Development of Oxygen Consumption Formula for Energy Expenditure Prediction among Young Industrial Workers

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The aim of this study was to develop oxygen consumption (VO_2) formula for energy expenditure prediction based on height (H), weight (W), age (A), and heart rate (HR) among young industrial workers and to see the validity of the formula.

The study was an experimental study with subjects consisted of 30 males (20 – 25 years old) of young industrial workers; 20 participants were generating VO_2 formula and 10 participants for validation. The experiment protocol used Keytel protocol which used a treadmill exercise. The validity involved 2 activities; running in treadmill and conducting manual material handling.

All determinant factors were strongly related to adjusted R^2 for VO_2 formula and VO_2 relative rate was 76.9% and 75.1% respectively. The formula used was:

VO_2 (L/min) = 1.117 – 0.012 H(cm) + 0.015 W(kg) – 0.039 A (yrs) + 0.019 HR(beat/min)

VO_2 relative rate (ml/kg/min) = 60.881 – 0.339 H(cm) – 0.949 A (yrs) + 0.351 HR(beat/min)

The result of validation for treadmill activity, VO_2 relative rate's data was similar between the actual value of experiments and estimation value from the formula with the R^2, i.e. 0.036. The validation for manual material handling activity was found different.

Keywords: *Oxygen consumption (VO_2); energy expenditure; maximum aerobic capacity; workload, ergonomics*

INTRODUCTION

One of the major approaches in determining human physical capacities and performance is the measurement of metabolic energy expenditure. Since the amount of energy generated (due to muscle contraction) is a function of oxygen utilized. An accurate assessment of an individual metabolic workload (and limit) can be done by measuring the amount of oxygen consumed (VO_2) while performing a task. VO_2 can thus be employed as a physiological indicator for activities involving large muscle groups and further as a mean in developing criteria for job

design (Åstrand dan Rodahl 1970; Brouha 1960; Kroemer 1997; Wicken 2004; McCormick 1993; Firstbeat Technologies 2007).

The value of energy expenditure can be estimated from VO_2. The conversion is 1 litre VO_2 equal with 5 kcal (4.7 – 5.05 kcal) energy expenditure (Åstrand dan Rodahl 1970). The other reference states 1 litre VO_2 similar with 4.8 kcal (Wickens et al. 2004).

Rising of productivity is an important for the industry advancement in Indonesia which is a labour-intensive industry. The management needs to know how to predict energy expenditure among their workers. The previous research (Kamalakannan 2007; Keytel 2005; Byrne & Hills 2002; Pennathur 2005; Iridiastadi 2005) discovers that oxygen consumption (VO_2) formula done in other countries sometimes are not applicable in Indonesia because the difference in body size and its relevant physiological function. Meanwhile, only few experiments conducted in Indonesia (Rakhmaniar 2007; Widyasmara 2007) which involved participants who were not workers.

The aim of this study is to develop VO_2 formula for energy expenditure prediction based on height, weight, age, and heart rate among young industrial workers. It also wants to see the validity of the formula.

METHODS

This was an experimental study whose participants were collected randomly by newspaper advertisement and leaflet to the industries in Bandung City, Indonesia. The requirements of participants were male around 20-25 years old, had work experience at least 1 year, worked in floor production with physical activities, no alcohol consumption, had no lung or heart medication or hospitalized for the past a year, had no musculoskeletal disorders records, had no any disabilities, and in good condition when joining experiments. 30 male participants involved in this study, 20 of them for generating VO_2 formula while 10 others were for validation.

Participants were workers from garment, manufacture, food, printing, textile, and electrical industries around Bandung City, Indonesia. After early screening, there were 30 participants who met requirements. The average age of participants was 22 years old (20 – 25 years old), average height was 158.8 cm (152 – 176 cm), average weight was 53.9 kg (43 – 79 kg).

Experiments were conducted in Laboratory of Work System Design and Ergonomics, Faculty of Industrial Engineering, Institut Teknologi Bandung, Indonesia. Physical environments were controlled by air conditioner, temperature was 20 - 25^{o}C and humidity was 60% - 68% based on

Indonesian Government Standard by Regulation of Ministry Health No. 261/MENKES/SK/II/1998 about the requirements of health environmental for industries.

Experiments used some tools and equipment like thermometer, hygrometer, weight and height scale, treadmill (Sportart 1060 HR – manual adjusted slope and digital display), Metabolic Analyzer (Metalyzer version ML3B made in Cortex Biophysics GmbH, Leipzig, German) with software Metasoft 2.0, polar heart rate including ultrasonic transmission gel, and questionnaires.

The experiment protocol used Keytel protocol which employing a treadmill exercise. There were two experiment steps: first, the participants were asked to run in treadmill with no slope (slope 0%) in speed 7 km/hr continuously until he was exhausted. Second, the participants ran in the treadmill with faster speed around 25%, 50%, and 75% from the maximum speed from previous step. Each speed implemented every 5 minutes continuously. The protocols for validity also consisted of 2 steps; running in the treadmill on their convenience speed for 10 minutes continuously and conducting manual material handling (lifting of 7 kg loads and carrying in 2 meters of distances) for 15 minutes continuously. The Experiments were only conducted in the morning (9 – 12 am) and during the experiments the participants were not allowed to speak. Each participant went through their second experiments 3 days after.

The stopping rules of the experiments were if the data had been fully collected so that the experiments was finished as protocol procedures, if the subject felt exhausted and would like to stop during experiments, if the heart rate > 85% from maximum Heart Rate (MHR= 220 – age), and if RER (Respiratory Exchange Rate) >= 1,0

Data processing used SPSS software version 20 with linear multiple regression test. Validation analysis compared the value of VO_2 by the formula with actual VO_2 by experiments of validation. The Ho hypothesis was a value of VO_2 by experiments of validation equivalent with value of estimation by VO_2 formula.

RESULTS

The average VO_{2max} was 3.730 L/min (3.024-5.268 L/min). All the determinant factors were strongly related to the formula with adjusted R^2 for VO_2 and VO_2 relative rate was 76.9% and 75.1% respectively. All variable data fulfilled the regression assumption so that it could be input into formula analysis as follow:

$VO_2 = 1.117 – 0.012\ H + 0.015\ W – 0.039\ A + 0.019\ HR$

VO_2 relative rate $= 60.881 – 0.339\ H – 0.949\ A + 0.351\ HR$

Whereas VO_2 is oxygen consumption (L/min), VO_2 relative rate is VO_2 in milliliters of oxygen per kilogram of bodyweight per minute (ml/kg/min), H is height (cm), W is weight (kg), A is age (years), and HR is heart rate (beat/min).

VO_2 relative rate's data in treadmill activity was similar between the actual value of experiments and estimation value from the formula with the R^2 was 0.036 or the power of value was too small; 3.6%. On the other hand, the result of validation for manual material handling activity was different. The differences showed higher by the R^2 were 0,399 (39.9%) and 0.563 (56.3%).

DISCUSSION

NIOSH (1981) states the average of maximum aerobic capacity for healthy man is about 15 kcal/min. If 1 L/min VO_2 is equivalent with 4.8 kkal/min (Wickens. 2004), it means 3.125 L/min VO_{2max}. The average VO_{2max} of this research was 3.730 L/min, it was higher than NIOSH recommendation. Since NIOSH considers more factors not only sex, age, height, weight, and heart rate but also safety, health, productivity, economic, social factors, etc., their recommendation is lower.

NIOSH (1981) also recommends energy expenditure not last than 33% of VO_{2max} for 8 work hour without excessive fatigue. Furthermore, energy expenditure for Indonesian industrial workers is 5.952 kkal/min or 1.24 L/min of VO_2.

The previous research (Pennathur 2005), VO_{2max} for 16 male and 5 female American Mexico's students was 4.8 L/min (SD = 1.75) or 56.32 mL/min/kg (SD = 12.2). Kroemer et al. (1997) describes some factors influence aerobic work capacity are age, sex, anthropometry, health, environmental, and motivation. The research by Manuaba (1989) concludes anthropometry among Indonesian workers is smaller than American workers. That's why, VO_{2max} among Indonesian workers smaller than American Mexico's students.

Then, the formula of this research liked to compare with previous research (Kamalakannan 2007, Keytel 2005, Widyasmara 2007, Rakhmaniar 2007), therefore data to calculate the formula was needed. The data of height, weight, and age were taken from this study. However, the heart rate data was taken from Astrand dan Rodahl (1970):

1. Height = 163.84 cm (64.5 inch)
2. Weight = 55.95 kg
3. Age = 22 years old

4. Heart rate based on workload

    - Rest/ no load = 60 beat/min
    - Low = 80 beat/min
    - Medium = 112.5 beat/min
    - High = 137.5 beat/min
    - Extremely high = 162.5 beat/min

Table 1. The result of VO_2 (L/minute) for 4 types of workload from several formulas by some researches

Workload	This research	Research by (Widyasmara 2007)	Research by (Keytel 2005)	Research by (Kamalakannan 2007)
Low	0.652	0.623	0.545	0.032
Medium	1.207	1.241	1.565	0.801
High	1.745	1.761	2.351	1.441
Extremely high	2.220	2.191	3.136	2.082
Average	1.456	1.442	1.899	1.073
SD	0.677	0.670	1.108	0.904

The table shows the result of formula calculation of this research and Widyasmara (2007) is similar. The respondents of those researches were Indonesia male with similar age range. This research involved respondents of 20 – 25 year old while the research by Widyasmara (2007) took 17 – 23 year-old respondents. There is also a huge difference between research conducted Keytel (2005) and Kamalakannan (2007), particularly at medium and high workload. The different is minor for low workload between Keytel (2005) and this research. Respondents in Keytel (2005) were 115 of American (72 males and 43 females) within 19 – 45 years old. Meanwhile, the respondents in Kamalakannan (2007) were 13 of African (8 males and 5 females) within 22 – 55 years old. As sex, age, and ethnic have influenced anthropometry, the anthropometry has impact to VO_2. Therefore, the prediction of energy expenditure by VO_2

formula should be used carefully, especially if the formula is developed with different respondents in age, sex, and ethnic.

The result validity of VO_2 by manual material handling activity is different because the experiment activity was different. The experiment conducted treadmill activity, while the validation experiment conducted manual material handling activities consisted of lifting, carrying, and lowering. The VO_2 incensement during the manual material handling activity was slow showed by the average of VO_2 is 1.10 L/min so that the workload during MMH activity was below industrial workers physical capacity. The physiological workload of the lung and the heart during MMH activity was not so huge considering the muscle activity during MMH activity is more static than dynamic. This is in accordance with the experiment (Iridiastiadi 1997) that shows maximum aerobic capacity on treadmill activity is larger than MMH combination activity.

Adversely, the result of validation shows the same result of VO2' with the treadmill protocol. However, the power of the value is too small, which is 3.6%. Due to the respondents involved in validation experiment were less than in formula experiments. Both experiments were conducted in the same way on the treadmill, but with different protocol. In conclusion, this estimation formula needs advanced experiment before being implemented in industry to predict the energy expenditure among the workers. A few things must be concerned, this formula fits with the 20-25 years old male workers, similar job with the activity on the treadmill, easily changed heart rate because of emotional stress, drinking coffee or tea, working in static position (static/bad posture), or working in high temperature environment (Wickens 2004).

CONCLUSION

This research was an initial study which opened to many. It is expected next researchers can develop similar research with several of respondents with different range of age and sex because there are so many female industrial workers in Indonesia and the productivity age in Indonesia is 19–55 years old. It will be better if the activity in estimation formula development is specific with the task in the industry.

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