Original Article

Relationship between leg length and energy expenditure during walking

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Abstract:

A study was conducted to compare the energy expenditure (EE) during walking at two different speeds. The objective of this study was to determine the relationship between leg length (LL) and energy expenditure during walking. A total of 191 students took part in this study. A questionnaire was used to collect information on the subjects' medical history, background and physical characteristics. Energy expenditure for eight minutes of treadmill walking at two different speeds (4.6km.h⁻¹ and 5.4km.h⁻¹) were measured using HR-VO₂max conversion process technique. Multiple regression analysis revealed that there is a significant relationship between energy expenditure during walking and leg length as the speed of walking increased. This study suggests that estimating energy expenditure of walking plays an important role in total energy requirement that progressively and slowly effect weight management and health. It is also inferred that estimation of energy expenditure of walking needs to be explores further based on individuals' physical characteristics and physical activity level as well as weight and walking speed.

Key Words: walking, energy expenditure, leg length

Introduction

Walking is a major daily physical activity for almost all healthy individuals. Walking is one of the most recommended physical activity due to its simplicity, inexpensiveness, and being widely accepted by the society and can be incorporated into daily life and sustained until old age (Bird, Radermacher, Sims, Feldman, Browning & Thomas 2010). Walking is a complex functional skill that is a result of the integration of physical characteristics, skeletal, muscular and nervous systems as they interact with the environment. Any imbalances of these systems is likely to cause an increased in energy cost (Rose & Gamble 2006). American College of Sport Medicine (ACSM) has made it known to the public that at least 30 minutes of moderate intensity physical activity, five times a week is recommended to promote health and increase lifestyle activity (ACSM 2009). Physical activity need not only occurred through sports or gym-based exercises, but also through lifestyle based activities such as walking (Gilson, McKenna, Cooke & Brown 2007). Another study conducted by Mackey, Bohle, Taylor, DiBiase, McLoughlin and Purnell (2011) stated that walking has been described as a near perfect exercise, in that its energy expenditure can be one of the best approaches to monitor individual's health, based on walking efficiency. The Healthy People 2010 initiative, a recommendation originating from Tokyo, Japan and adopted by the United States public health agencies, recommended 10,000 steps per day (Macpherson, Purcell & Bulley 2009). For an adult, approximately 1,800 – 2,200 steps equals to 1.6 kilometer. Research showed that adults walk approximately 3 to 5 kilometers (4,000 to 6,000 steps) per day (Laurson, Eisenmann, Welk, Wickel, Gentile & Walsh 2008; Welk, Differding, Thompson, Blair, Dziura & Hart 2000), and people must, on the average walk an additional 4,000 steps. The duration for walking 4,000 steps at a brisk pace could be achieved in approximately 30 minutes (Weary 2007) which is equivalent to the physical activity level recommended by the Centers for Disease Control and Prevention, and the ACSM.

Energy expenditure of any group in a population is determined by the structure of the group (age, gender, body mass, stature), the patterns of physical activity and the climate (Manini 2010). Therefore although most studies have found different results about differences in energy expenditure (per unit kilogram/time) with regard to physical characteristics and gait parameters, how walking gait should be adapted to minimize energy expenditure and how walking activity should be continuously planned to keep energy cost as low as possible without stopping or early onset of fatigue should be researched. For the past twenty-five years, it has been generally accepted that energy expenditure of human body is an important criterion in studies of exercise physiology and diseases such as obesity, diabetes, hypertension and in preserving lifespan (DeLany & Lovejoy 1996; Maddison 2007; Titze, Martin, Seiler, Stronegger & Marti 2001). The assessment of energy expenditure of

walking in real life has become increasingly important, since it may help to identify inactive lifestyles and motivate towards more active lifestyle.

Gender is a factor that influences movement patterns during walking (Chiu & Wang 2007; Chung & Wang 2010). Even though their research findings suggest that higher energy expenditure demand is displayed by males and is related to the presence of a greater muscle mass at a given speed, Kito and Yoneda (2006) indicated that small stride length increases energy expenditure. Speed is one of the significant factors that directly affect energy expenditure. While the speed formula defines speed as the multiplication of stride length and stride frequency, it is apparent that modifications of stride length and stride frequency as the speed changes affect the energy expended during walking (Rose & Gamble 2006). Moreover, height and leg length are generally greater in males compare with females, and increased leg length may decrease the requirement of walking at a given speed. While considering the U-shaped relationship between walking speed and energy expenditure (Sparrow 2000), it is important to recognize the significantly higher correlation in regression of energy expenditure and physical characteristics of individuals.

This article is part of a study which attempts to investigate energy expenditure of walking among university students. This article will specifically provide information on the relationship between leg length and energy expenditure.

Material & Methods

This study employed an experimental cross-sectional research design using quantitative method for data collection. A questionnaire was used to collect data for demographic description of the subjects. The experimental methodology employed to measure energy expenditure (HR-VO₂max monitoring method) provided information about energy expenditure of walking at two different speeds.

Participants for this study were 191 undergraduate students (96 male and 95 female), aged between 20 to 25 years, from different faculties. The samples for this study were purposively selected among university athletes and non athletes. It should be noted that purposive sampling method is valid and it approximates a random sample of the population based on purpose of the study (Tabachnick, Fidell & Osterlind 2007).

For the purpose of this study, leg lengths of both sides were measured from greater trochanter to lateral malleolus. During measurement, subjects were instructed to sit on the measuring table with their legs straight and the angle of 90° line joining anterior superior iliac spine. This means that the trunk-leg position is 90° and the legs is 15 to 20cm apart and parallel to each other.

For the HR-VO₂max conversion process, energy expenditure was measured with subjects walking on the treadmill. The systematic process of the protocol to monitor energy expenditure includes taking the resting heart rate, determining the age-predicted HR_{max}, walking HR, estimated %HRRreserve and estimated VO₂max using Queens' College Step Test. Each walking test was performed for 8 minutes at two speeds of 4.6km.h⁻¹ and 5.4km.h⁻¹. During each test a heart rate monitor and a pedometer counted the heart rate activity and cadences. Data were analyzed using a statistical software, with the probability of significance set at $p \geq 0.05$.

Results

Pearson correlation coefficient tests were conducted in order to investigate the relationship between the leg length and energy expenditure of walking at the first speed, 4.6km.h⁻¹ (EE1) and the second speed, 5.4km.h⁻¹ (EE2) for males and females. Table 1 show the results of the analysis conducted.

Table 1. Correlation between energy expenditure and leg length at two walking speeds

Gender	Groups	r
Male	EE1-LL	0.14
	EE2-LL	-0.19*
Female	EE1-LL	-0.23*
	EE2-LL	-0.37**

* $p \leq 0.05$; ** $p \leq 0.01$

Results showed no significant correlation between energy expenditure of walking at a speed of 4.6km.h⁻¹ and the leg length of the participants [$r(96)=0.14$, $p > 0.05$]. Unexpectedly, leg length is not an independent variable to predict energy expenditure of walking at this speed as a casual speed of walking. When the speed of walking changed to a faster speed of 5.4km.h⁻¹, a significant correlation between energy expenditure and leg length was observed in male participants [$r(96) = -0.19$, $p \leq 0.05$]. Therefore, at this speed, the leg length emerged as an independent predictor for energy expenditure.

As for female participants, there is a significant correlation between energy expenditure and leg length at the walking speed of $4.6\text{km}\cdot\text{h}^{-1}$ [$r(95)=-0.23$, $p\leq 0.05$] and at the walking speed of $5.4\text{km}\cdot\text{h}^{-1}$ [$r(95)=-0.37$, $p\leq 0.01$]. Hence, for female, leg length emerged as an independent variable for energy expenditure, which means that increase leg length would decrease energy expenditure.

Discussion

Even though, the energy requirement of physical activity and walking is typically estimated by body weight factor, the correlation between leg length and energy expenditure during walking, efficiency of walking, and speed of walking have been examined in some biomechanical and physiological researches. A study by Bereket (2005) revealed that the type of relationship between speed of walking, leg length and VO_2 consumption remain unclear. Sparrow (2000) noted that leg length, size of body, and proportions were predictor of gait mode changes. Since findings by Hoyt and Taylor (1981) exposed that leg length and mass parameter were excellent predictor for gait mode changes in quadrupeds switching from walk to trotting or galloping in order to increase speed but energy cost of locomotion remains unchanged. Therefore, it might effect on human walking gait at different walking speeds as well as gait transition speed from walking to running.

To a large degree, energy cost of walking is particularly determined by body weight, it is not clear how leg length and mass distribution influence this cost. Besides, not enough research has been carried out to make any conclusive statements regarding the effects of leg length on energy expenditure in different genders. It is possible that gender differences in leg length are more obvious and relevant for speed of walking. Therefore, to shade some lights on the correlation between leg length and energy expenditure during walking at the two speeds of $4.6\text{km}\cdot\text{h}^{-1}$ and $5.4\text{km}\cdot\text{h}^{-1}$, discussion will be done according to gender.

Relationship between leg length and energy expenditure during walking in male subjects

In this study there is no significant correlation between energy expenditure during walking at speed of $4.6\text{km}\cdot\text{h}^{-1}$ ($76.7\text{m}\cdot\text{min}^{-1}$) and the leg length in male participants ($r[96]=0.14$, $p>0.05$). When the speed of walking changed to a faster speed of $5.4\text{km}\cdot\text{h}^{-1}$ ($90\text{m}\cdot\text{min}^{-1}$), a negative significant correlation between energy expenditure and leglength was observed in male participants ($r[96]=-0.19$, $p<0.05$). Therefore, at this speed, the leg length emerged as an independent predictor for energy expenditure. It means increase of leg length could affect on decreasing energy expenditure, but it will be an accessory of speed of walking.

Interestingly, while the correlation between leg length and energy expenditure during walking at a slower speed was positive but not significant, however, at a faster speed the correlation between leg length and energy expenditure was negatively significant among the male participants. A possible reason for this inconsistency in findings is the that the correlation between leg length and energy expenditure during walking may be related to the discrepancy between the target speed and the unknown comfortable walking speed within the group, as well as the large discrepancy between the range of stride length in male participants. These results implies that leg length is not an independent variable to predict energy expenditure during walking at a slow speed or comfortable speed of walking for male with the mean leg length of $85.1 \pm 4.8\text{cm}$. Kramer and Sarton-Miller (2008) reported that not only people can defer substantially in leg length affecting both self-selected walking speed and VO_2 consumption, but other variables are also important in mechanical energy calculations.

The results of this study are in agreement with the study of Wu (2007) that observed weak correlation between energy expenditure index and leg length in healthy adults at speed of $64.3\text{m}\cdot\text{min}^{-1}$ and lower, and significant correlation at speed of $78\text{m}\cdot\text{min}^{-1}$ and above. Wu also reported that at the most economical speed, the correlation between leg length and energy expenditure is -0.20 . Similarly, Thomas, Buckon, Schwartz, Sussman and Aino (2009) noted submaximal activity responses are highly dependent on body size, age and maturational changes. Also, energy efficiency variables which compensate for leg length effect on metabolic energy expenditure can be evaluated in future studies.

Relationship between leg length and energy expenditure during walking in female subjects

This study found that there is a significant correlation between energy expenditure during walking at the speed of $4.6\text{km}\cdot\text{h}^{-1}$ ($76.7\text{m}\cdot\text{min}^{-1}$) and the leg length in female participants ($r[95]= -0.23$, $p<0.05$). Hence, at this speed leg length emerged as independent variable predictor for energy expenditure meaning increase in leg length could effect on decreasing energy expenditure. When the speed of walking changes to a faster speed of $5.4\text{km}\cdot\text{h}^{-1}$ ($90\text{m}\cdot\text{min}^{-1}$), a significant correlation ($r[95]= -0.37$, $p<0.05$) between energy expenditure and leg length was observed in female participants. Therefore, at this speed, leg length also emerged as independent predictor for energy expenditure, which indicates that increase in leg length could effect on reducing energy expenditure during walking among female participants with the average leg length of $77.4 \pm 4\text{ cm}$.

Research by Bereket (2005) showed that in general, energy cost of locomotion among children, adolescents, and larger individuals were different. The results of such studies have consistently shown that VO_2 consumption for both walking and running was lower in older and larger individuals due to the body size like

standing height and leg length that effect on the size of stride length. Furthermore, Badaly and Adolph (2008) in their study of 55 infants illustrated that those who had longer leg length produced longer step, and walked faster easily. Rose and Gamble (2006) also reported that with age, as leg length and height continue to increase, stride length and speed of walking also increases.

Conclusion

This article presents the empirical evidence of the correlation between energy expenditure during walking at two different speed and leg length of male and female participants. The results showed that there is a weak correlation between leg length and energy expenditure in males compared to females. This weak correlation indicates that there is a relationship between leg length and stride length frequency, which in turn effects on speed and efficiency of walking. The results of the current study suggest that the use of a large sample with widely varying leg length in different speeds, age and fitness level in empirical studies will allow a clearer picture of effectiveness of leg length on energy expenditure during walking. Importantly, if future investigation could uncover the role of body size, especially leg length as an effective variable on efficiency of walking, it seems fair that evaluation of running tests and related norms at schools for different age groups and gender be reviewed as well as other diverse abilities of students. Therefore, future investigations should examine and explore these facts.

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