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Energy Expenditure through Walking: Meta Analysis on Gender and Age

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Abstract

The purpose of this paper is to argue that, in the case of human gait, the (Energy Expenditure) is only minimized to more qualified walking in different gender and ages. This paper defines EE,walking gait and the impact of gender and age on EE. While there is no significant difference in EE of walking for both gender, in different ages EE of walking could be minimized by stride length, step length and wide step which affect selected speed of walking . Ideally, it will promote greater understanding of the relationship between EE, walking and health.

Keywords: Energy expenditure; Walking gait; Age; Gender; Healthy lifestyle; Metabolic energy

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1. Introduction

The assessment of energy expenditure (EE) in real life has become increasingly important, since it may help to identify inactive lifestyles and motivate toward more active lifestyle. Whereas the assessment of EE can play a role in promoting a healthy lifestyle and preserve lifespan, its measurement are also important in the study of relationship between physical activity and health (Rennie, Hennings et al., 2001; Pulkkinen, Saalasti et al., 2005). Also, it is a pre-requisite to monitor population health and design effective intervention (Titze, Martin et al., 2001; Manini, 2009) and influences our mental and physical health, which in turn increases our capacity to move (Zhang, 2002). In addition, it is obvious that EE of locomotion is a major focus in human energy budget and Walking is the major type of physical activity in daily activity for many individuals (Macpheson, Purcell et al., 2009).

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In general, walking is one of the most recommended physical activity due to its simplicity, inexpensiveness, and being widely accepted by the population. Additionally, many investigations focus on walking gait to evaluate EE in different condition and population. It could accurately show highly different variables in EE (Waters & Mulroy, 1999; Pfeiffer, Schmitz et al., 2006; Anjos, Wahrlich et al., 2008; Ekkekakis, Backhouse et al., 2008).

Many studies on human locomotion have suggested that gaits are selected on the basis of metabolic energy consideration. In human walking a unit distance reaches a minimum around 1.3 m/s (4.8km/hr) and then begins to increase the above and below of its an dramatically increasing in energy cost (Dal, Erdogan et al., 2010). Also, during 15 minutes moderate walking will burn 52 extra calories. Previous studies have shown a U-shaped relationship between walking speed and energy cost of transport (Sparrow, 2000; Willis, Ganley et al., 2005). Therefore human have a strong tendency to walk in a way that minimizes metabolic energy cost (Alexander, 2002; Pontzer, Raichlen et al., 2009).

Human walking is a system well suited to study these general principles. Human adults walk at a characteristics speed, stride, step length, and step width, but mechanisms responsible for this ubiquitous and reproducible behaviour remain unknown. Therefore, increased understanding of this phenomenon has obvious benefits for public health, physical activity changes and related diversity programs. The purpose of this review is to outline the basic principles of EE relevant to human walking gait; detail the EE of walking –as a most common prolong period of daily activity – in different gender and ages.

2. Energy Expenditure

Energy expenditure (EE) refers to the amount of energy (calories), that a person uses to breathe, circulate blood, digest food, and be physically active. To prevent weight gain, energy intake (caloric intake) must be balanced with EE (McArdle, Katch et al., 2006). Simply, EE is the combination of internal and external activity done by the body. Internal activity involves two main processes: digestion of food and basal EE. The external activity that goes into EE incorporates all movement, from sitting in a chair to running on a treadmill (Rennie, Hennings et al., 2001). EE estimation can be applied to both personal and professional purpose, including management, promotion of physical activity and lifestyle assessments, and fitness training. It is often assessed along with energy intake for weight management purposes (Pulkkinen, Saalasti et al., 2005). In addition to health promotion and health-related research, EE measurements can also be utilized in fitness and athletic training**.** Physical activity is defined as any bodily movement produced by skeletal muscles that result in EE. The amount of energy required to accomplish an activity can be measured in kilojoules (kJ) or kilocalories (kcal); 4.184 kJ is essentially equivalent to 1 kcal (Rennie, Hennings et al., 2001).

Furthermore, studies found that EE of human body is an important criterion in studies of exercise physiology and diseases such as obesity, diabetes, and hypertension. The study of EE of human body will help to reveal the potential compensatory strategies that preserve lifespan (Maddison DeLany & Lovejoy 1996; Titze, Martin et al. 2001; Zhang, 2002; Manini, 2009). Total EE is comprised of four major components (Figure. 1) that include: **(a)** Resting metabolic rate (RMR) that accounts for 60–80% of the total EE and can be further divided into sleeping and arousal EE, (b) thermic effect of food (TEF) metabolism uses 10%of total, (c) Activity EE (AEE) is the most variable component and can be divided into: 1) Volitional exercise (i.e. jogging, walking for exercise, etc.) and 2) Non-exercise activity thermo genesis (NEAT) that is the energy expended from spontaneous physical activities that include non-volitional movements (i.e. fidgeting) but is often defined as any EE outside formal volitional exercise programs. Exercise and NEAT can comprise 20–50% of total (Visser, 2004; Manini, 2009).

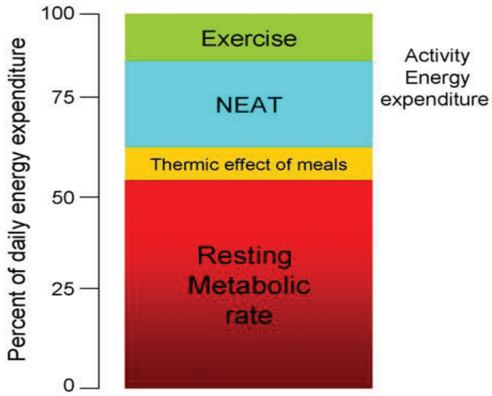

Figure1. Categories of total energy expenditure (Manini, 2009).

It should be expressed Activity associated EE (AEE), i.e. the EE associated with muscular contractions to perform body postures an movements is the most variable component of total EE (Westerterp 2008). AEE of a subject with an average PAL is one-third of total EE (Westerterp, 2008) which is approximately equal to the Manini's reported. Therefore, the EE is analyzed in different components and also in relationship with physical activity in daily life (Visser, et al. 2004). An average person at rest required 72 kcal per hour while for walking at speed 80 m per minute requires 240 kcal per hour (Rose & Gamble, 2006). Heart rate (HR) is probably the most frequently used indirect parameter in EE assessment (Ltd, 2007).

2.1. The Factors contributing to EE

Factors that determine the EE of any group or population include the following:
2.1.1 The demographic structure of group, including age, body mass, stature and sex distribution;
2.1.2. The patterns of physical activity by different sectors of the population;
2.1.3. The proportion of adult, women pregnant and or locating at any time;
2.1.4. The growth and body size of children;
2.1.5. The level of maintenance metabolic (equivalent to the BMR);
2.1.6. The energetic efficiency of muscular work
2.1.7. The climate; Exposure to hot and cold environments cause small increase total daily energy expenditure. For example, the resting metabolism of people living in tropical climate is average 5% to 20% higher than counterparts in more temperate regions (Ulijaszek, 1995; McArdle, Katch et al. 2006).

2.2. Metabolic EE in movement

When the intensity of the organic cell tissue metabolism increases the body also increases its metabolism proportional to the total EE (Visser et al., 2004). Compared with sustained exercise (e.g. walking, jogging…) metabolic EE may not to be an important consideration in movements that recruit only low levels of muscle activity, are isolated, are infrequent, or are of short duration (Sparrow, 2000). According Sparrow and Newell (1998) motor behaviour is described "the process by which organisms convert chemical energy, through the metabolism of foodstuffs, to mechanical energy, in order to interact adaptively with their environment"(Sparrow & Newell, 1998). Therefore, mechanical energy is provided by muscle activation and muscle is the primary site of the energy transaction in movement. In considering control of metabolic EE in movement, it should be focused on muscle and on the potentially relevant muscle-related signal that are available to the central nervous system (CNS). Walking and handwriting, for example, mobilize muscles of markedly different mass and entail different global metabolic EE (Sparrow, 2000).

Furthermore, the minimal energy hypothesis proposes that the CNS selects a walking speed to minimize the energy cost of transport (Ralston, Herman et al., 1975). According Willis studies, it should be expressed that the human CNS selects a walking speed that is supported predominantly by fat oxidation, and that the perception of effort may contribute to this selection (Willis, Ganley et al., 2005). In addition, sustained performance of either walking or handwriting may be threatened, not by generalized exhaustion, but bye one onset of fatigue in any of participating muscles. Therefore, minimal energy as a determinant of endurance pales in comparison to the critical importance of fuel selection.

2.3. Fuel oxidation and energy expenditure of walking

This evolutionary argument advances the concept that it would be important for the human CNS to naturally select a walking speed that required little or no net CHO depletion. Moreover, minimizing net CHO depletion from the very beginning of the trek would defend the ability to engage in burst activity as might be demanded by sudden environmental change or predator activity. Although the enormous energy of fat stores could support very long range locomotion, CHO must be spared from use to support such routine locomotion activity because it is decidedly the fuel of choice for high-intensity activity (Ralston, Herman et al., 1975; Willis, Ganley et al., 2005). Therefore, While the goal of walking is progression in the forward direction and the dynamic of walking approach (based on Inverted Pendulum Theory) domain on walking gait, EE of moderate walking select by fat fuel more than CHO.

3. Walking and Gait

Normal human walking can be defined as a gait that humans use at low speeds. A less formal definition is given by the Oxford dictionary, is ‘way of walking’ or style of locomotion. Therefore, it makes more sense to discuss difference in gait between two individuals than a difference in walking (Racic , Pavic et al., 2009). As walking is an activity that is handily integrated into daily life for majority of people, it is also important to provide recommendations in groups of people who have different long-term conditions and different demographic structure. Macpheson et al. (2009) found that walking for 10,000 steps at about 4.2 km/hr would achieve approximately 336 kcals per day (near 80min) while walking at a moderate intensity for 30 min translates to between 3000 and 4000 step for 150 kcals. Macpheson further compared different intensities, with a view to clarifying the intensity level for the 10,000 steps/day with 30 min of moderate intensity walking for adults (20-25 yrs, male & female). Focusing firstly, on EE, the findings suggest that most young adults would achieve daily physical activity EE if walking 10,000 steps at either of the speeds, although EE was significantly higher at the faster speed (Macpheson, Purcell et al., 2009).This is a useful preliminary finding as there is evidence that less fit people find higher intensities of physical activity unpleasant, which is unlikely to facilitate participation (Haskell, Lee et al., 2007). Environmentally friendly, walking is low impact and low intensity, making it a great exercise for most people of all ages, gender and fitness levels.

3.1. Spatial and temporal parameters of gait

Parameters used in gait analysis related to time and spaces are known as temporal and spatial parameters, respectively. Sometimes, both terms are referred together as time–distance parameters. Typically measured spatial parameters are stride length, step length, and step width, while temporal parameters commonly in use are walking speed and cadence (also known as step frequency) (Collins 2001; Kuo, 2001; Racic , Pavic et al. 2009). Stride length consists of two step lengths, left and right. Therefore, the step length is the distance between the feet in direction of progression during one step. It is usually measured between two consecutive heel strikes. Step width, also known as the stride width, walking base or base of support, is side-to-side distance between the paths taken by the two feet. Cadence denotes the number of steps taken in a given time, commonly expressed in steps per minute. In biomechanics, natural or free cadence describes a self selected walking rhythm. Walking speed is the rate of motion typically measured in meters per second). Natural (normal) walking speed is about 1.5 m/s (5.00km/hr). While Wu (2007) found the average comfortable walking speeds for males 89 m/min (1.5 m/s) and for the females74 m/min (1.2 m/s). It is obvious that type of walking program who people engage is determined by speed of walking. At each speed we use the stride length that minimized energy cost and at any particular speed we seem to choose our stride length, step length, width step and shape factor to minimize energy cost (Sparrow, 2000; Alexander, 2002; Doke, Donelan et al., 2005; Wu, 2007). In addition, the term preferred walking speed (PWS) describes the normal self-selected that individuals walk economically (Waters & Mulroy, 1999; Racic , Pavic et al., 2009; Dal, Erdogan et al., 2010). On the other hand, slow walking refers to speeds below the self-selected speed. It should be emphasized that the body’s increase in stature influence on temporal- spatial parameters (Rose & Gamble, 2006). As these parameters are demonstrated in table 1, although the pattern of mature walking was established between 3 and 4 years, growth changes go along throughout puberty. The temporal-spatial parameters stabilize by age 20 and remain largely unchanged during most of adult life.

Table 1.Comparison of Temporal-Spatial parameters in different ages (Rose & Gamble, 2006).

Age (yr)	Velocity (cm/sec)	Cadence (step/min)	Stride length (cm)	Opposite toe-off (%cycle)	Duration of stance (%)	Duration Swing (%)
3	86	154	66.8	15.5	65.5	35.5
4	100	152	77.9	14.2	63.7	37.3
5	108	154	84.3	13.4	63.5	37.5
6	109	146	89.3	13.4	63.6	37.4
7	114	143	96.5	12.4	62.4	38.6
20-25	153	115	158.8	9.0	60.0	41.0
30-35	145	111	156.9	11.0	61.0	39.0
40-45	159	122	155.9	11.0	61.0	39.0
50-55	155	118	157.9	10.0	60.0	40.0
60-65	147	115	153.0	11.0	61.0	39.0

3.2 Kinds of walking in daily life

Everybody wants to feel and look better in the life. Walking on a regular basis can help accomplish these goals. Everybody has own walking gait resemble own unique finger print. However, the level of walking chosen to do will have an impact on individuals' overall workout and they will be provided with a basis for future fitness choices. These four types of walking vary based on the frequency; the intensity and the time spent doing them (Rockville, 1988; Ty, 1996).

3.3 Lifestyle Walking (casual)

This is the most common form of walking. All of us do it. It is the type of walking which done when people going to walk around the mall to shop or take the kids out for a walk in the park. It is low intensity and may or may not spend a lot of time doing it. When individuals get up and move, they perform lifestyle walking. In different population speed of lifestyle walking has been reported minimum 3.5 and maximum 4.2 km/hr (Minetti, Lucap et al. 2001; Willis, Ganley et al. 2005; Dal, Erdogan et al. 2010).

3.2 Fitness Walking (Brisk)

This is a step up from lifestyle walking and is designed to specifically getting heart rate up. If somebody goes for a walk with the goal of exercising or walking on a treadmill daily, this is the definition of fitness walking. It elevates heart rate and helps to burn extra calories. The average fitness walker prefer to moves at speed from 4.5 to 5.6 km/hr (on a treadmill or over ground) at which the energy cost per unit distance is least (Alexander, 2002; Willis, Ganley et al. 2005; Rose & Gamble, 2006). For fitness walker it is usually primary form of exercise supported by other activities.

3.3 High-Energy Walking (very brisk)

The high-energy walkers are trailblazer and they burn a ton of calories in this heightened state. They are walking fast enough to complete a 10-minute mile. This type of walking is literally just a step below jogging or running because you are moving so fast. They will be hot, sweaty and their heart rate will be pounding. This is a primary form of cardio and it is the anchor of their overall workout program. The high-energy walker likely walks only 2 to 3 times a week, but maximizes their burn during this part of their walk. Their speed should be upper 6.2km/hr (Macpheson, Purcell et al., 2009). Individuals may alternate with fitness walking if they want to walk more often.

3.4 The Walk/Run

Some studies labelled the walk/run are a hybrid activity. This is a type of walking that lets increase the speed without overdoing it. It alternates walking and running in order to increase the calorie burn and heart rate. It is an intense form of workout. For some people, it involves walking for five minutes, running for two, walking for five and running for two. At speed up to 7.2 km/hr (2m/s), walking requires less energy than running, and we walk. At higher speeds, running is more economical, and we run (Doke, Donelan et al. 2005). These types of sprints increase how much individuals get out of their workout in the same amount of time they spend on a regular fitness walk and such.

4. Considerable Parameters Involved in EE Walking

Historically, walking intensity and EE were predicted via combinations of speed and body mass (Brooks et al. 2005), while several studies suggested other factors such as gender, age, preferred walking speed (PWS),terrain, climate, culture and wider ranges in body type should also be studied in the future (Niang & McFadyen, 2005; Chung & Wang, 2009; Dal, Erdogan et al., 2010). Since the EE of walking is typically expressed relative to total body mass, in this review, gender and age were studied that may help explain child – adults differences in related with walking energy cost.

4.1. Gender

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 sex were observed at the customary slow, normal, or fast speeds (Waters & Mulroy, 1999). While Rose and Gamble reported significantly lower values of EE for women than for men at speed 91 and 109 m per minute. The authors attributed this to a smaller step length in women. Recent studies, however, indicate that smaller step length increases EE. Result from the investigation revealed that absolute and mass- related values of gross and net VO_2 were significantly greater in male compared to female, but gross VO_2 expressed relative to fat-free mass was not different between sexes (Waters & Mulroy, 1999; Rose & Gamble, 2006).

According Raymond and et al. studies, 39 normal and obese men and women a level treadmill at six speeds (0.50–1.75 m/s), even among normal-weight individuals, sex may affect the net metabolic rate measured during walking. However, normal-weight women have smaller standing metabolic rates (per kg body weight) than normal weight men because of their smaller lean body mass (greater body fat percent). They resulted the greater net metabolic rate of obese women may be partly due to heavier and larger legs that require an increase in step width and leg swing (lateral leg swing) (Raymond, Emily et al., 2006). Like, in the study of Wu (2007) the average step frequency of 32 males and 32 female was the same. The differences in comfortable walking speed between the males and females were related to the greater stride length in men. Females have shorter stride length, so females need higher step frequency to maintain the same walking speed. Their results also showed that female subjects had higher physiological cost index values than the male subjects at each walking speed. Similarly, Brooks and et al. founded no gender difference for kilocalories per kilogram per kilometre suggests that a presumed shorter stride length that seventy two men and women, 35-45yrs old (women were 15 cm shorter than men) did not alter the mechanical efficiency of walking at self-selected speeds (Brooks, Gunn et al., 2005). In the study of Wu (2007), the average step frequency of males and female was the same. The differences in comfortable walking speed between the males and females were related to the greater stride length in men. Females have shorter stride length, so females need higher step frequency to maintain the same walking speed. Their results also showed that female subjects had higher EE values than the male subjects at each walking speed (Wu, 2007).

Moreover, other results show differences between men and women for O_2 rate in rest and during walking. In adults, normalization to body weight and normalization to dimensionless parameters eliminated the differences between genders. In children metabolic parameters were different for both sexes before net non-dimensional normalization although no significant differences in anthropometric data were found. The differences in children are probably due to differences in timing of maturation (Van de Walle, Gosselink et al., 2006; Geer & Shen, 2009). These finding suggest that leg length and body height are generally greater in males compared with females, but may explain only small differences in EE.

4.2. Age

None of the previously mentioned studies found a systematic effect of age on the EE of natural walking at least within an age range of 20 to 59 years when expressed per unit body weight. Martin et al. examined the effect of age and physical activity on walking economy in young (18 to 28 years) and older (66 to 86 years). Results from their study indicated that older subjects showed an 8% higher mean walking VO_2 (ml/kg/km) compared to younger subjects. They also indicated that child's lower efficiency can partly be explained by their high step rate that is energy-expensive per unit time (Rose & Gamble, 2006).

In comprehensive review of existing date, Morgan concluded that children are less metabolically economical than adults with the magnitude of differences in economy varying markedly among studies. In this review, a number of potential factors were identified that may help explain child-adult differences in relative walking energy costs. These include: (1) less efficient ventilation, (2) faster stride rates, (3) immature gait pattern, (4) larger surface area of body mass ratios, (5) shorter stature, (6) an imbalance between body mass and leg muscle contraction speed, (7) more distal distribution of mass in lower extremities, (8) a greater reliance on fat as a metabolic substrate, and (9) a reduced ability to use anaerobic energy sources (Tseh, Caputo et al. 2000; Rose & Gamble, 2006; Garatachea, Torres Luque et al. 2010).

The equation for O_2 cost at different speeds can be derived by dividing the walking speed in units of meters per minute yielding the following equations:

Children: O_2 cost= 0.188+2.61/*S*

Teens: O_2 cost=0.147 +1.68/*S*

Adults: O_2 cost=0.129+2.60/*S*

Children are less efficient walkers than adults (Figure. 2). Their basal metabolic rate is higher and they have a faster cadence to compensate for a shortened stride length. The combination of these factors results in a higher rate and cost of oxygen consumption for children than in adults. Children, however, have a higher aerobic reserve than adults owing to a higher maximum aerobic capacity when divided by body weight (Waters & Mulroy, 1999).

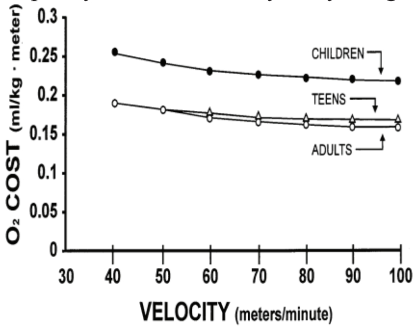

Figure.2 O_2cost–speed relationship in children, teens, and adults

Additionally, the current discoveries in EE research have the potential for building a basic understanding for the control processes that govern changes with age. The age associated reduction in total EE is caused by a combination of decreases in RMR and activity EE (AEE), which are both dictated in part to reductions in body mass and fat-free mass. The decline in RMR is manifested through reductions in organ mass and specific metabolic rate of tissues without a clear understanding about the contribution of each. AEE is carried as a familial trait and typically declines in a rapid manner after the age of 40 years and contributes substantially to the overall reduction in total EE. These new data suggest that any energy expended through physical activity may have a role in determining lifespan (Manini, 2009). These studies demonstrate that the EE to walk per kilogram does not change significantly with age for adults until older age is attained. The energy expended to walk expressed per unit body mass, however, decreases with age for children and adolescents (Rose & Gamble, 2006; Peterson & Martin, 2010; Van de Walle, Desloovere et al., 2010).

4.3. Culture

The findings indicate that the locations, culture of group and reasons for walking varied by level of walking activity, gender and age. This warrants further attention, as it may have implications for the choice and effectiveness of interventions to increase walking behaviour. Being properly informed about the benefits of exercise and creating more opportunities for safe walking, such as walking groups in different age, and linking it to activities such as shopping, may be effective in promoting walking activity (Bird, Radermacher et al., 2010). Increased participation in walking could be achieved through targeting specific cultural groups, where there may be a lack of awareness of the health benefits of regular walking. Walking in a social environment may promote compliance, through enjoyment and social commitment.

5. Energy Minimization in Waking Gait

Energy is used by the body in locomotion when muscles are active. The amounts of energy used by the muscle depend upon the force and rate of contraction and the number of contraction used during each phase of locomotory cycle. An examination of the optimization of these three factors provides an explanation of much of what is observed in human walking. Additionally, Sparrow emphasized the fact that EE during the period of walking is dependent upon both the number and speed of muscular contractions suggests that there will be a particular combination of stride rate and length that, if adopted, will be the most energetically efficient at a given speed (Sparrow, 2000). Alexander has argued that at any particular speed we seem to choose our stride length, duty factor, and shape factor to minimize energy cost. We prefer to walk at speeds closed to the speed about1.4 m/s at which the energy cost per unit distance is least. The energy cost of walking is increased on uphill slopes and also on soft ground. Consequently, zigzagging paths should be proffered to straight ones, up hills of more than critical gradient. Simple model of route selection over soft ground and over hills suggest that we may plan our routes to minimize energy cost. Like African women who seem to save energy by carrying loads on their heads. However, the mechanism is not fully understand why head leads can be carried so economically (Alexander, 2002).

While it is hard to clarify the absolute mechanical and metabolic energy cost for walking, it is worthwhile looking at these evidences in oxygen consumption and selection of speed and form of locomotion as some energy reservations in different age and gender. In order to calculate efficiency of whole body, two measures are required: energy input and energy output. In terms of human motion, efficiency is the ratio of mechanical work done to metabolic work expenditure. The phosphorylative coupling efficiency has been estimated at %60, while the contraction coupling efficiency is thought to be about 40%. In actual walking, it is different to experimentally isolated moving the legs from supporting body weight or redirecting the center of mass. When a leg is contact with ground, it is somewhat arbitrary to assign muscle activity to one function or another. But there might be a significant metabolic cost even if moving the legs were narrowed to the swing phase alone or change PWS, as evident by the finding of Doke et al., (Doke, Donelan et al. 2005).

6. Conclusion

In conclusion, EE of walking gait's studies provides opportunities to walk efficiently to improve health and prolong physical activity for different population. Although human adults walk at a characteristic speed, stride length, width step which minimize EE, each parameter is voluntarily controllable to minimize EE. The O_2 rate indicates the physiological effort of walking at the selected speed. While walking speed and stride length in an elderly group compared with young adults reduced, there is no significant different in their EE. It may be concluded that most studies have been found no consistent differences in walking EE (per kilogram) between adults, based on age and gender, whereas for children and adolescents, some differences occur according to their age and possibly gender. Therefore, meanwhile interpreting the effect of age and gender on walking EE, it is important to distinguish whether oxygen consumption is expressed per unit time, per unit kilogram, per lean body mass and walking in economical speed which minimizes EE by stride length, step length and width step. This knowledge will contribute to the success of walking program at schools allowing the students to better understand their own characters of walking such as walking speeds stride length and step width.

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