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

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SUMMARY

This study aims to correlate W_{mec} and C, with Eff. Twelve healthy men volunteered in the study. W_{mec} and C were measured during a treadmill running test which consisted in a rest period, incremental warm up and running test at 10km.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 (r<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 5km.h^{-1} to 10km.h^{-1}, and six minutes of running test at 10km.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 Dvidew 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 kinetic 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 \( \text{Eff} \) and \( W_{\text{mec}} \) (\( r=0.67 \)) assures that the higher efficiency during the running is related with a greater \( W_{\text{mec}} \). (Figure 1A). According to this, the correlation between \( C_t \) and \( \text{Eff} \) 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 \( \text{Eff} \) [1]. However, a weak correlation was shown between \( W_{\text{mec}} \) and \( C_t \) (\( r = 0.22 \)).

**Figure 1:** Relationship between (A) Mechanical Efficiency (\( \text{Eff} \)) and Mechanical Work (\( W_{\text{mec}} \)), (B) \( \text{Eff} \) and Cost of Running (\( C_t \)) and (C) \( C_t \) and \( W_{\text{mec}} \) (\( \alpha = 0.05 \)).

Regarding, the relationship between \( \text{Eff} \) and \( W_{\text{mec}} \) showed a stronger correlation compared with \( C_t \) and \( \text{Eff} \). Therefore \( C_t \) may have a greater influence on the behavior of \( \text{Eff} \) than \( W_{\text{mec}} \). 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 \( \text{Eff} \) 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 \( \text{Eff} \) and \( W_{\text{mec}} \) can be justified by the ratio between the mechanical and metabolic powers that comprise the equation of \( \text{Eff} \). 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 \( W_{\text{mec}} \) may explain a higher \( \text{Eff} \). 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 \( C_t \). [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 \( \text{Eff} \) would be mainly explained by the decrease in consumption of metabolic energy [1,3].

Therefore, it becomes important to understand the response of \( C_t \) relative to \( W_{\text{mec}} \). In the present study a weak relationship between these variables was demonstrated (Figure 1B). This result indicates that the motion production during running can be weakly related by \( C_t \), Taylor et al. [5] proposed a direct correlation between \( C_t \) with muscles force production acting on the running of mammals, that assumed greater \( C_t \) occur when muscles contract and perform \( W_{\text{mec}} \) [5,6]. However, it is known on the complexity of estimating precisely \( W_{\text{mec}} \) 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 \( W_{\text{mec}} \) 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 \( C_t \).

CONCLUSIONS

The main result of the study was the strong relation between \( \text{Eff} \) and \( W_{\text{mec}} \). Thus, it is believed that \( \text{Eff} \) of running is mainly influenced by \( W_{\text{mec}} \) instead of \( C_t \). Nevertheless, the values of \( W_{\text{mec}} \) must be optimized in relation to \( C_t \), providing to the runner a higher \( \text{Eff} \). 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