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Original Article

Walking Energy Cost of Subjects Suffering from Unilateral Chronic Ankle Instability

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ABSTRACT

The purpose of this study was to explore the effect of unilateral ankle instability on walking energy expenditure. Chronic ankle instability group consisted of 20 subjects their age average (21.4±5.55) years, height average (177.85 ± 4.96) cm and weight average (81.25 ± 6.87) kg, they were referred from orthopedic specialist. The control group consisted of 20 normal subjects, their age average (24.65 ± 4.61) years, height average (178.7 ± 3.76) cm and weight average (80.4 ± 12.43) kg. Participants walked on a treadmill at two speeds 5 km/h (comfortable walking) and 6.5 km/h (fast walking) for three min with resting period of twenty minutes between each test. Before testing there was 3 min warm up at 1.5 km/h, and after each test there was 3 min recovery at 1.5 km/h. The oxygen consumption and energy expenditure at the two speeds are measured by using ZAN 100 flow handy Π medical device with a PC- connected to open spirometry system. Results revealed that there was a significant increase in oxygen consumption and energy expenditure of the two groups as walking speed increased from 5 to 6.5 km/h. There was no significant difference in oxygen consumption and energy expenditure between both groups at walking speed 5 km/h. However, the oxygen consumption and energy expenditure of chronic ankle instability group was significantly higher than control group at walking speed 6.5 km/h. So, chronic ankle instability increased the walking energy cost especially during fast walking.

Key words: *Walking, chronic ankle instability, energy cost*

Kronik Ayak Bileği İnstabiletisi Olanlarda Yürüyüş Enerji Maliyeti

ÖZET

Bu çalışmanın amacı tek taraflı ayak bileği istikrarsızlığının yürümenin enerji harcamasına olan etkisini araştırmaktır. Çalışmaya kronik ayak bileği instabiliteli, yaş ortalaması (21.4±5.55), boy ortalaması (177.85 ± 4.96) cm ve kilo ortalaması (81.25 ± 6.87) kg olan 20 hasta alındı. Hastalar ortopedi uzmanına yönlendirildi. Kontrol gurubu olarak yaş ortalaması (24.65 ± 4.61), boy ortalaması (178.7 ± 3.76) cm ve kilo ortalaması (80.4 ± 12.43) kg olan 20 sağlık birey alındı. Katılımcılar her test arasındaki yirmi dakika dinlenme süresi bırakılarak üç dakika boyunca 5 km / h (rahat yürüyüş) ve 6.5 km / h (hızlı yürüyüş) ile bir koşu bandı üzerinde yürüdü. Test öncesi 1.5 km / h hızında 3 dakika ısınma ve test sonrasında 1.5 km / h hızında 3 dakika toparlanma yapıldı. Her iki hız testindeki oksijen kullanımı ve enerji tüketimi bilgisayar bağlantılı sipirometre sistemli ZAN 100 flow handy Π medical device ile ölçüldü. Sonuçlar : Her iki grupta, yürüme hızı 5 km/h den 6,5 km/h hızına çıkarılınca oksijen kullanımı ve enerji tüketiminde önemli artış görüldü. 5 km/h hızında her iki grup arasında oksijen kullanımı ve enerji tüketimi arasında fark yoktu. Hız 6,5 km/h hızına çıkıldığında kronik ayak bileği insitabiletisi olan hastalarda oksijen kullanımı ve enerji tüketimi kontrol gurubuna göre anlamlı derecede daha yüksek bulundu. Bundan dolayı; kronik ayak bileği instabiletesi özellikle hızlı yürüyüş sırasında yürüyüş enerji maliyetini arttırmıştır.

Anahtar kelimeler: *Yürüyüş, kronik ayak bileği instabilitesi, enerji maliyeti*

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INTRODUCTION

The ankle complex plays a fundamental role in human locomotion. Functionally, the two main joints are the ankle and subtalar complex between the talus and calcaneous. Ankle injuries are among the most common injuries, particularly in sport. They constitute between 10% and 15% of all injuries in sport with 85% of those involving sprains of lateral ligament complex (1).

Chronic ankle instability (CAI) may be manifested by recurrent injuries, chronic pain, tenderness and swelling on lateral aspect of the ankle joint that will lead to difficulties in walking and daily activities (2). Individuals with lateral ankle instability are characterized by deviation of their gait parameters than normal values and duration (3, 4). Individuals with ankle instability often present differences in ankle joint mechanics. These differences often go unnoticed during the gait cycle. These altered neuromuscular mechanics may lead to improper joint positioning and less coordinated movement during gait (5).

Muscle mechanical energy expenditure is an important concept since it reflects the neuromotor strategies used by the nervous system and is directly related to the efficiency of the task. Energy conservation is a defining characteristic in many common motor tasks and generally leads to a preferred mode in performing a given locomotor task (6). Motor impairments frequently result in increased energy expenditure, which may limit functional ability (7).

As soon as an individual begins to walk, a great increase in the energy expenditure occurs, reflecting the metabolic cost to the muscles for moving the body against gravity and of accelerating and decelerating the various body segments (8). The human body appears to have developed kinetically to minimize energy expenditure through decreasing the vertical displacement of centre of gravity and inertial changes (9).

The optimum walking speed (comfortable) using the least energy expenditure was found to be ranging from 65-80 m/min (8). Generally, conditions that affect either the motor control of gait and posture and/or conditions that affect joint and muscle structure and function will increase the energy cost of gait (10). As the walking velocity increases the energy cost increases in a curvilinear fashion with walking, and at the point where walking is not as efficient as running then energy cost increases in relative linear fashion just below maximal levels (11). Colak et al. (12) proved that the energy cost of level walking in chronic anterior cruciate ligament (ACL) deficient patients improves after ACL reconstruction. The ankle instability has obvious effect on the gait parameters and leads to compensatory motion of other body segments. Therefore, the purpose of the study was to explore the effect of unilateral chronic ankle instability on walking energy cost.

MATERIALS AND METHODS

Subjects

CAI group consisted of 20 male subjects participated in this study were randomly selected according to the following inclusion criteria; (1) a history of at least 1 unilateral lateral ankle sprain that required immobilization for at least 3 days; (2) at least 1 episode of giving way within the past year; (3) at least 1 recurrent sprain between 3 and 6 month before study participation; (4) report of pain, instability, and/or weakness in the involved ankle; (5) attribution of these signs to the initial ankle injury; (6) failure to resume all pre-injury level of activities; (7) no previous ankle fractures; (8) no previous head and acute lower extremity injury within the past 3 months; (9) no formal rehabilitation of the involved ankle. These requirements have been used previously as inclusion criteria for individuals with CAI (13, 14). an episode of re-injury between 3 and 6 months before enrolled in this investigation was required to ensure that subjects still had physical manifestations of CAI but that acute symptoms were resolved (14).

The control group consisted of 20 healthy male subjects matched with the study group according to age, height, weight, sex and physical activity level, uninjured controls were excluded if they were not free from lower extremity or head injuries for the previous 3 months or if they suffered from any equilibrium disorders or chronic

***Table 1**. Demographic data for CAI and healthy groups*

Groups	Healthy group, n = 20 Mean±SD	CAI group, n = 20 Mean ± SD
Age, years	24.65±4.61	21.4±5.55
Weight, kg	80.4±12.43	81.25±6.87
Height, cm	178.7±3.76	177.85±4.96
Body mass index, kg/m2	22.45±3.2	22.82±1.43

SD: standard deviation.

lower extremity disorders. All selected subjects were right handed to avoid the effect of dominance on performance while all the CAI group individuals were with unilateral right ankle instability for unifying of comparison between both groups. Table (1) presents the demographic characteristics of the participants.

Written consent was obtained from each subject before testing, and all subjects were screened to ensure that no trunk or lower extremities neuromuscular or musculoskeletal problems or vestibular impairments with residual deficits, after being informed about the study and test procedures, and any possible risks and discomfort that might ensue from the procedure. The study was approved by the research ethical committee of the Faculty of Physical Therapy, Cairo University.

Instrumentations

1. ZAN 100 flow handy Π medical device is a PC- connected open spirometry system, made in Germany. The device's software can calculate the walking speed, oxygen consumption (VO2 l/min and VO2 ml/kg) and carbon dioxide production (VCO2 l/min).

2. Treadmill RAN 770 CE, made in Germany which can act manually and/or computer controlled was used to work at two speeds 5 and 6.5 km/h. The system consists of a facemask or mouthpiece for collecting expired air. Sensors for analyzing oxygen and carbon dioxide content of expired air. There is a display unit connected to the treadmill to show the speed of walking, duration of the test and the distance walked by the subject.

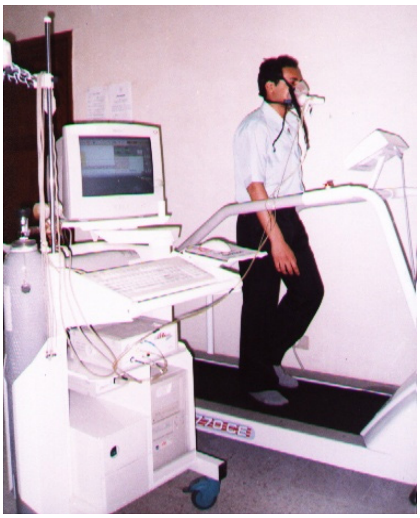

Figure 1*. Treadmill RAN 770 CE was controlled to rotate at walking speeds 5 and 6.5 km/h.*

Procedures

All participants had one to two practice sessions to become familiar and comfortable with the treadmill prior to oxygen consumption measurement, and received full explanation of the test steps, any questions were answered. The mean rate of oxygen consumption was determined over 3 minutes after steady state was reached

Before each test, the machine was calibrated with a reference gas mixture which was presented in the ambient gas tube, by connecting the small tube of the ambient gas tube to the calibration unit, open the gas pressure gauge, and waiting for few seconds until the device finish the calibration, then close the gas pressure gauge and the small tube return to special point at the side of the mouthpiece.

The treadmill operated on two speeds 5 and 6.5 km/h, each subject performed the two trials on the same day (Fig. 1), with a resting interval of 20 minutes in between (15). The slope of the walking treadmill was adjusted to be horizontal. Each speed operated for three minute. Waters (16) stated that the individual attain VO2 max after two to three minutes. The room temperature was controlled to be 20 degrees by air conditioning. Each test operated at the following steps.

1. Warm up: Measure the resting heart rate before the treadmill operated at speed 1.5 km/h for three minutes.

2.Testing speed 5 km/h (comfortable walking speed): The computer operated the treadmill automatically rotates at speed 5 km/h after the duration of warm up for three minutes.

3. Recovery period: The treadmill rotates at speed 1.5 km/h for three minutes.

4. Testing speed 6.5 km/h (fast walking speed): After resting period of 20 minutes repeat the previous steps, but the treadmill operates at speed 6.5 km/h at the loading test.

The oxygen consumption was used directly to calculate the energy expenditure by multiplying the value of oxy-

***Table 2**. Descriptive statistics of the effect of CAI on oxygen consumption (ml/kg/min) at walking speed 5 and 6.5 km/h.*

Walking speed	CAI group, n= 20 Mean±SD	Healthy group, n= 20 Mean±SD
5 km/h (comfortable)	15.25±4.40	17.8±4.73
6.5 km/h (fast)	19.45±6.85	23.25±5.40

gen consumption in liter (VO2 l/min) by 5 (k. calorie) of energy expenditure per minute (kcal/min).

Statistical analysis

Data was analyzed using the Statistical Package for Social Sciences (SPSS version 16). Analysis of variance (ANOVA) was used to investigate the effect of unilateral chronic lateral ankle instability on walking energy cost. The level of significant was set at 0.05 for all statistical tests.

RESULTS

Oxygen consumption

The oxygen consumption of healthy and CAI groups at walking speed 6.5 km/h was significantly higher than walking speed 5 km/h (P= 0.008 and 0.000) respectively. At walking speeds 5 km/h there is no significant difference between CAI and healthy group (P= 0.102), At walking speeds 6.5 km/h the oxygen consumption of CAI was higher than that healthy group (P= 0.000), as shown in Table (2).

Energy expenditure

The energy expenditure of healthy and CAI groups at walking speed 6.5 km/h was significantly higher than walking speed 5 km/h (P= 0.028 and 0.000) respectively. At walking speeds 5 km/h there is no significant difference between CAI and healthy group for energy expenditure (P= 0.620), At walking speeds 6.5 km/h the energy expenditure of CAI was higher than that healthy group (P= 0.046), as shown in Table (3).

***Table 3**. Descriptive statistics of the CAI effect on energy expenditure (kcal/min) at walking speed 5 and 6.5 km/h.*

Walking speed	Healthy group, n= 20 Mean ± SD	CAI group, n= 25 Mean ± SD
5 km/h (comfortable)	6.13±2.00	6.51±1.85
6.5 km/h (fast)	7.83±3.07	9.37±2.50

DISCUSSION

This study was conducted to explore the effect of unilateral CAI on walking energy cost. Interruption of the normal gait cycle and the energy conserving characteristics of trunk and limb motion results in increased energy expenditure. Nevertheless, in response to a gait disability, a patient will be adapted by performing compensatory gait substitutions to minimize the additional energy expenditure. The effectiveness and the associated costs of those compensations depend upon the severity of the disability and the patient's cardiovascular and musculoskeletal fitness (17). Because mobility impairments are likely to result in compensatory movement strategies, recognizing and understanding those strategies may be critical in designing effective interventions for preventing disability (18).

The results revealed a significant increase in the oxygen consumption and energy expenditure of CAI group and healthy group when the walking speed increased from 5 km/h (83 m/min) to 6.5 km/h (108 m/min) that was supported by the findings of Waters (16) who stated that there is a relationship between oxygen consumption and speed of walking. This relationship is approximately linear in the range of functional walking speeds between 40 and 100 m/min. In addition, this result is approved by the findings of Waters and Mulroy (17) who concluded that there is an increase in the O2 rate during the enhancement of walking speed.

Concerning the oxygen consumption values of the normal group at walking speeds 5 km/h and 6.5 km/h were (15.25 and 19.45 ml/kg/min, respectively) for normal group were around the value reported by Waters et al. (19) who stated that the of oxygen consumption of adults during walking speed from 40-100 m/min equals 18.4 ml/kg/min. Moreover, the values of the current study were agreed with the findings of Hsu et al. (20) who reported that during walking from 53.64 to 107.28 m/min, people with nonpathologic gait required energy expenditure from 9.00 to 16.43 ml/kg/min. For CAI group the oxygen consumption at walking speed 5 km/h was 17.8 ml/kg/min within normal ranges. However, the oxygen consumption at walking speed 6.5 km/h was 23.25 ml/kg/min that is higher than the values stated by Waters et al. (19) and Hsu et al. (20).

There was no significant difference between CAI and healthy group at walking speed 5 km/h that can be supported by the findings of Sasaki and Neptune (6) who concluded that the elastic energy utilization that stores and returns mechanical energy is considered to be an important metabolic energy saving mechanism. Gravitational potential and kinetic energy have the potential to be stored as elastic energy in connective tissue and tendinous structures, and subsequently released to do positive work at a later point in the gait cycle. Moreover, Inman et al. (21) stated that human locomotion involves smooth advancement of the body through space with the least mechanical and physiological energy expenditure.

However, at walking speed 6.5 km/h the oxygen consumption and energy expenditure of CAI were significantly higher than healthy group, that can be explained by increasing the speed of walking that imposed excessive stress over ankle joint that led to increase the oxygen consumption and energy expenditure, that can be referred to the finding of Monaghan et al. (22) who reported that CAI leads to changes in kinematics and kinetics of gait which are likely result in increased stress being applied to ankle joint structures during the heel strike and loading response phases of the gait cycle. This could result in repeated injury and consequent damage to ankle joint structures. Due to the risk of injury the subjects may do compensatory movement to avoid the recurrent injuries. Moreover, Testerman and Griend (23) demonstrated that the injury to the mechanoreceptors of the lateral ankle decreases the afferent feedback and consequently, the neuromuscular response, resulting in changes in postural or balance control. The increased walking energy cost of CAI is consistent with the findings of Bernardi et al. (24) who reported that the metabolic energy cost of walking increases in patients with locomotor impairment.

In addition, McGibbon et al. (18) reported that CAI leads to balance disturbance and increase the mediolateral sway during walking, which leads to compensatory action from other muscle to maintain the postural balance. On the same line Spaulding et al. (4) added that an individual with CAI have difficulty in maintaining postural control, local sensory deficits, slowed reflex response time of peroneals and may be associated with increase in the energy cost of walking.

Wikstrom et al. (25) demonstrated that subjects with CAI had significantly higher propulsive forces relatives to uninjuried controls during both planned and unplanned gait termination. This finding suggests a reduced ability to appropriately alter muscular activity to reduce the velocity of centre of mass while the lead limb is in contact with the ground. As a result CAI subjects had to produce significantly higher braking forces in their swing limb, injured or uninjured, to stop within one step during both planned and unplanned gait termination. This suggests that the demands of both planned and unplanned stopping lead to bilateral (feed-forward) alterations in neuromuscular control in CAI subjects also suggest the presence of feedback neuromuscular control deficits (Proprioceptive deficits). Moreover, Abdelraouf and Abdel-aziem (26) proved that unilateral CAI subjects were bilaterally significantly more inverted in the frontal plane, compared with controls in the entire parts of gait cycle and there was significant increase of ankle joint plantar flexion compared with control group.

These results means that the muscle around the ankle perform more functions during the phases of gait cycle than that reported by Zajac (27) who concluded that the muscles of the foot coordinate multijoint motion by generating forces that cause reaction forces throughout the body. Thus, a muscle can redistribute existing segmental energy by accelerating some segments and decelerating others. In the process, a muscle may also produce or absorb energy, in which case its summed energetic effect on the segments is positive or negative, respectively.

In conclusion, the oxygen consumption and energy expenditure of CAI and healthy groups were increased by increasing the speed of walking from 5 to 6.5 km/h. The walking speed 5 km/h failed to produce difference between CAI and healthy groups. However, at walking speed 6.5 km/h the oxygen consumption and energy expenditure of CAI group were higher than healthy group.

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