



EFFECT OF BODY COMPOSITION ON WALKING ECONOMY

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ABSTRACT

Purpose. The aim of the study was to evaluate walking economy and physiological responses at two walking speeds in males with similar absolute body mass but different body composition. **Methods.** The study involved 22 young men with similar absolute body mass, BMI, aerobic performance, calf and thigh circumference. The participants differed in body composition: body fat (HBF group) and lean body mass (HLBM group). In the graded test, maximal oxygen uptake (VO_{2max}) and maximal heart rate were measured. Walking economy was evaluated during two walks performed at two different speeds (4.8 and 6.0 km · h⁻¹). **Results.** The VO_{2max} was similar in both groups, as were the physiological responses during slow walking. The absolute oxygen uptake or oxygen uptake relative to body mass did not significantly differentiate the studied groups. The only indicator significantly differentiating the two groups was oxygen uptake relative to LBM. **Conclusions.** Body composition does not significantly affect walking economy at low speed, while during brisk walking, the economy is better in the HLBM vs. HBF group, provided that walking economy is presented as oxygen uptake relative to LBM. For this reason, we recommend this manner of oxygen uptake normalization in the evaluation of walking economy.

Key words: body fat, lean body mass, metabolic cost, oxygen uptake, exercise

Introduction

Walking, the most natural form of exercise, is aerobic exercise of low intensity. Regular physical activity such as walking also brings significant health effects [1]. Often, walking is the only possible exercise that can be performed by people with low exercise capacity (e.g. the elderly) or neurological disorders impairing motor coordination [2, 3]. Walking is a natural form of daily physical activity recommended for weight management [4]. Therefore, it is a frequently chosen form of exercise to evaluate exercise tolerance in people who are not able to perform high-intensity efforts, i.e. the elderly or obese. Exercise tolerance is mainly determined by the efficiency of the cardio-respiratory system, supplying the muscles at work with oxygen. Another factor influencing walking performance is walking economy. Walking economy is usually defined as the energy demand for a given sub-maximal walking speed, which is determined by measuring steady-state oxygen uptake and respiratory exchange ratios [5]. The metabolic and mechanical requirements of walking influence a broad array of structural, functional and health relationships. One of the determinants that can significantly affect walking economy is body build. Increased body mass and body composition

are considered to be significant determinants of exercise performance. Previous studies [6, 7] have proven that body composition considerably affects aerobic performance and cycling anaerobic power. Larger individuals expend more energy than smaller ones when the expended metabolic energy is expressed in absolute terms. However, relative to body mass, the energy expended to walk at a given speed can be greater for smaller than larger individuals. The influence of body size on walking/running economy is well documented, and better economy for participants with smaller body size is indicated [8]. Only a few previous studies [9, 10] attempted to assess the impact of body mass and composition on walking economy – these studies involved obese individuals. In obese subjects, increased absolute body mass is primarily due to an increase of body fat, but often, elevated levels of lean body mass compared with the sample with a lower absolute body mass are also noted for these participants [11]. The morphology of lower limbs was not taken into consideration in this study. The increase in mass in the distal parts of the body raises aerobic demand [12]: leg swing during walking/running comprises a large part of total energy expenditure of the exercise [13]. There is also a correlation between the maximal circumference of the calf and oxygen uptake at a fixed velocity [14].

As far as we know, the effect of body composition on walking economy is not well explained or documented.

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In people with a similar total body mass but different body composition, it is difficult to determine whether walking economy is affected by the level of body fat or muscle mass. Adipose tissue is passive during physical exercise and constitutes an additional load, increasing the energy expenditure of walking. On the other hand, the muscles active during exercise consume oxygen, and increased muscle mass (lean body mass) can cause a greater total cost of the exercise. In this study, we evaluated the effect of increased body fat or increased lean body mass on walking economy in participants with similar absolute body mass. We hypothesized that body composition significantly affected walking economy. The aim of the study was to evaluate walking economy and physiological response during walking at two different speeds in males with similar absolute body mass but different body composition.

Material and methods

Design

The study design and procedures were approved by the Commission of Bioethics at the Regional Medical Chamber. Each participant submitted a written consent to take part in the study and was acquainted with the procedures, apparatus and aim of the study. The study consisted of preliminary tests (anthropometric measurements) and research proper, involving two stress tests. During the first test (incremental test), maximal oxygen uptake and maximal heart rate were measured. In the second test, walking economy was assessed during two walks performed at two different speeds.

Preliminary tests

In the initial stage of the study, anthropometric measurements were taken in 1549 young men (aged 19–28 years). These measurements included body height (BH), body mass (BM), body fat percentage (%BF) and lean body mass (LBM). The aim of the measurements was to create the eligibility criteria for the two study groups, differing in body composition: the increased body fat (HBF) group and the increased lean body mass (HLBM) group. The eligibility criteria for the groups were as follows:

- a) both of the groups should be of similar BM, body mass index (BMI) and lower limb morphology;
- b) in the HLBM group, the qualified men had the LBM value above the 80th percentile (> 66.3 kg) of the results obtained among all the male subjects ($n = 1549$) and %BF between the 40th and 60th percentile (14.0–18.5%);
- c) the HBF group consisted of men whose LBM level was between the 40th and 60th percentile (59.0–64.3 kg), and whose %BF exceeded the 80th percentile (> 21.5%) of the results achieved among all the studied men.

The males who met the inclusion criteria in anthropometric measurements, did not present any medical

contraindications against performing physical effort, and provided a written consent to take part in the study were involved in the study. The males qualified for the exercise test underwent a medical check-up, including ECG and blood morphology.

Ultimately, 22 men were qualified to take part in the stress test, 11 in each group.

Participants

The study participants from both groups were of similar age and, in accordance with the eligibility criteria for both groups, had similar BM, BMI, aerobic performance and thigh and calf circumference. There was a statistically significant difference in their body composition, i.e. LBM and body fat. Thigh and calf circumference were similar in both groups. Maximal oxygen uptake (VO_{2max}) and maximal heart rate (HR_{max}) were similar in both groups (Table 1). The participants were physically active men, declared performing diverse physical activity (not more than 3 times a week), and did not perform sports competitively. None of the studied men from the HLBM group was a bodybuilder.

Anthropometric measurements

Body height was measured with the use of the Martin type anthropometer with 1 mm accuracy. Body mass and composition were assessed with a body composition analyser (Jawon IOI-353, Korea), and the method of bioelectrical impedance (eight electrodes, three measurement frequencies, tetrapolar electrode method) was applied. The following parameters were determined in the measurements: BM, %BF, fat mass (FM) and LBM. In addition, BMI was calculated for each participant. All anthropometric measurements were taken in similar environmental conditions (humidity, ambient temperature). The electrodes, hands and feet were degreased before each measurement. Body composition was assessed with the consideration of all circumstances that could have any effect on the measurement results [15]. In each test, thigh and calf circumference (the largest circumference) was measured with the use of a tape measure with 5 mm accuracy.

Exercise tests

Before the measurements began, the participants had been instructed on how to properly prepare for the exercise tests (diet, hydration, sleep time). They were recommended to avoid dehydration and to rest on the day preceding the exercise tests, and to come to the test after a light meal. During the incremental test (test 1) and submaximal walks on the treadmill (test 2), breathing indicators were measured with the Medikro 919 ergospirometer (Medikro, Finland), and heart rate (HR) was assessed with a HR monitor (Polar, Finland). The

Table 1. Age, body build, maximal oxygen uptake and maximal heart rate in men in the compared groups

Variables	HLBM		HBF		<i>p</i>
	mean	<i>SD</i>	mean	<i>SD</i>	
N	11		11		
Age (years)	21.1	1.22	21.8	3.12	0.48
BH (cm)	184.9	4.7	178.7	2.76	< 0.01
BM (kg)	82.6	3.73	81.2	3.99	0.41
LBM (kg)	69.2	4.2	62.4	2.00	< 0.01
%F	16.3	2.35	23.1	1.95	< 0.01
FM (kg)	13.4	1.86	18.8	2.44	< 0.01
BMI	24.3	1.41	25.4	1.16	0.10
Thigh circumference (cm)	58.4	2.30	58.2	3.26	0.83
Calf circumference (cm)	39.5	1.60	39.9	1.60	0.49
VO _{2max} (mL · kg ⁻¹ · min ⁻¹)	52.4	5.59	49.8	4.73	0.25
HR _{max} (beats·min ⁻¹)	200	8.6	201	10.2	0.87

BH – body height, BM – body mass, LBM – lean body mass, F – body fat, FM – fat mass, BMI – body mass index, VO_{2max} – maximal oxygen uptake, HR_{max} – maximal heart rate, HLBM – high lean body mass group, HBF – high body fat group

metabolic card was calibrated in accordance with the manufacturer's requirements before each test (volume and gas calibration).

Incremental test

The aim of the test was to measure the aerobic power (VO_{2max}) and HR_{max} for each participant. The subjects performed the test with a gradually increasing load until volitional failure. The test was carried out on a mechanical treadmill (h/p Cosmos, Saturn, Germany) and began with a 4-minute warm-up at the speed of 7 km · h⁻¹. Then, after the warm-up, the running speed was increased by 1.2 km · h⁻¹ every 2 minutes until the participant's refusal to continue the test owing to extreme fatigue. The criteria applied to determine VO_{2max} were as follows: the plateau in oxygen uptake, the respiratory exchange ratio of > 1.1, and attainment of a HR within 10 beats · min⁻¹ of the age-predicted maximum. However, in situations where no plateau was observed, but the rest of the criteria were met, the oxygen uptake (VO₂) peak was assumed as the VO_{2max} [16]. The participants were encouraged by the researcher to give their maximum effort throughout the test.

Walking economy

The aim of the test was to compare the physiological response during walking on the treadmill at two constant speeds (4.8 and 6.0 km · h⁻¹) in both groups. The test consisted of two walks, each lasting 6 minutes, with an interval of 3 minutes. All walks were performed with the treadmill inclined at 0%; the first walk was slow (4.8 km · h⁻¹), the second one was a quick walk (6.0 km · h⁻¹). During the test, the following indicators were recorded every 30 seconds: breathing frequency (BF), tidal volume

(TV), pulmonary ventilation (V_E), VO₂, and HR. We analysed the level of physiological indicators recorded in the steady state. In the case of VO₂, it was assumed that the steady state fluctuations should not exceed 0.1 L · min⁻¹ [17]. Walking economy was expressed as absolute VO₂ (L · min⁻¹) and VO₂ relative to BM (mL · kg⁻¹) or LBM (mL · kgLBM⁻¹).

The exercise intensity was expressed as %VO_{2max} and %HR_{max}. To assess the subjective rate of perceived exertion (RPE), the Borg scale was used (with the range of 6–20 points, where 6 = very, very light; 20 = very, very heavy exercise) [18].

Statistical analysis

The mean and standard deviation were calculated for each variable. Data distribution was checked with the Shapiro-Wilk test. The significance of differences between the anthropometric indicators was determined with the use of one-way ANOVA variance analysis. To analyse the significance of differences in the level of physiological parameters, two-way ANOVA variance analysis was applied. The influence of the following factors was analysed: the group, speed and interaction between these two factors (group × speed). The post-hoc analysis (Tukey test) was performed when the results of variance analysis showed a significant influence of a particular factor. Results were considered statistically significant when *p* < 0.05.

Results

The absolute VO₂ during the walks was similar in both groups (*F* = 0.22, *p* = 0.64) and significantly increased along with the growing speed in both groups (*F* = 47.4, *p* < 0.01). There were non-significant differences between

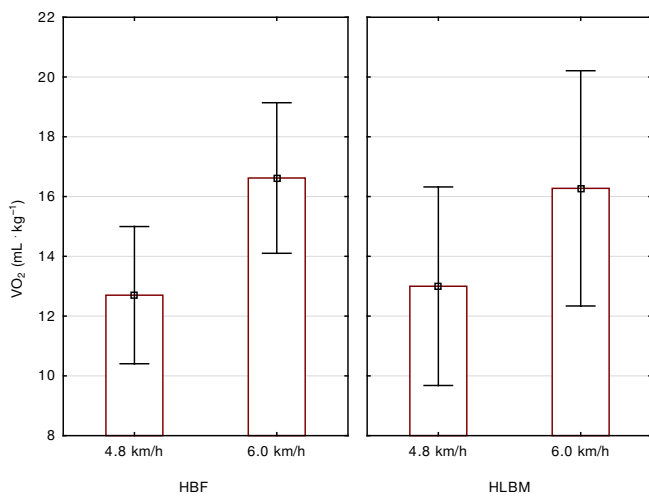


Figure 1. Relative oxygen uptake (mean \pm SD) in particular walks in the tested groups (VO_2 – oxygen uptake, HBF – high body fat group, HLBM – high lean body mass group)

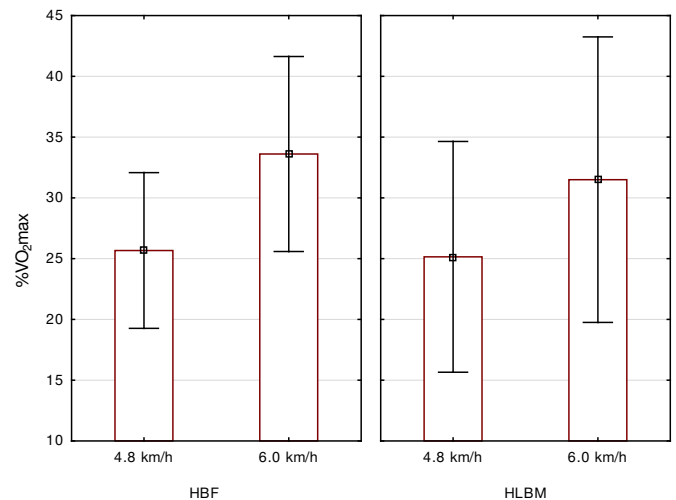


Figure 2. Walking intensity (mean \pm SD) in particular walks in the tested groups (VO_2 – oxygen uptake, HBF – high body fat group, HLBM – high lean body mass group)

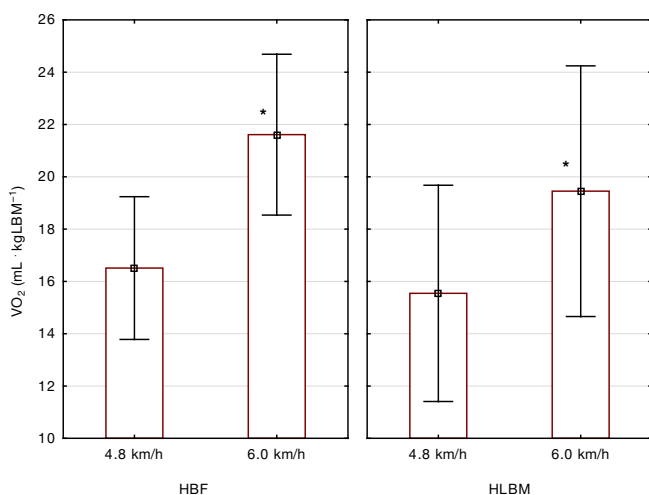


Figure 3. Oxygen uptake relative to lean body mass (mean \pm SD) in particular walks in the tested groups (VO_2 – oxygen uptake, HBF – high body fat group, HLBM – high lean body mass group, * significant [$p = 0.04$] difference between the groups)

the compared groups in the case of relative VO_2 ($F = 0.00$, $p = 0.96$, respectively) (Figure 1), exercise intensity expressed as $\%VO_{2max}$ ($F = 0.91$, $p = 0.35$) (Figure 2), pulmonary ventilation ($F = 0.02$, $p = 0.88$) and RPE ($F = 0.21$, $p = 0.65$). In the case of RPE, the post-hoc analysis showed only a significant increase in the RPE in the HBF group with increasing walking speed, while the participants from the HLBM group evaluated the intensity of both walks similarly (Table 2).

VO_2 as expressed relative to LBM significantly differentiated the study groups ($F = 7.56$, $p < 0.01$) and significantly increased with the walking speed ($F = 62.7$, $p < 0.01$). The post-hoc analysis showed that intergroup differences in the level of this indicator occurred only during walking at a higher speed (Figure 3, Table 3).

HR and intensity of work expressed as $\%HR_{max}$ showed no significant differences between the groups ($F = 2.53$, $p = 0.12$, and $F = 2.55$, $p = 0.12$, respectively) and did not change significantly with the increase in walking speed ($F = 7.94$, $p = 0.05$, and $F = 9.52$, $p = 0.05$, respectively). No significant changes were found with the increase of walking speed in the case of BF ($F = 2.13$, $p = 0.15$) or TV ($F = 1.90$, $p = 0.17$). These indicators did not show any significant intergroup differences either ($F = 0.09$, $p = 0.93$, and $F = 0.22$, $p = 0.64$, respectively).

None of the cases exhibited any significant interaction between the main factors analysed. In Table 2 and 3, the results of the post-hoc analysis (p -value) between the analysed factors are shown.

Discussion and conclusions

The results indicate that when walking at a low speed ($4.8 \text{ km} \cdot \text{h}^{-1}$), participants with the same absolute BM but different body composition present similar walking economy and physiological response. In the case of brisk walking ($6.0 \text{ km} \cdot \text{h}^{-1}$), the effect of increased body fat or increased LBM on walking economy was observed only after presenting VO_2 relative to LBM. It was significantly lower in the HLBM group as compared with the HBF group. However, the absolute VO_2 and VO_2 relative to BM were similar in both groups, which indicates that this method of data standardization is crucial in assessing walking economy, expressed as steady-state VO_2 . On the basis of our research, it seems that in the assessment of walking economy, relating VO_2 to LBM is the best way to present walking economy. However, walking economy is most often expressed relative to absolute BM [10, 11]. Using this manner of presenting VO_2 normalization (as well as in absolute values), the results of our study would indicate that the body composition does not significantly affect walking economy, regardless of the move-

Table 2. Physiological parameters of exercise at two walking speeds noted in the compared groups

Variables	Group/ significance	4.8 km · h ⁻¹		6.0 km · h ⁻¹		<i>p</i>
		mean	<i>SD</i>	mean	<i>SD</i>	
HR (beats · min ⁻¹)	HBF	97	10.1	108	10.4	0.18
	HLBM	91	14.9	102	15.0	0.23
	<i>p</i>	0.71		0.63		
%HR _{max}	HBF	48.3	3.88	53.9	3.55	0.13
	HLBM	45.6	7.36	50.9	7.40	0.16
	<i>p</i>	0.70		0.63		
V _E (L · min ⁻¹)	HBF	24.4	3.26	31.3	3.04	< 0.01
	HLBM	24.8	3.70	31.4	5.46	< 0.01
	<i>p</i>	0.99		1.00		
BF (breaths · min ⁻¹)	HBF	21.4	4.47	23.7	5.13	0.77
	HLBM	21.0	5.97	23.7	6.67	0.69
	<i>p</i>	0.99		1.00		
TV (L)	HBF	1.20	0.32	1.40	0.41	0.66
	HLBM	1.30	0.40	1.41	0.36	0.89
	<i>p</i>	0.93		0.99		
RPE	HBF	6.6	0.9	8.0	0.9	0.02
	HLBM	6.7	0.7	7.5	1.2	0.23
	<i>p</i>	0.99		0.82		

HR – heart rate, VE – pulmonary ventilation, BF – breathing frequency, TV – tidal volume, RPE – rate of perceived exertion, HBF – high body fat group, HLBM – high lean body mass group

Table 3. Walking economy and exercise intensity noted during steady state in the compared groups

Variables	Group/ significance	4.8 km · h ⁻¹		6.0 km · h ⁻¹		<i>p</i>
		mean	<i>SD</i>	mean	<i>SD</i>	
VO ₂ (L · min ⁻¹)	HBF	1.03	0.10	1.34	0.11	< 0.01
	HLBM	1.07	0.15	1.34	0.18	< 0.01
	<i>p</i>	0.88		0.99		
%VO _{2max}	HBF	25.7	3.20	33.6	4.01	< 0.01
	HLBM	25.2	4.74	31.5	5.87	< 0.01
	<i>p</i>	0.99		0.70		
VO ₂ (mL · kg ⁻¹)	HBF	12.7	1.14	16.6	1.25	< 0.01
	HLBM	13.0	1.66	16.3	1.96	< 0.01
	<i>p</i>	0.96		0.95		
VO ₂ (mL · kgLBM ⁻¹)	HBF	16.5	1.36	21.6	1.53	< 0.01
	HLBM	15.5	2.06	19.4	2.39	< 0.01
	<i>p</i>	0.62		0.04		

VO₂ – oxygen uptake, HBF – high body fat group, HLBM – high lean body mass group

ment speed, which would confirm previous reports [10, 11]. However, after presenting VO₂ relative to LBM, the walking economy turned out better in the HLBM group than in the HBF group. For this reason, on the basis of our research, we recommend presenting VO₂ relative to LBM when assessing walking economy in people with differing body composition.

The results of previous studies assessing walking economy in people with different body composition are inconclusive. Volpe Ayub and Bar-Or [10], evaluating the energy cost in boys with different body fatness (obese and non-obese) but similar absolute BM, concluded that the energy cost of locomotion is affected by absolute BM rather than body fat. On the other hand, Brownig

et al. [11] suggested that obesity did not impair walking economy across a range of walking speeds and grades. Chen et al. [19] observed a decrease in the efficiency of walking at normal speed with an increase in body fatness in both men and women. LeCheminant et al. [20] indicated significant differences in energy expenditure between normal weight and overweight women during walking as well. The divergence in the presented data may result from a large number of factors which may affect walking economy.

In our study, we focused on the impact of body composition on walking economy and attempted to isolate the impact of increased LBM or increased body fat on walking economy. For this purpose, only men with similar absolute BM, BMI, and lower limb morphology were qualified for the study. It can therefore be assumed that in our study, absolute BM [10] and calf circumference (leg morphology) [14] had no significant effect on VO_2 in steady-state conditions. In our opinion, this is the first study to successfully isolate and evaluate the impact of sole body composition on walking economy. The limitation of the study, however, is the significantly bigger BH (about 6 cm) in the HLBM group than in the HBF group. BH may affect the length and frequency of steps, and the increased frequency of steps can enlarge the metabolic cost of walking. Nonetheless, we decided to include individuals with greater BH in the tests because introducing another eligibility criterion for the groups would significantly decrease their size, which we wanted to avoid.

In the present study, we assessed walking economy on the basis of VO_2 measured for each participant during steady-state while performing an effort at a constant speed. Walking is a low-intensity effort, in which all energy processes employ the aerobic metabolism; thus, VO_2 reflects the total metabolic cost of an exercise. The intensity of walking in the study was low in both walks (up to approx. 35% $\text{VO}_{2\text{max}}$ and up to approx. 54% HR_{max}), which confirms that walking was an aerobic exercise. In more intensive exercises, above the anaerobic threshold (usually exceeding 40–60% $\text{VO}_{2\text{max}}$ and 70% HR_{max}), part of the energy is produced in anaerobic pathways, having no reflection in VO_2 ; in this type of exercise, an individual speed (intensity) should be chosen for the exercise to be carried out with a similar metabolic background [17]. In our study, the work intensity in both walks was similar in the two groups.

The metabolic cost of exercise is also affected by the functioning of the cardio-respiratory system: increases in the metabolic cost from augmented circulation, V_E and BF are the major factors that increase VO_2 [21]. Ventilatory work has been shown to account for 7–8% of the overall exercise energy cost [22]. In our study, the physiological response (HR , V_E) was similar in the two groups during both walks, and thus it affected the metabolic cost of walking in both groups in a similar way.

In the study, we wanted to compare the physiological responses in both groups at two different speeds in

order to verify whether the speed of locomotion would have an impact on the level of physiological responses in the tested participants from both groups. Selecting the walking speed, we adopted the following assumptions: the first speed (4.8 km · h⁻¹) should be similar to the natural human locomotion speed, while the second one should be higher but at the same time allowing the subject to walk without forcing a run (jog). Monteiro et al. [23] have shown that the transition from walking to running in young untrained men occurs on average at the speed of 6.9 km · h⁻¹ (6.4–7.5 km · h⁻¹); this is also why the selection of speeds in our study seems to be accurate.

Owing to the large number ($n = 1549$) of men participating in the preliminary studies, we decided to use the method of bioelectrical impedance to analyse body composition. While complying with all technical requirements [15], this method seems appropriate for the assessment of body composition in large study populations. It is also highly correlated with dual X-ray absorptiometry [24].

The results of our study are of great practical application. Walking economy may not only depend on the speed of movement, but also on the body composition of the studied individuals, which should be taken into account in exercise test designing (choice of walking speed) and in the interpretation of the obtained data (considering the level of LBM).

Body composition does not significantly affect walking economy at a low speed. For quick walking, the metabolic cost is lower in individuals with high LBM and decreased body fat as compared with those of similar BM but with increased body fat, under the condition that walking economy is expressed as VO_2 relative to LBM. Thus, the applied method of VO_2 normalization (mL · kgLBM⁻¹) is recommended in evaluating walking economy.

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