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%VdotO_2max as Physical Load Indicator Unit in Forest Work Operation

%VdotO_2max sebagai Unit Beban Kerja pada Operasi Pekerjaan Hutan

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Abstract

Most of forestry work has burdened forest workers with heavy workload, which is often exceeding their allowable workload. This workload has been widely measured through energy expenditure-based workload assessment (expressed in kcal/kg/min). However, this calculation method excluded physical characteristic of individual into its calculation, meanwhile it may greatly influenced metabolism system of an individual. Thus, there is a big possibility that the use of kcal/kg/min workload unit in comparing workload among different individuals conducting the same physical work had ended in an erroneous reading. Therefore, a study on alternative workload measurement that provides a fair assessment when the assessment is conducted among different individuals performing same physical activity is significantly important. This study proposed an alternative workload calculation approach, in which the workload unit was expressed in %VdotO_2max. The results showed that alternative workload measurement provided excellent accurateness similar to that provided by conventional workload assessment method. Further analysis showed that the proposed unit showed a fair reading when the analysis was carried out to more than one individual. This was because the proposed unit considered maximum physical work capacity (short term) of each individual in its calculation.

Keywords: forestry worker, workload, energy expenditure, kcal/kg/min, %VdotO_2max

Introduction

Forestry work is dangerous business. The work is facing various constraints, such as difficult working environment, heavy physical effort (which often exceeds limit of working capacity of the forest worker), and high risk of work accident. The situation could be worse in developing countries, including Indonesia, as consideration on occupational safety and health of forestry worker still remains low. Therefore, most of the worker is characterized with low work productivity (Yovi *et al*., 2005, 2006a) and high work-accident rate.

Contribution of forestry-ergonomics research in these countries has been insignificant due to lack of public support and ignorance of the benefit such industries could be benefited, if recommendations be implemented. Therefore, even though Indonesia Government has already issued several policies and laws to assure safety and health of forestry worker, problems on the two aspects still occurred in almost all workplaces.

To this, appropriate protection on safety and health of the forestry worker through ergonomics-based research is significantly important. In order to provide the appropriate safety and health protection, evaluation on physical load (workload) is very important. The evaluation could be used to harmonize the task of the worker with his or her allowable range of working capacity. Workload evaluation has become a very important aspect because as a human being worker has both capacity and limitation, both in physiological and psychological aspects. The capacity then should be used for their benefit, while the limitation should get an adequate compensation.

Expressing physical load, energy expenditure (stated in the magnitude of kcal/min or kcal/kg/min) has been widely used as indicator unit in estimating workload (Wickens *et al.*, 1997; Watanabe, 1980). However, it should be taken into consideration that human body is built from several complex systems that coordinates through great mechanisms to perform the myriad operation needed. Therefore, responds to such the input action on each human body would be different, depend on several factors: physical fitness, genetic, gender, age and physical

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condition that may vary among different individuals (Wickens *et al.* 1997). It can be concluded therefore, that different individual may experience and might be imposed with different level of actual workload, eventhough the rate of workload expressed in the unit of kcal/min is equal. On the other hand, this unit excludes the influence possibility of the mentioned factors into its calculation. As a result, there might be a severe error in interpreting workload burdened to different individuals performing same physical activity.

This erroneous can be avoided if a workload indicator unit derived from a comparative measurement system, in which the differences on physical characteristics of each individual are accommodated (Yovi, 2006b) is employed. This alternative unit expressed workload in a scale developed particularly for each individual, based on his or her maximum physical work capacity. By considering his or her maximum physical work capacity as 100% of workload, the workload during physical activity performed by different individuals can be fairly compared. Theoretically, this is because workload in its percentage is derived from a comparative measurement system in which the differences on physical characteristics of each individual are accommodated (Yovi, 2006b).

Energy required by human muscle for physical movement normally is originated through aerobic metabolism. Therefore, workload could be measured through calculation of $VdotO_2$ (oxygen uptake per unit of a known time; l/min). To assure a fair measurement when comparing workload burdened to different individuals, the unit is expressed in the magnitude of its percentage, as $\%VdotO_2max$ (percent oxygen uptake maximum). In this unit, physical load during actual work is expressed in a scale developed particularly for each individual, based on his or her maximum physical work capacity.

However, workload in forestry work could only be measured during actual physical activity conducted in actual work site (forest site). To this, simplicity and easiness on measurement procedure is a critical point. Thus, instead of calculating $\%VdotO_2max$ during actual work through indirect calorimetric that requires a circuit of respiratory gas analyzer (conventional method) that can be performed in laboratory only, a measurement method of workload estimation by the use of HR (heart rate) as primary data is proposed.

The idea is based on the fact that measurement of HR is widely applied to estimate $VdotO_2$ (Åstrand and Rhyming, 1954), as in body system O_2 (oxygen) is absorbed by blood through respiratory system (aerobic metabolism mechanism), besides the fact that it would be very difficult to measure physical load during actual work carried out in actual worksite by the use of respiratory gas analyzer. Even though the use of portable gas analyzer is possible, this equipment is very expensive and it may cause awkward and discomfort feeling to the worker, which may influence the physical load measurement it self. In contrary, HR can be recorded by a simple procedure by the use of portable HR memory.

The aim of this study was to analyze degree of agreement of workload calculated through HR-based method and indirect calorimetric method. Application of this alternative method is then expected to support development on workload measurement research, especially in Indonesian forestry.

Methodology

This study consisted of three works: (1) recalculation of workload ($\%VdotO_2max$) measured through indirect calorimetric method, (2) calculation of the same data through HR-based calculation method, and (3) degree of agreement analysis between the two calculation results. Primary data of this study was taken from a series of experiment conducted by Matsubara (Kyoto Prefecture University) carried out during 1988−1994. Number of respondents was 32, while physical activity performed was Step Test. Step Test was applied because the test is performed following a permanent protocol in order to avoiding every single difference on the physical activity measured. The test, is originated from Harvard Step Test, and was modified for a trouble-free procedure avoiding awkwardness may occur during the test (Takimoto *et al*., 1994).

Even though the Step Test was performed as a sub-maximal test, linear relation between HR and VO_2 and between HR and EE obtained from the test can be used to predict value of short-term maximum physical capacity expressed both in VO_2max and kcal/min (also called as energy expenditure maximum; EEmax) by extrapolating the age-predicted HRmax (maximum heart rate) into the particular linear equation (Noonan and Dean, 2000). The age-predicted HRmax was calculated by the use of equation: HRmax = 220–age (Åstrand and Rodahl, 1986; Farazdaghi and Wohlfart, 2001), regardless to the opinion that the age-predicted HR equation underestimates actual HRmax in older-adults.

Predicted $VdotO_2max$ was calculated by dividing predicted EEmax (cal/min) by energy yielded from the metabolism reaction (cal/l of O_2) that was calculated through Equation [3]. Due to difficulty in measuring RQ (respiratory quotient) value of an individual without respiratory gas analyzer, a constant value of 0.93 was used. By knowing predicted value of maximum physical work capacity in both unit of kcal/min and VtO_2max, $VdotO_2$ during 5 frequencies levels of Step Test and its relative physical cost expressed in %$VdotO_2max$ was calculated.

$$\mathbf{EE = (0.0158 \times \mathit{W} \times \mathit{H} \times \mathit{N} + ER) / W} \quad [1]$$

where,

EE = energy expenditure (kcal/kg/min)
W = body weight (kg); *H* = height of bench (m)
N = rate of step up and down per minute (5 levels)
ER = resting metabolic rate (kcal/min; equal with 1.2 basal metabolic rate)

$$VdotO_2max = \text{predicted EEmax (cal/min)} / Y(\text{cal/ml } O_2) \quad [2]$$

$$\mathbf{\mathit{Y} = 1231.54\ \mathit{X} + 3815.46} \quad [3]$$

where,

Y = energy produced in the reaction (cal)
X = RQ (0.93; Yovi, 2006b)

Further, to analyze degree of agreement between the two methods, the differences between the two measurements were plotted against the mean according to the method of Bland and Altman (1986). This analysis was carried out to find out whether the difference between alternative and conventional methods was related to the magnitude of measurement or not.

Results and Discussion

Results and discussion go straightforward as: (1) recalculation of workload measured through indirect calorimetric method, (2) calculation of workload predicted through HR data, and (3) degree of agreement analysis between the two calculation methods.

Workload measured through indirect calorimetric method Workload during Step Test performed by respondents is shown in Table 1. The table shows that HR increased linearly following the increasing rate of steps. In the same time, workload also increased. As HR is linearly related to oxygen consumption, it usually increases linearly with increase of oxygen uptake. This is due to energy yielding process in a form of aerobic metabolism. The higher the step rate, muscle fibers will conduct the greater contractility to achieve higher workloads. In order to produce the energy necessary for muscles to contract at high rates, oxygen is required in the term of aerobic respiration. The very close relationship between HR and oxygen intake statistically indicated by value of coefficient correlation (*r*) that pointed to 0. 91.

The value of workload shown in Table 1 also shows variation on physical fitness of each respondent. On all step rate level, workload varied to as much as 29−45%. This is indicates that different respondent burdened with different physical load, even they performed similar physical activity. And this differences were due to they physical fitness. The better the physical fitness is, the more his or her volume of lung, and heart pump blood consists of oxygen in the lower rate. *Vise versa*, the worse the physical fitness is, the smaller the lung capacity in absorbing oxygen, and as compensation, heart should work harder to pump blood required to deliver sufficient oxygen for energy yielding process.

Table 1. Workload During Step Test Calculated Through Indirect Calorimetric Method

Steps rate (step/min)	Average HR (beat/min)	Workload (%VdotO_2max)			
		Max	Min	AVG	SD
5	86	46%	17%	25%	7%
10	101	61%	26%	38%	9%
15	115	74%	34%	50%	11%
20	133	88%	43%	62%	13%
25	152	90%	56%	71%	11%

Table 2. Workload During Step Test Calculated Through HR Data

Steps rate (step/min)	Average HR (beat/min)	Workload (%VdotO_2max)			
		Max	Min	AVG	SD
5	86	41%	15%	23%	6%
10	101	57%	24%	36%	9%
15	115	73%	33%	49%	11%
20	133	88%	42%	62%	13%
25	152	92%	51%	71%	12%

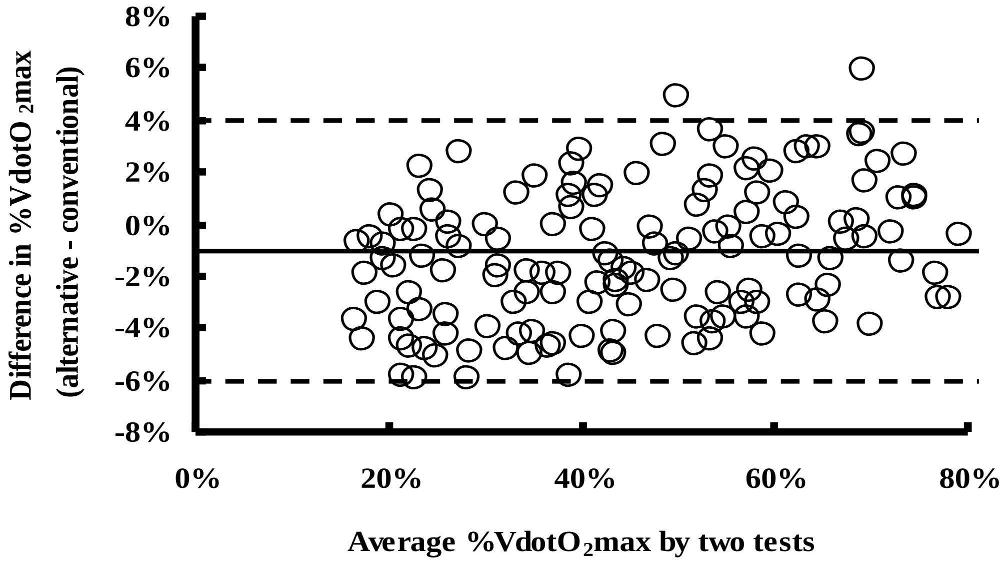

Figure 1. Difference of %VdotO_2max (Alternative Minus Conventional Methods) Against Average %VdotO_2max by 2 Methods (with 95% Limits of Agreement)

Calculation of workload predicted through HR data Calculated workload during step test through the use of HR data only is shown in Table 2. Both HR and workload calculated from HR data show same tendency. HR and workload rate increased as the physical work going harder. Similar with that shown in indirect calorimetric-based calculation, there is very close relationship between HR and percentage of maximum oxygen uptake, with coefficient correlation (*r*) up to 0.89.

However, workload calculated from HR data was a bit different with that from indirect calorimetric method, especially during lower level of step test (5, 10 and 15 step/min). The $VdotO_2$ varies directly with the level of activity in which one is engaged. The higher the $VdotO_2$, the more energy is being used. In relation with energy yielding mechanism, HR usually increases linearly with increase of $VdotO_2$. However, this is a typical feature. In some cases, the $VdotO_2$ increases relatively more than the HR as the work rate becomes very heavy. It is noted that during performing a light physical workload (with a less than 115 beat/min), the HR would be in a disproportional rate with an unequally significant increase in oxygen uptake, as well as energy expenditure. This is due to the presence of internal factors such as emotional stress and apprehension (physiological factor), or external factor such as laughing, drinking coffee or tea, and working with a static and awkward posture (Wickens, *et al*., 1997).

Åstrand (1986), based on Taylor *et al*. (1955) mentioned that running on the treadmill uphill (=>3º inclination) may bring the VO_2 to a higher maximal VO_2 than that performed horizontally. Possible explanation of this phenomenon might be that an efficient redistribution of blood, giving the exercising muscles an appropriate share of the cardiac output, is not brought about until the very heavy work rates are reached. The consequence is the maximal oxygen uptake will be underestimated by an extrapolation from the heart rate response to sub maximal loads. This indicates that HR alone does not assure accuracy in workload estimation.

However, as the *r* was near to 1.0, indicated that HR can be used to predict value of workload, calculating workload in the magnitude of $\%VdotO_2max$ by the use of HR data should be considered as a potential alternative. Recording HR data during actual physical work requires only a simple procedure, with very less expensive equipments. Considering this reasons, the study then tried to analyze degree of agreement in using HR-base workload measurement compared to indirect calorimetric method that assure the accuracy of workload calculation.

Degree of agreement analysis between the two calculation methods The two different results then were analyzed through analysis of degree of agreement *ad modum* Bland and Altman (1986). In this analysis, differences of physical load calculation obtained from the indirect calorimetric-based calculation (hereafter called as conventional method) and HR-based calculation (here after called as alternative method) were plotted against the mean of workload obtained from the two methods.

This analysis was carried out to find out whether the difference between alternative and conventional methods was related to the magnitude of measurement or not. The differences were not plotted against either test measurement (obtained through alternative method) or the standard measurement (obtained through conventional method), as the result will only show a relation, whether there is a true association between difference and magnitude or not, and it may lead to a data interpretation misleading (Bland and Altman, 1995).

Figure 1 shows the results of corresponding analysis on the variation of physical load expressed in $\%VdotO_2max$ obtained from conventional and alternative methods. Mean difference (n = 154) of physical load obtained from alternative method minus physical load obtained from conventional method) was -1% and the SD was 3%. Hence the lower 95% limit was -1% – (1.96 × 3%) = -6% and the upper 95% limit was -1% + (1.96 × 3%) = 4%.

The Figure 1 then shows that measurements by alternative method can be used interchangeably with that by conventional method, with 95% of the difference lie between the mean difference plus and minus 1.96SD. This analysis then indicates that estimating physical load expressed in the magnitude of $\%VdotO_2max$ among different individuals can be carried out through HR data-based calculation. As HR data can be recorded by a simple portable HR memory, this result then can be a basis in developing methods in accurate and fair physical load measurement during a field observation.

However, it should be taken into consideration that assumption used in this study was that in relation with energy yielding mechanism, HR usually increases linearly with increases of $VdotO_2$, regardless to the fact that this is a typical feature, as in some cases the $VdotO_2$ increases relatively more than the HR does as the work rate becomes very heavy.

Conclusion

The existence of the differences on characteristic of each individual should be taken into consideration in comparing physical load among different individuals. To this, a comparative-based %VdotO_2max as workload indicator unit should get a major consideration. The study revealed that physical load prediction obtained through alternative method (HR-based physical load prediction) can be used interchangeably with physical load prediction obtain through conventional method by the use of respiratory gas analyzer devise. This conclusion was indicated from result of degree of agreement analysis, with 95% of the difference lie between the mean difference plus and minus 1.96SD (the lower 95% limit was -6%; the upper 95% limit was 4%). In addition, as HR data can be recorded by a simple portable HR memory, this result then can be a basis in developing methods in accurate and fair physical load measurement during a field observation in supporting development of safety and health of forestry worker in Indonesia.

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