Electromyographic economy during running

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Abstract—Running is a series of rebound impacts on the ground that is alternated with aerial phases when none of the feet are in contact with the ground, but information using a novel technique electromyographic economy is lacking. So the objective of the study is to correlate the electromyographic economy with metabolic economy in the running at different speeds. Four individuals amateur running participated in the study. Electromyographic data and oxygen uptake were collected simultaneously at five speeds. Measurements were made of 16 muscles of the lower, trunk and upper limbs involved during running. In the analysis the data were converted from millivolts to Joules. Result only the 10 km.h⁻¹ speed showed a difference compared to the other speeds. The behavior of the electromyographic economy was in line with gas analysis, with a coefficient of determination of 88%. These findings suggest that the value of the electromyographic economy is lower than expected in the literature like as economy running obtained through oxygen consumption. Future research may continuous this study with more individuals and in other situations.

Keywords—Cost of transport, muscle activation, oxygen consumption, locomotion.

I. INTRODUCTION

Different factors influence the economy and efficiency running, such as maximal aerobic power and muscle fiber distribution [1]. Running has been classically described by the bouncing ball paradigm [2], modeled as a spring-mass system [2,3] see figure 1.

In this way the cost of transport, denomination used to walking, or running economy emerges as metabolic variable that explain mechanical parameters of locomotion, like spring-mass system during running. The classic definition of running economy is the metabolic demand per unit of travelled distance [1]. Understand the economy of locomotion and the determinant of running economy it means the assumption that the running economy is invariant across speed [2, 3].

The limbs and trunk should be tuned to work most effectively [2], thus, while our muscles may not be specialized solely for economizing locomotion, they do a pretty good job of reining in the costs over a larger range of speeds [3].

Besides this, muscle patterns leads to understand motor coordination, motor skills and locomotion patrons [4]. So electrical activity levels generated during contraction muscle are associated with an increases in oxygen consumption [5], probably due to the use of additional muscle fibers.

Recently was proposed an determination of the economy of the human walk (also called the cost of transport) based on electromyographic (EMG) data, for behavior of individual muscles per distance travelled [5] and for the sum of muscular groups for specific types of muscular contractions per distance travelled [6]. So the

Fig. 1: Running model as spring-mass system, where the spring was made by the combination of passive (tendons) and active (muscles) structures; the black ball represent the center of mass of body (adapted from Blickhan 1989 apud Minetti, Ardigo, Saibene 1994).
Electromyographic economy has been the same meaning of the classic running economy definition the difference is the data used were obtained from muscle activity.

However the concept of electromyogram economy has not been applied to the running. It would be expected that the economy of running based on muscle activation have relationship with the economy of running from the oxygen consumption per meter taken at different speeds. In addition, there is a gap in the literature if global muscle behavior reflects mechanical and metabolic patterns in running, as seen in walking.

So, the objective of this study is to correlate the electromyographic economy with metabolic economy in the running at different speeds.

II. MATERIALS AND METHODS

Four men participated (20.04±0.8 years, 22.5±0.5 BMI kg/m²) well trained, amateur runner, perform protocols on the treadmill at constant speed (GE, T 2100). Surface electromyography data of 16 muscles (DelysTriino Trademark) with sample rate 2000 Hz and oxygen uptake (Cosmed K5) breath by breath were collected simultaneously. Were performed five running speeds in randomized order: 8, 9, 10, 11 and 12 km.h⁻¹. Subjects running during five minutes at each speed, between each test, the subjects were allowed to rest until the oxygen consumption levels were close to those at rest (usually for 5–6 minutes).

A. Electromyographic economy.

Muscles monitored were: the propelling muscles: tibialis anterior (TA), gastrocnemius medialis (GaM), vastus lateralis, rectus femuralis (RF), biceps femurals (BF - long head), gluteus maximus (GM), glutus medius (Gme). Postural muscles: rectus abdominis (RA), obliquus internus (OI), obliquus externus (OE), erector spinae longissimus (LO), erector spinae iliocostalis (IC), trapezius descendens (TrD), trapezius ascendens (TrA). Upper limbs: deltoideus anterior (DA) and latissimus dorsi. All muscles were monitored on the right side of the body, recommended for literature [7].

The raw EMG data were band-pass filtered with a zero-lag, third-order Butterworth filter with cut-off frequencies at 10 and 500 Hz [8]. After filtering EMG data, phases define the time interpolated over base with 200 points and normalized by the peak value of the EMG data. For electromyographic economy ten steps were evaluated, each step was divided by first stance phase (eccentric contraction), second stance phase (concentric contraction) and balance phase (isometric contraction) with accelerometer information. So the integral of the rectified EMG (iEMG) signal was determined for each muscle at each phase.

The iEMG activity in orthostasis was subtracted from the mean iEMG signal. So iEMG signal of each muscle during each phase step were converted separately in counts units and into metabolic equivalent [6] for each type of contraction (stance phase division).

EMG analysis was the same used by [6], however we clarify it here. Fist the iEMG activity of each muscle in orthostasis was subtracted from the mean iEMG signal of each phase. Then iEMG signal of each phase step were converted in counts units. EMG eccentric (EMG_ecc) and EMG isometric (EMG_iso) were obtained in counts units (100 counts correspond to 1 mV.s⁻¹). The metabolic equivalent was obtained through linear regression equation of previous experimental study [9] for each type of contraction. The follows regression equations transform counts units to metabolic data, oxygen consumption (VO₂), as equations (1), (2) and (3):

\[ VO_2^{neg} = 0.0015 \cdot (EMG_{ecc}) + 0.3353 \]  
\[ VO_2^{pos} = 0.0042 \cdot (EMG_{con}) + 0.1493 \]  
\[ VO_2^{iso} = 0.0041 \cdot (EMG_{iso}) + 0.1394 \]

VO₂neg is the oxygen consumption for negative mechanical work, VO₂pos is the oxygen consumption for positive mechanical work, VO₂iso is the oxygen consumption for isometric contraction [9]. The sum of all metabolic equivalents (ml) were weighted for the total number of analysed muscles (n) as so the mass of participant (kg).

Next steps are equals the classic running economy determination. Finally the normalized sum of metabolic equivalents were converted in Joules using a energetic equivalent. This was obtained adjusting the respiratory quotient (20.9 for running) [2] and was subsequently divided by the running speed (m.s⁻¹) [1,2] to determine the electromyographic economy in J.kg⁻¹.m⁻¹.

B. Running economy.

Running economy (source metabolic data) was determined through oxygen consumption with portable gas analyzer (K5 Cosmed). The mean VO₂ (in mL.kg⁻¹.min⁻¹) during the last two minutes of running at each speed was used. Fist was subtracting the resting VO₂ in orthostasis. The energetic equivalent was obtained after adjusting for the respiratory quotient (20.9 for running) [2] and was subsequently divided by the running speed (m.s⁻¹) in order to determine the running economy in J.kg⁻¹.m⁻¹ according the literature [1, 2, 6].

C. Statistics.

For statically analysis [10] repeated measures with ANOVA two way (speed and economy type) to test the speeds effects with Bonferroni post hoc. Thus, the coefficient of determination (trend line) were used for correlation. Besides this to evaluate the agreement between the two methods we performed the Bland-Altman analysis. The p<0.05 used at SPSS 20.0 software.

III. RESULTS

Electromyography economy as well running economy present linear characteristic, the coefficient of determination (r) was 0.88 for electromyography economy and 0.91 for economy of running (Fig 2)

The average value for electromyography economy is 3.07 ± 0.27 J.kg⁻¹.m⁻¹ and running economy is 3.42 ± 0.28 J.kg⁻¹.m⁻¹. When compared the same speed there are not differences between electromyography economy and running economy.

Interestingly to note, the results of both the approaches used for the economy analysis for running were not statically different and near of classical literature mean (3.72 J.kg⁻¹.m⁻¹ for intermediate level subject competing in middle distances) [2,3]. Only one speed, 10 km.h⁻¹. (intermediary), showed difference between the speed range...
and among the protocols. To confirm the result more individuals will be tested.

![Graph](image)

**Fig. 2:** Mean and standard deviation (SD) for electromyography economy (EMG_eco) and running economy (R_eco) at five speeds. * represent significant difference only at 10 km.h⁻¹.

Figure 3 presents electromyography economy data difference against average of running economy data, method may be regarded as a gold standard (represent by metabolic economy) it is presumably more accurate than the other method (electromyographic economy). Results including the analysis of limits of agreement and confidence intervals: BIAS -0.04, upper limit 1.28 and lower limit -1.49.

![Graph](image)

**Fig. 3:** The Bland-Altman analysis: mean difference against average of electromyography economy and standard measurements (represented by running economy) with 95% limits of agreement (+1.96 standard deviation and -1.96 standard deviation). Bias represent the mean of difference about two methods of economy determination.

**IV. DISCUSSION**

The present work shows the energy cost of running (or commonly called running economy), i.e. the metabolic demand per unit of travelled distance, is invariant across speed in the same subject evaluated, as already presented in other previous studies [2,3]. The electromyographic economy correlates with running economy. Also Bland-Altman analysis show a relation, whether there is a agreement between electromyography economy data and running economy data.

During running, musculotendinous structures runner’s legs alternately store and return elastic energy, so that can be described as the spring-mass model. Thus, the bouncing ball has a crucial role to explain energy consumption [1,2,3].

At the intermediate speed of the protocol, there were higher values of electromyographic economy when compared to the values on other speeds and metabolic rate. The literature present that the mechanical running characteristics, represent for spring-mass system, is independently of speed [2]. Recently was reported that runners who presents elevated vertical oscillation during the running movement indicating a less efficient running style [11].

Besides that the different result for intermediate speed may be representing some physiological demand. We speculate it may have occurred at this speed due lower metabolic comfort and possible muscle adaptation to the movement of the running. Some runners showed at intermediate speed different values of energy expenditure and running economy through assesses individual physiological, gait patterns, and training characteristics [12].

There is a relationship between muscle activation and muscle forces generation, which is not completely linear [8]. EMG range is a function of both muscle fiber recruitment and motor unit firing frequency [4]. But at the same time it would be expected that the values recorded with electromyography would be increasing with the increase in the speed of the running movement due to greater difficulty to maintain the center body mass moving quickly [1,3].

This increase at EMG data with increment speed of the movement is true when analyzed the muscle activation in respect to time [4], no in relation the energy required perspective [5,6]. So electromyography economy reflects global muscle metabolism and is related to the number of activated motor units to propulsive and postural energetics demands. Our results agree with the muscle synergy hypothesis that showed human motor control during running at different speeds by changing only few neuromusculoskeletal parameters [13].

Recently study [14] demonstrated over a wide range of running velocities the volume of active leg muscle recruitment, and consequently rate of force production, found that cost was nearly constant, indicating coherence with the metabolic requirements during running.

In addition to metabolic, cardiorespiratory, and biomechanical factors, neuromuscular characteristics are also important aspects for running economy. The interaction between the neural and muscle systems (i.e. neuromuscular system) is fundamental to all movement and generate mechanical propulsion and therefore converted into performance [3,13].

Thus, physiological and neuromuscular characteristics refer to the interaction between these systems and their ability to convert power output. Furthermore, there is relation between running economy and mean stance phase contact times during constant velocity running, suggesting muscle power characteristics play an important role in determining running performance in trained runners [12].

In a recent study, we demonstrated the electromyography cost of walking reflects the integrative composite of a variety of physiological, mechanical and muscle characteristics [6],

**Fig. 3:** The Bland-Altman analysis: mean difference against average of electromyography economy and standard measurements (represented by running economy) with 95% limits of agreement (+1.96 standard deviation and -1.96 standard deviation). Bias represent the mean of difference about two methods of economy determination.
similar as in the present findings to running. Is an inherent difficulty to determine the contribution by individual muscle [15] but were showed the global effect (considering each type of contraction in their respective phases) that are of primary and in our opinion more applicable.

Comparing different metabolic energy expenditure of seven models the differences on outputs are affect only by the subject’s weight when calculated metabolic cost [13]. In the present study both type determination of economy were normalized by individual weight.

This way, comprehension of the energetic function of muscle during human locomotion can contribute to a better prescription of this modality. These findings helping sports training also has important clinical and rehabilitations implications used be biomechanics insight to shed light on running injury patterns.

V. CONCLUSION

The muscle energetics model used in the research highlighted here has been shown to yield good predictions global muscle activation cost for running or electromyographic economy. This is an especially promising path for improving our understanding of human locomotor energetics. For to confirm the results more individuals and different situations should be tested.

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REFERENCES