Estimation of the gait energy expenditure*

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ABSTRACT

The aims of this study were: 1) to propose predictive equations for gait energy expenditure (GEE) of young individuals in three situations: a) when the identification of the gait velocity is possible; b) when heart rate (HR) monitoring is possible; and c) when neither the velocity identification nor the HR monitoring is possible; and 2) to validate the GEE made by the HR Polar M71® monitor. Thirty individuals (16 males, 22.7 ± 2.6 years and 14 female, 22.1 ± 2.1 years), non-athletes, physical education students were instructed to walk on the treadmill with 1% inclination, in self-selected low, moderate and high intensity velocities, during 6 minutes in each velocity. The $\dot{V}O_2$, measured by the Aerosport Metabolic Analyzer Teem 100, HR and GEE estimated by the monitor, were registered in the last 2 minutes of each load. It was concluded that the best GEE prediction is done with the use of the gait velocity and the individual's body weight. HR for prediction of GEE should be accompanied by the gender and rest HR. The perceived exertion scale proposed in this study should be utilized only when it is not possible to register the velocity or the HR. The use of other scales of perceived exertion is encouraged. The HR Polar M71 monitor is a valid instrument for GEE estimation, with the limitation that is necessary that HR exceeds 100 bpm. Its precision is enhanced at high intensity gait.

Keywords: Perceived exertion. Heart rate monitor. Oxygen consumption. Gait.

INTRODUCTION

The importance of physical activity in people's daily lives has been demonstrated over the last decades. Among other objectives, it is practiced with the aim to keep good health and prevent diseases. Regular physical activity in the prevention of diseases and premature deaths, as well as in maintenance of quality of life has recently received recognition as a target of public health[1]. Among the benefits from regular physical activity, decrease of the risk of development of cardiovascular diseases, diabetes, hypertension, among others, can be mentioned. Physical activity contributes to the general strengthening of muscles, bones and joints and also helps to control body weight[1-10]. It is worth mentioning as well the role of the physical activity in the prevention and treatment of obesity which is the excessive accumulation of adipose tissue in the body[11]. In Brazil, data from the National Institute of Eating and Nutrition showed that 32% of the results presented some degree of surplus weight[12].

Restriction of caloric intake and increase of the energetic cost through exercise are effective ways for body fat reduction as well as for normalization of blood pressure and blood lipidic profile[13]. Walking is the most popular exercise and therefore, very used in programs of weight control and reduction of risk factors of coronary disease[14-16]. Besides intensity and duration, in some cases, it is also important to quantify the caloric cost caused by the gait for its prescription and control. Small benefits can be reached in activities in which the energetic cost is of at least 150 daily kcal[10]. When the aim of the gait practice is the reduction of body weight, the energetic cost is an important parameter to be used by the physical education professionals in its prescription.

The amount of energy expenditure in different activities varies with the intensity as well as the kind of exercise[1,11]. However, there are some individual variations due to differences in the level of activity, age, sex, size weight and body composition which justify the existence of many methods for measurement and estimation of the exercise energetic cost. In order to measure the energetic cost, indirect calorimetry by the measurement of the oxygen uptake is usually used; however, such method depends on costly procedures which restrict its use almost exclusively to laboratory environments and research situations. In field situations, where the measurement of the gait energetic expenditure (GEE) is not very viable, it is usually estimated.

According to Di Prampero[17], the first trials to describe the human locomotion were dedicated to quantify the GEE and occurred in the second half of the XIX century. The values registered at that time varied from 0.32 and 0.51 $kcal.kg^{-1}.km^{-1}$ for velocities between 3.2 and 4.8 $km.h^{-1}$ – values surprisingly close to the ones currently found. For Di Prampero[17], the energetic expenditure of the human locomotion above rest levels is function of the velocity multiplied by a factor which varies according to a kind of dislocation as well as environmental conditions, such as air resistance. The American College of Sports Medicine[18] proposed that for the GEE estimation on flat surface, the rest cost of 3.5 $mlO_2.kg^{-1}.min^{-1}$ (0.0175 $kcal.kg^{-1}.min^{-1}$) is considered and 0.1 $mlO_2.kg^{-1}.m.min^{-1}$ (0.0005 $kcal.kg^{-1}.m.min^{-1}$) for the horizontal velocity.

In many field situations, it is not possible to measure the completed distance in the gait, making hence, the use of GEE in relation to the velocity prediction equations impossible. In these situations, heart rate (HR) monitors, accelerometers, pedometers, compendiums and so forth can be used[19-22]. The heart rate (HR) measurement has been widely used in the field to estimate the energetic cost of the physical activity, due to its practicality, especially with the popularization of the HR monitors as well as the strong correlation that it has with the energetic cost during dynamic exercise which involves large muscular mass[23-25]. Currently, HR monitors such as the ones by Polar, series M and S, which have among their functions the estimation of the energetic cost of the physical activity are available in the market. Nevertheless, even with their easy use, their acquisition especially for large groups is still costly. Therefore, the development of a GEE prediction equation which does not use the velocity or the HR as independent variables is justified.

Thus, the development of this study is justified with two aims: 1) the development of GEE prediction equations in young individu-

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als and 2) validation of the GEE estimation performed by the Polar M71® heart rate monitor also in young individuals. Three situations have been considered for the first aim: 1) when the velocity is possible to be identified; 2) when the HR monitoring is possible; and 3) when neither the velocity identification nor the Hr monitoring is possible.

MATERIAL AND METHODS

Sample – 30 young Physical Education college students, non-athletes were evaluated (16 males and 14 females). The sample characteristics are on table 1.

Procedures – Initially, after the methodology has been clarified, the subjects signed a free and clarified consent form. Afterwards, a questionnaire was applied in order to have the physical activity level evaluated (PAL) in a 0-7 point scale[26] and the anthropometric measurements were taken as well. In order to have the weight checked a *Filizola* electronic scale was used. The individuals were bare feet and wearing the least garment as possible. Height measurement was performed in stadiometers attached to the wall. The Jackson, Pollock and Ward[27] and Jackson and Pollock[28] equations have been used for body composition estimation from the skinfolds thickness, measured with the *Lange* compass. After anthropometry, while the individuals remained in supine position for 10 minutes, rest heart rate (HRr) was registered by the Polar M71® monitor.

After the initial procedures, each individual was told to walk on the ergometric treadmill with 1% of inclination, at low, moderate and high intensities, at self-selected velocities, during 6 min at each intensity. The GEE, measured by the Teem 100 Metabolic Analyzer by Aerosport, as well as the HR and GEE estimated by the HR monitor, were registered in the two last minutes of each load.

Statistical treatment – Description of the sample as well as the results obtained during the gait was conducted through mean and standard deviation. In order to describe the correlation among the studies' variables, the Pearson correlation coefficient was used. The identification of the GEE prediction equations was performed by multiple regression with progressive inclusion of the independent variables using the Statistica 6.0 program. The t-student test for paired data was used for comparison of the measured GEE values estimated by the HR monitor. The significance level established was $P < 0.05$. In order to obtain the comparison of the regression equations, the correlation and the estimation standard error (ESE) which is the square root of the means of the residue squares (estimated predicted value).

RESULTS

The studied individuals were young (age mean of 22.7 ± 2.6 years for males and 22.1 ± 2.1 for females), with fat percentage within the limits considered normal and physical activity level of 4.0 ± 2.0 for males and 4.8 ± 2.2 for females in a 0-7 points scale, according to what is shown in table 1.

TABLE 1
Characteristics of the studied sample

	Male (N = 16)		Female (N = 14)	
	Mean	Standard deviation	Mean	Standard deviation
Age (years)	22.7	2.6	22.1	2.1
Weight (kg)	69.4	6.5	58.3	7.6
Height (cm)	178.0	7.3	164.8	6.7
PAL (points 0-7)	4.0	2.0	4.8	2.2
Fat (%)	8.1	3.4	21.5	3.8
HRr (bpm)	57.5	7.9	63.8	6.3

The velocities self-selected by the individuals, the HR values reached at each intensity and the GEE, measured and estimated by the monitor, are presented in tables 2 and 3 in figure 1. Since the monitor estimates the energetic expenditure only for HR higher than 100 bpm, the GEE cannot be estimated for all individuals of the sample in all intensities, especially in the lowest ones. The t-Student test showed that there is not significant difference between the measurements taken by the Teem 100 and the Polar M71® in any of the intensities. The comparisons in the low and moderate intensities (especially the low one, in which it was possible to register only 9 individuals – all female) were harmed, since they have been with a lower number of subjects, once in these

TABLE 2
Velocity, heart rate and energetic expenditure by gait intensity of the male group

Intensity	Velocity (km/h)		Heart rate (bpm)		GEE Teem 100 (kcal)		GEE Polar (kcal)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Low	4.3	0.5	87.7	9.4	3.4	0.9	–	– (N = 0)
Moderate	5.7	0.5	100.1	10.2	4.8	1.2	6.5	1.2 (N = 5)
High	7.4	0.5	130.3	14.4	8.4	2.2	9.5	2.2 (N = 14)

TABLE 3
Velocity, heart rate and energetic expenditure per gait intensity of the female group

Intensity	Velocity (km/h)		Heart rate (bpm)		GEE Teem 100 (kcal)		GEE Polar (kcal)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Low	4.0	0.3	101.0	9.3	3.4	0.5	2.9	1.5 (N = 9)
Moderate	5.4	0.5	116.8	8.9	4.2	0.6	3.9	0.5 (N = 14)
High	6.7	0.7	145.6	17.1	6.2	1.4	6.2	1.6 (N = 14)

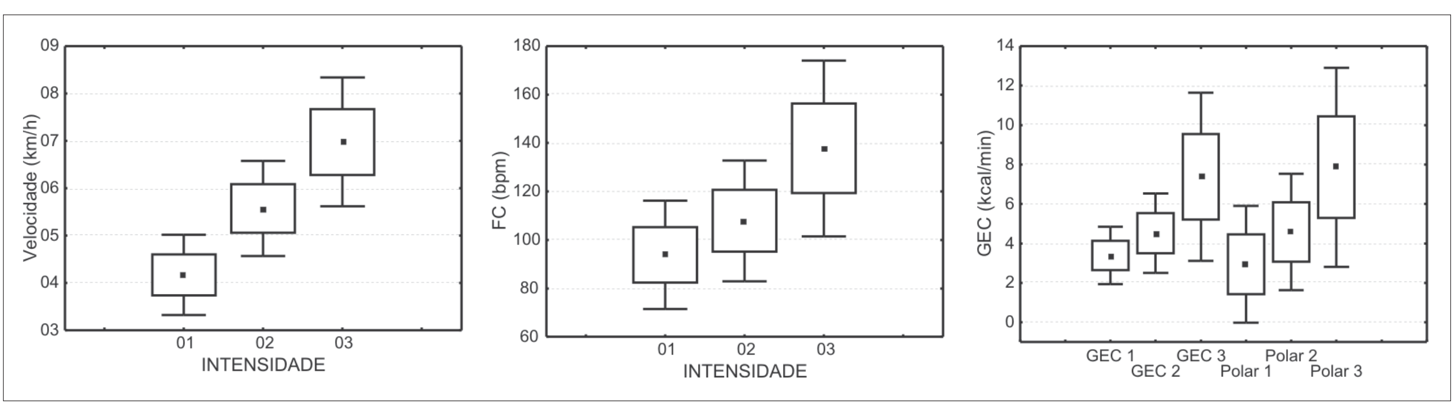

Figure 1 *– Mean, Standard deviation and 1.96* velocity, heart rate and measured (GEE) and estimated by the monitor (Polar) gait energetic expenditure standard deviation, in the low (1), moderate (2) and high intensities (3). Grouped male and female data.*

intensities some subjects did not reach the minimum HR of 100 bpm, needed for the GEE monitor estimation. Figure 3 shows the relationship between GEE measured and estimated, arranging the female and male groups in the three intensities. It is observed that the regression line is closer to the identity line as the gait intensity increases. Concerning the ESE values, in percentage terms, they were at the order of 10. 23 and 21% of the GEE mean in the intensity.

Table 4 shows the correlations among the studies variables. Only the velocity and the HR have significant correlation with the GEE. In figure 2, the following ratios are represented: A) HR x velocity, B) GEE X velocity C) GEE x Velocity. It is observed that, concerning the HR, the square adjustment (R^2 = 0.58; ESE = 14.8 bpm) was slightly better than the linear one (R^2 = 0.54; ESE = 15.6). The same fact has occurred concerning the GEE, whose square adjustment (R^2 = 0.75; ESE = 0.87 kcal/min) was slightly higher to the linear one (R^2 = 0.72; ESE = 0.91 kcal/min). However, since the differences between adjustments quality are relatively low, it is possible to estimate the GEE through linear equations, with no important estimation errors. Since the HR and GEE have the same behavior concerning velocity, they keep a linear ratio between each other.

The prediction equations of the gait energetic expenditure (table 5) were divided in four groups: 1) equations in which the gait velocity is used; 2) equation in which the HR is used; 3) equations in which the perceived effort exertion is used; and 4) with use of all variables from the study. In the four groups, the equations have been arranged from the simplest (lowest number of variables) to the most complex (highest number of variables), according to re-

TABLE 4
Correlation matrix among the study's variables

	1	2	3	4	5	6	7	8	9
1 – Age	1.00								
2 – Weight	**–0.25**	1.00							
3 – Height	**–0.29**	**0.83**	1.00						
4 – PAL	**–0.30**	0.05	–0.08	1.00					
5 – F%	–0.14	**–0.50**	**–0.72**	**0.29**	1.00				
6 – HRr	–0.16	–0.18	**–0.31**	0.04	**0.42**	1.00			
7 – Velocity	0.08	–0.01	0.04	0.08	–0.10	–0.07	1.00		
8 – HR	–0.16	–0.20	**–0.28**	0.16	**0.40**	**0.41**	**0.74**	1.00	
9 – GEE	–0.06	0.20	0.16	0.14	–0.10	–0.08	**0.85**	**0.69**	1.00

Significant correlations (P < 0.5) in bold.

TABLE 5
Prediction equations of the gait energetic expenditure

Num	Equation	R^2	ESE
	Using gait velocity		
A1	Kcal/min = 1.22V – 1.98	0.74	0.91
A2	Kcal/min = 1.22V + 0.04P – 4.74	0.78	0.84
A3	Kcal/min = 1.24V + 0.06P + 0.03F% – 6.09	0.79	0.82
	Using heart rate		
B1	Kcal/min = 0.05HR – 1.08	0.48	1.30
B2	Kcal/min = 0.07HR – 1.64 (M/F) + 162.57	0.65	1.07
B3	Kcal/min = 0.07HR – 1.27 (M/F) – 0.08HRr + 129.36	0.73	0.94
	Using effort intensity exertion		
C1	Kcal/min = –1.06 (LMH) + 113.46	0.23	1.56
C2	Kcal/min = –1.11 (LMH) + 0.05P – 115.27	0.30	1.50
C3	Kcal/min = –1.12 (LMH) + 0.05P + 0.12PAL – 115.26	0.32	1.49
	Using all independent variables		
D1	Kcal/min = 1.22V – 1.98	0.74	0.91
D2	Kcal/min = 1.22V + 0.04P – 4.74	0.78	0.84
D3	Kcal/min = 1.07V + 0.05P – 0.40 (LMH) + 36.67	0.79	0.82

V = Gait velocity (km/h); W = Body Weight (kg); HRr = Rest heart rate (bpm); M/F = Male (100) and female genders (101); LMH = Low (101), Moderate (102) and High (103) perceived intensity exertion; HR = Gait heart rate (bpm); PAL = Physical activity level (0 – 7); F% = Body fat percentage.

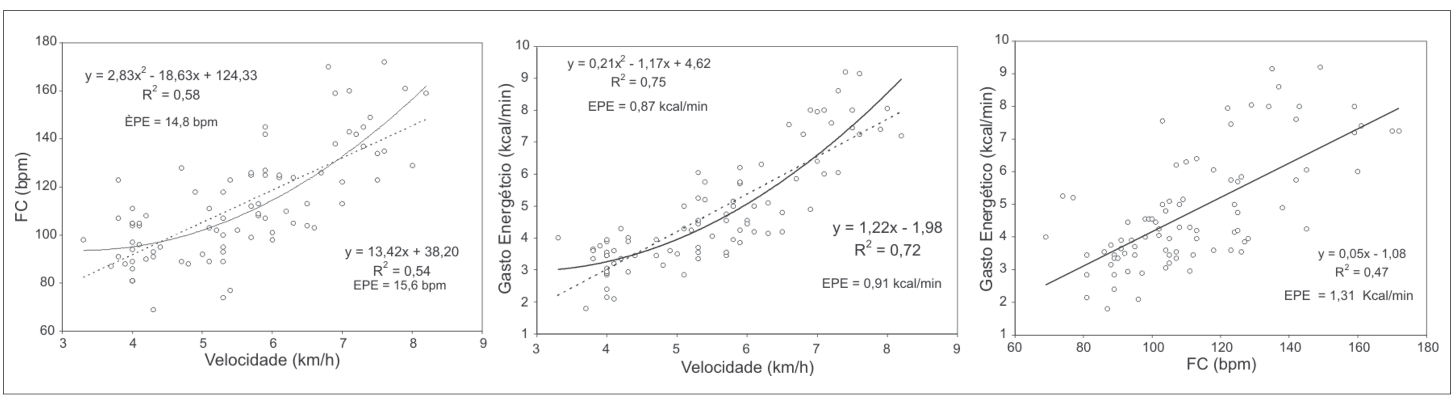

Figure 2 *– Ratios: heart rate x velocity (left); energetic expenditure x velocity (center); and energetic expenditure x heart rate (right)*

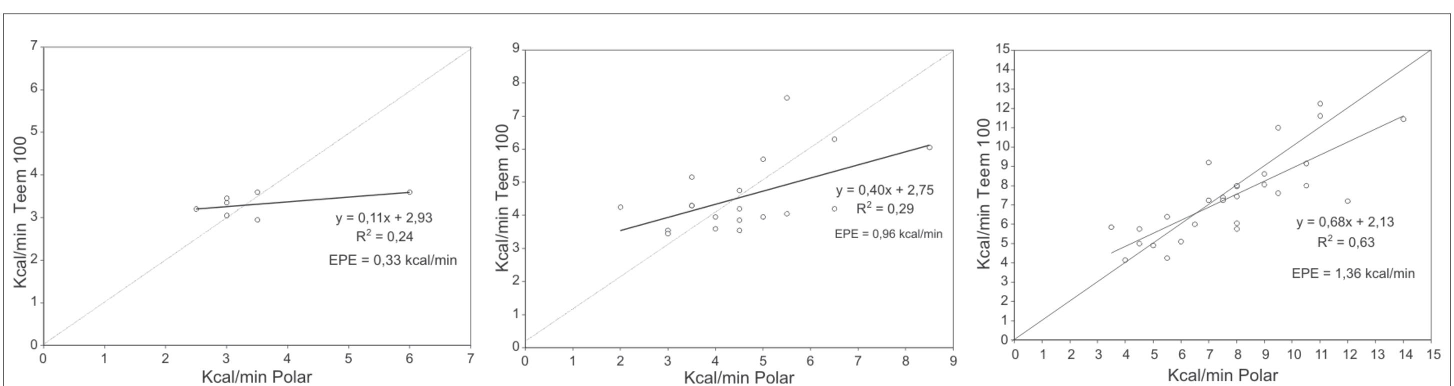

Figure 3 *– Ratio measured energetic expenditure and estimated by the monitor (Polar), in the Low (left), Moderate (center) and High Intensities (right)*

sults derived from the multiple regression process with progressive inclusion (forward stepwise). It is observed in group D, in which all variables are inserted as independent variables in the multiple regression, that the A1 and A2 equations are repeated, showing that, even in a wide number of variables, velocity and body weight are the best GEE predictors.

DISCUSSION

According to Di Prampero[17], from the middle of the XIX century the GEE has been studied and its best predictor is the gait velocity, followed by the individual's weight. In mechanical matters, this ratio would be predictable, once velocity and weight determine the generated mechanical power, which in return, determines the metabolic power needed to perform the task. Currently, strategies relatively accurate for GEE estimation which use as independent variables the gait velocity and the individual's weight are available[1,18]. Even considering the convincing knowledge on this field, studies for GEE estimation are still justified.

The determination of the gait velocity is actually a simple calculation which involves the space derivative (completed distance) in relation to time. Nevertheless, in situations in which the gait is usually performed, the itinerary distance measurement is not viable. People walk in streets of the neighborhood where they live, in parks, irregular distances and other places with no completed distance marks. For these cases, when the GEE estimation is intended, it is necessary to have the estimation performed from other independent variables. Due to its strong correlation with the oxygen uptake, the HR is most chosen variable in most cases. The popularization of the Hr monitors occurred over the last years has made these devices more accessible and their use during the gait has been spread. The technological development has loaded the HR monitors with functions which allow many calculations, among them the energetic expenditure.

Despite the relative popularization of the HR monitors, their use is restricted to few subjects who practice physical activity. Further studies on other ways of estimating the GEE which are not costly such as accelerometers, GPS equipment and so on are needed. The use of variables of easy measurement would be recommended. The perceived exertion effort is one interesting variable for the GEE estimation due to the easiness to obtain it – there is no need of any equipment – besides its proved correlation with the HR[29].

This study was conducted in order to test the GEE estimation validity performed by the Polar M71 HR monitor as well as to study other possibilities of estimation with the use of variables of easy measurement. Physically active young adults, from both genders participated in the study. The sample choice for the current stage of the proposal is suitable. The inclusion of other variables such as age, body weight and physical conditioning level should be included in future studies in which wider breadth of results' generalization is intended.

The results obtained in the study have evidenced its importance and validity of the prediction functions. The GEE values found are according to classic studies of the field[25]. The ratio between energetic expenditure and gait velocity was not linear, as has been reported in the literature[30]. Moreover, the mean values found for the GEE are close to the ones predicted by the ACSM equation[18]. The studied subjects were able to easily select gait velocities according to the proposed intensity (low, moderate and high). The capacity of discrimination of the gait intensity was evidenced due to the finding of significant difference ($P < 0.05$) between the mean velocities grouped by intensity and also due to the velocities dispersion of the same intensity was small, suggesting hence that there is a certain similarity in the velocity in which people walk. The fact that people select similar velocities when asked to walk in a given intensity causes a correlation between perceived effort intensity and GEE.

As expected, the proposed equations (organized in groups) have shown that the best GEE predictor is the gait velocity. In the group A equations small reductions of the ESE were obtained as anthropometric variables concerned with the individuals body mass, such as weight and fat percentage, have been added. In this group, a lower ESE than 1.0 Kcal/min is obtained. Concerning the predicting capacity of the equations, it is suggested that whenever possible, the completed distance and the time spent in the gait should be measured in order to obtain the best GEE estimation. The estimation can be slightly improved as the individual's weight is known.

The ESE of the group B equations which use the HR, can be expressively reduced with the addition of gender and HRr of the individual. A prediction with ESE lower than 1 kcal/min is obtained with these three variables, which is close to the results obtained in group A. It is suggested that the HR can be used as GEE predictor, as long as it is concerned with gender and HRr.

Groups C of equations, in which the perceived effort exertion is used as GEE predictor, presented the highest ESE, which slightly decrease with the addition of the body weight and PAL of the individual. It is suggested that the perceived effort exertion should be only used in situations in which it is not possible to identify the gait velocity and the HR. The ESE of this group is of approximately 1.5 kcal/min, which can represent an error of 30% in the GEE estimation for a gait of moderate intensity. An explanation for the low prediction capacity of the perceived effort intensity may be the existence of only three levels in the scale (L, M and H). Perhaps the use of a scale with more levels, such as the Borg scale, could have increased the discrimination degree and consequently the GEE prediction capacity.

Group D represents the regression with all the variables of the study. The inclusion of the perceived effort exertion does not add expressive improvement in the GEE prediction. It suggests that even if a wide range of independent variables is available, the best prediction is performed with the use of the gait velocity as well as the weight of the individual.

Concerning the measurement of the Polar energetic expenditure, despite its validity, the Polar M71® monitor is limited to the estimation of energetic expenditure only above 100 bpm. This value is not reached by some individuals in gaits of low and moderate intensities. On the other hand, the validity of the estimation done by the M71® Polar increases as the gait velocity increases. The best prediction is performed in the high intensity, in which the HR of 130 bpm for males and 146 bpm for females are registered. This fact can be explained by the sigmoid behavior of the HR curve concerning the effort intensity[31]. The HR curve presents flattening in its inferior and superior portions. Its central portion – between 130 and 170 bpm – is the one that best adjusts to a line, and therefore, the one that best associates with the effort intensity.

CONCLUSION

Even if a wide group of independent variables is available, the best prediction performed is through the use of the gait velocity and the individual's weight. The HR for GEE prediction should be followed by the individual's gender as well as HRr. Making use of the three-leveled scale, the perceived effort exertion should be used only when neither the gait velocity nor the HR is possible to be registered. We suggest that other studies with other scales should be tried. The Polar M71 HR monitor is valid for the GEE estimation as long as the HR overpasses 100 bpm – which does not occur for some young individuals in low and moderate intensity gaits, and its accuracy is better in high intensity gaits, with HR between 130 and 150 bpm.

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