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ASSESSMENT OF ENERGY EXPENDITURE OF WALKING BASED ON HEART RATE MONITORING BY GENDER

FARIBA HOSSEIN ABADI[1], GUNATHVAN ELUMALAI[2] & HASTI SATTARI[3]

[1]Faculty of Physical Education, Shahid Rajaee Teacher Training University, Lavizan, Tehran, Iran

[2]Faculty of Sports Science and Coaching, University Pendidikan Sultan Idris, Malaysia

[3]Faculty of Education, University Kebangsaan Malaysia, Selangor, Malaysia

ABSTRACT

It is a fact that the assessment of energy expenditure can play a pivotal role in promoting a healthy lifestyle and preserve lifespan. The study regarding energy expenditure index (EEI) of walking can be designated as the most recommended strategy to evaluate the oxygen uptake accurately and indirectly among people. Moreover, heart rate (HR) and walking speed have been previously shown to be linearly related to oxygen uptake at sub-maximal exercise levels. Combination of these two parameters yields a single value in beats per meter i.e. the energy expenditure index (EEI). This study was aimed to determine the differences of EEI of walking between males and females. Ninety six healthy students of age in average 22.3±1.5years from University Kebangsaan Malaysia (48 females and 48 males) participated in this study to be investigated for EEI values at speed of casual walking; 76.7m.min^{-1}. Information regarding the subject's medical history was acquired by a questionnaire. In addition, physical characters (weight, height and leg length) were measured using stadio meter, digital weighing scale and a non-elastic tape for both groups. The heart rate (HR) was assessed at resting position as well as walking on a treadmill with a HR monitor in order to determine the EEI of walking. The mean EEI values for females and males were 0.58 (±0.08) and 0.51 (±0.06) beats.m^{-1} respectively. The results of t-test demonstrated a significant difference between EEI's females and males (t= -4.527, *p*=0.00) at speed 4.6km.h^{-1}. In conclusion, this inconsistency might be explained by greater variability of subject's weight, leg length, height to leg length ratio, resting heart rate, speed, and gait parameters of walking which significantly influenced on EEI of walking in both genders.

KEYWORDS: Energy Expenditure Index, Walking, Casual Walking Speed, Gender

INTRODUCTION

Recently, the energy expenditure of ambulation has also been proved useful in walking gait research and the rate of oxygen cost is an indicator of the efficiency of walking. While, past investigation have typically used the traditional parameter of measuring energy expenditure based on oxygen uptake or (e. g., Douglas bag method) as well as electromyography, kinetic and kinematic analyses to evaluate the efficiency of locomotion, each of them have limitations and not available in the recreational and educational communities. Conversely, heart rate is an easily measurable parameter and has been found to be an accurate and convenient tool to estimate of energy expenditure during steady state sub maximal work like walking (Astrand & Rodahl, 1986; Balderrama, Ibarra, De La Riva, & López, 2010). However, the use of heart rate to measure energy expenditure is influenced by many factors (e. g., emotional stress, fitness, medication, and the mechanical work done (Wu, 2007).

Mac Gregor (1979), developed accurately estimated energy expenditure index (EEI) based on the heart rate value and shown the linearly relation to $\dot{V}O_2$consumption with heart rate. The EEI was defined as the difference of walking heart rate and resting heart rate divided by walking speed. Moreover, this measuring equation not only is convenient to apply in gyms, recreational camp communities and clinics (Rose, Gamble, Lee, Lee, & Haskell, 1991), but also the influences of emotional stress, medication, and fitness are very small (Graham, Smith, & White, 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 in 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 group, the patterns of physical activity and the climate (Manini, 2009).However, the EEI has not been applied widely to measure energy expenditure of walking in population, because of the influence of factors like age, gender, and physical characteristics which affect the gait parameters is still unidentified (Graham, et al., 2005; Wu, 2007). Considering to the results by Hoyt and Taylor (1981) Minetti et al. (2001), Alexander (2002) and Dal et al. (2010) suggested that slow walking causes early fatigue for individuals and naturally walking should have been done at an average economical speed which reported in the range near 1.2 to 1.5m.s^{-1}.likewise, Sparrow (2000) reported the most economical walking with minimum energy cost occurring approximately at speed of 75 m.min^{-1}; 4.5km.h^{-1}. U-shaped speed's theory images that a unit distance in human walking reaches a minimum around the comfortable speed and then begins to increase the above and below of comfortable speed and causes a dramatic increase in energy cost (Willis, Ganley et al. 2005). Therefore, EEI values could be varied with walking speeds and in this study 76.7 m.min^{-1} (4.6km.h^{-1};~ 3.00 mph) was assumed as a casual walking speed.

In Malaysia, EEI has not been applied extensively to measure 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. This study, aimed to investigate the differences in EEI values of walking and analyze the relationship of EEI with height, weight and leg length, height to leg length ratio among both gender at speed of 76.7 m.min^{-1} as a casual speed of walking.

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 increase the energy cost (Cavangna, 1986). Gender is also a factor that influences movement patterns during walking (Chiu & Wang, 2007; Chung & Wang, 2009). Even though findings suggest that the higher energy expenditure demand display by males was related to the presence of a greater muscle mass, resent studies indicate that small stride length increase 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 review of Waters and Mulroy, 225 normal subjects between the ages of 6 and 80 years, no significant differences in oxygen consumption due to gender were observed at the customary slow, normal, or fast speeds. These finding suggest, the differences between men and women approximately related to the rate of O_2uptake per kilogram. More specifically, Geer and Shen (2009), stated that in children, metabolic parameters were different for both genders before net non-dimensional normalization, although no significant differences in anthropometric data were found. They reported that the differences are probably due to differences in timing of maturation; similarly it was reported by Van de Walle et al. (2006).

Rose and Gambel (2006), stated significantly lower values of energy expenditure for women than for men at speed 91 and 109 $m.min^{-1}$. They indicated that smaller step length increases energy expenditure. Result from the investigation revealed that absolute and mass- related values of gross and net $\dot{V}O_2$ were significantly greater in male compared to female, but gross $\dot{V}O_2$ expressed relative to fat-free mass was not different between genders. These finding suggest that the higher locomotors $\dot{V}O_2$ display by male was related to the presence of a greater muscle mass. Leg length and height are generally greater in males compared with females, but may explain only small differences in energy expenditure. Furthermore, at a given speed of locomotion individuals select a stride length that results in lower energy cost, stride length larger or shorter than preferred considerably increase the energy cost that is a marker of the efficiency of walking (Alexander, 2002).

Casual walking speed was significantly slower in female as compared to male young adults (Rose & Gamble, 2006). Likewise, Rose et al. (1991) investigated EEI of walking from 103 children and adults aged 6 to 18 on treadmill in different speeds. The result for the eldest group (15-18 years) EEI was 0.45 $beats.m^{-1}$ for males and 0.49 for females as the most economical walking, while the comfortable speed was $75m.min^{-1}$. Similarly, Wu (2007) calculated the EEI for 46 (23males and 23 females) in different speed. The average EEI for males at speed of 77.79 $m.min^{-1}$ was 0.42 $beats.m^{-1}$, while 0.51 $beats.m^{-1}$ reported for females. The results revealed a significant difference between EEI of males and females in different speed that can be related to the weight, and leg length.

METHOD

Ninety six healthy college students (48 males and 48 females) aged 22.4 ±1.5from UKM participated in this study. All subjects have not been involved in any exercise, activities or working outs during their daily life. Participants with past history of cardiopulmonary, neurological or musculoskeletal diseases that could affect walking economy were excluded.

Instrument

The instruments of this study were as follow

Motorized Treadmill

Treadmill STAR TRAC S SERIES TREADMILLS OWNER'S MANUAL USA model was used in this study. The screen of the treadmill showed the speed, time, distance and grade (which the slope was set to horizontal). The treadmill was calibrated to start at speed from 2 $km.\ h^{-1}$ and reached to the target speed 4.6 $km.\ h^{-1}$ ($1.25m.s^{-1}$;$76.7m.min^{-1}$; near 3mph) till 20th second. Elevation of the treadmill was set at 0% grade and subjects were not allowed to hold onto the handrails.

Heart Rate Monitor (HRM)

Heart rate monitor model: Polar FS1/FS2c/FS3c™ Own Zone. After the Polar Transmitter is connected to Elastic Strap, subject wears them and centers the Polar Transmitter on the chest at the level of the xiphoid process. Wrist Monitor (Receiver Unit) was worn by the investigator who stayed within 3 to 3.5 feet (maximum 1m) of the subjects.

Pedometer Model

YAMAX DIGI WALKER CW 701-SERIES Japan as one of the most accurate pedometer (Crouter, 2005) to record the cadences (step frequency) while walking on treadmill. The pedometer was worn on the left side and the numbers of cadence (step frequency) recorded right away at the end of the test before leaving the treadmill.

Procedure

Pre-Test Requirements

Information regarding the subject's age, gender, physical activity background, medical history and current medical statue and the confidence of health groups were obtained from subjects by a questionnaire. Before starting the protocol, each subject was familiarized with treadmill walking for a few minutes while the speed of treadmill was slowly increased to reach the target speeds. Physical characteristics; weight, height, and leg length were respectively measured with a standard scale, stadio meter and meter/tape. Leg lengths of both sides were measured from greater trochanter to lateral malleolus.

Resting Heart Rate ($HR_{resting}$)

Before the walking tests, each sample person lay quietly on a bed for 5 minutes until the heart rate reached a stable count, then RHR were recorded every 10 seconds during an interval of the last 2 minutes which reached as the lowest level during the 5 minute rest period. The $HR_{resting}$ was determined by averaging the all 10- second HRs.

Tests

Participants walked by their own free style of walking gait for 8 minutes at speed of 76.7m.min^{-1} (4.6 km.h^{-1}). Each subject wore Polar Transmitter and Elastic Snap at the level of xiphoid process, and the Pedometer at the left side of waist to measure the cadences while HR was measured during walking on treadmill. Wrist Monitor was worn by investigator who stayed the subject within 3 to 3.5 feet.

HR was measured by averaging the respective 10-seconds interval HR during last 4 minutes (4th to 8th minutes) which recorded. Right at the end of test, before leaving treadmill, the cadences (step frequency) recorded by pedometer monitor. Considering to walking speed formula which is: Walking Speed (m.s^{-1}) = stride length × stride frequency (Stride length = step length × 2). Stride length (SL) calculated by: Walking Speed/ (cadence × 2); the calculated speed in units of km.h^{-1} was converted to units of m.s^{-1} to be used for this formula. Step width was determined as the medial–lateral distance between the locations of sequential left and right heel and it was measured after drawing the straight line between marked footprint of 5 steps length.

It was recorded in centimeter to one decimal place and measured by average of 5 steps while the subjects walking on ground. This trail was repeated for two times.

RESULTS AND DISCUSSIONS

The average mean, ±SD, minimum, and maximum values of age, weight, height, BMI, leg length, the height to leg length ratio and $HR_{resting}$ in females, males and all subjects illustrated in Table 1. It shows males had lower $HR_{resting}$, higher weight, height, and leg length than females while their BMI and height to leg length ratio were approximately similar.

Table 1: Demographics of Physical Characteristics Values of Participating Subjects

Variables	Females (N=48)	Males (N=48)	All (N=96)
Age (years) Range	22.4±1.5 20-25	22.1±1.5 20-25	22.25±1.5 20-25
Height Range (cm)	156.9±5.5 147-168.2	170.2±6.7 156.4-187.8	163.6±6.1 147-187.8
Weight Range (kg)	56.8±11.6 40.8-91.1	67.8±12.7 45.3-98.3	62.3±12.1 40.8-98.3
BMI Range ($kg.m^{-2}$)	23.0±4.3 18.2-35.5	23.4±4.1 16.1-33	23.2±4.2 16.1-35.5
LL (cm) Range	76.9±4.1 78.9-99.1	84.3±4.9 74.2-94.5	80.6±4.5 74.2-99.1
Height/LL Range	2.04±.057 1.85-2.14	2.02±.06 1.90-2.14	2.03±.059 1.85-2.14
$HR_{resting}$ (bpm) Range	73.5±6.0 62-87	68.5±6.6 56-90	71±6.3 56-90

BMI= body mass index; LL= leg length; bpm= $beats.min^{-1}$, values= mean ±SD, Range=minimal and maximal values.

Table 2 shows a list of gait parameters measured during walking on the treadmill at speed of 76.7 $m.min^{-1}$. Stride length for all subjects were134.02±0.06 cm (step length 67.01 cm) and stride frequency was 57.44±2.49 stride per min (Cadence: 114.88 $steps.min^{-1}$) during walking on the treadmill at speed of 76.7 $m.min^{-1}$. Step width for males (11.05±1.8cm) was significantly more than females (6.65±1.9cm). In this study females have shorter stride length than males, so females need higher stride frequency to maintain the same walking speed.

Table 2: Demographic Values of Gait Parameters for Females, Males and all Subjects

Variables	Females	Males	All
Stride length Range (cm)	1.31±0.06 1.22-1.50	1.37±0.06 1.23-1.51	1.34±0.06 1.22-1.51
Stride frequency Range	58.63±2.5 51.13-62.9	56.25±2.48 50.75-62.2	57.44±2.49 50.75-62.9
Step width Range (cm)	6.65±1.9 4.8-14.3	11.05±1.8 7.2-15.5	11.05±1.8 4.8-15.5

All subjects were easily able to accomplish the walking test at speed 76.7$m.min^{-1}$ (4.6$km.h^{-1}$). As Table 3 shows, more than 50% of males had EEI less 0.5 ($beats.m^{-1}$), while only 16.7% of females set in this range. Also, 45.8% of females EEI were within the range 0.5-0.6 ($beats.m^{-1}$), and 35.4% of males were in this range. Moreover, no EEI's males were at above 0.7 ($beats.m^{-1}$), while 10.4% of EEI's females were in this range. While the average of EEI values for males were 0.51($beats.m^{-1}$) and more than 52.1% of them had EEI values less than 0.5 (Table 3 & Figure 1).

Table 3: EEI Range and Percentages Cases for Females, Males and all Subjects

EEI Range ($Beats.m^{-1}$)	Females %	Males %	All %
<0.4	-	2.1	1
0.4-0.5	16.7	50	33.3
0.5-0.6	45.8	35.4	40.6
0.6-0.7	27.1	12.5	19.8
>0.7	10.4	-	5.5

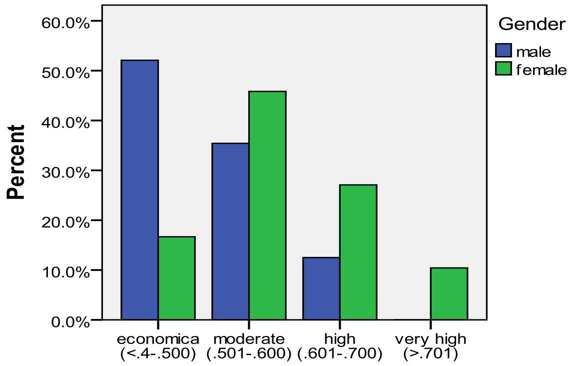

Fig 1. EEI categorized besed on comparing to comfortable walking speed (beats/m)

Figure 1

According to Rose et al. (1990), the average of EEI values for the group (15-18 years) was 0.45 beats.m-1 for males and 0.49 for females at speed 75m.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 64.37m.in-1. Similarly, according to Wu (2007) studies the average of most economical walking speed noted 77m.min-1and EEI for males was 0.42 beats.m-1 and for females 0.51 beats. m-1. Even though, those EEI were more than EEI in this study, it seems for males were still near the range of economical EEI at the range of speed with which walking remain economical.

Moreover, Mac Gregor (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 0.35beats.m-1, which is lower than the mean of the most economical EEI value not only for our females, but also for males' subjects.

Table 4: Comparing EEI Values of Walking for Males and Females

EEI	Mean±SD(Beats.m^{-1})	Mean Difference	t	Significance (2-Tailed)
Females	0.581±0.08	-0.07*	-4.528	p<0.00
Males	0.511±0.06			

Note: * The differences mean is significant at the 0.05 level (2-tailed).

Using "t- test" for EEI of walking on each gender, it was observed that there were significant difference in the EEI values between females and males at speed of 76.7m.min^{-1}(p=0.001) as an assumed economical speed of walking.

Table 4 showed the average ±SD, minimum, and maximum of EEI values for females and males while walking on treadmill at speed of 76.7m.min^{-1}

The EEI values have been assumed in the Gaussian distribution. The EEI average ±standard error for female was 0.581±0.08 beats.$m^{-1}$and for males was 0.511±0.06 beats.m^{-1}. As illustrated in Table 4, the difference between the average EEI female and males was statistically significant (p< 0.00).

Table 5: The Coefficient Correlation between Physical Characteristics and EEI Values of Females as Well as between Males

EEI (Beats/m)	*r* Value Weight	*r* Value Height	*r* Value Leg Length (LL)	*r* Value (Height/LL)
Females	0.17	-0.1	-0.23	0.32*
Males	0.16	0.14	0.31*	-0.41**

Note: * The differences mean is significant at the 0.05 level (2-tailed).
** The differences mean is significant at the 0.001 level (2-tailed).

Table 6: The Coefficient Correlation between Leg Length Height /LL Ratio and Stride Length for Both Genders

Stride Length (cm)	*r* Value Leg Length (LL)	*r* Value Height/ LL Ratio
Females	0.42**	-0.22
Males	0.34**	-0.28

Note: * The differences mean is significant at the 0.01 level (2-tailed).

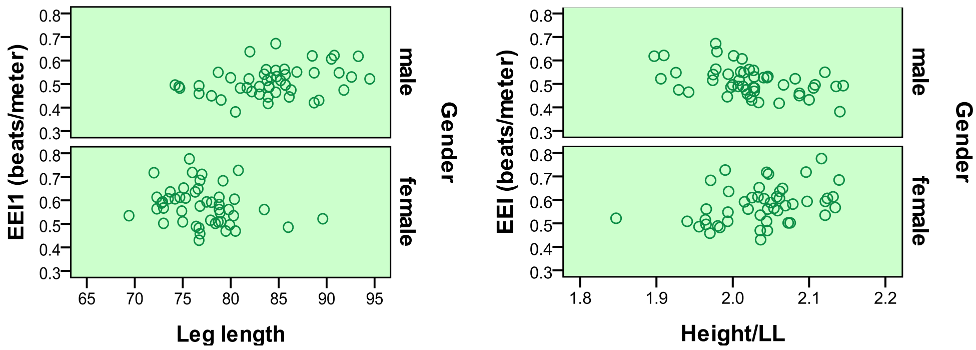

Figure 2: Scatter Plot of EEI vs. Leg Length (LL) and Height/LL in Male and Female

Table 4 shows a list of the Pearson Correlation Coefficient between EEI andfour factors of physical characteristics (height, weight, leg length, and height to leg length ratio)for both genders. There was weak relationship between EEI and weight as well as height factor. Figure 2 shows the positive relationship between EEI and leg length for males and negative for females. This study shows similar results with Wu (2007) and Rose et al. (1991) for negative relationship between EEI of females and the leg length specially when speed of walking arises. On the other hand, walking with decreasing in stride length could cause increasing EEI in that speed. Alike, Kito et al. (2006) suggested that when we walk casually, cycle duration is the dominant factor rather than stride length to minimize energy cost. As Kuo (2001) originally hypothesized a cost for moving the legs to explain 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, Donelan, & Kuo, 2005). Indeed, Kramer and Sarton-Miller (2008) reported that people can differ substantially in leg length affecting both self-selected walking velocity and $\dot{V}O_2$, Other variables are also important in mechanical energy calculations.

CONCLUSIONS

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 76.7 m.min^{-1}. The results have demonstrated that male are preferably comfort table than female while walking at the speed of 76.7 m.min^{-1} (near 3mph) as a casual speed. It seems that female tend to increase stride length in order to keep up with the predetermined walking speed. Moreover, the positive correlation between heights to leg length ratio indicates that male can prefer higher walking speed than76.7 m.min^{-1} as a comfortable speed. Since females had shorter stride length, and then 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 might considered as combined factors to contribute the efficiency of walking and increasing velocity. 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 EEI walking and health among males and females.

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