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VO_{2max} Capacity and Prediction Model Development for Construction Workers

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Abstract. The physical capacity (VO_{2max}) of construction workers is an important factor in their work performance and safety. This study aimed to investigate the effect of age, body mass index (BMI), and waist circumference (WC) on VO_{2max}, and developed a prediction model for VO_{2max} of Indonesian construction workers. The study involved 45 healthy male construction workers who have no history of illness that affect physical capacity. VO_{2max} was measured using a treadmill with the Bruce protocol. Data on age, BMI, and WC were collected and analyzed using multiple regression analysis to develop the prediction model. The average VO_2max of workers was 3.98 ± 1.18 l/min. Age, BMI, and WC were found to affect VO_{2max} of Indonesian construction workers. Age had a negative correlation with VO_{2max}, while BMI and WC had a positive correlation. The results suggest that VO_{2max} of younger construction workers is higher than that of older workers. The prediction model developed in this study using WC as a predictor can be used to estimate VO_{2max} in Indonesian construction workers. This finding may have important implications for the health and safety of construction workers, as well as for the design of effective training and intervention programs to improve their physical capacity.

***Keyword**: physical capacity; construction workers; prediction model VO_{2max}; age; BMI; WC.*

1 Introduction

Construction workers perform physically demanding tasks that require high energy metabolism and considerable muscle strength [1]. The nature of construction work is often heavy and labor-intensive, which can place significant demands on workers' physical capacity [2]. Due to the labor-intensive nature of the industry, many construction employees are required to do tasks beyond their physical capacity. High work demands have negative effects on productivity at work, musculoskeletal diseases, early retirement, high accident and sickness rates, and chronic weariness [3].

The work performed should not exceed the physical capacity of the worker, as it will cause excessive load. Overload causes employees to experience acute

symptoms, problems, and repercussions such as musculoskeletal illnesses and reduced cardiovascular function, weariness, lower productivity, an increase in workplace complaints, human mistake, or accidents. [4], [5]. It is critical to keep physical demands on construction workers within acceptable ranges in order to sustain production without jeopardizing safety and health [3].

Work demands refer to each individual's physical response to a given load. Physical response is greatly influenced by individual factors (age, training, and nutrition) and environmental factors (temperature and humidity). An ideal work demand measurement should consider these factors [4]. However, as a result of the enormous number of individual and environmental factors that influence physical demands, it is extremely difficult to take them all into account. As a result, only certain elements are examined, while others, such as body temperature owing to heat stress, are overlooked. Because physiological signals are captured in physiological measures, they may be used to quantify the influence of all elements on employees' physical needs [3].

In physically demanding employment, the worker's physical ability becomes a significant aspect in workplace efficiency, preventing excessive strain and the detrimental repercussions of everyday muscular activity. However, there is frequently a mismatch between physical labor demands and worker physical capabilities, resulting in poor worker health [5]. A healthy balance between the two is required for people to work for extended periods of time [6]. The effects of excessive physical job demands differ according to each individual's physical capabilities [2]. Physical ability deteriorates as we age. Older employees will be working at or near their maximum capacity, with substantially higher relative physical demands [7]. Physical capacity is assessed based on person's aerobic capacity, which is the amount of oxygen a person consumes maximally (VO_{2max}) [2].

VO_{2max} is an indicator of the capacity of a person's cardiovascular and respiratory systems to be able to perform physical activity for a long time [2]. VO_{2max} is the highest value of VO_2 that a person can achieve during physical capacity testing through cycling or treadmill tests performed until fatigue is reached. VO_{2max} was used to determine the aerobic capacity of sportsmen and workers. The higher the VO_{2max}, the lower the workload when working [8]. There are several individual factors that can affect VO_{2max}, namely gender, age, BMI, physical activity, WC, body fat %. these factors are often used as predictors in predicting VO_{2max} [2],[8],[9],[10]. Understanding the physical capacity of construction workers and developing strategies to improve it is crucial for maintaining a healthy and productive workforce.

2 Related Study

Several studies measured workers' VO_{2max} and developed VO_{2max} prediction models. Vandersmissen et al [11]. measured the VO_{2max} of Belgian firefighters to evaluate the physical capacity of workers who often perform high-intensity work. The variables of age, WC, test type, test performance level, and test center have a significant effect on VO_{2max}. Bugajska et al research [2] evaluated the work capacity of active polish workers with VO_{2max} obtained from heart rate (HR) estimation and evaluated workload. The study also showed that VO_{2max} decreases with age, so older workers will work close to their maximum capacity. Only a small percentage of older workers can work for a long time and not cause workload. Brighenti-Zogg et al. [12] determined the physical performance criteria of different occupational groups by investigating the physical activity and energy expenditure of workers in Switzerland. The results showed that VO_{2max} will decrease with age, and men's VO_{2max} is higher than women. There was no difference in VO_{2max} between occupational groups (low, medium, and high) when stratified by gender. Dey et al. [13] measured the VO_{2max} of Indian underground mine workers, the results of the study showed that the cardiovascular fitness of young workers was better than old workers. Older workers have a tendency to require more oxygen while working than their younger coworkers. The occupational stress of older workers is higher than younger workers.

Prieto et al. [14] conducted a study to determine the relationship between age, aerobic capacity, and health indicators (Exercise type and physical fitness) in 3 groups of rescue groups (beach workers, firefighters, and mine worker rescuers). VO_{2max} was lower in older workers which affected the effectiveness of rescue tasks in each group. Oestergaard et al. [15] evaluated the physical capacity of offshore wind technician workers. The results showed that the VO_{2max} of these workers was higher than other blue-collar workers in previous studies. The workers' cardiorespiratory fitness level decreased with age. Daneshmandi et al. [8] conducted a study to evaluate VO_{2max}, and determine what factors affect VO_{2max}, and developed a regression equation for VO_{2max} of Iranian industrial workers. The results of the study showed that age, BMI, and hours of exercise had an effect on VO_{2max}. while body weight, height, nature of the body, and work schedule had an effect on VO_{2max}.

Wier et al. [10] developed three VO_{2max} prediction models, namely the BMI, WC, and % body fat models with gender, age, score, physical activity, and BMI/WC/% body fat as predictor variables. Age has a negative correlation with VO_{2max}. physical activity shows a positive correlation with VO_{2max}. The more often physical activity is done, the VO_{2max} increases. BMI, WC, and % body fat have a negative correlation with VO_{2max}. The more a person's BMI, WC, and body fat %

increase, the VO_{2max} decreases. The body fat % model was the selected prediction model in the study. Matsuo et al. [9] also developed three VO_{2max} prediction models, namely BMI, WC, and body fat % models with gender, age, score, physical activity, and BMI / WC / body fat % as predictor variables. The study is a follow-up study from the study of Wier et al. [10] where the population is workers in Japan.

In Indonesia, several studies have measured VO_{2max} in industrial and military fields, developing VO_{2max} prediction models with heart rate, age, gender, weight, and height as predictors. However, no association was found between predictor factors and VO_{2max}. Several studies conducted outside of Indonesia have looked at the relationship between gender, age, score, physical activity, exercise time, test duration, test type, BMI, WC, and body fat% and VO_{2max}; and developed prediction models based on some of these predictor variables [8],[9],[10],[11]. However, to the best of the authors' knowledge, no previous studies have examined the VO_{2max} capacity of construction workers in Indonesia, assessed the relationship between age, BMI, and WC with VO_{2max}, or developed a prediction model for VO_{2max} using these three predictor variables. The current study aimed to investigate construction workers' physical capacity (VO_{2max}), examined the relationship between age, BMI, and WC and VO_{2max}, and developed a VO_{2max} prediction model in construction workers.

3 Material & Methods

3.1 Participants

This study recruited 45 male construction workers who were physically and mentally healthy, and had no history of chronic diseases such as cardiovascular disease, or acute diseases such as asthma. Participants ranged in age from 18 to 60 years nd were recruited from the city of Bandung in Indonesia. G*power statistic was used to obtain the minimum number of respondents in this study to obtain a power value of 80% and α 0.05. The effect size used in the g*power statistic uses the pearson correlation coefficient (*r*) from previous research [9]. Respondents participated in the study voluntarily and received information about the purpose and protocol of the study. All participants signed a consent form before the study.

3.2 Procedure

Respondents took aerobic capacity measurements (VO_{2max}) maximally on a treadmill using the Bruce protocol [16]. The VO2 master analyzer and wahoo as

a heart rate meter were used for aerobic capacity testing. Before beginning the VO_{2max} measurements, respondents were given the Borg Rating of Perceived Exertion (RPE) as an estimate of respondent fatigue throughout testing. The VO_{2max} test was divided into seven phases, for three minutes. Respondents were instructed to communicate their RPE at each stage by pointing to the numbers on a sheet of paper displayed while jogging on the treadmill. Figure 1 shows VO_{2max} measurements

Figure 1. VO_{2max} Measurement

Respondents were not permitted to speak during the test. If any of the following situations occur, the test will be terminated: 1) the respondent gave up; 2). heart rate (HR) has reached HRmax for 10 s; and 3). The RPE value of respondents was ≥ 18. The RPE scale ≥ 18 indicates that exertion has approached its maximum limit. After the maximum condition was reached, the respondent will cooldown on the treadmill for three minutes.

3.3 Data Analysis

Statistical analyses used SPSS version 24. Pearson correlation was used to determine the relationship between age, BMI, and circumference and VO_{2max}. Multiple linear regression analysis was used to determine the effects of age, BMI, and circumference on VO_{2max}; and to develop a VO_{2max} prediction equation. Adjusted squared multiple correlation coefficient (R^2), Akaike's information criterion (AIC), and Bayesian information criterion (BIC) were used as the model selection criteria.

4 Result

Table 1 shows the characteristics of respondents. The mean VO_{2max} of the workers was 3.98 ± 1.18 l/min. Tables 2 and 3 show the mean, standard deviation, and absolute (l/min) and relative (ml/min/kg) VO_{2max} intervals based on the age of the respondents. This study will use VO_{2max} absolute

Table 1. Characteristics of respondents (N=45)

Variable	Range	Mean	SD
Age (years)	19-60	38.69	11.94
Weight (kg)	43.8 -77.2	58.76	7.93
Height (cm)	152.8-182	164.66	6.58
BMI (kg/m^2)	17.02-26.36	20.91	2.49
WC (cm)	66.54-96.26	76.40	7.22

Table 2. Aerobic Capacity (VO_{2max}) by age (N = 45)

Age (years)	N	VO_{2max} (ml/min/kg)		
		Mean	SD	Interval
20-30	15	76.19	19.93	33.12-105.54
30-40	8	71.03	12.40	47.95-91.41
40-50	11	63.77	18.27	28.34-94.32
50-60	11	63.66	11.52	49.73-87.53

Table 3. Aerobic Capacity (VO_{2max}) by age (N = 45)

Age (years)	N	VO_{2max} (L/min)		
		Mean	SD	Interval
20-30	15	4.36	1.38	2.07-6.70
30-40	8	4.38	1.18	2.49-6.39
40-50	11	3.63	1.01	1.36-4.9
50-60	11	3.46	0.70	2.48-4.37

The pearson correlation in table 4 shows that age, BMI, and WC were correlated with VO_{2max} (*p value* <0.05). Age was negatively correlated with VO_{2max} with a low degree of association. BMI and WC were positively correlated with VO_{2max} with a low and moderate relationship, respectively

Table 4. Pearson correlation coefficient between VO_{2max} and other variables

	Age	BMI	WC
r (pearson correlation)	-0.275	0.379	0.424
P value	0.033	0.005	0.002

Multiple linear regression analyses was used to determining the significance of age, BMI, and WC on VO_{2max}; and create a VO_{2max} prediction model. There are two VO_{2max} prediction models in this study, namely the BMI model and the WG model as in tables 5 and 6.

Table 5. Significant Variable

Model	variable	Sig
BMI model	Age	0.010
	BMI	0.002
WC Model	Age	0.017
	WG	0.001

Table 6. Regression coefficients for prediction of VO_{2max}

Model	Intercept	Variable independent			R^2
		Age	BMI	WC	
BMI Model	0.901	-0.036	0.215	-	0.272
WC Model	-0.516	-0.032	-	0.075	0.285

Table 5 presents the variables in each model (BMI and WC models) that had a significant effect on VO_{2max} ($p < 0.05$). Age and BMI had a significant effect on VO_{2max} with p-values of 0.01 and 0.002. Age and WC had a significant effect on VO_{2max} with p-values of 0.017 and 0.001, respectively. Table 6 shows that the R^2 WC model was higher than BMI model. The VO_{2max} prediction coefficient contained in table 6 can be written in mathematical form is as model (1) and (2)

BMI model :

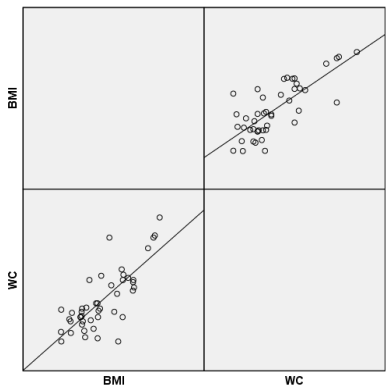
$$y = 0.91 - (0.036\ x\ age) + (0.215\ X\ BMI) \quad (1)$$

WC model :

$$y = -0.516 - (0.032\ x\ age) + (0.075\ X\ WC) \quad (2)$$

5 Discussion

BMI and WC prediction models were created separately to predict VO_{2max} because they refer to research conducted in [15,16]. BMI and WC were strongly correlated with a Pearson correlation coefficient (r) of 0.773 (p-value 0.000). The greater the WC, the greater the BMI. If these two variables are combined in one model to predict VO_{2max}, autocorrelation will occur in the model with a VIF value of > 2. Figure 2 shows the strong relationship between BMI and WC.



Picture 2. Relationship line between BMI and WC

Age was negatively correlated with VO_{2max}. The older the worker, the VO_{2max} will decrease [7],[8]. This study also confirms previous findings that age has a substantial influence on VO_{2max} [7],[8],[9],[10]. BMI and WC ere inversely related to VO_{2max}. The VO_{2max} decreased when the BMI and WC increased [8],[9],[10]. However in this study, BMI and WC did not have a negative correlation value, but a positive correlation as in table 4. Daneshmandi et al [8], Matsuo et al. [9], and Wier et al. [10] reported the correlation of BMI and VO_{2max} were -0.158, -0.392, and -0.20. The correlation of WC and VO_{2max} was -0.24 [9] and-0.392 [10].

The regression coefficient values of BMI and WC were negative in previous studies [8],[9],[10]. While this study shows the same results, the regression coefficient values of the two variables are positive as shown in table 6. VO_{2max} in this study uses the same absolute value as in the study by Daneshmandi et al [8]. While research by Matsuo et al [9] and Wier et al. [10] used relative VO_{2max} values. VO_{2max} relative was obtained by dividing absolute VO_{2max} by body weight. The number of respondent samples in this study was indeed very small when compared to previous studies [8],[9],[10] which amounted to 500, 196, 2801. However, this research sample is more specific to one group of workers compared to previous studies with a very broad research sample of workers. The R^2 values of the two prediction models were also smaller than those reported in previous studies [9],[10].

Wier et al. [10] produced R^2 models of BMI and WC of 0.80 and 0.81. Meanwhile, Matsuo et al. [9] produced R^2 BMI and WC models of 0.59 and 0.61. R^2 may be influenced by the sample size because Wier et al. [10] had a very large sample size compared to Matsuo et al. [9]. The predictor variables in this study were age and BMI/WC. Whereas Wier et al. [10], and Matsuo et al. [9] totaled four predictor variables namely gender, age, physical activity score, and

BMI/WC/ body fat percentage. Gender was not included as a predictor variable in this study because construction workers were predominantly male. Body fat percentage was also not considered a predictor because there was no adequate tool to measure body fat %. Gender and body fat percentage have moderate and strong correlations [9],[10] which may affect R^2.

Table 7. Model Selection Criteria

Model	Adjusted R^2	AIC	BIC
BMI Model	0.237	23.119	30.346
WC Model	0.251	20.464	27.691

Table 7 shows the model selection criteria based on the Adjusted R^2, AIC, and BIC. The WC model was favored because it had a better adjusted R^2, as well as a lower AIC and BIC than the BMI model, despite having a relatively low adjusted R^2.

The VO_{2max} prediction model developed in this study is a useful tool for estimating a person's maximum oxygen consumption without the need for direct testing by inputting age, bmi, and wc into equation (1) and (2). However, it should be noted that the accuracy of the model may be affected by biases in the selection and representation of respondents. To achieve more accurate VO_{2max} predictions, practitioners must obtain precise and unbiased measurements [10]. One limitation of this study was the exclusion of gender, physical activity, and body fat percentage as predictors of VO_{2max}, resulting in a relatively low R^2. Future studies should consider incorporating these variables as predictors, as they have been found to have moderate to significant associations with VO2max in previous research. By including these additional predictors, future models could achieve better predictive accuracy and ultimately provide more reliable estimates of VO_{2max} in construction workers [9],[10].

Conclusion

The study showed that age was negatively correlated with VO_{2max}. BMI and WC were positively correlated with VO_{2max}, was expected to be negatively correlated. The R^2 of the BMI and WC models were very low at 0.272 and 0.285, respectively. The VO_{2max} prediction model should consider physical activity and body fat % as predictors to obtain a good goodness of fit (R^2).

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