Paper

Gender effect on accuracy of Lifecorder EX during walking and running

Shinji TAKAHASHI[*1] Koya SUZUKI[*1] Yudai YOSHIDA[*2] Yosuke SAKAIRI[*2] and Tomohiro KIZUKA[*2]

*1 Faculty of Liberal Arts, Tohoku Gakuin University
2-1-1 Tenjinzawa, Izumi-ku, Sendai, Miyagi, 981-3193 Japan
shinji@izcc.tohoku-gakuin.ac.jp
*2 Graduate School of Comprehensive Human Science, University of Tsukuba

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Lifecorder EX (LC) is a useful accelerometer to assess physical activity, but its accuracy has not been assessed sufficiently: the effect of gender on LC accuracy remains unclear. This study was undertaken to examine gender effects on the LC accuracy to estimate the metabolic equivalent (MET) and LC accuracy during walking and running. The 45 healthy Japanese participants (23 male, 22 female) examined in this study were divided into two groups: a calibration group (16 male, 14 female) and a cross-validity group (7 male, 8 female). The participants performed 5 min of treadmill walking at 3.6, 4.8, and 6.0 km•h^{-1}, and treadmill running at 7.2 and 9.6 km•h^{-1}. The LC was placed on the waist. Simultaneous measurements obtained using the LC and an indirect calorimeter (IC) were recorded continuously during exercises. The gender effect was analyzed from data of the calibration group using mixed models. The LC accuracy was assessed with the cross-validation group using three-way repeated ANOVA models and root mean squared error (RMSE). In the calibration group, the results of mixed models revealed that the gender had no influence on the relationship between the IC measurements and the LC estimates (p > 0.577). In the cross-validation group, although no significant difference was found between the IC measurements and the LC estimates at any treadmill speed (p > 0.061), RMSE at running speeds (7.2 and 9.6 km•h^{-1}) rapidly increased more than those during walking. The results suggest that the LC can assess MET of men and women accurately, but the LC was unable to estimate MET during running.

Key words : Physical activity, accelerometer, validation, MET, mixed models

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1. Introduction

To simplify the objective assessment of physical activity during daily living, many motion monitors have been developed to measure the acceleration of body movement (Campbell et al., 2002; Eston et al., 1998; Freedson et al., 1998; Kumahara et al., 2004; Rowlands et al., 2004). Lifecorder EX (LC; Suzuken Co. Ltd., Nagoya, Japan) is a uniaxial accelerometer. The LC is one of the most popular devices used in sports- and exercise-related fields of Japanese research (Ayabe et al., 2004; Higuchi et al., 2003). This device classifies activity intensity into 11 levels (activity levels 0, 0.5, 1, 2, 3, 4, 5, 6, 7, 8, and 9) based on the detected vertical acceleration. According to the manufacturer's default settings, activity levels 0–0.5 represent sedentary activity, activity levels 1–3 represent light activity (< 3.0 metabolic equivalents; MET), activity levels 4–6 represent moderate activity (3.0–6.0 MET), and activity levels 7–9 represent vigorous activity (> 6.0 MET). The LC computes step counts, total, and activity-related energy expenditure every 4 s. Moreover, it summarizes those records every 2 min. These data are stored in internal memory for 200 days, and can be downloaded to a personal computer. Additionally, users can immediately access the data from the last 7 days directly on the LC display without downloading. These functions provide useful information to both users and researchers.

Although previous results of studies have suggested that the LC is a useful device for physical activity assessment (Abel et al., 2008; Crouter et al., 2003; Kumahara et al., 2004), some aspects of the LC remain unclear. Abel et al. (2008) reported that the LC systematically overestimated women's physical activity energy expenditure (kcal•kg^{-1}• min^{-1}). Abel et al. were unable to reveal the cause of the systematic gender difference because the estimation algorithm of the LC is considered proprietary information of the manufacturer, and is therefore confidential.

The unit an accelerometer records is generally counts per minute, as calculated using an algorithm for integrating raw acceleration. It is characterized by dynamic range, sampling interval, sampling frequency, and frequency response (Chen and Bassett, 2005; Ridgers and Fairclough, 2011). Therefore, it is possible to consider which accelerometers have what positive and negative features. However, the unit used for the LC, activity levels, is unique. For that reason, we cannot discern details of handling of the raw data and estimation method of the LC. To date, only one reported study has calibrated the relationship between measured MET and the LC outputs (Kumahara et al., 2004). Kumahara et al. demonstrated that the calibration equation used to estimate MET by the LC outputs was accurate. However, this previous study had several limitations. First, all participants in the study were men. Second, a small sample size was tested ($N = 10$). If gender influences the relationship between MET and the LC, as Abel et al. (2008) reported, then the calibration equations for MET and LC of men and women should be done separately. This study was designed to examine the gender differences to the relationship between MET and the LC during walking and running by calibrating the relationship of MET and the LC. We then assess the LC accuracy to estimate MET.

2. Methods

2.1. Participants

We recruited voluntary participants from a population of staffs, undergraduate students and graduate students at a Tohoku Gakuin University. This study finally examined 45 healthy Japanese participants (23 male, 22 female). The participants were asked to refrain from alcohol use and strenuous physical activity for 24 h before exercise tests, and from food or caffeine during the 2 h preceding the experiments. Written informed consent was obtained from all participants before exercise tests. The study protocol was approved by the Human Subjects Committee of Tohoku Gakuin University. We divided the participants randomly into two groups: one group was the calibration group and the other was the cross-validation group. For the assignment of the two groups, we had designed so that the calibration group had the larger sample size than the cross-validation group because the dataset of the calibration group would be used to calculate a calibration model. Finally, a number of the calibration group was 30 participants (16 male, 14 female) and a number of the cross-validation group was 15 participants (7 male, 8 female). Table 1 presents characteristics of the participants. Differences of characteristics between the two groups were not significant.

2.2. Exercise test protocol

Each participant visited our exercise laboratory

Table 1. Participant characteristics (mean±SD).

Group	Gender	Age (y)	Height (cm)	Weight (cm)	BMI (kg•m^{-2})
Calibration	male ($N = 16$)	23.5±2.8	171.4±4.7	66.5±8.9	22.5±2.1
($N = 30$)	female ($N = 14$)	20.5±1.4	161.2±6.7	51.6±5.0	19.9±1.9
Cross-validation	male ($N = 7$)	22.0±1.6	173.8±6.2	66.5±8.1	22.0±2.3
($N = 15$)	female ($N = 8$)	22.0±3.7	158.3±5.3	52.2±7.9	20.8±2.1
Total	male ($N = 23$)	23.0±2.6	172.2±5.3	66.5±8.6	22.4±2.1
($N = 45$)	female ($N = 22$)	21.1±2.5	160.1±6.4	51.8±6.2	20.2±2.0

Note: BMI= body mass index. No significant difference of characteristics was found between the calibration group and cross-validation group.

1.5 h before the exercise test began. After height and weight measurements, participants were familiarized with a motor-driven treadmill (O2road; Takei Scientific Instruments Co. Ltd., Niigata, Japan) for 3 min at 3.6 km•h^{-1}. Participants then took a rest for over 30 min in a comfortable chair until their oxygen uptake ($\dot{V}O_2$) returned to baseline (less than 5.0 ml•kg^{-1}•min^{-1}).

Participants then completed an exercise test on the treadmill (horizontal slope). The protocol of the exercise test consisted of five speeds (3.6, 4.8, 6.0, 7.2, and 9.6 km•h^{-1}). We instructed participants to walk at 3.6, 4.8, and 6.0 km•h^{-1} and run at 7.2 and 9.6 km•h^{-1}. Participants walked or ran at each speed for 5 min: intervals of 3 min rest were provided between each period of walking or running. The participants were connected to an indirect calorimeter (IC; MetaMax-3B; Cortex, Leipzig, Germany) via a facemask. $\dot{V}O_2$ was measured continuously throughout the familiarization and exercise test.

2.3. Lifecorder EX

The LC, which weighs 60 g, is 7.25 cm wide × 4.15 cm high × 2.75 cm long. During recording, the LC samples vertical acceleration with a sampling frequency of 32 Hz, using a ceramic piezoelectric uniaxial accelerometer. The dynamic range of the accelerometer is 0.06–1.94 G. The accelerometer signal proceeds through an analogue band pass filter. It is then digitized. Maximum acceleration greater than 4 s is recorded as activity intensity, and activities were categorized into 11 activity levels. The LC was placed on the non-dominant (e.g. right-handed participants wore the devise on the left waist) in line with the anterior superior iliac spine of each participant.

2.4. Indirect calorimeter

MetaMax-3B measurements were used as validity criteria. We calibrated the IC before each test according to the manufacturer's guidelines. The turbine flow meter (range: 0.05–2.00 l•s^{-1}) was calibrated with a 3.0 l calibration syringe, and the O_2 and CO_2 analyzers were calibrated with room air and a calibration gas of known O_2 (15.94%) and CO_2 (3.97%) composition. Reportedly, the IC device significantly overestimated $\dot{V}O_2$ by approximately 4% compared with the Douglas bag measurement (Vogler, Rice, & Gore, 2010). Therefore, we corrected $\dot{V}O_2$ by multiplying the IC measurements by 0.961. The breath-by-breath data were averaged every 30 s. MET was calculated by dividing the $\dot{V}O_2$ by 3.5. The IC was attached to the chest by a harness.

2.5. Data reduction

The internal clocks of the IC and LC were initialized and set to standard time before each test. All measurements were converted to a synchronized unit time of 1 min. The LC activity levels, recorded every 4 s, and the IC, recorded every 30 s, were averaged for 1 min. To ensure the steady state of the measures of MET and LC activity levels, averaged data from the last 2 min (4 and 5 min) at each speed were calculated. We then checked the respiratory exchange ratio (RER). The averaged MET at RER > 1.0 were excluded from statistical analyses. These averaged MET and LC activity levels were then used for additional analyses.

2.6. Statistical analysis

Statistical analyses were performed using SPSS 16.0 (SPSS Inc., Chicago, IL). First, we calibrated the relationship between the LC measurements and MET by the IC using by calibration group data. MET were characterized in three separate models, as shown below.

Model 1: $y_{ij} = \beta_0 + \beta_1 x^2_{ij} + \beta_2 x_{ij} + b_i x_{ij} + e_{ij}$ (1)

Model 2: $y_{ij} = \beta_0 + \alpha + \beta_1 x^2_{ij} + \beta_2 x_{ij} + b_i x_{ij} + e_{ij}$ (2)

Model 3: $y_{ij} = \beta_0 + \alpha + \beta_1 x^2_{ij} + \beta_2 x_{ij} + \alpha\beta_1 x^2_{ij} + \alpha\beta_2 x_{ij} + b_i x_{ij} + e_{ij}$ (3)

Therein, y_{ij} represents MET for the jth observation on the ith participant, x is the LC (activity level) as a continuous variable, α is the main effect of gender as a dichotomous variable (male, female), β_0, β_1, and β_2 respectively represent the intercept and slopes of x and x^2, $\alpha\beta_1 x^2$ and $\alpha\beta_2 x$ are interactions of gender and x^2 and x, b_i denotes each participant's random slope deviation, and e_{ij} is the random error. Parameters were estimated using the restricted maximal likelihood method.

Model 1 includes the assumption that gender did not affect the relationship between MET and LC. Model 2 includes the assumption that gender accounts for the relationship between MET and LC as a constant difference. Model 3 includes the assumption that constant differences and different slopes of the LC to MET exist according to gender. Three models were compared using -2 log likelihood (-2 LL) and Akaike's information criterion (AIC) (Heck et al., 2010). The model with highest goodness-of-fit among the three models was chosen as the calibration model of the LC.

Cross-validity of the calibration model was tested using the cross-validation group. Estimates and measurements were compared using a three-way ANOVA model in mixed models, in which the response variable was MET and the explanatory variables were method (IC and LC), gender (male and female), speed (5 levels), various interactions (method•gender, method•speed, gender•speed, and method•gender•speed), and the random intercept for each participant. If any interaction related to gender was significant, then we examined the influence of gender using a two-way ANOVA model in mixed models. Explanatory variables were the measurement method and the gender for each speed as a post hoc analysis. Similarly, if any interaction related to speed was found to be significant, then we examined the differences between the IC and the LC using paired *t*-tests for each speed. The significance level for the three-way ANOVA model was $p = 0.050$, and alpha levels of each post hoc analysis were $p < 0.0083$ (0.050/6) adjusted using Bonferroni correction. We also calculated the root mean squared error (RMSE) at each speed to verify the biases of the error.

3. Results

3.1. Calibration model

Table 2 shows mean and standard deviations of the MET by the IC and the LC activity levels for the calibration group. Two failures occurred during exercise tests. One case was that of a man at 7.2 km•h^{-1}: a sampling tube of the IC became disconnected form the facemask while he was running. The other case was that of a woman at 9.6 km•h^{-1}: she was unable to continue running because of exhaustion.

Table 3 presents the results of the three calibration models. For Model 1, LC^2 ($F_{1,\ 146.5} = 50.1$, $p < 0.001$) and LC ($F_{1,\ 168.6} = 48.2$, $p < 0.001$) were significantly correlated with MET. Similarly, for Model 2, LC^2 ($F_{1,\ 145.8} = 50.0$, $p < 0.001$) and LC ($F_{1,\ 167.7} = 47.9$, $p < 0.001$) were significant, but no significant influence of gender ($F_{1,\ 173.4} = 0.3$, $p = 0.577$) was found. For Model 3, although LC^2 ($F_{1,\ 144.4} = 49.6$, $p < 0.001$) and LC ($F_{1,\ 164.4} = 47.2$, $p < 0.001$) were significant, gender ($F_{1,\ 144.0} = 0.1$, $p = 0.819$) and two interactions (gender•LC^2, $F_{1,\ 144.4} = 0.0$, $p = 0.850$; gender•LC, $F_{1,\ 164.4} < 0.1$, $p = 0.846$) were not significant.

Comparing the -2 LL of each model revealed that Model 1 and Model 2 fit the data better than Model 3 did (Model 1 vs. Model 3, $p < 0.001$; Model 2 vs. Model 3, $p = 0.010$). The difference of -2 LL of Model 1 and Model 2 was not significant ($p = 0.242$). AIC of Model 1 was smaller than those of Model 2 and Model 3. Therefore, we selected Model 1 as the calibration model, written as the following.

$$MET = 1.007 + 0.048 \cdot LC^2 + 0.508 \cdot LC \quad (4)$$

The adjusted coefficient of determination of the model was 0.86 and standard error of the estimate was 0.99 MET.

3.2. Cross-validity

Two samples of data for women at 9.6 km•h^{-1} were excluded from analyses because the RER of these samples were higher than 1.0. Figure 1 shows the changes of the IC and the LC against treadmill speeds for each gender. For the cross-validation group data, the coefficient of

Table 2. Means ± SD for the indirect calorimeter and the Lifecorder EX of the calibration group; results are shown separately for each speed and gender.

Items	Gender	0.0 km•h^{-1} (M = 16; F = 14)	3.6 km•h^{-1} (M = 16; F = 14)	4.8 km•h^{-1} (M = 16; F = 14)	6.0 km•h^{-1} (M = 16; F = 14)	7.2 km•h^{-1} (M = 15; F = 14)	9.6 km•h^{-1} (M = 16; F = 13)
IC (MET)	Male	1.2 ± 0.3	3.0 ± 0.6	3.7 ± 0.7	4.9 ± 1.1	7.1 ± 1.3	9.3 ± 1.8
	Female	1.3 ± 0.4	3.4 ± 0.7	4.1 ± 0.9	5.6 ± 1.2	7.7 ± 1.4	9.4 ± 1.3
LC (activity levels)	Male	0.3 ± 0.2	2.5 ± 0.3	3.8 ± 0.5	5.0 ± 0.5	7.7 ± 0.4	8.1 ± 0.4
	Female	0.4 ± 0.2	2.9 ± 0.6	4.3 ± 0.5	5.5 ± 0.4	7.7 ± 0.4	8.5 ± 0.3

Note: IC = indirect calorimeter; LC = Lifecorder EX. Values in parentheses under speeds represent sample sizes for each speed.

determination was 0.77 and standard error of the estimate was 1.30 MET. The results of a three-way ANOVA revealed that the main effect of speed ($F_{5, 141.1} = 585.9$, $p < 0.001$) and the interaction of method and speed ($F_{5, 141.1} = 2.8$, $p = 0.018$) were significant, although main effects of method ($F_{1, 141.1} = 1.7$, $p = 0.199$) and gender ($F_{1, 13.0} = 2.4$, $p = 0.144$), and interactions of method and gender ($F_{1, 141.1} = 0.8$, $p = 0.386$), gender and speed ($F_{5, 141.1} = 0.9$, $p = 0.513$), and method•gender•speed ($F_{5, 141.1} = 0.4$, $p = 0.841$) were not significant.

Based on the ANOVA results, we compared the LC with the IC using paired *t*-tests for each speed. Table 4 presents the IC measurements and the LC estimations at each speed and gender. No significant difference was found at any speed ($|t_{14}| \leq 2.0, p \geq 0.061; t_{12} = 0.6, p = 0.538$ at 9.6 km•h^{-1}). Table 4 also shows RMSE, which gradually increased as the walking speed increased. Then it rapidly increased to more than 1.00 MET during running.

4. Discussion

4.1. Major findings

The LC has useful features to monitor physical activity in daily living. However the influence of gender on LC accuracy has not been verified sufficiently. In this study, we examined the relationship between MET and the LC during walking and running to assess the influence of gender. Results obtained by comparison of calibration models show that Model 1, including no gender effect assumption, was superior to Model 3, which included the assumption that the relationship of LC to MET differed by gender. Although Model 2, including a constant difference of gender, was also better than Model 3, the main effect of gender in Model 2 was not significant. Furthermore, for results of cross-validation analysis, gender did not significantly affect the differences of the IC measurements and the LC estimates. These results demonstrated no significant influence of gender on the relationship between MET and LC activity levels.

4.2. Influence of gender

Abel et al. (2008) reported that the total and estimated activity energy expenditure (kcal•kg^{-1}•min^{-1}) of women by the LC and the manufacturer's algorithm were significantly higher than those in men, although the gender difference was not significant in IC measurements. However, the results of this study revealed that women showed higher MET than men in both IC measurements and the LC estimates at all speeds (see Table 2). Consequently, the relationship between MET and the LC outputs was not

Table 3. Results obtained for three models.

	Model 1			Model 2			Model 3		
Terms	*estimate*	*SE*	*p* value	*estimate*	*SE*	*p* value	*estimate*	*SE*	*p* value
Intercept	1.007	0.126	< 0.001	1.060	0.237	< 0.001	1.042	0.265	< 0.001
x^2 (LC^2)	0.048	0.007	< 0.001	0.048	0.044	< 0.001	0.047	0.010	< 0.001
x (LC)	0.508	0.073	< 0.001	0.508	0.044	< 0.001	0.522	0.106	< 0.001
α (gender = male)				-0.096	0.172	0.577	-0.059	0.255	0.819
α (gender = female)				Referent	-	-	Referent	-	-
αx^2 (gender = male)							0.003	0.014	0.850
αx^2(gender = female)							Referent	-	-
αx (gender = male)							-0.029	0.148	0.846
αx (gender = female)							Referent	-	-
-2 log likelihood	438.550*			439.918*			449.863		
AIC	442.550			443.918			453.863		

Note: LC = Lifecorder EX; *estimate* = regression coefficient and main effect; *SE* = standard error of the coefficient; AIC = Akaike's information criterion.
Asterisk (*) denotes that the model fits the data significantly better than Model 3 does.

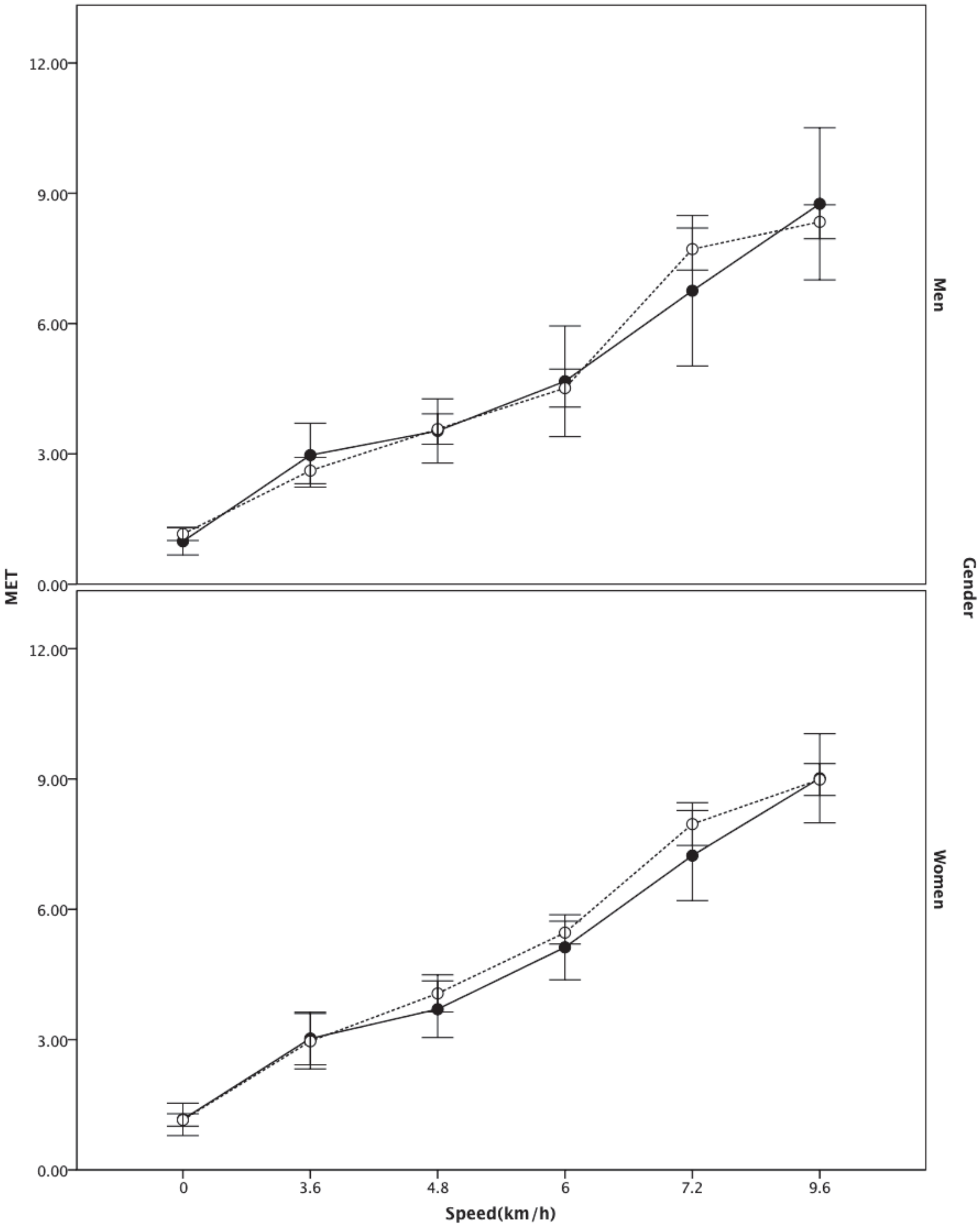

Figure 1. Comparison of MET predicted using the Lifecorder EX and MET measured using indirect calorimetry in cross-validation group data. Closed symbols (●) and solid lines show indirect calorimetry data. Open symbols (○) and dashed lines show the Lifecorder EX data. Error bars show standard deviations.

significantly different between men and women overall.

Freedson et al. (2008) reported that the energy expenditure of women was 8–11% higher than that of men at 4.83 or 5.63 km•h^{-1} walking. Freedson et al. reported that a biomechanical factor might explain the gender difference. Welk et al. (2000) showed that step counts of women at 6.44 km•h^{-1} walking were 6.5% higher than those of men. Welk et al. also detected that step counts during walking correlated negatively with stride length. These results suggest that women must make many more steps than men at the same speed walking to compensate for shorter stride length.

The higher step counts might elevate records of accelerometers because the record of accelerometers is

Table 4. Means±SD for MET and root mean squared error by gender, speed, and measurement methods.

Activities	Method	Men (MET)	Women (MET)	Total (MET)	Difference (%)	RMSE (MET)
0.0 km•h^{-1}	IC	1.2±0.3	1.4±0.4	1.3±0.3		
	LC	1.4±0.2	1.4±0.1	1.4±0.1	13.7±34.8	0.35
3.6 km•h^{-1}	IC	3.2±0.7	3.2±0.6	3.2±0.6		
	LC	2.8±0.3	3.2±0.6	3.0±0.5	-4.0±18.5	0.47
4.8 km•h^{-1}	IC	3.7±0.7	3.9±0.7	3.8±0.7		
	LC	3.8±0.3	4.3±0.4	4.0±0.5	8.5±22.0	0.68
6.0 km•h^{-1}	IC	4.9±1.3	5.3±0.7	5.1±1.0		
	LC	4.7±0.4	5.7±0.3	5.2±0.6	4.6±17.4	0.69
7.2 km•h^{-1}	IC	7.0±1.7	7.4±1.0	7.2±1.4		
	LC	7.9±0.5	8.2±0.5	8.0±0.5	15.3±22.3	1.52
9.6 km•h^{-1}	IC	9.0±1.8	9.2±1.0	9.1±1.4		
	LC	8.5±0.4	9.2±0.3	8.8±0.5	-0.9±14.0	1.00

Note: IC = measurements obtained using indirect calorimetry; LC = estimations obtained using the Lifecorder EX with the calibration model (Model 1); RMSE = root mean squared error. No difference between the IC and LC is significant ($p < 0.0083$) at any speed.

defined as the change of acceleration produced by the human body over a sampling interval (Chen and Bassett, 2005; Ridgers and Fairclough, 2011). In fact, for typical accelerometers (Actigraph, TriTrac-R3D, and RT3), it has been reported that output of women is higher by 3–15% than output of men during walking and running (King et al., 2004). Given that gender difference increases the accelerometer outputs as well as energy expenditure equally, a gender difference does not change the relationship between MET and the LC.

In both the previous study (Abel et al., 2008) and the present study, it is common to that women showed higher energy expenditure estimated by the LC than men, although estimation methods were different. Therefore, the different results were caused by the IC measurements. It is mentioned above that the women consume more energy than men during walking and running. Given that, the energy expenditure of women in the previous study might be too low. Although we cannot find any well-grounded reasons of the low IC measurements in the previous study, female subjects in the previous study might have superior energy cost or there might be simply measurement error by researchers.

4.3. Accuracy of Lifecorder EX

The coefficient of determination (0.86) used for the calibration group data were high relative to the results of previous calibration studies using accelerometers (Freedson et al., 1998; Leenders et al., 2003; Nichols et al., 1999). Regarding the results of cross-validation, the coefficient of determination (0.77) was high; furthermore, no significant difference was found between the IC and the LC for any of the five treadmill speeds.

Although some results showed LC accuracy, RMSE showed a systematic error in the LC estimates. RMSE increased rapidly to more than 1.0 MET at running (see Table 4). This result represents a systematic error of the LC during running. Similar systematic error was reported by Kumahara et al. (2004) and Abel et al. (2008). Kumahara et al. reported that the cause of the systematic error was that the accelerometer was reaching the upper limit of its dynamic range. The LC measures vertical acceleration within the range of 0.06–1.94 G. Because the magnitude of vertical acceleration at 11.7 km•h^{-1} measured using a force plate is 2.7 G (Kyrolainen et al., 2001), it is likely that acceleration exceeds the upper limit of the sensor. Because the cause of the systematic error is within the device itself, the LC cannot accurately estimate energy expenditure during running. Therefore, the LC can accurately estimate physical activity energy expenditure during walking, but the LC accuracy decreases during running.

5. Conclusions

In this study, we examined the LC accuracy during walking and running to assess the influence of gender. Results show that gender has no influence on the LC estimates. For both genders, it can accurately assess physical activity intensity during walking. However, the LC estimate is affected by systematic error during running.

Limitation

There is a limitation in this study. The participants in this study were only young persons. Gait and some physiological indexes concerned about health and physical activity (e.g. resting metabolic rate, heart rate, oxygen uptake) are different among children, young adults, and elderly persons. For applying the results of this study to other populations, further investigations are needed in various populations.

Conflict of interest

Results of the present study do not constitute an endorsement of the product by the authors or by the Japanese Society of Test and Measurement in Health and Physical Education. No financial support for this study was obtained from Suzuken Co. Ltd.

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