ISB 2013 BRAZIL
XXIV CONGRESS OF THE INTERNATIONAL SOCIETY OF BIOMECHANICS
XV BRAZILIAN CONGRESS OF BIOMECHANICS

MECHANICAL EFFICIENCY, ENERGETIC COST AND MECHANICAL WORK IN THE HUMAN RUNNING

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SUMMARY

This study aims at correlate W_{mec} and C_r with *Eff*. Twelve healthy men volunteered in the study. W_{mec} and C_r were measured during a treadmill running test which consisted in a rest period, incremental warm up and running test at $10 km.h^{-1}$. The biomechanical data, rest oxygen consumption (VO_2) and exercise VO_2 data were obtained. Relationships between variables were investigated using Pearson's product–moment correlation coefficient ($\alpha<0.05$). The results demonstrated a strong significant correlation only between *Eff* and W_{mec} (r =0.67). Meanwhile, the correlations between *Eff* and C_r (r=-0.55), and W_{mec} with C_r (r=0.22) were not significant. Therefore, it's believed that *Eff* of running is mainly influenced by W_{mec} instead of C_r. Furthermore, it seems that the energy cost has greater influence of intrinsic factors (as the muscle force generation) and not only by the production of movement.

INTRODUCTION

Conceptually the efficiency of human motion is determined as the amount of metabolic energy expended for producing motion [1]. It is known that during the running competition, the more efficient runner has a certain advantage because simultaneously optimizes biomechanical and energetic components involved in that activity [2].

The analysis of motion can be represented by the mechanical work (W_{mec}), which represents the variation of mechanical energy acting during running [2]. At the same time, the metabolic component can be measured through analysis of the oxygen consumption. This analysis takes into consideration only the energy expenditure generated for exercise and can be denominated as energy cost of running (C_r) [3]. The influence of these two parameters upon the mechanical efficiency (*Eff*) of running is unclear. Therefore, this study aims at correlate the running biomechanical and metabolic components (C_r and W_{mec}) with *Eff*.

METHODS

12 physically active and healthy men volunteered to take part in the present study (mean ± DP - age: 23±2 years; height: 1.79±0.05m; weight 78.3± 8.0kg). This study was approved by UFRGS Research Ethics Committee.

An initial session was held to collect sample characterization and to familiarize subjects with the test procedures. Another session was performed to obtain the data corresponding to W_{mec}, *Eff* and C_r variables. It consists in a treadmill running test compounded of a five minutes rest period on standing position for obtain rest oxygen consumption (VO_2), five minutes of incremental warm up starting at $5 km.h^{-1}$ to $10 km.h^{-1}$, and six minutes of running test at $10 km.h^{-1}$ speed.

To evaluate the ventilatory data, a portable gas analyzer was used. The sampling rate of the collected values was 10s, and the data were acquired using the Aerograph software. To calculate C_r the mean value of VO_2 at exercise was subtracted from the mean value of VO_2 in rest. The mean VO_2 at rest was obtained from the values collected in the last 3 minutes in orthostasis position. During running, the mean value for VO_2 was obtained from the data collected from the 3rd to the 4th minute as the biomechanical images shoots. Besides, VO_2 values were relativized to the body weight.

The biomechanical data were measured with an image analysis system comprising a digital camera, with a sampling frequency of 200 Hz positioned perpendicular to the treadmill. Reflective markers were attached to the left sagittal plane as reference for kinematic analysis. The total time of 10 seconds was considered to evaluation. During this time, individuals could run a minimum of 10 steps for further analysis. The Dvideow software was used to evaluate the images. Mathematical routines were created in MATLAB 5.3 software to determine the magnitudes of the following biomechanical parameters: step frequency (SF), step length (SL), contact time (CT), aerial time (AT), vertical kinect energy (KE_v), gravitational potential energy (PE_g), total mechanical energy (E_{tot}), external work (W_{ext}) and internal work (W_{int}). These parameters were employed to calculate W_{mec} and *Eff*, which was determined as the ratio between mechanical and metabolic powers (P_{mec} and P_{met}, respectively). In order to analyze the collected data, descriptive statistics were used, with the data presented as means ± SD. The Shapiro-Wilk test was used to verify the normal distribution of data. Relationships between variables were investigated using Pearson's product–moment correlation coefficient. Statistical significance was accepted when $\alpha < 0.05$.

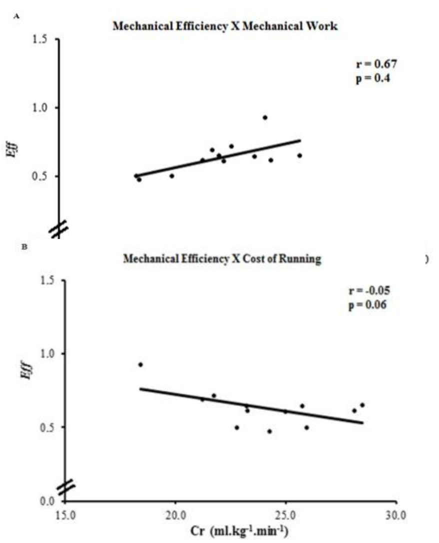
RESULTS AND DISCUSSION

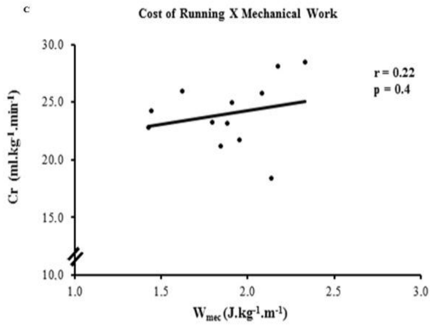
The strong positive correlation demonstrated between *Eff* and W_{mec} (r=0.67) assures that the higher efficiency during the running is related with a greater W_{mec}. (Figure 1A). According to this, the correlation between C_r and *Eff* showed a negative (r = - 0.55) and it was not significant (Figure 1B). Such behavior was expected, since subjects with less energy expenditure during the running can be related to a higher *Eff* [1]. However, a weak correlation was shown between W_{mec} and C_r (r = 0.22).

Fugure 1: Relationship between (A) Mechanical Efficiency (E*ff*) and Mechanical Work (W_{mec}), (B) *Eff* and Cost of Running (C_r) and (C) C_r and W_{mec} ($\alpha = 0.05$).

Regarding, the relationship between *Eff* and W_{mec} showed a stronger correlation compared with C_r and *Eff*. Therefore C_r may have a greater influence on the behavior of *Eff* than W_{mec}. This behavior emphasizes the importance of motion production during running, rather than the expenditure of metabolic energy. However, some authors have reported the aerobic contribution as the main predictor of *Eff* for runners [2,3]. The biomechanical components of running have been widely studied and have not presented a great influence as the metabolic component on sport performance, [4].

Indeed, the relationship between *Eff* and W_{mec} can be justified by the ratio between the mechanical and metabolic powers that comprise the equation of *Eff*. This ratio is represented conceptually by the amount of metabolic energy expended during the performance. It is known that the efficiency is defined as the capability to produce a large amount of movement with minimum expenditure of energy. Probably, a greater W_{mec} may explain a higher *Eff*. However, studies examining the response of these variables with different interventions reported that the performance of an aerobic, strength, or concurrent training directly influences the metabolic component as C_r. [4]. Such influence, however, does not occur with the biomechanical parameters which don't change after the intervention period. Thereby, it is assumed that a possible change in the *Eff* would be mainly explained by the decrease in consumption of metabolic energy [1,3].





Therefore, it becomes important to understand the response of C_r relative to W_{mec}. In the present study a weak relationship between this variables was demonstrated (Figure 1B). This result indicate that the motion production during running can be weakly related by C_r. Taylor et al. [5] proposed a direct correlation between C_r with muscles force production acting on the running of mammals, that assumed greater C_r occur when muscles contract and perform W_{mec} [5,6]. However, it is known on the complexity of estimating precisely W_{mec} produced only by joint action of the muscles due to tendons action during the production of motion [1]. It is known that at low/intermediate running speeds W_{mec} values are dependent on the muscular action, while the tendons respond with greater predominance at high speeds in the muscle-tendon unit (UMT) [6]. Thus, low speed as used in this study (10 $km.h^{-1}$), present greater involvement of muscles during contraction of UMT, did not influence the values of C_r.

CONCLUSIONS

The main result of the study was the strong relation between *Eff* e W_{mec}. Thus, it is believed that *Eff* of running is mainly influenced by W_{mec} instead of C_r. Nevertheless, the values of W_{mec} must be optimized in relation to C_r, providing to the runner a higher *Eff*. In other words, the amount of metabolic energy expenditure must be the minor possible for a specific motion production.

ACKNOWLEDGEMENTS

This study was supported by CAPES and CNPq.

REFERENCES

1. CAVAGNA GA and KANEKO M. Mechanical work and efficiency in level walking and running. *Eur J Physiol*, **268**: 467-481, 1977.
2. CAVANAGH PR and KRAM R. The efficiency of human movement – a statement of the problem. *Med Sport Sci*, **17**: 326-331, 1985.
3. DI PRAMPERO PE, et al. The energetics of endurance running. *J Appl Physiol*, **55**: 304–308, 1986.
4. TAIPALE RS, et al. Strength training in endurance runners. *Int J Sports Med*, **31**: 468-476, 2010.
5. TAYLOR CR, et al. Energetic cost of generating muscular force during running. *J Exp Biol*, **86**: 9-18, 1986.
6. SIH BL and STUHMILLER JH. The metabolic cost of force generation. *Med Sci Sports Exerc*, **35**: 623-629, 2003.