PAN
OPEN ACCESS
https://doi.org/10.20463/pan.2022.0002
Physical Activity and Nutrition | 2022;26(1):008-013

Comparison of energy expenditure and substrate oxidation between walking and running in men and women

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Received: 2022/01/30, Revised: 2022/03/19, Accepted: 2022/03/22, Published: 2022/03/31

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While the previous studies compared metabolic and cardiovascular adaptations between “fast interval walking” and “continuous walking”, no direct comparison between them has been conducted so far.

[Purpose] The present study compared energy metabolism between walking and running at equivalent speeds during two incremental exercise tests.

[Methods] Thirty four university students (18 males, 16 females) were recruited. Each participant completed two trials, consisting of walking (Walk) and running (Run) trials on different days, with 2-3 days apart. Exercise on a treadmill was started from initial stage of 3 min (3.0 k/m in Walk trial, 5.0 km/h in Run trial), and the speed for walking and running was progressively every minute by 0.5 km/h. The changes in metabolic variables, heart rate (HR), and rating of perceived exertion (RPE) during exercise were compared between the trials.

[Results] Energy expenditure (EE) increased with speed in each trial. However, the Walk trial had a significantly higher EE than the Run trial at speeds exceeding 92 ± 2 % of the maximal walking speed (MWS, $p < 0.01$). Similarly, carbohydrate (CHO) oxidation was significantly higher in the Walk trial than in the Run trial at above 92 ± 2 %MWS in males ($p < 0.001$) and above 93 ± 1 %MWS in females ($p < 0.05$).

[Conclusion] These findings suggest that EE and CHO oxidation during walking increase non-linearly with speed, and walking at a fast speed causes greater metabolic responses than running at the equivalent speed in young participants.

[Keywords] fast walking, running, energy expenditure, carbohydrate oxidation, fat oxidation

INTRODUCTION

Regular endurance training improves glucose[1] and fat[2] metabolism and cardiovascular function[3], and reduces body weight and fat mass[4]. Walking is a prevalent endurance exercise modality. Previous studies using normal walking showed improvements in the maximal oxygen uptake and exercise capacity in patients with type 2 diabetes[5] and in the fitness variables and lipid profile in postmenopausal women[6]. However, the findings were not consistent, and several studies failed to find benefits following walking exercise intervention[7].

The absence of a benefit of walking may be due to insufficient exercise intensity; brisk (fast) walking may overcome this problem. Previously, Nemoto et al.[8] found that 5 months of fast walking training, consisting of repeated walks first at 3 min 70 – 85 % of peak aerobic capacity (fast walk) followed by 3 min at ≤ 40 % peak aerobic capacity (slow walks) resulted in greater increases in peak aerobic capacity and thigh muscle strength and a greater reduction in systolic blood pressure than continuous walking at moderate intensity. Morikawa et al.[9] reported that fast walking training for 4 months increased the peak aerobic capacity and improved variables related to lifestyle diseases. However, the previous studies compared metabolic and cardiovascular adaptations between “fast interval walking” and “continuous walking”[10,11] and there has been no direct comparison between “fast walking” and “running”. During running, the energy expenditure (EE) increases linearly with running speed, while the EE during walking increased non-linearly, resulting in greater EE during walking compared with running above a certain speed[12]. However, since walking speed was not controlled strictly (self-controlled speed) in that study, the absolute (km/h) and relative (percentage of maximal walking speed or peak oxygen uptake) intensities for augmenting EE are not clear.

Therefore, the present study compared energy metabolism (*e.g.*, EE and substrate oxidation pattern) between walking and running at equivalent speeds. We hypothesized that EE and carbohydrate (CHO) oxidation while walking would be greater than those while running when the speed is close to the maximal walking speed. The findings of the present outcomes are expected to contribute to clarifying characteristics of energy metabolism during fast walking and designing the exercise protocol for weight management.

METHODS

Participants

Based on the preliminary experiment, we estimated that the difference in EE between running and walking trials at an equivalent speed would be "moderate-large". Therefore, the sample size was calculated by α=0.05, β=0.20, power (1-β)=0.8, effect size=0.7 using G-power (G power ver.3.1, Heinrich-Heine University Dusseldorf, Germany), and the sample size of n=15 in each group (males, females) was obtained. Therefore, we recruited 34 participants (18 males, 16 females) in consideration of dropout or missing data.

The present study recruited 34 university students [18 males, 16 females; males: age 23 ± 3 years (mean ± SD), height 170.1 ± 5.7 cm, and weight 64.9 ± 8.7 kg; females: age 22 ± 1 years, height 158.3 ± 6.3 cm, and weight 51.5 ± 6.8 kg]. All participants were informed about the experiment and possible risks and gave informed consent. This study was approved by the Ethics Committee for Experiments of Ritsumeikan University and was conducted in accordance with the Declaration of Helsinki.

Experimental overview

Each participant completed a walking (Walk) trial and running (Run) trial on different days, at the same time of day. In the present study, the Walk trial was conducted initially, followed by Run trial, with 2-3 days apart. Changes in metabolic variables (energy expenditure, CHO oxidation, and fat oxidation), heart rate (HR), and rating of perceived exertion (RPE) during exercise were compared. Participants were asked to avoid strenuous exercise and consuming caffeine and alcohol for at least 24 hours before each trial and to fast for at least 2 hours before the trial.

Exercise trial

In the Walk trial, participants began walking on a treadmill (Elevation series E95Ta; Life Fitness, Tokyo, Japan) at 3.0 km/h for 3 min, and the walking speed was increased progressively by 0.5 km/h per min until the participants failed to maintain the prescribed speed; this determined the maximal walking speed (MWS). In the Run trial, they started to run on a treadmill at 5 km/h for 3 min. The running speed was then increased by 0.5 km/h per min until the speed was 2–3 km/h more than the MWS (Figure 1).

Measurements

Metabolic variables

Expired gas samples were collected breath-by-breath during each trial using an automatic metabolic cart (AE-300S; Minato Medical Science, Tokyo, Japan). The data obtained were averaged every 30 s. Before the measurements each day, the O_2 and CO_2 sensors were calibrated using known concentrations of gases, and the volume transducer was calibrated using a 2 L syringe. The EE was calculated from the equation of Weir[13]. The rates of CHO and fat oxidation were calculated using the following formulas of Jeukendrup and Wallis[14]:

$$\text{CHO oxidation (g/min)} = 4.210 \times \dot{V}CO_2 - 2.962 \times \dot{V}O_2$$
$$\text{Fat oxidation (g/min)} = 1.695 \times \dot{V}O_2 - 1.701 \times \dot{V}CO_2$$

where $\dot{V}O_2$ and $\dot{V}CO_2$ are the oxygen consumption and carbon dioxide production, respectively.

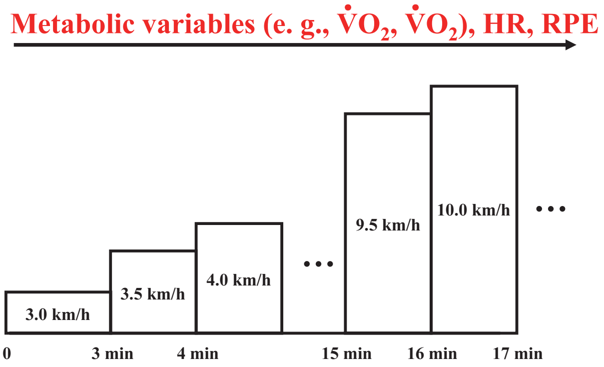

Figure 1. Experimental overview. Each participant completed a walking (Walk) and running (Run) trial on different days, at the same time of the day. Walk trial was started from 3.0 km/h for 3 min, and Run trial was started from 5.0 km/h for 3 min. Walking and running speeds were increased progressively by 0.5 km/h per min. HR; heart rate. RPE; rating of perceived exertion.

HR and RPE

HR was measured continuously (every 5 s) during each trial using a wireless HR monitor (RCX5; Polar Electro, Kempele, Finland). RPE was evaluated using a 10-point scale[15] at the end of each speed.

Comparison of metabolic responses between two trials

To compare the metabolic responses (*i.e.*, EE, CHO oxidation, and fat oxidation) between the two trials with different speeds in the final stage, the speeds in each stage were expressed individually as relative values: 5 km/h (initial speed in the Run trial) was defined as the 0 % phase, whereas MWS was the 100 % phase. In the Walk trial, the speeds at each stage were expressed as relative percentages of MWS (%MWS)

Statistics

All data are presented as the mean ± SD. Two-way repeated measures analysis of variance (ANOVA) was used to assess the interaction (condition × speed) and main effects (condition and speed) of each variable. When the ANOVA revealed a significant interaction or main effect, Tukey test was as a post-hoc analysis to identify differences. Statistical significance was set at $p < 0.05$.

RESULTS

EE

Figure 2 shows typical change in EE in the Walk and Run

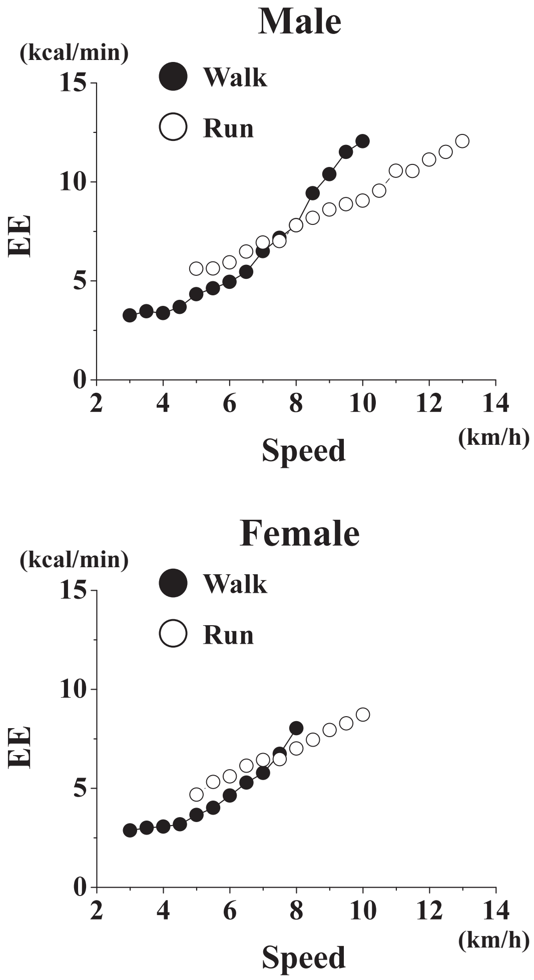

Figure 2. A typical change in energy expenditure. EE; energy expenditure.

trials. In the Run trial, EE increased linearly with speeds (5–13 km/h), while in the Walk trial, EE increased non-linearly, and increased rapidly at above 8.0 km/h. At 8–10 km/h, EE was greater in the Walk trial than in the Run trial. Moreover, a similar trend was observed in a female participant.

Figure 3 shows the change in EE at six different relative speeds (phases 0–100 %). There were significant main effects of speed (both $p < 0.001$) and condition (males $p < 0.05$, females $p < 0.001$), and their interaction (both $p < 0.001$). In males, EE was significantly lower in the Walk trial than in the Run trial during phases 0–40 % (57 ± 5 % to 74 ± 3 %MWS) (all $p < 0.001$). By contrast, EE tended to be higher in the Walk trial than in the Run trial during phases 80–100 % (92 ± 2 % to 100 %MWS) (80 % phase $p < 0.01$, 100 % phase $p < 0.001$). In females, EE was significantly lower in the Walk trial during the phases 0–50 % (66 ± 5 % to 83 ± 3 %MWS) (all $p < 0.001$). However, the Walk trial had a significantly higher EE than in Run trial in the 100 % phase (100 %MWS) ($p < 0.01$).

Substrate oxidation pattern

Figure 4 shows the substrate oxidation at six different relative speeds. CHO oxidation showed a significant main effect of speed (both $p < 0.001$) and the interaction (both $p < 0.001$), but not for the main effect of condition. In males, CHO oxidation was significantly lower in the Walk trial than in the Run trial during phases 0–40 % (57 ± 5 % to 74 ± 3 %MWS) (0 % phase, 40 % phase $p < 0.05$, 20 % phase $p < 0.001$). In contrast, it was significantly higher in the Walk trial during phases 80–100 % (92 ± 2 % to 100 %MWS) (all $p < 0.001$). In females, CHO oxidation was significantly lower in the Walk trial than in the Run trial during phases 0–50 % (66 ± 5 % to 83 ± 3 %MWS) (0 % phase, 50 % phase $p < 0.05$, 25 % phase $p < 0.01$). However, CHO oxidation was significantly higher in the Walk trial during phases 75–100 % (93 ± 1 % to 100 %MWS) (75 %

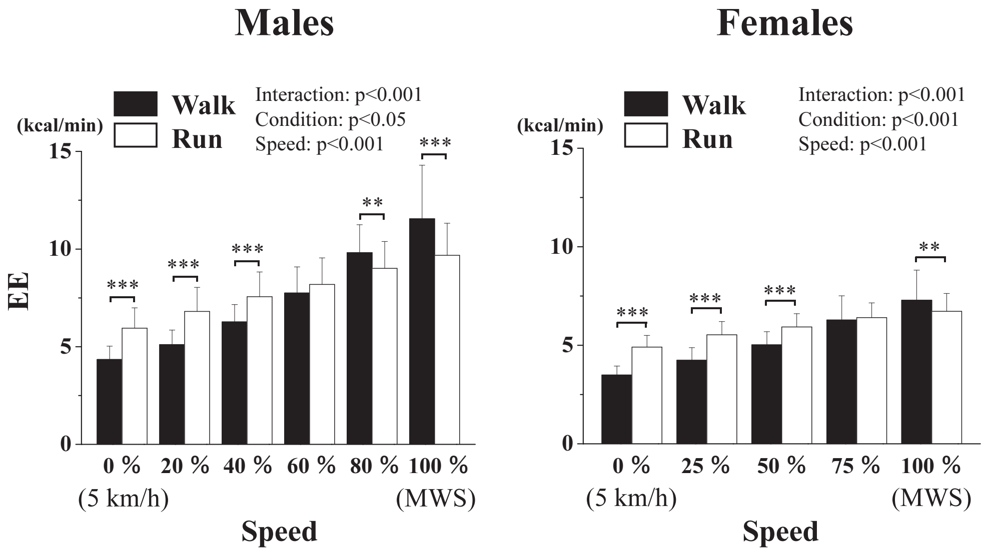

Figure 3. Comparison of energy expenditure (EE) at different speeds in males and females. Values are means ± SD. Significant difference between conditions in each relative speed (* $p<0.05$, ** $p<0.01$, *** $p<0.001$). EE; energy expenditure. MWS; maximal walking speed.

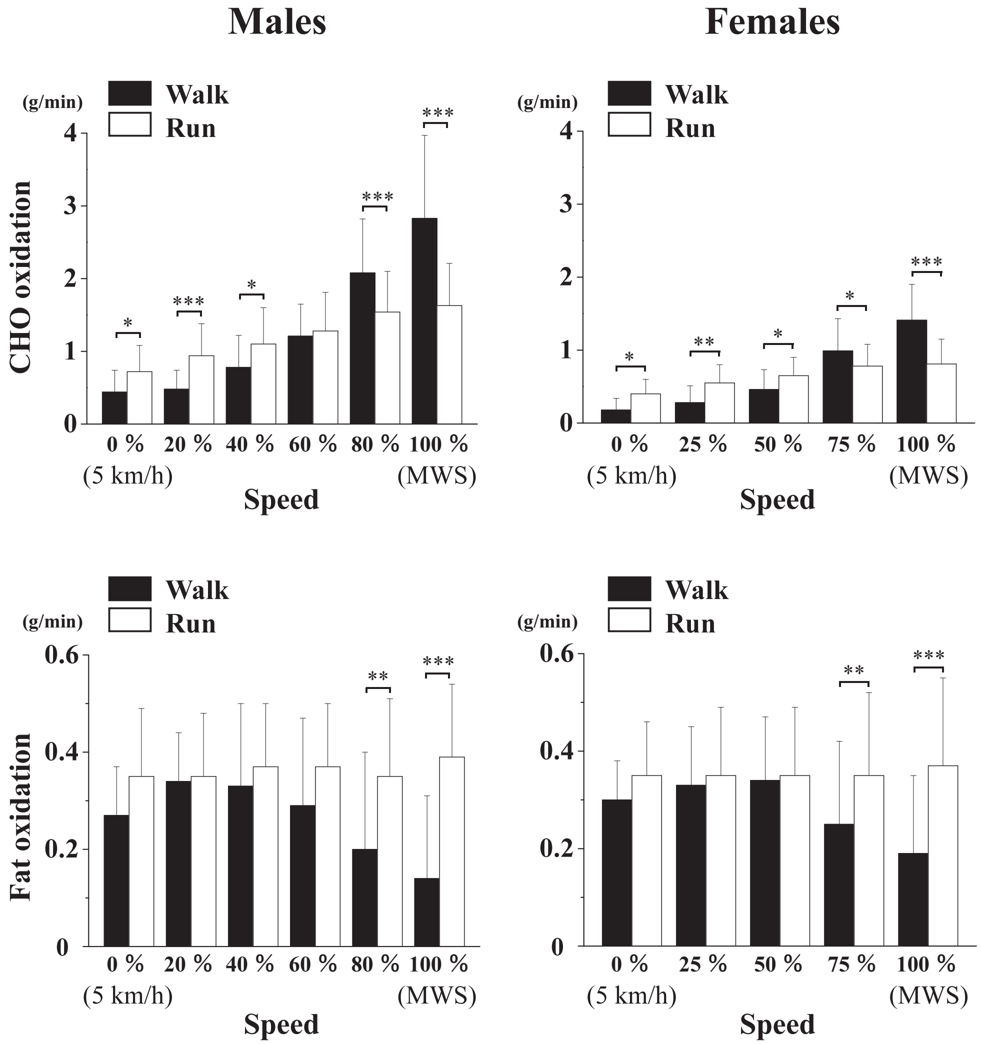

Figure 4. Comparison of carbohydrate (CHO) oxidation and fat oxidation in males and females. Values are means ± SD. Significant difference between conditions in each relative speed (* $p<0.05$, ** $p<0.01$, *** $p<0.001$). CHO; carbohydrate. MWS; maximal walking speed.

phase $p < 0.05$, 100 % phase $p < 0.001$).

Fat oxidation showed significant main effects of speed (male $p < 0.001$, female $p < 0.01$) and condition (male $p < 0.01$, female $p < 0.05$) and their interaction (both $p < 0.001$). In males, fat oxidation was significantly lower in the Walk trial than in the Run trial during phases 80–100 % (92 ± 2 % to 100 %MWS) (80 % phase $p < 0.01$, 100 % phase $p < 0.001$). In females, fat oxidation was significantly lower in the Walk trial during phases 75–100 % (93 ± 1 % to 100 %MWS) (75 % phase $p < 0.01$, 100 % phase $p < 0.001$), while no significant difference was observed during phases 0–50 %.

HR and RPE

As shown in Table 1, HR showed a significant main effect of speed (both $p < 0.001$) and the interaction (both $p < 0.001$), but not for the main effect of condition (males $p = 0.217$, females $p = 0.124$). In males, HR was significantly lower in the Walk trial than in the Run trial during phases 0–20 % (57 ± 5 % to 66 ± 3 %MWS) (all $p < 0.05$). However, HR was significantly higher in the Walk trial during phases 80–100 % (92 ± 2 % to 100 %MWS) (all $p < 0.001$). In females, HR was significantly lower in the Walk trial during phases 0–50 % (66 ± 5 % to 83 ± 3 %MWS) (0 % phase $p < 0.001$, 25 % phase $p < 0.01$, 50 % phase $p < 0.05$).

In males, RPE$_{\text{breath}}$ showed significant main effects of speed ($p < 0.001$) and condition ($p < 0.001$) and their interaction ($p < 0.05$). Moreover, it was significantly higher in the Walk trial than in the Run trial during all phases (0 % phase $p < 0.05$, 40 % phase, 60 % phase $p < 0.01$, other all $p < 0.001$). However, in females, RPE$_{\text{breath}}$ showed significant main effects of speed ($p < 0.001$) and condition ($p < 0.001$), but not their interaction ($p = 0.275$). For RPE$_{\text{leg}}$, there were significant main effects of speed (both $p < 0.001$) and condition (both $p < 0.001$) and their interaction (both $p < 0.001$). In males, RPE$_{\text{leg}}$ was significantly higher in the Walk trial than in the Run trial during all phases (0 % phase $p < 0.05$, 20 % phase $p < 0.01$, other all $p < 0.001$). Similarly, in females, RPE$_{\text{leg}}$ was significantly higher in the Walk trial during all phases (0 % phase $p < 0.05$, other all $p < 0.001$).

Table 1. Comparisons of HR and RPE.

			Relative Speed 0 % phase (5 km/h)	20 % phase	40 % phase	60 % phase	80 % phase	100 % phase (MWS)
Males								
Speed		(km/h)	5.0 ± 0.0	5.8 ± 0.3	6.5 ± 0.3	7.2 ± 0.4	8.0 ± 0.5	8.8 ± 0.7
		(%MWS)	57 ± 5	66 ± 3	74 ± 3	83 ± 3	92 ± 2	100 ± 0
HR (bpm)		Walk	105 ± 11 *	113 ± 14 *	123 ± 14	135 ± 15	152 ± 20 ***	165 ± 20 ***
		Run	112 ± 9	120 ± 11	126 ± 12	132 ± 12	140 ± 14	142 ± 20
RPE	breath	Walk	1.9 ± 0.8 *	2.4 ± 0.9 ***	2.7 ± 0.9 **	3.3 ± 1.2 **	4.1 ± 1.5 ***	4.8 ± 2.0 ***
		Run	1.4 ± 0.6	1.6 ± 0.7	2.0 ± 0.8	2.6 ± 0.9	3.1 ± 0.9	3.4 ± 1.0
	leg	Walk	2.1 ± 0.5 *	2.6 ± 0.8 **	3.3 ± 1.0 ***	3.9 ± 1.2 ***	5.4 ± 1.6 ***	6.4 ± 2.1 ***
		Run	1.4 ± 0.5	1.8 ± 0.6	2.2 ± 0.7	2.4 ± 0.9	2.9 ± 1.1	3.4 ± 1.1

Females							
Speed		(km/h)	5.0 ± 0.0	5.8 ± 0.3	6.4 ± 0.3	7.1 ± 0.5	7.7 ± 0.6
		(%MWS)	66 ± 5	75 ± 3	83 ± 3	93 ± 1	100 ± 0
HR (bpm)		Walk	105 ± 12 ***	115 ± 12 **	125 ± 15 *	146 ± 18	152 ± 18
		Run	121 ± 16	129 ± 16	135 ± 16	140 ± 14	146 ± 14
RPE	breath	Walk	2.3 ± 0.6 *	2.8 ± 0.7 ***	3.2 ± 0.8 **	3.8 ± 0.8 ***	4.4 ± 1.0 ***
		Run	1.7 ± 0.6	2.0 ± 0.5	2.4 ± 0.6	2.9 ± 0.7	3.4 ± 0.7
	leg	Walk	2.3 ± 0.6 *	3.1 ± 0.6 ***	3.7 ± 0.7 ***	4.9 ± 1.1 ***	5.8 ± 1.5 ***
		Run	1.8 ± 0.6	2.1 ± 0.6	2.6 ± 0.7	3.1 ± 1.0	3.3 ± 1.0

Values are means ± SD. Significant difference between conditions in each relative speed (* $p<0.05$, ** $p<0.01$, *** $p<0.001$). HR; heart rate. RPE; rating of perceived exertion. MWS; maximal walking speed.

DISCUSSION

A unique point of this study was the comparison of EE and substrate oxidation between "walking" and "running" at equivalent speeds in males and females. The main finding was that the EE during walking was higher than that during running when the walking speed was above at least the 80 % phase (equivalent to 92 ± 2 %MWS). Moreover, both male and female participants showed similar phenomena, without apparent gender difference. This suggests that the metabolic response during walking is specific and more enhanced than while running at the same speed for specific speeds.

EE in the Run trial increased linearly with speed. However, the EE in the Walk trial increased notably rapidly above 7.5 km/h. Rotstein et al.[16] pointed out that the preferred transition speed from "walking" to "running" was significantly lower than the energetically optimal transition speed, but the specific speed for increasing energy expenditure is not clear. Here, the walking speed at the threshold for excess EE (*vs.* the Run trial) appeared at the 60 % phase (83 ± 3 %MWS) in males and 75 % phase (93 ± 1 %MWS) in females. Moreover, the absolute speed for the excess EE was 8.0 ± 0.5 km/h in males and 7.7 ± 0.6 km/h in females. Interestingly, these speeds are comparable to the reported speed of the transition from walking to running[17]. As a potential factor for the rapid increase in EE during walking, Mercier et al.[17] demonstrated that the stride while walking was longer than that while running at an equivalent speed. Furthermore, unbalanced posture during fast walking might augment muscle activity, with a concomitant increase in EE compared to running at an equivalent speed.

The substrate oxidation pattern is strongly affected by the exercise intensity[18]. Walking predominantly uses fat as a fuel, augmenting fat oxidation during and after exercise[19]. In our study, however, the Walk trial had significantly higher CHO oxidation than the Run trial during the 80–100 % phase (92 ± 2 % to 100 ± 0 %MWS) in males and 75–100 % phase (93 ± 1 % to 100 ± 0 %MWS) in females. Unfortunately, we were unable to determine the blood lactate and glucose concentrations following the exercise, but the use of higher walking speed above the 80% phase (92 ± 2 %MWS) appeared to facilitate CHO metabolism.

Heart rate was significantly higher in the Walk trial than in Run trial above the 80 % phase (92 ± 2 %MWS) in males, but the difference was not evident in females. Moreover, RPE for breath and legs sustained higher values in the Walk trial. In general, RPE is related to exercise intensity[20], which may also be influenced by exercise modality and physical fitness level. The comparison of physiological variables between the two trials was started at 5 km/h in the present study. The absolute MWS was 8.8 ± 0.7 km/h in males and 7.7 ± 0.6 km/h in females. The difference in MWS between genders might be associated with the different HR between the Walk and Run trials.

From a practical viewpoint, these findings would be valuable for developing fast walking training programs. Although we were unable to evaluate mechanical variables (*e.g.*, pitch, stride, and ground reaction force), walking would have a lower ground reaction force than running due to the continuous contact of either foot with the ground. The smaller mechanical stress during exercise may be preferable for specific populations, such as people with low fitness levels or obesity, and for older adults. Although MWS varies with age and fitness level, the present results indicate that walking at an intensity of 92 %MWS or greater is more effective for increasing energy expenditure than running at equivalent speed. Karstoft et al.[21] reported usefulness of fast walking in elderly with type 2 diabetes. In this study, the exercise program consisted of 3 min fast walking at 89 % of peak oxygen uptake ($\dot{V}O_{2peak}$) and subsequent 3 min slow walk at 54 % of $\dot{V}O_{2peak}$ (10 repetitions in total), and the average walking speed during fast walking phase was 6.0 ± 0.1 km/h. Therefore, we think that fast walking at 92% of MWS would be applicable among untrained people, based on the participant's fitness levels.

In conclusion, the EE and CHO oxidation during walking were more profound than those during running, at least above the 80% phase (equivalent to 92 ± 2 %MWS). The findings suggest that EE and CHO oxidation increase non-linearly during walking, and walking at fast speeds causes greater metabolic responses compared with running at equivalent speeds in both males and females.

ACKNOWLEDGEMENTS

We would like to thank all the subjects who participated in the study.

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