

	Normal weight (N = 979, 68.9%)				Overweight (N = 441, 31.1%)			
			Walking	MVPA (excluding walking)			Walking	MVPA (excluding walking)
	N	%	Adjusted OR (95% CI)	Adjusted OR (95% CI)	N	%	Adjusted OR (95% CI)	Adjusted OR (95% CI)
Residential density								
High	432	44.1	1.15 (0.89–1.50)	0.77 (0.57–1.03)	180	40.8	1.39 (0.94–2.07)	0.80 (0.49–1.29)
Low	547	55.9	1.00	1.00	261	59.2	1.00	1.00
Access to shops								
Good	553	56.5	1.61 (1.24–2.10)*	1.21 (0.90–1.63)	256	58.0	1.15 (0.78–1.70)	1.31 (0.81–2.11)
Poor	426	43.5	1.00*	1.00	185	42.0	1.00	1.00
Access to public transport								
Good	817	83.5	2.30 (1.57–3.38)*	1.23 (0.82–1.84)	360	81.6	1.17 (0.71–1.91)	1.28 (0.69–2.37)
Poor	162	16.5	1.00*	1.00	81	18.4	1.00	1.00
Presence of sidewalks								
Yes	604	61.7	1.29 (0.98–1.68)	1.04 (0.77–1.40)	267	60.5	1.43 (0.96–2.12)	0.93 (0.58–1.49)
No	375	38.3	1.00	1.00	174	39.5	1.00	1.00
Presence of bike lanes								
Yes	242	24.7	1.12 (0.83–1.51)	1.09 (0.78–1.52)	127	28.8	1.30 (0.85–1.99)	0.74 (0.43–1.26)
No	737	75.3	1.00	1.00	314	71.2	1.00	1.00
Access to recreational facilities								
Good	482	49.2	1.42 (1.09–1.84)*	1.29 (0.96–1.72)	221	50.1	1.75 (1.18–2.58)*	1.54 (0.96–2.47)
Poor	497	50.8	1.00*	1.00	220	49.9	1.00*	1.00
Crime safety at night								
Not safe	237	24.2	0.87 (0.64–1.17)	1.07 (0.77–1.49)	116	26.3	0.80 (0.52–1.25)	1.17 (0.70–1.95)
Safe	742	75.8	1.00	1.00	325	73.7	1.00	1.00
Traffic safety								
Not safe	354	36.2	1.16 (0.89–1.51)	1.03 (0.77–1.39)	159	36.1	1.06 (0.71–1.58)	1.20 (0.74–1.93)
Safe	625	63.8	1.00	1.00	282	63.9	1.00	1.00
Seeing people being active								
Yes	535	54.6	1.49 (1.15–1.94)*	1.32 (0.98–1.77)	250	56.7	1.41 (0.95–2.09)	2.27 (1.38–3.75)**
No	444	45.4	1.00*	1.00	191	43.3	1.00	1.00**
Aesthetics								
Yes	351	35.9	1.74 (1.33–2.29)*	1.29 (0.96–1.74)	149	33.8	1.14 (0.76–1.71)	1.28 (0.79–2.07)
No	628	64.1	1.00*	1.00	292	66.2	1.00	1.00

Table 2. *Cont.*

	Normal weight (N = 979, 68.9%)				Overweight (N = 441, 31.1%)			
			Walking	MVPA (excluding walking)			Walking	MVPA (excluding walking)
	N	%	Adjusted OR (95% CI)	Adjusted OR (95% CI)	N	%	Adjusted OR (95% CI)	Adjusted OR (95% CI)
Connectivity of streets								
Yes	700	71.5	1.48 (1.11–1.98)*	1.45 (1.04–2.03)**	321	72.8	1.05 (0.68–1.62)	0.79 (0.48–1.32)
No	279	28.5	1.00*	1.00**	120	27.2	1.00	1.00
Maintenance of sidewalks								
Good	555	56.7	1.49 (1.14–1.94)*	1.10 (0.82–1.47)	256	58.0	1.11 (0.75–1.64)	0.82 (0.51–1.30)
Poor	424	43.3	1.00*	1.00	185	42.0	1.00	1.00
Maintenance of bike lanes								
Good	479	48.9	1.58 (1.22–2.04)*	1.14 (0.85–1.52)	216	49.0	1.01 (0.69–1.48)	0.90 (0.57–1.43)
Poor	500	51.1	1.00*	1.00	225	51.0	1.00	1.00
Traffic safety for bicyclists								
Not safe	427	43.6	0.96 (0.74–1.24)	0.89 (0.67–1.19)	192	43.5	1.16 (0.79–1.71)	0.92 (0.57–1.47)
Safe	552	56.4	1.00	1.00	249	56.5	1.00	1.00
Crime safety during the day								
Not safe	106	10.8	1.45 (0.96–2.18)	1.10 (0.69–1.74)	46	10.4	0.48 (0.24–0.94)*	0.88 (0.41–1.92)
Safe	873	89.2	1.00	1.00	395	89.6	1.00*	1.00
Presence of destination								
Yes	511	52.2	1.61 (1.24–2.10)*	1.12 (0.83–1.50)	247	56.0	1.63 (1.10–2.41)*	1.22 (0.76–1.96)
No	468	47.8	1.00*	1.00	194	44.0	1.00*	1.00
Household car or auto bikes								
One or more	845	86.3	0.60 (0.41–0.88)*	1.43 (0.91–2.26)	394	89.3	0.54 (0.28–1.02)	1.56 (0.66–3.69)
None	134	13.7	1.00*	1.00	47	10.7	1.00	1.00

Adjusted for age, marital status, educational level, household income, and employment status.
*, ** statistically significant ($p < 0.05$).

Furthermore, significant interactions regarding walking were observed between BMI status and 2 environmental correlates: access to public transport ($P = 0.03$) and crime safety during the day ($P = 0.01$) (Table 3).

Table 3. Significance of interactions between BMI status and environmental variables by binary logistic regression models.

	P value for interaction term with BMI status	
	Walking	MVPA (excluding walking)
	P value	*P* value
Residential density (High)	0.46	0.66
Access to shops (Good)	0.16	0.83
Access to public transport (Good)	0.03**	0.94
Presence of sidewalks (Yes)	0.75	0.60
Presence of bike lanes (Yes)	0.67	0.19
Access to recreational facilities (Good)	0.31	0.52

Table 3. *Cont.*

	P value for interaction term with BMI status	
	Walking	MVPA (excluding walking)
	P value	*P* value
Crime safety at night (Safe)	0.85	0.73
Traffic safety (Safe)	0.65	0.55
Seeing people being active (Yes)	0.76	0.14
Aesthetics (Yes)	0.08	0.70
Connectivity of streets (Yes)	0.18	0.06
Maintenance of sidewalks (Good)	0.22	0.28
Maintenance of bike lanes (Good)	0.06	0.40
Traffic safety for bicyclists (Safe)	0.39	0.76
Crime safety during the day (Safe)	0.01**	0.69
Presence of destination (Yes)	0.99	0.75
Household car or auto bikes (One or more)	0.93	0.66

Adjusted by age, marital status, educational level, household income, employment status and BMI status. ** statistically significant ($p < 0.05$).

4. Discussion

In the present study, the perceived environmental attributes were significantly associated with PA among normal-weight and overweight Japanese men. The most important finding of the present study was that common environmental correlates of PA were observed between normal-weight and overweight men. Three environmental factors, good access to recreational facilities, seeing people being active, and presence of destination, were positively associated with meeting PA recommendation by either walking or MVPA (excluding walking). The results suggested that increasing the mix of utilitarian destination, supportive environment for seeing people being active, and convenience of accessing recreational facilities could encourage both normal-weight and overweight men to engage in sufficient PA for different purposes. In addition, these factors have been consistently revealed as environmental features related to PA among general populations in both Western countries and Japan [20,23,36-38]; this might strengthen the evidence for some common environmental features associated with PA among countries with different cultures and environments.

Conversely, access to public transport and safety from crime during the day were revealed as different environmental correlates of PA between normal-weight and overweight men based on likelihood ratio tests. This finding indicated that BMI status would be a potential moderator between the perceived environment and PA. Different environmental correlates of PA between socio-demographic subgroups have been examined in previous studies [22-26]. Different socio-demographic correlates of PA have also been reported among three BMI groups [27]. In addition, a previous study has observed that several perceived environmental factors (infrastructures, access to destinations, social environment and aesthetics) were associated with meeting the recommended PA level among overweight/obese women [22]. However, whether overweight men have different environmental correlates of PA than normal-weight men has not been discussed or analyzed as much as they have for women. A possible mechanism underlying the observed significance in perceived good access to public transport among normal-weight men alone is that overweight men are less likely to walk or cycle for transport in their daily lives than normal-weight men, regardless of the accessibility of public transport within their neighborhoods. Regarding the significant contribution of safety from crime only among overweight and obese men, they might be more sensitive to the presence of crime than normal-weight men because they may more easily experience discriminative and stigmatic treatment in their growing stage [39]. Therefore, the perception of an unsafe neighborhood environment might have a negative influence on their PA.

The findings of the present study suggest that consideration of not only general environmental correlates but also unique environmental correlates of PA among overweight and obese populations promote PA more effectively among these populations when environmental approaches for PA interventions are developed. One effective strategy for future environmental interventions aimed at increasing PA levels is promoting or changing their awareness of these environmental correlates. In addition, intervention approaches for rearranging or improving these environmental variables could be beneficial. For these approaches, it might be necessary to establish partnerships and collaborations with different sectors or organizations [40]. For example, neighborhood safety could be improved by cooperating with local authorities in organizing community groups to prevent crime. Furthermore, it could also be effective to cooperate with different government departments and non-government agencies (e.g., transportation department, local government, and transportation agencies) to adjust the location of public transport or number of services for transport-related walking.

The finding of the study indicated that the perceived environment-PA association was more related to normal-weight men than overweight men; while 11 perceived environmental factors associated with PA were found in normal-weight men, only four factors were significantly associated with PA in overweight men. This finding has not been reported in previous studies. Two studies have emphasized a stronger influence of perceived PA environment on older adults than on younger adults [24], as well as adults with disabilities than those without disabilities [41]. There are two implications of this finding. First, compared with normal-weight men, the environmental correlates of PA in overweight men were not detected well using IPAQ-E. As a result, objective measurements should be utilized to further examine the association between environmental factors and meeting the PA recommendation, especially on the walking behavior of overweight men. The second implication is that other factors (such as psychosocial correlates) might be more strongly associated with PA in overweight men than in normal-weight men. Thus, future studies are needed to identify the multiple levels of correlates associated with PA among normal-weight an overweight men.

In accordance with results from previous studies [18,33], the association of environmental factors from the IPAQ-E results were more related with walking than MVPA (excluding walking) between both normal-weight and overweight men in the present study. These results implied that walking behavior might be influenced more by the neighborhood environment than other types of PA behaviors. For future studies, it might be important to examine other correlates of specific MVPA behaviors.

For overweight men, seeing people being active was the strongest perceived environmental factor positively associated with engaging in 150 minutes of MVPA (excluding walking) per week. In previous studies, seeing people being active has been reported as a positive environmental correlate of being physically active [22,36]. The implication of the result is that overweight groups may need more social support to engage in MVPA (excluding walking), such as leisure-time PA, sports, and recreational activity [42-44].

Some limitations of the current study should be considered. First, the study had a cross-sectional design, making it impossible to determine causality. Second, the main measurements, which included BMI, environmental factors, and PA, were measured only by self-administrated questionnaires and could be subject to bias. The self-reported results may cause an underestimation of weight status [22] and an inaccurate estimation of PA time due to recall bias. Finally, the study has a limited ability to obtain representative samples because it relies on an internet-based survey. The respondents of internet-based surveys might have characteristics, such as younger, more educated, higher-income, having greater access to the internet, and more likely to respond to a survey, if they are interested in its contents or are attracted by the incentives offered for participation [45,46]. Thus, the results in the present study may be less applicable to those who have received less education and not applicable to the general population.

5. Conclusions

Both common and different environmental correlates of PA were observed among normal-weight and overweight men. The findings of the current study contribute evidence to the literature on moderators between environmental factors and PA. Findings from the present study suggested that developing different environmental intervention approaches might be needed to promote PA effectively for overweight populations compared with normal-weight populations. In addition, compared with normal-weight men, the perceived environmental correlates of PA in overweight men were not well defined. Future studies should consider examining multiple levels of correlates associated with different kinds of PA by utilizing both perceived and objective measurements among men with different BMI statuses.

Acknowledgements

The present study was supported by a Grant-in-aid from the Ministry of Health, Labour, and Welfare of Japan (Comprehensive Research on Prevention of Cardiovascular Diseases and Other Lifestyle Related Diseases: H20-Junkankitou-Ippan-001); Grant-in-aid for scientific research (C) 20500604 from the Japan Ministry of Education, Culture, Sports, Science, and Technology; Grants-in-Aid for Scientific Research (No. 20800054) from the Japan Society for the Promotion of Science; and Global COE Program "Sport Sciences for the Promotion of Active Life" from the Japan Ministry of Education, Culture, Sports, Science, and Technology.

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British Journal of Nutrition (2011), **105**, 1681–1691
doi:10.1017/S0007114510005441

Real-time estimation of daily physical activity intensity by a triaxial accelerometer and a gravity-removal classification algorithm

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(Received 14 June 2010 – Revised 18 November 2010 – Accepted 19 November 2010 – First published online 25 January 2011)

Abstract

We have recently developed a simple algorithm for the classification of household and locomotive activities using the ratio of unfiltered to filtered synthetic acceleration (gravity-removal physical activity classification algorithm, GRPACA) measured by a triaxial accelerometer. The purpose of the present study was to develop a new model for the immediate estimation of daily physical activity intensities using a triaxial accelerometer. A total of sixty-six subjects were randomly assigned into validation (*n* 44) and cross-validation (*n* 22) groups. All subjects performed fourteen activities while wearing a triaxial accelerometer in a controlled laboratory setting. During each activity, energy expenditure was measured by indirect calorimetry, and physical activity intensities were expressed as metabolic equivalents (MET). The validation group displayed strong relationships between measured MET and filtered synthetic accelerations for household (r 0·907, $P<0·001$) and locomotive (r 0·961, $P<0·001$) activities. In the cross-validation group, two GRPACA-based linear regression models provided highly accurate MET estimation for household and locomotive activities. Results were similar when equations were developed by non-linear regression or sex-specific linear or non-linear regressions. Sedentary activities were also accurately estimated by the specific linear regression classified from other activity counts. Therefore, the use of a triaxial accelerometer in combination with a GRPACA permits more accurate and immediate estimation of daily physical activity intensities, compared with previously reported cut-off classification models. This method may be useful for field investigations as well as for self-monitoring by general users.

Key words: **Non-exercise activity thermogenesis: Accelerometry: Household activity: Locomotive activity: Metabolic equivalents**

Low physical activity (PA) levels in daily life are probably correlated with obesity and other diseases[1]. According to the International Association for the Study of Obesity, prevention of weight regain in formerly obese individuals requires 60–90 min of daily moderate activity or lesser amounts of vigorous activity, with 45–60 min of daily moderate activity required to prevent the transition to overweight or obese[2]. In addition to exercise, non-exercise activity thermogenesis, a much larger part of daily PA, may also contribute to obesity prevention[3,4]. Therefore, assessment of the type, quantity and intensity of PA is important for the development of strategies to prevent obesity and chronic diseases. However, accurate methods for the measurement of energy expenditures (EE) induced by various PA under free-living conditions are still under consideration.

At present, several methods are used for the measurement of EE in a field setting[5,6]. The doubly labelled water method displays high accuracy for the measurement of 24 h EE under free-living conditions. However, this method can only evaluate total EE and cannot provide day-to-day or minute-by-minute variations. Although questionnaires could individually measure PA intensity and EE (as value by intensity × time) in addition to the PA type, the accuracy of these methods is not sufficient[7]. On the other hand, accelerometers are objective, small, non-invasive tools for measuring PA intensity and EE, with the potential to measure locomotive

Abbreviations: ACC_{fil}, filtered synthetic acceleration; ACC_{unfil}, unfiltered synthetic acceleration; EE, energy expenditure; GRPACA, gravity-removal physical activity classification algorithm; MET, metabolic equivalent; PA, physical activity.

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as well as household activities[8–10]. Furthermore, activity monitors such as accelerometers or pedometers may serve as useful tools for promoting active life behaviour[11,12].

At the least, uniaxial and triaxial accelerometers can accurately estimate the intensity of ambulatory activities[13–15]. However, the intensities of household activities such as vacuuming and sweeping cannot be accurately estimated by accelerometers, possibly leading to underestimation of total EE by algorithms based on locomotive activities[14]. Indeed, different relationships between counts per minute and metabolic equivalents (MET) observed for locomotive *v.* household activities led to MET underestimation for household activities[13–15]. Time spent in sedentary and light activities is also underestimated by locomotion-based equations[16]. Therefore, accurate MET estimation for household and sedentary activities is required in addition to locomotive activity.

Recently, several studies have attempted to discriminate between PA types using accelerometer counts[17–26]. Although these algorithms have improved accuracy for estimating the MET of various activities compared with single regression models, some limitations remain: percentage of correct classification was slightly lower in some types of PA[21,22]; multiple sensors make it difficult to continuously wear the device on the body[26]; estimation is a complex procedure requiring large amounts of data, a barrier for applied researchers as well as for the general public. An accelerometer-based algorithm that accurately and immediately estimates PA intensity would be a useful tool for assessing PA in free-living conditions, as well as for promoting active life behaviour in general users. We have recently developed a simple but accurate algorithm for the classification of locomotive and household activities, using the ratio of unfiltered to filtered synthetic acceleration (ACC_{unfil}/ACC_{fil}) combined with a gravity-removal PA classification algorithm (GRPACA)[27]. A correct classification percentage of almost 100 % was achieved during our selected activities. Furthermore, we have confirmed the separation of sedentary activities from both locomotive and household activities by accelerometer counts. Therefore, the purpose of the present study was to develop a new model for instantly estimating the intensity of daily PA using a triaxial accelerometer.

Subjects and methods

Subjects

A total of sixty-six subjects (thirty-one males and thirty-five females) volunteered to participate in the present study. The present study was conducted according to the guidelines laid down in the Declaration of Helsinki, and all procedures involving human subjects were approved by the Ethical Committee of the National Institute of Health and Nutrition in Tokyo, Japan. Subjects were excluded from the study if they had any contraindications to exercise, or if they were physically unable to complete the activities. Descriptive characteristics of the study subjects are presented in Table 1. Subjects were randomly assigned into validation (*n* 44) and cross-validation (*n* 22) groups. Before measurement, the purpose

Table 1. Physical characteristics of the subjects in each group

(Mean values and standard deviations)

	Validation group*						Cross-validation group*						Total					
	Men (*n* 21)		Women (*n* 23)		All (*n* 44)		Men (*n* 10)		Women (*n* 12)		All (*n* 22)		Men (*n* 31)		Women (*n* 35)		All (*n* 66)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Age (years)	42·2	14·4	43·0	13·1	42·6	13·7	41·9	14·3	42·0	11·4	42·0	12·8	42·1	14·6	42·6	12·7	42·4	13·5
Height (cm)	170·2	5·8	159·3	5·4	164·5	7·8	170·2	7·5	156·9	5·2	162·9	9·2	170·2	6·5	158·5	5·5	164·0	8·4
Weight (kg)	68·3	15·1	55·6	9·8	61·6	14·1	68·2	11·9	54·9	7·6	61·0	11·8	68·3	14·3	55·3	9·2	61·4	13·4
BMI (kg/m^2)	23·4	4·2	21·9	3·7	22·6	4·0	23·4	3·2	22·3	2·9	22·8	3·1	23·4	4·0	22·0	3·5	22·7	3·7

*Subjects were randomly assigned into validation (67 %) and cross-validation (33 %) groups matched for age, height and weight.

and procedure of the study were explained in detail. Informed consent was signed by all subjects.

Anthropometric measurements

Before performing PA, body weight was measured by a digital scale to the nearest 0·1 kg, with the subjects dressed in light clothing. Barefoot standing height was measured to the nearest 0·1 cm using a wall-mounted stadiometer (YL-65S; Yagami, Nagoya, Japan). BMI was calculated as body weight (kg) divided by height squared (m^2).

Experimental protocol

Fasting subjects visited the laboratory in the morning of the experimental day. After anthropometric measurements, they performed fourteen activities with a facemask and Douglas bag while wearing a triaxial accelerometer on the left side of the waist. The selected activities were as follows: (1) sedentary activity – resting in the supine position as BMR, resting in the sitting position as RMR and personal computer work; (2) household activity – laundry, dishwashing, moving a small load (5 kg) and vacuuming; (3) locomotive activity – slow walking (3·3 km/h), normal walking (4·2 km/h), brisk walking (6·0 km/h), normal walking while carrying a bag (3 kg) in the hand, jogging (8·4 km/h) on a track, and ascending and descending stairs at personal normal speeds without using handrails. These activities were chosen as representative activities of daily life, based on our observations in a preliminary study using the activity records of other subjects. The subjects were permitted to consume only drinking-water during the experiment. They were instructed to lie down quietly for 30 min, and then BMR was measured for two periods of 10 min, followed by RMR measurement for 10 min. Subsequently, the other activities were performed for 3–7 min. The entire experimental protocol took each subject about 4·5 h to complete, and there was enough rest between activities to eliminate any carry-over effect from one activity to another. Each subject performed the experiment following the same schedule. The expired air for the subject in each activity was collected under a steady state. We defined the beginning of the steady state as 2–3 min after starting an activity, depending on the activity intensity[28]. This experimental protocol has previously been described in detail[27].

Indirect calorimetry

During each activity, the subject's expired air was collected in a Douglas bag. Expired O_2 and CO_2 gas concentrations were measured by MS (ARCO-1000; Arco System, Kashiwa, Japan), and gas volume was determined using a certified dry gas meter (DC-5; Shinagawa, Tokyo, Japan). For each measurement, the gas analyser was initially calibrated using a certified gas mixture and atmospheric air. EE was estimated from VO_2 and VCO_2 using Weir's equation[29]. MET values as reference were calculated as EE during the activities divided by the measured RMR.

Triaxial accelerometer

We used a triaxial accelerometer with 4 GB of memory consisting of Micro Electro Mechanical Systems-based accelerometers (LIS3LV02DQ; ST-Microelectronics, Geneva, Switzerland), which respond to both acceleration due to movement and gravitational acceleration. The sensor was built into a plastic case without a liquid crystal display and was designed to be clipped to a waist belt (size: 80 × 50 × 20 mm; weight: approximately 60 g including batteries). Anteroposterior (x-axis), mediolateral (y-axis) and vertical (z-axis) acceleration measurements were obtained during each activity at a rate of 32 Hz to 12 bit accuracy. The range of the acceleration data of each axis is ±6 G, resulting in a resolution of 3 mG. The acceleration data were uploaded to a personal computer.

The signals obtained from the triaxial accelerometer were processed in the following way. Each of the three signals from the triaxial accelerometer was passed through a high-pass filter with a cut-off frequency of 0·7 Hz, in order to remove the gravitational acceleration component from the signal. We calculated the synthetic acceleration of all three axes (vector magnitude $\sqrt{x^2+y^2+z^2}$) using signals before and after high-pass filtering. Then, the ratio of ACC_{unfil} to ACC_{fil} was calculated. The acceleration signals, calculated as the average of the absolute value of the accelerometer output of each axis from 10 s epochs at the middle of each activity, were processed to various acceleration output variables. In our previous study, we reported the algorithm for the classification of household and locomotive activities by the ACC_{unfil}:ACC_{fil} ratio which resulted in almost 100 % correct demarcation for our eleven selected activities[27].

A commercial product (Activity Style Pro HJA-350IT; Omron Healthcare, Kyoto, Japan) has been developed from the prototype accelerometer that we made in the present study. This commercial device measures 74 × 46 × 34 mm and weighs 60 g, including batteries. The liquid crystal display in this device has several modes that provide different types of information: (1) a research mode that provides no information; (2) a mode that displays step counts; (3) a mode that displays real-time MET intensity. Both devices are shown in Fig. 1.

Statistical analysis

All values are presented as means and standard deviations. Differences are considered to be statistically significant if the P value is less than 0·05. The relationship between measured MET and the ACC_{fil} count in the validation group was evaluated by Pearson's correlation coefficient (r) and the standard error of the estimate. Linear and non-linear regression models were used in the validation group to develop equations to predict MET based on the intensity of PA, as measured by the ACC_{fil} count. Differences between measured and estimated MET in the cross-validation group were assessed by one-way ANOVA followed by Dunnett's *post hoc* test or a paired t test. Bland–Altman plots were used to graphically show the variability in individual error scores in the cross-validation group[30]. All statistical analyses were

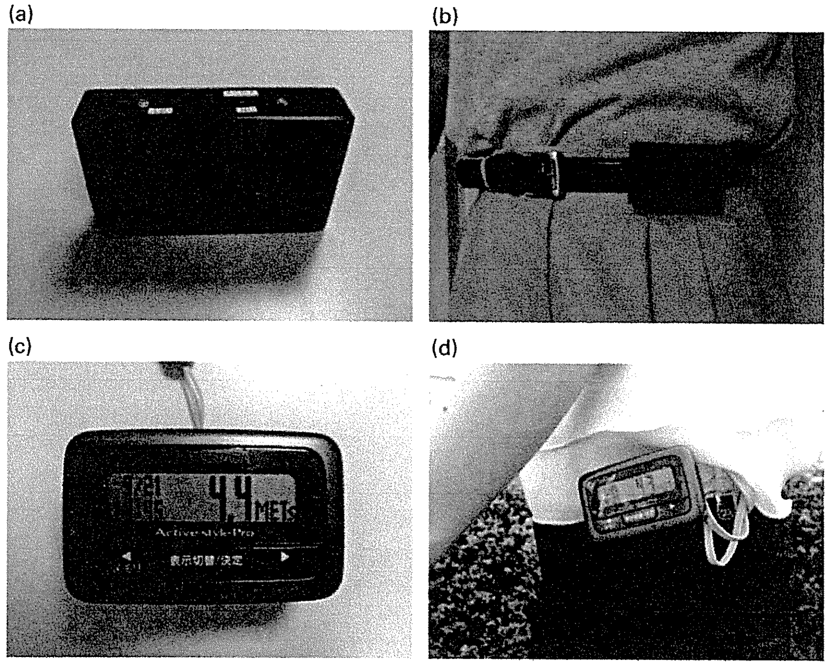

Fig. 1. Prototype accelerometer used in the present study and a commercial accelerometer based on the algorithm developed in the present study. (a) Prototype accelerometer that was used to perform all measurements; (b) subjects wore the prototype accelerometer on the waist with a clip during the entire protocol; (c) commercial accelerometer based on the algorithm that was developed in the present study; (d) real-time metabolic equivalents (MET) are shown on the liquid crystal display (LCD) of the commercial accelerometer (the LCD can also show step counts).

Table 2. Energy expenditure, metabolic equivalents (MET), accelerations and acceleration ratios for each activity in the validation group
(Mean values and standard deviations, *n* 44)

	Energy expenditure (kJ/min)		MET*		MET†		Unfiltered synthetic acceleration (mG)		Filtered synthetic acceleration (mG)		Ratio of unfiltered synthetic acceleration to filtered synthetic acceleration	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Light activity												
Resting in the sitting position (*n* 44)	4·142	0·79	–		–		5·6	1·8	2·6	0·6	2·15	0·63
Resting in the supine position (*n* 44)	3·765	0·79	0·91	0·05	0·89	0·10	4·6	2·4	2·1	0·7	2·14	0·88
Personal computer work (*n* 42)	4·602	1·00	1·12	0·08	1·08	0·12	10·2	3·7	5·7	1·7	1·80	0·37
Household activity												
Laundry (*n* 44)	9·706	2·59	2·34	0·37	2·26	0·31	154·1	38·4	50·2	11·5	3·11	0·57
Dishwashing (*n* 43)	7·614	2·01	1·84	0·34	1·77	0·30	56·8	17·9	26·3	6·7	2·20	0·64
Moving a small load (*n* 44)	18·32	4·98	4·40	0·68	4·27	0·63	360·5	51·9	157·1	21·5	2·32	0·35
Vacuuming (*n* 42)	12·34	3·01	2·97	0·52	2·88	0·53	153·2	34·3	82·8	24·9	1·92	0·39
Locomotive activity												
Slow walking (*n* 44)	13·01	3·39	3·12	0·45	3·03	0·42	245·5	47·4	240·1	48·1	1·02	0·02
Normal walking (*n* 44)	15·22	3·81	3·67	0·55	3·56	0·49	320·8	48·7	313·8	48·7	1·02	0·02
Brisk walking (*n* 44)	19·53	5·10	4·70	0·76	4·56	0·75	428·4	69·6	426·8	72·2	1·01	0·02
Walking while carrying a bag (*n* 44)	17·90	4·14	4·33	0·60	4·20	0·59	361·5	51·8	355·7	51·9	1·02	0·02
Jogging (*n* 44)	39·24	9·37	9·42	0·98	9·16	1·18	974·2	118·6	954·0	116·7	1·02	0·02
Ascending stairs (*n* 39)	31·54	6·86	7·64	0·75	7·32	0·61	232·4	29·5	220·1	29·1	1·06	0·04
Descending stairs (*n* 41)	13·38	3·31	3·20	0·44	3·09	0·42	287·9	50·6	277·2	49·4	1·04	0·02

* MET were calculated as energy expenditure for each activity divided by energy expenditure for resting in the sitting position.
† MET were calculated as energy expenditure for each activity divided by 4·184 kJ/kg per h.

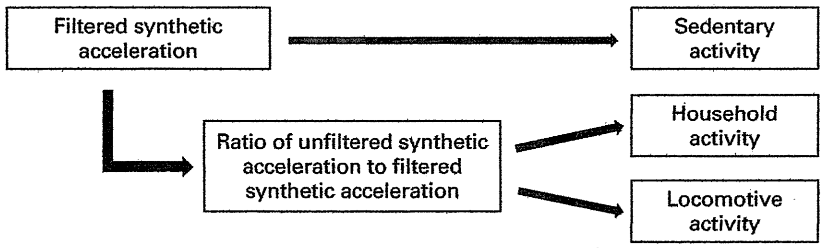

Fig. 2. Algorithm for the classification of three different activity types, using a triaxial accelerometer.

performed using SPSS version 15.0J for Windows (SPSS, Inc., Chicago, IL, USA).

Results

Data collected during the present study were analysed if both MET and ACC could be correctly measured during each activity. Mean EE, MET, ACC_{unfil}, ACC_{fil} and the ACC_{unfil}:ACC_{fil} ratio for each activity are shown in Table 2. As suggested previously[16], the one-regression models overestimate MET for light activity; we observed a similar result (data not shown). Therefore, we modelled the classification of our selected activities into three types of activities: sedentary, household and locomotive (Fig. 2). Sedentary activities are discriminated from household and locomotive activities, because ACC_{fil} for sedentary activities was lower than for other activities. Household and locomotive activities are classified by the ACC_{unfil}:ACC_{fil} ratio according to our previous study (1·16)[27].

Fig. 3 depicts the relationship between measured MET and ACC_{fil} during household and locomotive activities performed by the validation group. The correlation coefficients for locomotive (r 0·961, $P<0·001$), household (r 0·907, $P<0·001$) and combined household and locomotive activities (r 0·930, $P<0·001$) were high. We developed linear and non-linear regressions for estimating the intensities of household and locomotive activities; ascending and descending stairs were excluded from developing regressions, because the relationships between MET and ACC_{fil} for ascending and descending stairs differed from the relationship for the other locomotive activities (Table 3). As a result, the linear regression calculated

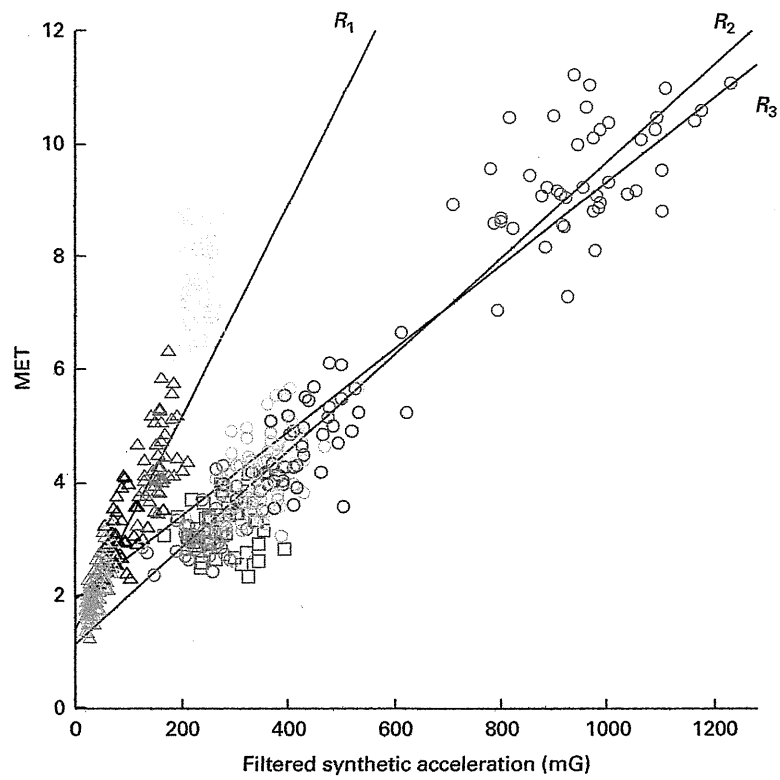

Fig. 3. Relationships between measured metabolic equivalents (MET) and filtered synthetic accelerations during locomotive and household activities in the validation group (n 44). R_1 (r 0·907, $P<0·001$), regression line for household activities only; R_2 (r 0·930, $P<0·001$), regression line for combined household and locomotive activities; R_3 (r 0·961, $P<0·001$), regression line for locomotive activity only. Ascending and descending stairs were removed from the regression analyses for R_1, R_2 and R_3. △, Laundry; △, dishwashing; △, moving a small load; △, vacuuming; ○, slow walking; ○, normal walking; ○, brisk walking; ○, walking while carrying a bag; ○, jogging; , ascending stairs; □, descending stairs.

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Table 3. Equations for estimating metabolic equivalents (MET) in locomotive and household activities by using filtered synthetic acceleration (ACC_{fil}, mG) in the validation group (*n* 44)

(*r* Values and standard errors of the estimate (SEE))

	Equation	*r*	SEE (MET)
Linear regression model			
Model 1			
Locomotive plus household activities	$MET = 1.9494 + 0.0074 \times ACC_{fil}$	0·930*	0·804
Model 2			
Locomotive activity only	$MET = 1.1372 + 0.0085 \times ACC_{fil}$	0·961*	0·658
Household activity only	$MET = 1.4023 + 0.0188 \times ACC_{fil}$	0·907*	0·460
Non-linear regression model			
Model 3			
Locomotive activity only	$MET = 0.8944 + 0.0126 \times ACC_{fil}^{0.947}$	0·961*	0·657
Household activity only	$MET = 0.8149 + 0.1014 \times ACC_{fil}^{0.701}$	0·910*	0·453
Sex-specific linear regression model			
Model 4			
Locomotive activity only (male)	$MET = 0.8766 + 0.0088 \times ACC_{fil}$	0·968*	0·634
Locomotive activity only (female)	$MET = 1.3488 + 0.0083 \times ACC_{fil}$	0·955*	0·658
Household activity only (male)	$MET = 1.4022 + 0.0181 \times ACC_{fil}$	0·911*	0·446
Household activity only (female)	$MET = 1.3951 + 0.0195 \times ACC_{fil}$	0·907*	0·470
Sex-specific non-linear regression model			
Model 5			
Locomotive activity only (male)	$MET = 0.6714 + 0.0120 \times ACC_{fil}^{0.959}$	0·968*	0·633
Locomotive activity only (female)	$MET = 0.5367 + 0.0284 \times ACC_{fil}^{0.834}$	0·956*	0·654
Household activity only (male)	$MET = 1.3172 + 0.0254 \times ACC_{fil}^{0.939}$	0·911*	0·445
Household activity only (female)	$MET = 0.2828 + 0.2393 \times ACC_{fil}^{0.563}$	0·915*	0·451

* $P<0.001$.

with combined data of household and locomotive activities had a lower *r* value compared with all other regressions for locomotive activities only. Regressions for only household activities had slightly lower *r* values than those for all activities, but the regression standard errors of estimate were improved. Table 4 shows the cross-validation for all regressions. Significant differences were observed between measured values and values estimated from model 1 for most activities. However, models 2–5 accurately estimated the intensity of most household and locomotive activities, with the exceptions of ascending and descending stairs from models 2–5 and normal walking from models 2, 4 and 5, although the differences for normal walking were relatively small. In the cross-validation group, household and locomotive activities were correctly classified 100 % of the time by the ACC_{unfil}:ACC_{fil} threshold reported previously[27]. Bland–Altman plots showed that there was improved accuracy of individual activities with models 2–5 compared with model 1 (Fig. 4). Although all models tended to underestimate higher vigorous intensity activity with significant r^2 values ($P<0.05$), household activities were clearly well estimated by models 2–5. The results of the present study remained consistent, whether estimated from linear or non-linear regressions or from sex-specific regressions.

Fig. 5 depicts the relationship between measured MET and ACC_{fil} during sedentary activities performed by the validation group. We selected three activities to represent sedentary activities. As shown in Fig. 5, we calculated the regression equation for estimating the intensity of sedentary activities by including dishwashing with the lowest MET on average in our selected household and locomotive activities. The threshold for the classification between sedentary activities and other activities was determined by the point of intersection in the linear regressions for sedentary activities and household activities (29·9 mG). With these threshold and regression equations, resting in the supine position (mean difference 0·04 (SD 0·06) MET, $P<0.01$), personal computer work (mean difference −0·03 (SD 0·09) MET, NS) and dishwashing (mean difference 0·02 (SD 0·31) MET, NS) were estimated adequately in the cross-validation group.

Final model for estimating intensity of physical activity (n 66)

If $29.9\,\text{mG} > ACC_{fil}$,

$$\text{Sedentary activity: } MET = 0.8823 + 0.0351 \times ACC_{fil}.$$

If $29.9\,\text{mG} \leq ACC_{fil}$,

Then if $1.16 \leq ACC_{unfil} : ACC_{fil}$ ratio.

$$\text{Household activity: } MET = 1.3435 + 0.0196 \times ACC_{fil}.$$

Else if $1.16 > ACC_{unfil} : ACC_{fil}$ ratio.

$$\text{Locomotive activity: } MET = 1.1128 + 0.0086 \times ACC_{fil}.$$

Discussion

We have developed a new model to estimate the intensity of daily PA, using a triaxial accelerometer in combination with a novel PA classification algorithm. We classified PA into

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Table 4. Absolute and percentage of differences between measured and estimated metabolic equivalents (MET) from five equation models for household and locomotive activities in the cross-validation group

(Mean values and standard deviations, *n* 22)

	Model 1†				Model 2‡				Model 3§				Model 4‖				Model 5¶			
	Absolute difference		% Difference		Absolute difference		% Difference		Absolute difference		% Difference		Absolute difference		% Difference		Absolute difference		% Difference	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Laundry (*n* 22)	0·12	0·33	8·3	16·0	0·07	0·30	5·3	14·4	0·09	0·30	6·0	14·4	0·07	0·30	5·4	14·6	0·09	0·31	6·1	15·0
Dishwashing (*n* 21)	0·36	0·27	23·7***	21·3	0·11	0·27	9·0	19·1	0·03	0·29	3·8	19·6	0·11	0·27	8·8	19·0	0·03	0·31	3·9	20·6
Moving a small load (*n* 22)	−1·46	0·72	−30·4***	10·3	−0·22	0·69	−3·0	14·4	−0·25	0·70	−3·5	14·3	−0·22	0·72	−2·7	14·8	−0·23	0·72	−2·9	14·7
Vacuuming (*n* 22)	−0·46	0·73	−10·4**	19·7	−0·05	0·64	3·0	22·2	0·04	0·64	6·2	23·0	−0·05	0·64	3·1	21·9	0·04	0·65	6·0	22·4
Slow walking (*n* 21)	0·63	0·42	21·5***	14·8	0·10	0·45	4·2	14·6	0·07	0·47	3·2	15·0	0·12	0·41	4·8	13·6	0·06	0·44	2·9	14·3
Normal walking (*n* 21)	0·67	0·48	19·8***	15·1	0·23	0·50	7·6*	14·3	0·22	0·50	7·4	14·4	0·22	0·48	7·4*	13·7	0·23	0·48	7·7*	14·0
Brisk walking (*n* 22)	0·34	0·70	9·1	15·7	0·03	0·72	2·4	15·1	0·04	0·72	2·6	15·2	0·04	0·69	2·5	14·7	0·09	0·69	3·6	15·0
Walking while carrying a bag (*n* 22)	0·34	0·59	9·8*	15·3	−0·06	0·61	0·1	14·6	−0·06	0·61	0·1	14·7	−0·06	0·57	0·1	13·8	−0·03	0·58	0·7	14·1
Jogging (*n* 20)	−0·50	1·39	−3·8	13·9	−0·18	1·44	−0·4	14·9	−0·23	1·43	−0·9	14·7	−0·17	1·42	−0·3	14·7	−0·19	1·38	−0·6	14·3
Ascending stairs (*n* 19)	−4·13	0·78	−53·3***	4·9	−4·69	0·78	−60·6***	4·5	−4·73	0·78	−61·2***	4·6	−4·68	0·81	−60·5***	4·8	−4·75	0·80	−61·4***	4·7
Descending stairs (*n* 20)	1·13	0·73	40·7***	30·0	0·68	0·78	25·6**	29·2	0·66	0·79	25·1**	29·5	0·70	0·79	26·2**	28·9	0·69	0·81	26·1**	29·6

Mean values were significantly different compared with measured MET: $^{*}P<0·05$, $^{**}P<0·01$, $^{***}P<0·001$.
† Linear regression model for estimating locomotive and household activities together.
‡ Linear regression model for estimating locomotive and household activities separately.
§ Non-linear regression model for estimating locomotive and household activities separately.
‖ Sex-specific linear regression model for estimating locomotive and household activities separately.
¶ Sex-specific non-linear regression model for estimating locomotive and household activities separately.

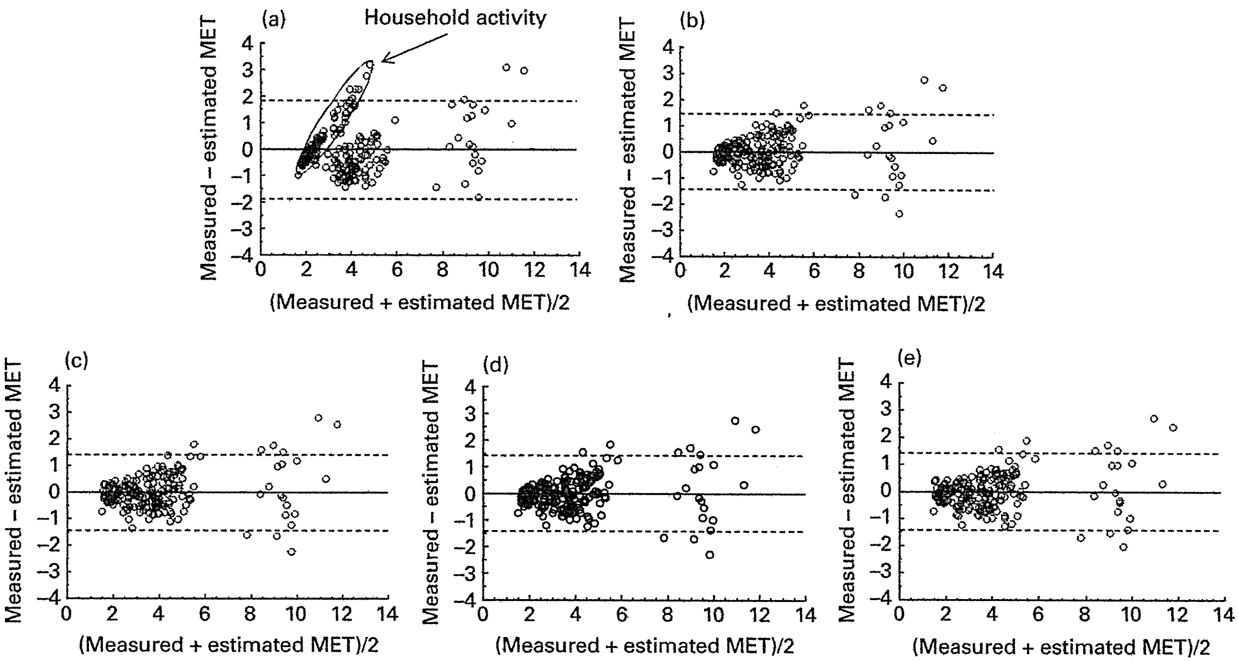

Fig. 4. Bland–Altman analysis. Differences between measured and estimated metabolic equivalents (MET) are plotted against measured and estimated mean MET for household and locomotive activities. (a) Model 1, linear regression model for estimating locomotive and household activities together (r 0·237); (b) model 2, linear regression model for estimating locomotive and household activities separately (r 0·207); (c) model 3, non-linear regression model for estimating locomotive and household activities separately (r 0·219); (d) model 4, sex-specific linear regression model for estimating locomotive and household activities separately (r 0·212); (e) model 5, sex-specific non-linear regression model for estimating locomotive and household activities separately (r 0·207). —, Mean; - - -, 95 % CI of the observations.

locomotive, household and sedentary activities with thresholds determined by the ACC_{unfil}:ACC_{fil} ratio (GRPACA) or accelerometer counts[27]. The rate of correct classification was excellent: 100 % of the activities performed by our subjects were correctly classified as locomotive or household. With our new classification algorithm, the regressions clearly improved the accuracy of estimating the intensity of various PA, compared with a non-classification model. This novel method is capable of estimating the intensity of PA accurately and immediately, serving as a practical field tool for researchers as well as for general users.

In agreement with previous studies[18–21,31], we observed that the multiple equation model improved the accuracy of estimating household and locomotive activity intensities, compared with the one-equation model; accuracy improvements occurred for household activities in particular. With the exceptions of ascending and descending stairs, average percentage differences were within 10 % in the two-equation model, with more than 10 % differences in several activities in the one-equation model. Furthermore, we attempted to estimate the intensity of PA with non-linear regression and sex-specific regression (or non-regression) models. Prediction errors obtained from the linear and non-linear regression models were comparable in the present study (Table 4). While it is still controversial whether the linear or non-linear regression model is a better predictive model[8], inclusion of the GRPACA did not necessitate non-linear or sex-specific regression equations. To our knowledge, there is no evidence of a quadratic relationship between MET and accelerometer counts in various PA. Therefore, the linear regression model may obtain comparable predictions as the non-linear regression model in the present study, under actual free-living conditions. Furthermore, the sex-specific equation model did not provide a more accurate estimation (Table 4), indicating that we have developed new equations by linear regressions without taking sex into account.

Accurate estimation of sedentary activities is important, as many people perform sedentary activities at least several hours/d[32,33]. Previously developed accelerometer-based models overestimate the intensity of sedentary activities[16]. In the present study, sedentary activities clearly had lower accelerometer counts than other activities. Initially, we hypothesised that the cut-off threshold between intensities of sedentary and other activities should be the midpoint of the highest sedentary accelerometer count and the lowest accelerometer count from the other activities. However, in the present study, we observed a small gap between sedentary and household activities in the relationship between MET and ACC_{fil}. Therefore, we developed the equation for sedentary activities by including dishwashing, which displayed the lowest accelerometer counts of our household or locomotive activity. Using this consideration, activities about 1·5 MET could be estimated accurately. Therefore, we have classified an activity of less than 2 MET as a sedentary activity, using a cut-off threshold determined by accelerometer counts.

Although PA intensity estimates were improved with our model, we could not directly compare the present results with previously reported models designed for data collecting