ENERGY COST DURING WALKING AND RUNNING A SAME DISTANCE IS ASSOCIATED WITH VERTICAL OSCILLATION ON GRAVITY CENTER.

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The purpose of this study was to evaluate which factors are involved in energetic cost of running and walking a same distance (2,000 meters). Eight healthy men were submitted to walking (5.5km/h) and running (11Km/h) tests, when oxygen consumption, for energy expenditure of exercise, was monitored, and images of volunteers were recorded for vertical oscillation of gravity center. Both, total oxygen consumption and estimated energetic cost were significantly higher during the running test ($p<0.05$) (88.66 ± 12.27 L O_2, 418.88 ± 59.14 Kcal) compared to the walking one (66.31 ± 10.18 L O_2, 319.61 ± 9.06 Kcal), as well as the vertical oscillation on gravity center (3.29 ± 0.42cm and 2.89 ± 0.42cm, running and walking, respectively). These findings suggest that the higher energetic cost of running may be associated with increased vertical oscillation on gravity center during running.

KEY WORDS: energetic cost, running, walking, gravity center

INTRODUCTION:

The energetic costs of locomotion depend largely on body size, gait and speed. It has been suggested that energetic cost of walking and running increases progressively with the speed of movement (Dill, 1965; Bransford and Howley, 1977). Differences in energetic cost between running and walking have been also demonstrated (Falls and Humphrey, 1976; Keren et al., 1981). A previous work in quadrupeds has found that the amount of energy used to run a mile is nearly the same when running at high speed or at a leisurely pace (Kram and Taylor, 1990), whereas research with humans has shown they tend to expend more energy on running than walking (Chang and Kram, 1999; Gottschall and Kram, 2003; Holt, Hamill and Anders, 1991).

Walking has been classically described as the inverted pendulum/rolling egg paradigm, while running has been described as the bouncing ball/pogo-stick paradigm (Margaria, 1976). According these paradigms vertical oscillation has an important contribution to the higher energetic cost of running. During walking, the pendulum movement of the legs, mainly determined by the gravitational force on their center of mass, implies a minimum energy expenditure. Increasing the velocity during running requires a higher hip flexing than the one necessary to the natural pendulum movement. According to Hall, the oscillation of the center of gravity on the vertical plane is higher during running, leading to a higher energy expenditure (Hall, 2000).

In the walking model, potential and kinetic energies are continuously exchanged, resulting in a total mechanical energy with a smaller change over the stride with respect to the two components taken separately. Such mechanism minimizes the net energy needed to drive the moving system.

In contrast to walking, during running these energies change in phase during the stride, and thus no exchange occurs between potential and kinetic energies during ground contact. In this gait, elastic energy has a crucial role on exchanging with the sum of the other two energy types. In contrast to an ideal pogo-stick, some mechanical energy is necessary to keep the system moving. While recent literature has pointed out that propulsive muscles in running tend to work almost isometrically during the bouncing phase (Roberts et al., 1997), the observed elevation of energetic consumption is explained by the moderately high forces that muscle sustains (Kram and Taylor, 1990).

In this study, vertical oscillation on gravity center and oxygen consumption were evaluated during running and walking, in order to determine which factors are involved on energetic cost of running and walking at a same distance.

METHODS

Eight healthy men (mean age 24.25 ± 2.92 years, mean height 178.75 ± 4.54 cm, mean body mass index 75.45 ± 7.66 and mean percent of fat 10.68 ± 3.25 %) have been recruited for the present study, approved by the Ethical Committee for Human Experimentation from the Centro Universitário de Belo Horizonte. Volunteers were non-smokers, presenting no orthopedic limitation or have been used any medication with metabolic effects recently.
The evaluation whether walking and running a same distance differs at energetic cost and vertical oscillation on gravity center was taken by submitting the men to a running test (2,000 m at 11km/h) and also to a walking one (2,000 m at 5.5km/h) in two different non-consecutive days, both performed at a treadmill (Inbrasport). During both, the oxygen consumption was measured by indirect calorimetry, using gas analyzer VO2000 (Inbrasport). Before each test, the volunteers were allowed to get familiarized with respiration trough gas analyzer, for 5 minutes at rest, and then for a 1 min walk in the treadmill at 4.5 km/h. Rest heart rate was measured during the first 5 minutes of adaptation. Following this period the velocity was increased until it reached running or walking test speed. Oxygen consumption measurements were initiated two minutes after test beginning.
For the analysis of vertical oscillation on gravity center during the tests, images of volunteers were recorded using a Sony DFC F-828 camera (40 frames per second), assembled on a Tripod VCT-D480RM Sony. Camera was positioned to maintain volunteer in the center of the image, meters away from treadmill. Marks were made on skin of volunteers with the measure of the distance between the beginning of iliac cristae to the floor and also from the femur beginning to the floor. Images captured during tests were then analyzed by Adobe After Effects (Adobe) and ImageTool (Evans Technology, Inc.,). The software was calibrated through a reference object of known dimensions maintained at the same plane of volunteers during tests. Gravity center was estimated according to the anthropometric parameters described at Winter, 1979.
Before each day test, the volunteers were submitted to anthropometric evaluation. The time and composition of diet before each day test were also recorded. Environmental temperature at test days was maintained between 20 and 24^{o} C.
The collected data were analyzed through paired t test with $p<0.05$.

RESULTS

Eigth healthy men were submitted to a 11km/h running and a 5.5km/h walking at treadmill, both with a distance of 2000 m, at two non consecutive days. No differences were observed comparing body mass index (75.45 ± 7.66 and 75.05 ± 7.71, first and second test day, respectively) and rest heart rate (63.13 ± 10.4 and 61.75 ± 9.36, first and second test day, respectively) at both test days
The O_2 consumption (figure 1A) and energetic cost (figure 1B) were measured during running and walking tests. Both were significantly higher ($p<0.001$) during running compared to walking test.

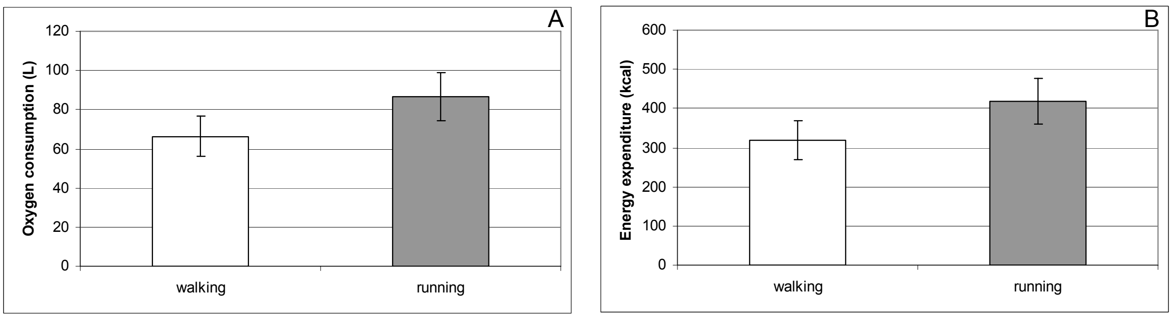

Figure 1 – Oxygen consumption and caloric expenditure during walking and running tests.

In order to evaluate whether differences on energetic cost was due to higher vertical oscillation on gravitational center during running and walking tests, images of volunteers were also recorded during them (figure 2). Vertical oscillation on gravity center was significantly higher during running ($p<0.001$) compared to walking.

Figure 2 – Vertical oscillation on gravity center during walking and running.

Also the macronutrients and the diet caloric content ingested by volunteers at both test days were evaluated (table 1). No statistical significance was observed in the comparisons during the tests days, neither at diet macronutrients composition nor at energetic content.

Table 1 – Macronutrients and caloric content of diet ingested by volunteers during tests days.

Test day	Proteins (%)	Carbohydrates (%)	Lipids (%)	Caloric content (Kcal)
Day 1	12.11 ± 1.87	60.50 ± 9.99	27.39 ± 8.11	763.69 ± 358.9
Day 2	12.51 ± 1.97	60.30 ± 8.2	27.19 ± 7.23	699.17 ± 261.51

DISCUSSION

Data presented here show an energetic cost 24% higher during the running test than on the walking test, both performed at the same distance (figure 1). This find is in accordance with Hall et al. (2004), who have also reported a higher energetic cost comparing a 10.0 km/h running to a 5.0 km/h walking, both performed at 1,600m. Also, Saibene and Minetti (2003) and Walker et al. (1999) have demonstrated a higher energetic cost during running.
According to the inverted pendulum/rolling egg paradigm for walking and the bouncing ball/pogo-stick paradigm for running (Margaria, 1979), the vertical oscillation has an important contribution to the higher energetic cost of running. During walking, the pendular movement of legs, mainly determined by action of gravity force on mass center, implies on minimal energy expenditure. Increasing the velocity during running requires a higher hip flexion than the one necessary to the natural pendulum movement. During running the oscillation on gravity center on the vertical plane is higher, leading to bigger energy expenditure (Hall, 2000). Data presented here show an increased vertical oscillation on gravity center during running compared to walking (figure 2).
Many other factors may influence locomotion energetic cost like speed, body size, gender, age, rest metabolic rate, environmental conditions and cloths. The influence of all these factors on the present study was minimized since cloths and environmental conditions were controlled on both test days, and on statistical analysis employed data on running and walking was compared for each volunteer. Although diet content has not been controlled, it was recorded for each day test, and no difference on macronutrient or on caloric content was observed that could influence oxygen consumption rate (table 1).
Running and walking are two of the most common forms of aerobic exercise. Since it is highly recommended for the purpose of physical fitness and weight control it is important that

the metabolic and biomechanical requirement of various physical activities be accurately known. Data presented here can be used to prescribe exercise in order to achieve negative caloric balance, also considering other factors as time expending during exercising and orthopedic limitation, such as articular problems, overweight, and others.

CONCLUSION:

The study presented here shows that running has a higher energetic cost compared to walking the same distance, what might be associated to a higher vertical oscillation on gravity center during running. This knowledge may be useful on exercise prescription in order to achieve negative caloric balance, also considering factors as time for exercise practice and orthopedic limitations.

REFERENCES:

Bransford, D.R.; Howley, E.T. (1977). Oxygen cost of running in trained and untrained men and women. *Med Sci Sports.* 9(1):41-4.

Bunc, V; Dlouha, R. (1997). Energy cost of treadmill walking. *J Sports Med Phys Fitness*. 37(2):103-9.

Chang, Y.H.; Kram, R. (1999). Metabolic cost of generating horizontal forces during human running. *J Appl Physiol.* 86(5):1657-62.

Dill, D.B. (1965). Oxygen used in horizontal and grade walking and running on the treadmill. *J Appl Physiol.* 20:19-22.

Falls, H.B.; Humphrey, L.D. (1976). Energy cost of running and walking in young women. *Med Sci Sports*. 8(1):9-13.

Gottschall, J.S.; Kram, R. (2003). Energy cost and muscular activity required for propulsion during walking. *J Appl Physiol.* 94(5):1766-72.

HALL, C. et al. (2004). Energy expenditure of walking and running: comparison with prediction equations. *Med. Sci. Sports Exerc.*, 36(12), 2128-2134.

Holt, K.G.; Hamill, J.; Andres, R.O. (1991). Predicting the minimal energy costs of human walking. *Med Sci Sports Exerc.* 23(4):491-8.

Keren, G.; Epstein, Y.; Magazanik, A.; Sohar, E. (1981). The energy cost of walking and running with and without a backpack load. *Eur J Appl Physiol Occup Physiol.* 46(3):317-24.

Kram, R.; Taylor, C. (1990). Energetics of running: a new perspective. *Nature*. 346:265-267.

Margaria, R.(1976). Biomechanics and energetics of muscular exercise. Clarendon Press, Oxford. 1976.

Roberts, T.J.; Marsh, R.L.; Weyand, P.G.; Taylor, C.R. (1997). Muscular force in running turkeys: the economy of minimizing work. *Science.* 275(5303):1113-5.

Saibene, F.; Minetti, A. E. (2003). Biomechanical and physiological aspects of legged locomotion in humans. *Eur. J. Appl. Physiol.* 88: 297-316.

Serway, R.; Jewett, J. (1998). Principles of physics. *Saunders College Publishing.* p. 25-50.

Walker, J. L. et .al. (1999). The energy cost of horizontal walking and running in adolescents. *Med. Sci. Sports Exerc.,* 31(2): 311-322.

Winter, D.A. (1979). Biomechanics of human movement, New York: John Wiley.