Development of a Protocol for Determining and Classifying of the Physical Workload in Forestry Activities

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***Abstract*—**In field conditions, forest work can be extremely heavy under the view point of physical effort. In order to classify the physical workload, the aerobic capacity, expressed in maximum oxygen consumption (VO_{2max}), when associated with other factors such as age, gender and body mass of workers during the performance of their activities, can provide accurate answers about the physical workload of these workers. Thus, this study aimed at the development of equations for VO_{2max} determination from maximum heart rates of work, body mass and gender of the workers, besides the proposition of a protocol to classify the physical workload for different forestry activities from VO_{2max}. Based on the nomogram proposed by Per-Olof Astrand, taking as a basis the body mass and heart rate variables, all the combinatory possibilities for the determination of VO_{2max} were explored, generating 319 and 383 combinations for the female and male genders, respectively. Nonlinear regression models were adjusted by adopting the values found for VO_{2max} as dependent variable and body mass and heart rate as independent variables. The model chosen for VO_{2max} estimation was adjusted to the data with great precision, considering the results of the regression statistical analysis, demonstrating that the adjusted equations present a high predictive power to estimate the VO_{2max} in forest workers, being applicable for the physical workload determination. Moreover, the protocol proposed for classification of physical workload has practicality and efficiency, and its use is viable in field conditions, showing consistent results, which improves working conditions in situations where workers are confronted with realities that disrupt and surpass their capacities.

***Keywords*—**Ergonomics, forestry, heart rate, worker's health.

I. Introduction

THE Brazilian forestry sector occupies a prominent position in the country's economy and has been growing at positive rates in the last decades. In face of a scenario of labor scarcity in rural areas, the mechanization of forestry activities is a reality when seeking to increase productivity and reduce costs in forestry companies. However, there are still several situations on which human force is essential, especially in terrains with rugged topography and for small-scale forest producers, for which mechanization is not technically and economically accessible. In these cases, the activities are carried out by forestry workers, men and women, with high energy expenditure; a process that can lead to the development of musculoskeletal disorders, and they are repetitive and require constant lifting and manual transportation of loads and also subject workers to physical workloads in questionable quantities under the optics of the limits recommended by different national and international standards.

The appearance of fatigue symptoms due to physical overload depends on the effort developed, the duration of work and the individual conditions, such as health, nutrition and conditioning conditions resulting from the practice of the activity. As fatigue increases, the pace of work, attention and speed of reasoning are reduced, making the worker less productive and more subject to errors and accidents [1].

In order to determine the physical workload in forestry workers, the most commonly used method takes into consideration only the heart rate of the workers which considers that the cardiovascular load at work corresponds to the percentage of the heart rate during work in relation to the maximal heart rate usable [2], allowing to classify work (or activity) as very light, light, moderately heavy, heavy and extremely heavy [3]. However, there are factors that influence the heart rate response to work such as ambient temperature, emotional state, weight (mass), previous food intake, body position, muscle groups exercised, continuous or discontinuous nature of the activity, and if muscles act statically or in a more dynamic way [4]. The authors suggest that heart rate and oxygen uptake tend to be linearly related over a wide range of intensities of aerobic work. From the knowledge of this relation, the heart rate of the work provides an estimation of the oxygen uptake (and, subsequently, of the energy expenditure) during the work execution and, therefore, it is possible to classify the activities considering the energy necessary for their accomplishment according to the physical workload.

For humans, oxygen (O_2) is essential for the development of their vital functions, including physical performance. However, to perform physical work there is a need to increase the air supply to the lungs, increasing blood circulation and activating specific metabolic pathways in skeletal muscle resulting in increased uptake and utilization of O_2. Integrated responses of the respiratory, cardiovascular and muscular systems in exercises involving large muscle groups increase up to a limit that defines VO_{2max} or maximal aerobic condition

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of the individual. Thus, the maximum capacity of an individual to perform aerobic work (aerobic capacity) can be defined by VO_{2max}, which is the transformation of chemical energy into mechanical work, corresponding to a physical effort resulting from labor activity [5]. Cardiorespiratory capacity is defined as the ability to perform dynamic physical activities which involve large muscle mass with moderate to high intensity for prolonged periods [6]. The VO_{2max} or oxygen consumption rate during work execution reflects the capacity of the heart, lungs and blood to carry oxygen to the muscles during the execution of tasks; and the use of oxygen by muscles during the exercise [7]. On the other hand, the individual capacity for heavy muscle work for extended periods of time will depend primarily on the oxygen supply available for the muscles [8]. The common tests to predict VO_{2max} using the heart rate are based on the essentially linear relation between heart rate and oxygen uptake for various intensities of a physical work [4], because if a large amount of blood is pumped at each heartbeat, only a small increase in heart rate becomes necessary to release an adequate volume of oxygenated blood for the muscles to work [9]. On the other hand, there are direct and indirect ways to predict VO_{2max}, the direct way being through the analysis of expired gases during a Cardiopulmonary Exercise Testing [10]. The indirect tests, based on the linear relationship between heart rate and oxygen consumption [11], can be performed on treadmills, cycle ergometers (ergometric bicycles) and bench test [12], using nomograms, formulas and regression equations developed from direct measurements. However, the application of these tests involves a series of sophisticated and high cost equipment, which for the correct use of a complex structure, usually available in clinics or laboratories, is necessary, which makes it impossible to apply it in tests of large populations and in field conditions, as in the case of forestry works.

Diverse studies have proposed equations and models for the prediction of maximal oxygen consumption (e.g. [8], [13]-[16]), however all of these studies have as basic premise the performance of some test for the determination of the independent variables. On the other hand, the application of field tests that provide the prediction of VO_{2max} through mathematical models is a very attractive alternative, since it allows the reduction of the operational costs and favors the application in large scale in diverse environments [17], as in the case of the forestry work. In this way, this study had as objectives to adjust equations to determine VO_{2max} from the maximal work heart rates, mass and gender of the workers, based on Astrand's nomogram [8]; and to develop a protocol to classify the physical workload for different forestry activities from the maximal oxygen consumption (VO_{2max}).

II. Materials and Methods

From the nomogram proposed by Per-Olf Astrand [8], [12], based on the variables mass (in kg) and heart rate (in beats per minute, bpm), all combinatory possibilities for VO_{2max} determination were explored, being generated 319 and 383 combinations (VO_{2max} x kg x bpm) for the female and male genders, respectively. Thereafter, the data were typed on a basis for further analysis. Data assessment was carried out using the statistical SAS Software version 9.1 [18]. Nonlinear regression analyzes were used to adopt the values found for VO_{2max} as a dependent variable and the values of mass and heart rate as independent variables.

With the data combinations of the variables, applying nonlinear regression techniques, the model (1) was adjusted for each gender.

$$Y = \exp\left(\beta_0 + X_1^{\beta_1} + X_2^{\beta_2} + \varepsilon\right) \quad (1)$$

on which Y = dependent variable; X_1 and X_2 = independent variables; β_0, β_1 and β_2 = parameters of the models; and ε = random error.

The accuracy of the adjusted equations was evaluated through the coefficient of determination (R^2), the squared correlation coefficient between the observed values and predicted values ($R_{y\hat{y}}^2$), the standard error of estimate in percentage ($S_{y\hat{y}}\%$) and the mean residue in percentage (MRE%), according to the methodology established in [19].

The values of VO_{2max} estimated by the adjusted equations were compared to those obtained from the Per-Olof Astrand nomogram [8], and the "t" test was applied to the means of two independent populations, at the 99% confidence level, with the main hypothesis being that the means of the observed and estimated values are statistically equal (H_o: $\mu_1 = \mu_2$).

The estimates of (VO_{2max} were obtained for each forestry worker and using the adjusted equations from the observed data of maximal heart rate (bpm) and mass (kg). This value should be corrected according to the age range of the sampled worker (Table I), since a reduction in heart rate according to age is a natural process [12]. After this correction, it is still necessary to express the maximal oxygen consumption relative to the body weight, i.e., transforming the value obtained (in l/min) to ml/kg/min, thus making it possible to compare individuals that differ in body weight. Finally, the value found can be used to determine the physical workload imposed by the activity performed.

TABLE I
Age Correction Factor for Maximal Oxygen Consumption [12]

Age (years)	Correction factor
15	1.10
25	1.00
35	0.87
40	0.83
45	0.78
50	0.75
55	0.71
60	0.68
65	0.65

Finally, for the classification of physical workload levels, a five-level model was developed from the models proposed in [4] and in [20], based on VO_{2max} estimated by the equations developed in this study, for the male and female genders.

For the validation of the results found after the application of the proposed methodology, data were collected from forestry workers in different activities and the methodology proposed by this study was applied, and the results were compared with the classification in [3], obtained from the methodology proposed in [2], which considers only the heart frequencies.

III. Results and Discussion

A. Statistical Analyzes

The model chosen for the estimation of maximal oxygen consumption based on the heart rate and the mass of the individuals, for both sexes, was adjusted to the data with great accuracy, given the values of the coefficients of determination, correlation coefficients, standard errors of estimates and the mean residuals in percentage (Table II). The adjustments with coefficients of correlation and determination equal to or greater than 90% and mean percentage error of less than 10% are considered appropriate [21]. In addition, all coefficients were significant at the 99% probability level by Student's t-test.

TABLE II

EQUATIONS ADJUSTED FOR THE ESTIMATION OF MAXIMAL OXYGEN CONSUMPTION (VO_{2MAX}, IN L/MIN) OF THE INDIVIDUALS DURING WORK, CONSIDERING BODY MASS (M, IN KG) AND MAXIMAL HEART RATE (BPM, IN BEATS PER MINUTE)

Gender	Equations	R^2	$R_{y\hat{y}}^2$	$S_{y\hat{y}}\%$	MRE%
Male	$VO_{2MAX} = \exp(-7.543 + BPM^{0,339} + M^{0,249})$	0.98	99.4%	3.30	-0.01
Female	$VO_{2MAX} = \exp(-8.548 + BPM^{0,342} + M^{0,304})$	0.99	99.6%	3.05	0.14

R^2 – coefficient of determination; $R_{y\hat{y}}2$ = squared correlation coefficient between the observed values and predicted values; $S_{y\hat{y}}\%$ = standard error of estimate in percentage; MRE% = mean residue in percentage.

In the comparison between the values observed and estimated by the adjusted model, after the application of the t-test for the means of two independent populations, at the 99% confidence level, it was observed that the means of the observed and estimated values are statistically equal (Table III), allowing a safe use of the equations adjusted for both genders.

TABLE III

RESULT OF THE "T" TEST FOR THE OBSERVED (OBS) AND ESTIMATED (EST) VO_{2MAX} VALUES, CONSIDERING TWO SAMPLES IN PAIR FOR MEANS (A = 99%)

Parameters	Male		Female	
	Obs	Est	Obs	Est
Mean	3.620	3.621	2.899	2.896
Variance	1.253	1.221	0.976	0.951
Observations	383	383	319	319
Pearson Correlation	0.994		0.996	
Hypothesis of the mean difference	0		0	
g.l.	382		318	
$t_{calculated}$	0.069		0.795	
Descriptive level	0.945		0.427	
$t_{critical}$	2.589		2.591	

Obs.: as, for both cases, $t_{calculated} < t_{critical}$, H_0 is accepted, i.e., $\mu_1 = \mu_2$.

B. Determination of the Maximum Oxygen Consumption (VO_{2max})

Although VO_{2max} is an important variable for the determination of the physical workload, its direct measurement is restricted due to the high costs involved. Similarly, the indirect tests also have restrictions of applicability to big sample groups or in field conditions, reality observed in the forestry sector. The survey through estimating equations becomes a practical and efficient form.

The estimation equation is defined as that on which VO_{2max} is dependent on variables, as the heart rate, among others, obtained after the performance of a physical activity [16]. Several authors have been searching for the development of models of equations for the estimation of VO_{2max} (e.g., [8], [13]-[16]). However, the two most frequently used equations in protocols in Brazil are the algorithm proposed in [22] and the cited in [23], even though [16] affirms that none of them was previously validated in Brazil and that they induce to an overestimation of the predicted values.

Besides the maximal heart rate, when considering the weight of the workers, the adjusted equations demonstrated to absorb the influence of other variables during the determination of the VO_{2max} (Fig. 1). In this case, individuals with the same heart rate but different body mass showed differences in oxygen uptake, as people with greater body mass spend more energy to perform the same activity than those who had lower mass. This occurs because the energy spent during the performance of the activity with the support (leaning) of the body weight increases directly with the transported body mass [4].

Thus, the regression equations adjusted in this study allow the estimation of VO_{2max} from the variables maximal heart rate and mass of forestry workers using low cost equipment as for example portable heart rate collectors (or monitors) and portable scales, providing great accuracy in the evaluation of the cardiorespiratory aptitude in the absence of gas analyzers or other equipment, and allowing the individualization of the test protocol in function of the characteristics of the evaluated worker.

Monitoring the heart rate in forestry workers is a methodology widely diffused and used in several studies [24], [25]. Among the several variables which compose the general physical aptitude, the aerobic capacity is one of the most important, since from its evaluation it is possible to obtain data on the cardiorespiratory system of an individual and of which form various physiological functions are adapted to metabolic needs when performing a physical activity. Thus, the aerobic capacity is an essential variable for physical aptitude. The maximal capacity of transport and use oxygen during work (VO_{2max}) is considered by many exercise scientists as the most valid measure of cardiovascular conditioning, thus being an excellent indicative of the answer of the individual to physical workload imposed by the activity performed [26].

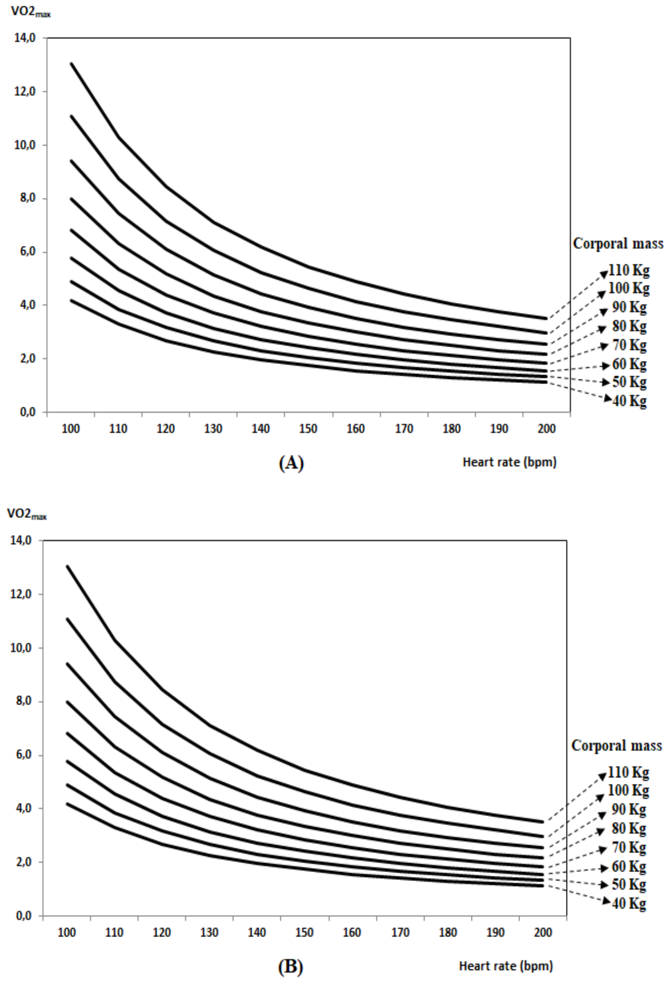

Fig. 1 Relationship between the maximal oxygen consumption (VO_{2max}), maximal heart rate (bpm) and body mass (kg) for workers of the male (A) and female (B) genders, of different rates of body mass

C. Classification of the Physical Workload

Reference [3] states that the physical workload of the human being can be determined through the evaluation of the energy expenditure of the activity or through physiological indexes such as heart rate. The heart rate is an indirect indicator of the workload, being obtained by arterial palpation or with the use of electronic measurers.

For the classification of the physical workload, the most widely used methodology in the forestry sector is that proposed in [2]. However, when considering only the heart rates, this methodology does not consider some of the factors that influence the answer of the heart rate to work, such as ambient temperature and mass of the worker, among others, and if muscles act statically or in a more dynamic way [4].

For this reason, the classification of the physical workload from the maximum oxygen consumption (VO_{2max}), as presented in Table 4, considering the energy that men and women need to perform physical activities, including a wide range of occupational tasks, can be used for the determination of the physical capacity of the worker, the duration of the working and break hours, also as their frequency, in order to promote improved health, comfort, safety and welfare of the forestry workers.

TABLE IV
CLASSIFICATION OF THE PHYSICAL WORKLOAD BASED ON THE ENERGY EXPENDITURE (kcal/min), CALCULATED FROM THE MAXIMAL OXYGEN CONSUMPTION (VO_{2MAX})

Workload Level	Energy Expenditure		
	VO_{2max} (ml/kg/min)	kcal/min	METs
	Men		
Light	< 15.2	< 3.0	< 4.0
Moderate	15.2 – 22.9	3.0 – 4.6	4.0 – 6.0
Heavy	23.0 – 31.6	4.7 – 6.3	6.1 – 8.3
Very Heavy	31.7 – 40.5	6.4 – 8.1	8.4 – 10.6
Excessively Heavy	> 40.5	> 8.1	> 10.6
	Women		
Light	< 12.5	< 2.5	< 2.7
Moderate	12.5 – 19.8	2.5 – 4.0	2.7 – 4.3
Heavy	19.9 – 27.1	4.1 – 5.4	4.4 – 5.8
Very Heavy	27.2 – 34.4	5.5 – 6.9	5.9 – 7.4
Excessively Heavy	> 34.4	> 6.9	> 7.4

Obs.: MET = metabolic equivalent, defined as the quotient between the metabolic rate associated with activity and resting metabolic rate.

The classification presented in Table IV can also be determined from the energy expenditure of the activity performed (kcal/min), considering that 1 liter of consumed oxygen is equal to approximately 5 kcal [12]. This classification can be very useful when aiming to determine the metabolic rate in the performance of a certain activity (expressed in kcal/hour) used for example to determine the limits of occupational exposition to heat according to the current Brazilian legislation (Regulatory Norm Nº 15, from Brazilian Ministry of Labour and Employment). Still, another possibility is the classification of the physical workload using the metabolic equivalent (MET).

As 1 MET is equal to an oxygen uptake in rest of approximately 250 ml per minute for a mean weight man and 200 ml per minute for a mean weight woman, the work performed with 2 METs requires twice the rest metabolism, or approximately 500 ml of oxygen per minute for a man, 3 METs equal three times the energy expenditure in rest, and so on [4].

Comparing the results after the application of the methodology proposed in this study with the classification proposed in [27], it was verified that there are no tendencies of over or underestimation of the physical workload (Table 5).

Thus, it becomes possible its application in larger populations and populations in field conditions without prejudice to the results of the evaluations, reminding that by considering the mass of the workers the results become more individualized.

TABLE V
RESULTS OF THE EVALUATION OF THE PHYSICAL WORKLOAD FOR FORESTRY WORKERS OBTAINED FROM THE CLASSIFICATION IN [27] AND FROM THE METHODOLOGY PROPOSED IN THIS STUDY

Activity	Gender	Mass (kg)	Age (years)	MHR (bpm)	VO_{2max} (ml/kg/min)	Physical Workload	
						Protocol 1	Protocol 2
Manual hole-digging	Male	80	38	176	34.33	H[a/]	VH
Cut with chainsaw	Male	76	48	164	27.44	MH[a/]	H
Mechanic Auxiliary	Male	83	28	110	15.28	L[a/]	M
Operation of track tractor	Male	78	47	114	14.78	L[a/]	L
Semi-mechanized mowing	Male	72	35	161	29.75	M[b/]	H
Semi-mechanized hole-digging	Male	65	29	179	39.38	H[b/]	VH
Semi-mechanized hole-digging	Male	78	32	177	36.62	H[c/]	VH
Seed harvesting	Male	81	43	160	28.50	H[d/]	H
Manual mowing	Male	73	32	162	31.44	H[d/]	H

On which: MHR = maximal heart rate during the working hours; VO_{2max} = maximal oxygen consumption estimated by the equations proposed in this study, corrected by age; M = Moderate; L = Light; MH = Moderately Heavy; H = Heavy; VH = Very Heavy; Protocol 1 = classification proposed in [27]; Protocol 2 = classification proposed in this study.
[a/] Field measurements performed by the authors.
[b/] [28].
[c/] [24].
[d/] [29].

D. Conclusions

The equations adjusted have elevated prediction power to estimate the maximal oxygen consumption (VO_{2max}) in forestry workers, from the maximal work heart rate and their body mass.

The estimated values of VO_{2max} by the adjusted equations, after the correction by the age of the worker and the energy expenditure determined, showed to be applicable for the determination of the physical workload.

The protocol proposed for the classification of the physical workload presents practicality and efficiency, and its use is viable in larger populations and in field conditions, showing consistent results.

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Como citar esse artigo:

SCHETTINO, S.; MINETTE, L.J.; SCHETTINO, C.F.; PAULA JUNIOR, J.D. Development of a protocol for determining and classifying of the physical workload in forestry activities. In: ICFNRE 2019 - International Conference on Forests and Natural Resources Engineering, 2019, Kuala Lumpur - Malasia. ICFNRE 2019 - Conference **Proceedings**. Kuala Lumpur: International Research Conference, 2019. v. 1. p. 434-438.