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Assessment of Energy Expenditure of Walking Based on Heart Rate Monitoring

Norlena Salamuddin, Fariba Hossein Abadi and Tajul Arifin Muhamad
Faculty of Education, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia

Abstract: Assessment of energy expenditure can play a fundamental role in the promotion of healthy lifestyle. Studies regarding Energy Expenditure Index (EEI) designates walking as the most recommended strategy to accurately and indirectly evaluate the oxygen uptake among the public in general. Furthermore, Heart Rate (HR) and walking speed have previously been shown to be linearly related to oxygen uptake at sub-maximal exercise levels. The present study aims at determining the differences of EEI of walking between males and females. About 96 healthy students (48 female and 48 male), with a mean aged of 22 (±1.5) years, participated in this study which investigates the EEI values at the speed of casual walking which is 4.6 km h^{-1}. Participants' medical history were noted and physical characteristics (weight, height and leg length) stride length and frequency were measured. The HR was assessed at resting position as well as while walking on the treadmill with a HR monitor. Results of this study shows a significant difference between the EEI values of male and female participants ($t = -4.527$, $p>0.01$).

Key words: Energy expenditure index, walking heart rate, casual walking, gait parameters, oxygen, medical

INTRODUCTION

The energy expenditure of ambulation has been proved useful in walking gait research and the rate of oxygen cost is a good indicator of the efficiency of walking. Past researches have typically used the traditional parameter of measuring energy expenditure based on oxygen uptake (e.g., Douglas bag method) as well as electromyography, kinetic and kinematic analyses to evaluate the efficiency of locomotion, each of them have some limitations and are not readily available in the recreational and educational communities. On the contrary, heart rate is an easily measurable parameter and has been found to be an accurate and convenient tool to estimate energy expenditure during steady state sub maximal work like walking. Furthermore, for normal healthy people measuring heart rate is a convenient method for predicting energy expenditure since it is linearly related to the rate of oxygen uptake (ACSM, 2010; Astrand and Rodahl, 1986; Balderrama *et al*., 2010).

However, MacGregor (1979) accurately developed an estimated Energy Expenditure Index (EEI) based on the heart rate value and showed the linear relation of O_2 consumption with heart rate. EEI is defined as the difference of walking heart rate and resting heart rate divided by walking speed (MacGregor, 1979). Due to the linear relationship established between heart rate and oxygen consumption at sub maximal workloads (Thomas *et al*., 2009), these indexes are considered a reasonable alternatives to direct measurement of oxygen consumption. In addition, this equation formulated by MacGregor (1979) not only is convenient to apply in gyms, recreational camps, communities and clinics (Rose *et al*., 1991) but also its influence on emotional stress, medication and fitness are very small (Graham *et al*., 2005).

On the other hand while walking is an activity that is conveniently incorporated into daily life for many individuals, it is also important to provide recommendations for groups of people who have different long-term conditions and different demographic structure. Additionally, energy expenditure of any group or population is determined by the demographic structure of the group, the patterns of physical activity and the climate (Manini, 2009). However, EEI has not been applied widely to measure energy expenditure of walking in various population because of the influence of factors; like age, gender and physical characteristics that affect gait parameters which is still unidentified (Graham *et al*., 2005; Wu, 2007).

Researches by Hoyt and Taylor (1981), Minetti *et al*. (2001) and Alexander (2002) suggested that slow walking causes early fatigue for individuals, therefore walking should be done at an average economical speed which is reported to be in the range of 1.2-1.5 m sec^{-1} (Alexander, 2002; Hoyt and Taylor, 1981; Minetti *et al*., 2001).

Corresponding Author: Norlena Salamuddin, Faculty of Education, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia

Likewise, Sparrow (2000) reported that the most economical walking with minimum energy cost occurs approximately at the speed of 75 m min^{-1} (4.5 km h^{-1}) (Sparrow, 2000). Besides, Dal *et al*. (2010) concluded that the normal ranges of walking speed in adults vary between 60 and 100 m min^{-1}.

The U-shaped speed's theory states that a unit distance in human walking reaches a minimum around the comfortable speed and then begins to increase to above and below comfortable speed which causes a dramatic increase in energy cost (Sparrow, 2000). Therefore, EEI values varies with walking speeds and in this study, a walking speed of 4.6 km h^{-1} (1.25 m sec^{-1}; 76.7 m min^{-1}; near 3 mph) was assumed as a casual walking speed.

Many studies on human locomotion have suggested that gaits are selected on the basis of metabolic energy consideration. Individuals at a given speed of locomotion select gait parameters (stride length and stride frequency) that result in lower energy cost; larger or shorter stride length considerably increases energy cost (Cavangna and Franzetti, 1986).

Gender is also a factor that influences movement patterns during walking (Chiu and Wang, 2007; Chung and Wang, 2010). Even though, past research findings suggested that the higher energy expenditure demands displayed by males was related to the presence of a greater muscle mass, recent studies indicate that small stride length increases energy expenditure. Moreover, leg length and height are generally greater in males as compared to the females and increased leg length may decrease the requirement of energy for walking at given speed (Sparrow, 2000).

Several investigators have reported higher rates of oxygen consumption in males while walking. Others have reported higher values in female subjects or no significant difference. In a review by Waters and Mulroy (1999), 225 normal subjects between the ages of 6 and 80 years found no significant differences in oxygen consumption due to gender when observed at the customary slow, normal or fast speeds of walking. These finding suggested that the differences between men and women were approximately related to the rate of uptake per kilogram of body weight (Waters and Mulroy, 1999). Other results show differences between men and women for rate during rest and walking.

More specifically, Geer and Shen (2009) stated that in children, metabolic parameters were different for both genders before non-dimensional normalization sets in, although no significant differences in anthropometric data were found. They reported that the differences are probably due to differences in timing of maturation (Geer and Shen, 2009; Van de Walle *et al*., 2006).

Rose and Gamble (2006) stated significantly lower values of energy expenditure for women than for men at speeds of 91 and 109 m min^{-1}. They indicated that smaller step length increases energy expenditure. Result from this investigation revealed that absolute and mass-related values of gross and net O_2 were significantly greater in male compared to female but gross O_2 expressed relative to fat-free mass was not different between genders. This finding suggest that the higher locomotion O_2 displayed by male was related to the presence of a greater muscle mass. Leg length and height are generally greater in males compared to females but may explain only small differences in energy expenditure (Rose and Gamble, 2006).

While Workman and Armstrong (1963) found that body height had a small but consistent effect on the predicted value of oxygen uptake while walking, Sparrow (2000) noted that short people uses more oxygen to walk than tall people of the same body weight at all walking speeds. Furthermore, at a given speed of locomotion individuals select a stride length that results in lower energy cost, longer or shorter stride length than the preferred stride length considerably increases the energy cost which is a marker of the efficiency of walking (Alexander, 2002). In addition, the findings from Waters revealed that during self-paced walking, heart rate was slightly but significantly higher in female young adults (104 beats min^{-1}) and seniors (106 beats min^{-1}) as compared to male adults (94 beats min^{-1}) and seniors (97 beats min^{-1}). On the other hand, walking speed was significantly slower in female young adults (76 m min^{-1}) compared with male young adults (84 m min^{-1}) (Waters and Mulroy, 1999). Moreover, Bassey *et al*. (1982) reported that women has a walking heart rate that is 4.4 beats min^{-1} higher when height and weight of the subjects were controlled.

Booyens and Keatinge (1957) illustrated notably lower values of energy expenditure for women than for men at the speeds of 91 and 107 m min^{-1} and they predicts lower values for women than for men and attributed this feature to the smaller step length in women.

Recent studies, however points out that a smaller step length may cause higher energy expenditure. However, Ralston (1976) did not report any significant difference between gender in locomotion energy cost and concluded that gender is not a factor which has any effects on walking energetic.

Rose and Gamble (2006) revealed that casual walking speed was significantly slower in female as compared to male young adults. Likewise, Rose *et al*. (1991) investigated EEI of walking for 103 children and adults aged between 6-18 on a treadmill using different speeds. The result indicated that for the eldest group (15-18 years), the EEI was 0.45 beats m^{-1} for males and 0.49 beats m^{-1} for females is the most economical walking, at a comfortable speed of 75 m min^{-1}. Similarly, Wu (2007) calculated the EEI for 46 individuals (23 males and 23 females) at different speeds of walking. The average EEI for males at the speed of 77.79 m min^{-1} was 0.42 beats m^{-1} while 0.51 beats m^{-1}were reported for females. The findings of study revealed that walking speed, weight, height and leg length significantly influenced the EEI between gender (Wu, 2007).

EEI has not been applied extensively to Malaysian population and the influence of physical characteristics (height, weight and leg length) and gait parameters (e.g., stride length, stride frequency and step width) is still unknown. The aim of this study is to investigate the differences in EEI values of walking and analyze the correlation of EEI with height, weight, leg length and height to leg length ratio between gender at a casual walking speed of 4.6 km h^{-1}.

This study measures EEI via a heart rate monitor while subject walks on a treadmill at a given speed of 4.6 km h^{-1}. The given speed combine with a selected stride length is assumed to result in lower energy cost. It is hypothesized that that there is no significant correlation between gender and EEI. It is also assumed that there is no significant relationship between weight, height, leg length and the EEI values among the subjects.

MATERIALS AND METHODS

A total of 96 healthy college students (48 males and 48 females) without any regular exercise background with an average age of 22.4 (±1.5) years participated in this study. Participants were advised on food, caffeine and alcohol intake prior to taking the test. All participants have not been involved in any regular exercise, activities or work outs in their daily life. Participants with past history of cardiopulmonary, neurological or musculoskeletal diseases and any athletic background that could affect walking economy were excluded. All subjects were able to accomplish the walking test at the of speed 4.6 km h^{-1}.

The treadmill was calibrated to start at the speed of 2 km h^{-1} and reached to the target speed of 4.6 km h^{-1} at the 20th sec. Elevation of the treadmill was set at 0% grade and participants were not allowed to hold onto the handrails. Participants wore a heart rate monitor around their chest and a pedometer was used to record the step frequency while walking on the treadmill.

Information regarding the participant's age, gender, physical activity background, medical history and current medical state were obtained before beginning the test. Physical characteristics measurement of weight, height and leg length were also recorded. Leg lengths for both sides were measured from the greater trochanter to lateral malleolus. Resting heart rate and stride length were also measured and recorded. Working heart rate were recorded at every 10 sec interval for the last 4 min of the test. Step frequency were recorded at the end of the test before participants leaves the treadmill.

Stride length, walking speed and EEI values were calculated for each participant. Data were then analyzed using Pearson correlation and t-test to answer the research questions.

RESULTS

Demographic values for physical characteristics of subjects are shown in Table 1. The mean values for females are height 156.9 (±5.5) cm, weight 56.8 (±11.6) kg, BMI 23.0 (±4.3) kg m^{-2}, leg length 76.9 (±4.1) cm, height to leg length ratio 2.04 (±.057) and resting Heart Rate (HR$_{rest}$) 73.5 (±6.0) bpm. Meanwhile, the values for males are height 170.2 (±6.7) cm, weight 67.8 (±12.7) kg, BMI 23.4 (±4.1) kg m^{-2}, leg length 84.3 (±4.9) cm, height to leg length ratio 2.02 (±.06) and HR$_{rest}$ 68.5 (±6.6) bpm. Males had lower resting heart rate, higher weight, height and leg length than females while their BMI and height to leg length ratio were approximately similar.

Table 2 shows the information regarding the gait parameters measured during normal and comfortable walking on the ground and walking on the treadmill at a speed of 4.6 km h^{-1}. Step width for males (11.05±1.8cm) was significantly more than females (6.65±1.9 cm). Preferred stride length on ground were 1.28±0.07 and 1.40±0.09 m in females and males, respectively. Stride length and stride frequency were 1.31±0.06 m and 58.7±2.5 sec min^{-1} for females and 1.37±0.06 m and

Table 1: Physical characteristics values of samples

Variables	Females (N = 48)	Males (N = 48)	All subjects (N = 96)
Height (cm)	156.9±5.5	170.2±6.7	163.6±6.1
Weight (kg)	56.8±11.6	67.8±12.7	62.3±12.1
BMI (kg m^2)	23.0±4.3	23.4±4.1	23.2±4.2
LL (cm)	176.9±4.1	84.3±4.9	80.6±4.5
Height LL^{-1}	2.04±0.057	2.02±0.06	2.03±0.059
Hr$_{rest}$ (bpm)	73.5±6.0	68.5±6.6	71.0±6.3

*Values = Mean±SD; BMI = Body Mass Index; LL = Leg Length; Height LL^{-1} = Height to Leg Length ratio; HR$_{rest}$ = Resting Heart Rate; bpm = Beats min^{-1}

Table 2: Values of gait parameters among gender (N = 48)

Variables	Females	Males	All subjects
Step width (cm)	6.65±1.9	11.05±1.8	11.05±1.8
Preferred stride length on ground (m)	1.28±0.07	1.40±0.09	1.39±0.08
Stride length (m) speed; 4.6 km h^{-1}	1.31±.06	1.37±0.06	1.34±0.06
Stride frequency (sec min^{-1})	58.7±2.5	56.3±2.48	57.5±2.49

Table 3: EEI values of walking at 4.6 km h^{-1} between genders

EEI	Mean±SD (beats m^{-1})	Mean difference	t-value	p-value
Females	0.581±0.08	-	-	-
Males	0.511±0.06	-0.07	-4.528	0.000

Table 4: EEI range and percentages cases for females, males and all subjects

	Females	Males	All subjects
EEI range (beats m^{-1})	(%)		
Economical: <0.4-0.50	16.7	52.1	34.4
Moderate: 0.501-0.60	45.8	35.4	40.6
High: 0.601-0.70	27.1	12.5	19.8
Very high: <0.701	10.4	-	5.2

Table 5: Correlation between physical characteristics and EEI values for both genders

EEI beats m^{-1}	r value weight	r value height	r value leg length	r value (height LL^{-1})
Females	0.34*	-0.14	-0.29*	0.32*
Males	0.16	-0.11	-0.21	0.41*

*Significant 0.05 level

56.3±2.48 sec min^{-1} for males during walking on treadmill at the given speed. In this study, females have shorter stride length than males so females need higher stride frequency to maintain the same walking speed.

As illustrated in Table 3, EEI values while walking on treadmill at the speed of 4.6 km h^{-1} in female was 0.581 (±0.08) beats m^{-1} and for males was 0.511 (±0.06) beats m^{-1} which shows the difference between EEI values of females and males was statistically significant ($p<0.05$).

Table 4 show >50% of males had EEI of <0.5 beats m^{-1} which is categorized as economical walking while only 16.7% of females were in this range. While 45.8% of female's EEI and 35.4% of male's EEI were within the moderate range of 0.5-0.6 beats m^{-1}. However, no EEI values of above 0.7 beats m^{-1} were recorded for male subjects while 10.4% of female subjects' EEI value were in this range which is categorized as very high thus not economical. According to Rose *et al.* (1991), the average EEI value for the 15-18 years old age group was 0.45 beats m^{-1} for males and 0.49 for females at speed 75 m min^{-1} as the comfortable speed while the average of most economical walking speed judged from EEI values (0.41 beats m^{-1}) for adults was 64.37 m min^{-1} (Rose *et al.*, 1991). Similarly, according to Wu (2007), the average most economical walking speed were noted at 77 m min^{-1} and EEI for males was 0.42 beats m^{-1} and for females 0.51 beats m^{-1}. Even though, the EEI stated by other the above researchers were more than EEI found in this study, it seems that for the male subjects were still near the range of economical EEI at the range of speed where walking remains economical. Moreover, MacGregor (1979) used the EEI to study a normal girl walking on the floor and found that the girl's EEI value at the self-selected comfortable speed was 0.35 beats m^{-1} which is notably lower than the mean of the most economical EEI value not only for females but also for males subjects in this study.

Table 5 shows the pearson correlation coefficient between EEI and four factors of physical characteristics (height, weight, leg length and height to leg length ratio) for both genders. There was a weak relationship between EEI and height in female as well as males. Analysis shows a positive and significant correlation between EEI and weight only for females (r = 0.34). The results demonstrated that correlation between EEI and leg length was negative and is significant only for females (r = -0.29), therefore weight and leg length were noticeably predictors for EEI. This study found a positive correlation between EEI (at speed 4.6 km h^{-1}) and height to leg length ratio in females (r = 0.32) and males (r = 0.41) as the best predictor for both gender. Likewise, Sparrow *et al.* (1996) revealed that proportion of limb has an effect on efficiency of walking and are predictors of transition velocities.

This study shows similar results with Wu (2007) and Rose *et al.* (1991) for negative relationship between EEI of females and the leg length, especially when speed of walking is involved. The weak correlation between EEI, weight and leg length in males may indicate that slow or fast speeds may change the correlation between EEI and physical characteristics.

On the other hand, walking with decreasing stride length could cause increasing EEI at a particular speed. Similarly, Kito and Yoneda (2006) suggested that when walking casually, cycle duration is the dominant factor rather than stride length to minimize energy cost. As Kuo (2001), originally hypothesized the cost for moving the legs explains that humans do not walk with short steps to minimize the costs of transitioning between inverted pendulum arcs.

Large increases in metabolic cost for leg swinging may be sufficient to explain the increasing cost of walking with step frequency (Doke *et al.*, 2005). Indeed, Kramer and Sarton-Miller (2008) reported that people can differ substantially in leg length affecting both self-selected walking velocity and O_2 other variables are also important in mechanical energy calculations (Kramer and Sarton-Miller, 2008). In term of gait parameters, stride length and frequency of walking on treadmill at speed 4.6 km h^{-1}, the findings of this study are in agreement with the study by Kito and Yoneda (2006) and Kuo (2001).

DISCUSSION

The findings of this study have revealed that EEI values of walking for female subjects are higher than male subjects while walking at the speed of 4.6 km h^{-1}

(76.7 m min^{-1} about 3 mph). The results have demonstrated that male are preferably comfortable than female while walking at this speed as a casual walking speed. It seems that female tend to increase stride length and stride frequency in order to keep up with the predetermined walking speed. Moreover, the positive correlation between heights to leg length ratio indicates that male prefer higher walking speed than 4.6 km h^{-1} as a comfortable speed. Since females had shorter stride length, thus they tend to require higher step frequency to maintain the same walking speed. Even though, the resting heart rate of females were higher than males, other physical characteristics like weight, leg length and height to leg length ratio are considered as combined factors that contributes to the efficiency of walking and increasing velocity. In summary, although it is an established fact that resting heart rate is known to increase with decreased body size and level of fitness, differences in anthropometric parameters which alter stride length can promote greater understanding of the relationship between EEI of walking and health among males and females. Developing EEI of walking with anticipating the influence of anthropometric parameters can provide a simple and inexpensive normative standard to monitor walking efficiency. Further investigations is required for developing EEI in diverse ages, exercise levels and at multiple speeds of walking.

CONCLUSION

In this study, this differences might be explained by the great variability of participants' weight, leg length, resting heart rate, speed and gait parameters which significantly influenced the EEI of walking in both genders.

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