PLUX REAL-TIME SPORTS EVALUATION
A New Real-time Tool for Sports Evaluation

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Abstract: In this paper we present a new tool for athletes performance evaluation in real-time using two different biosignals (ECG and accelerometry). From the accelerometer signal, the level of activity was extracted based on a validation protocol, in which metabolic equivalent tasks (METs) values were calculated in real-time from a body-acceleration signal. METs values were obtained from various lifestyle and sporting activities, and compared with the results from the reference work (Crouter et al., 2006b) for the same activities. The results obtained showed correlation with the Crouter model. With the results we can conclude that present tool allows the assessment of the athlete performance based on ECG and accelerometer signals, being a versatile tool, which can be used by sports professionals and non-professionals.

1 INTRODUCTION

The need to obtain results in sports and a sustained evolution of athlete's physical condition lead to continuous training assessment.

Athletic performance is evaluated by measuring specific variables which provide information about the athlete physical condition (Morrow Jr et al., 2010). Providing feedback to the athlete and coach is a major factor in the improvement of sport skill performance. Nowadays this feedback can provide the athlete and the couch with a real-time assessment tool of the athlete's performance.

1.1 Athlete's Performance Evaluation

The athlete's performance can be assessed through intensity. Intensity is defined as the amount of effort that the body is exposed during the performance of a certain task. However, while duration and frequency are easily measured, the intensity is not. The amount of effort can be assessed using internal, external loads or both. Since the same external load applied to different athletes can frequently produce different physiological responses, the importance of assessing internal load has increased. The intensity assessed using internal load parameters is usually estimated through physiological parameters, such as:

- Heart Rate (HR);
- Percentage of maximum Heart Rate (%HR$_{max}$) (Robergs and Landwehr, 2002);
- Percentage of Heart Rate reserve (%HRR) (Borresen and Lambert, 2009);
- Training Impulse (TRIMP) (Borresen and Lambert, 2009);
- Metabolic Equivalent Task (MET).

MET is utilized to quantify the intensity in terms of the energy expenditure and defined as the resting metabolic rate, that is, the amount of oxygen consumed at rest.

METs can be obtained from the magnitude of the accelerometer signal. Using this magnitude, Counts are determined and then converted into METs through a non-linear signal processing algorithm using two regression equations based on the method described by Crouter et al. (Crouter et al., 2006b). For this operation, the range of the accelerometer is divided into levels of 0.001664 g, being each level considered 1 Count. The number of Counts are determined by how many levels the difference of the magnitude of the acceleration between samples correspond to (Actigraph, 2011).

In the present work, a new tool to assess in real-time the athlete's performance is presented. This tool allows the acquisition, visualization and processing of biosignals in real-time, providing feedback of physiological parameters both for athletes and coaches, in

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order to evaluate the athlete's performance.

The rest of the paper is organized as follows: Section 2 describes the PLUX Real-Time Sports Evaluation tool; Section 3 describes the validation procedure of METs real-time algorithm; Section 4 details the main results and Section 5 highlights the main results and future work.

2 PLUX REAL-TIME SPORTS EVALUATION

PLUX Real-Time Sports Evaluation (PRTSE) is a tool to assess athlete's performance in real-time. This tool was implemented and built in independent blocks, which are responsible for different options (visualization, processing, saving data). The processing option features two types of algorithms to compute intensity in real-time based on Heart Rate (HR-based Intensity) and accelerometer signal (Accelerometer-based Intensity).

2.1 HR-based Intensity

The HR-based intensity block processes, in real-time, an ECG signal, in order to calculate the %HR$_{max}$, %HRR and TRIMP. For that, from the ECG signal, R-peaks are detected using a buffer which contains the acquired data from an ECG sensor. The R-peaks will be used for calculating the R-R intervals in order to obtain HR, in beats-per-minute (BPM). With HR, %HR$_{max}$, %HRR and TRIMP are calculated.

2.1.1 HR-based Intensity Real-time Algorithms

The algorithm used for detecting R-peak is based on a method developed by Pan and Tompkins (Pan and Tompkins, 1985).

The heart rate monitors show a relatively stable HR between measures, by computing a mean R-R interval to reduce the heart rate variability between R-peaks (Achten and Jeukendrup, 2003). Therefore, PRTSE obtains the R-R intervals from a 4 seconds buffer and the HR and other HR-related parameters are computed, and shown every 2 seconds.

The algorithm computes the HR from consecutive R-peaks from equation (1):

$$HR_i = \frac{60}{(R_i) - (R_{i+1})} \tag{1}$$

with R_i being the time instant where beat i was detected and HR_i being HR calculated from the i-th R-R interval, with i ranging from 1 to number of peaks-R – 1 in the 4 seconds ECG-signal buffer. A mean HR, HR_{mean}, is obtained in each 2 seconds using the HR_i obtained from the 4 seconds buffer.

Using HR_{mean}, the algorithm will compute the following parameters through equations (2), (3) and (4) in each 4 seconds from the ECG-signal buffer:

$$\%HR_{max} = \frac{HR_{mean} \times 100}{HR_{max}} \tag{2}$$

$$\%HRR = \frac{HR_{mean} - HR_{rest}}{HR_{max} - HR_{rest}} \times 100 \tag{3}$$

$$TRIMP = \frac{HR_{mean} - HR_{rest}}{HR_{max} - HR_{rest}} \times \Delta t \times Y \tag{4}$$

where the Δt_i is 2 seconds since this value is calculated and accumulated each 2 seconds and Y_i is the lactate profile determined using the athletes gender and the ΔHR_{ratio}.

2.2 Accelerometer-based Intensity

Accelerometer-based intensity block runs a real-time algorithm for accelerometer signal processing. There are several equations available to predict the METs based on accelerometer-data (Crouter et al., 2006b; Crouter et al., 2006a). The algorithm of Accelerometer-based intensity block obtains the Actgraph's $counts \times min^{-1}$ (Actigraph, 2011) and calculates the corresponding METs using the model of Crouter (Crouter et al., 2006b).

2.2.1 Accelerometer-based Intensity Real-time Algorithms

For the algorithm developed in the present work, a real-time band-pass filter was implemented based on a Infinite Impulse response model expressed as follows:

$$y[n] = \frac{1}{a_0}\left(\sum_{i=0}^{R} b_i x[n-i] - \sum_{j=1}^{S} a_j y[n-j]\right) \tag{5}$$

where R is the feedforward filter order, b_i are the feedforward filter coefficients, S is the feedback filter order, a_i are the feedback filter coefficients, $x[n]$ is the input signal and $y[n]$ is the output.

The coefficients b_i and a_i are determined for a band-pass Butterworth of 4 th order with corner frequencies of 0.25 and 2.5 Hz.

This filter records and uses the last input and output samples, $x[n-1]...x[n-R]$ e $y[n-1]...y[n-S]$, respectively, and update them each new sample acquired.

The input signal, x, corresponds to the unfiltered z-axis acceleration signal and the output signal, y, to the filtered z-axis acceleration signal.

Then, the filtered z-axis acceleration signal is subsampled at 10 Hz and the $counts \times min^{-1}$ and the coefficient of variation of $counts$, $c_v = \frac{\sigma}{\mu}$, are determined each 10 seconds over a period of one minute. Using the obtained values of $counts \times min^{-1}$ and c_v the METs value is determined using Crouter's model (Crouter et al., 2006b).

The output values presented to the user, in visualization, are the METs. If the user chooses to write the data from Accelerometer-based intensity block, the parameters recorded are the $counts \times min^{-1}$ and METs.

Although the presented tool assess the performance of athletes based on the ECG and accelerometer signals, the lack of tools to evaluate in real-time the athlete's performance based on ECG parameters doesn't allow to compare our cardiovascular results with standard. However, from preliminar study no missing cycles were verified. This shows that used algorithm is a robust one with good accuracy; hence the cardiovascular parameters were extracted directly from the computed R-peaks. Thus, the validation of PRTSE outcomes is focused on METs procedures, which is reported by Crouter model, allowing the comparisons between our results and the literature.

3 METHODS

3.1 Acquisition System and Sensors

To acquire the acceleration signal necessary for this validation a triaxial accelerometer sensor (ACC), xyzPLUX, was used. The acquisition system used was the bioPLUX clinical (PLUX - Wireless Biosignals, 2007). This system is wireless and is responsible for the signal's analog to digital conversion, using a 12 bit ADC, and bluetooth transmition of data to a computer. This system can acquire data at a maximum sampling rate of 1000 Hz.

Since the accelerometer-based intensity uses the inferior-superior axis, only the inferior-superior axis of the accelerometer was connected to the bioPLUX.

3.2 Procedures

To validate the real-time algorithm for METs calculation based on the model defined by Crouter (Crouter et al., 2006b) two sets (Set 1 and Set 2) of various lifestyle and sporting activities were performed. These activities were selected based on those used by Crouter to validate his model.

For the Set 1, each of these activities were repeated five times, except walking up and down the stairs, walking at an average speed of 4.9 km/h and 6.2 km/h and running at an average speed of 9.5 km/h that were repeat two times.

Each repetition had a duration of 10 minutes, producing a total of 60 METs values per repetition, since the algorithm determines the METs each 10 seconds.

The mean value and standard deviation of METs per min were calculated to compare with Crouter model results for each activity.

After that, modifications to the algorithm were made and a new set of activities, Set 2, were performed, this time with only one repetition. The values obtained from the algorithm were, again, compared with Crouter model.

4 RESULTS/DISCUSSION

In this section, the obtained outcomes will be present and discussed based on Crouter study (Crouter et al., 2006b).

For the activities Lying, Standing and Computer work, Crouter reported results and the PRTSE results, from both sets, were all equal to 1.00 ± 0.00 METs. For the Filling activity, Crouter's results, PRTSE first set and PRTSE second set obtained METs values of 1.30 ± 0.67, 2.44 ± 0.05 and 2.44 ± 0.06, respectively. For the activity of Slow walk, the results were 3.73 ± 0.42, 9.38 ± 0.54 and 5.36 ± 1.31 and for the Brisk walk, 4.71 ± 0.58, 11.83 ± 1.42 and 7.89 ± 1.27. For the Ascending/ Descending stairs the results were 6.08 ± 1.29, 6.77 ± 1.69 and 5.72 ± 1.54. Finally, for Slow run, the results were 7.76 ± 0.96, 91.83 ± 5.81 and 43.58 ± 9.0.

For the PRTSE's results of the first set of activities, it's possible to note that, for the first three activities, the results from our tool show equal values when compared with the results by Crouter (Crouter et al., 2006b) for the same activities.

In the Filling activity, the PRTSE overestimates the value of METs, when compared with the results from Crouter. This might be explained by a different intensity when performing this activity in the validation of PRTSE's METs algorithm. Since a work rate or intensity it's not defined for this activity, a different work rate or intensity might explained the difference between our results and Crouter's.

For the Ascending/Descending stairs activity, PRTSE showed a close value from Crouter's result for this activity. The difference between the results can also be explained by the differences in intensity of this activity performance.

For the Slow, Brisk walk and Slow run, an increase of METs values is verified. This trend is reported in the literature, since Crouter results show that there is an increase of the METs values with an increase of the activity intensity. Despite the same trend, the obtained results are higher than Crouter's, but are correlated in most of the situation.

The overall difference in the results for walking and running may be due to the filter applied, possibly, because it allows higher frequencies than the Actigraph thus verifying the high levels of METs for these activities.

Therefore, another set of activities were performed using the METs algorithm with a lower upper cutoff frequency.

The values of Lying, Standing and Computer work activities, from the second set of activities, estimated using the METs algorithm were not significantly different from the METs, in (Crouter et al., 2006b).

All other estimated values, using METs algorithm from PRTSE, overestimate the measured values presented by Crouter for these activities (Crouter et al., 2006b) with exception of Ascending/descending stairs that was underestimated. Although these results, it's possible to note that the overall results improve when compared with the results from the first set.

According to these results, we can state that our hypothesis concerning the filter was correct and the METs algorithm will need more adjustments to allow the use of the EE-based Intensity monitor from PRTSE.

5 CONCLUSIONS AND FUTURE WORK

The PRTSE represents a new tool capable of assessing athletes performance using different physiological parameters, allowing to improve the athlete evaluation. Concerning to METs results, in activities with high level of intensity, higher values than Crouter model were verified, showing the need of further adjustments in the filtering, in order to obtain results closer to Crouter model. This tool can be used both by professionals and non-professionals of sports.

In the future work we plan to improve the EE-based intensity monitor algorithm based on the Crouter model and create our own METs model using the 3-axis accelerometer signal for various activities, trying to fill the gap of the Crouter model in activities with METs values between 1 and 2.4 METs. Since this new tool is capable of expansion, we intend to allow the assessment of the athletes performance using other parameters, such as the critical velocity and power, instantaneous acceleration, velocity and distance.

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