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Physical Work Load Affects the Maximum Oxygen Uptake

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Abstract: Purpose: Maximum oxygen uptake ($\dot{V}O_2$max) is known to be influenced by life-style factors, such as exercise and smoking. We aimed to further test the hypothesis that, besides these, work form also contributes to increase $\dot{V}O_2$max among workers. Method: Three thousand six hundred and forty eight male workers with age 38.3 ± 12.1 and 1,575 female workers with age 35.6 ± 11.1, ranging from 20-year old to 69-year old, who participated in Total Health Promotion Plan at workplaces in Fukui Prefecture in 1998 were selected. Data on $\dot{V}O_2$max were analyzed for age, systolic blood pressure (SBP), body mass index (BMI), work form (sedentary, standing or ambulatory), exercise, and smoking. Results: Multiple regression analysis showed that work form ("standing", "ambulatory"), and exercise habits might increase $\dot{V}O_2$max while BMI, age, and SBP might decrease $\dot{V}O_2$max in male participants. Exercise habits were suggested to increase $\dot{V}O_2$max while BMI, SBP, and age might decrease $\dot{V}O_2$max in females. In females smoking, was suggested to increase $\dot{V}O_2$max. Conclusion: After adjusting for age, BMI, SBP, exercise, and smoking, it was suggested that the physical work load, represented by the work form, may contribute to increases in $\dot{V}O_2$max in males. Implications of smoking among females with respect to $\dot{V}O_2$max is discussed.

Key words: $\dot{V}O_2$max, Work load, Sedentary, Ambulatory, Physical activity, Exercise, Obesity, Hypertension

Introduction

As a consequence of the WHO Ottawa Charter of 1986, Industrial Safety and Health Law was revised in Japan in 1988. It prescribes that execution of health promotion measures for workers is an obligation of employers. In line with this, Total Health Promotion Plan (THP) has been instituted[1]. THP includes not only medical examination, but also investigation of life-style, and assessment of physical fitness. Determination of the maximal oxygen uptake ($\dot{V}O_2$max) as an indication of a whole body endurance is included in physical fitness assessment. Based on these results, guidance for health care and psychological counseling are provided to employees.

It is reported that $\dot{V}O_2$max is influenced by life-style, such as exercise and smoking[2-9, 30, 32, 33]. Moreover, the preceding researches reported that the fall in $\dot{V}O_2$max is closely connected with cardiovascular system disorders, such as heart diseases, and hypertension[7, 10–15, 31–32]. Based on this evidence and from a viewpoint of preventive medicine, $\dot{V}O_2$max is being used as a health index in THP.

Brody[16] proposed in 1945 when work load was severe that work severity during the work shift should not exceed 50% of $\dot{V}O_2$max so that the work strength is effectively limited.

Since then, mechanization in the work environment and automation have advanced further and, as a result, work

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intensity in recent years has decreased remarkably and industries with low work intensity tend to prevail. According to Andersen[17] in 1996, $\dot{V}O_2$max measurements amongst male government officials, white-collared workers and university students, were significantly higher than that in blue-collared workers and the unemployed. His interpretation was that physical activity in persons of the upper class was gained largely through leisure-time activity. Furthermore, he proposed that gymnastics classes at schools for occupational training improved life-style and endurance of students.

Work intensity, which is low in many industries, and working duration, which is 8 h per day, for five days to six days per week, may, over a protracted period of time, affect $\dot{V}O_2$max among workers. To analyze the relationship between work intensity and $\dot{V}O_2$max for the purposes of occupational health, work form (sedentary, standing, ambulatory) was chosen as an indication of physical activity in the present study.

In particular, in order to consider the effects of work load on $\dot{V}O_2$max, we took the work form as another measure of physical activity independent of exercise habits[7, 24–26, 33].

Subjects

According to the Industrial Safety and Health Law, the Japan Assembly approved THP policy in association with the budget. In line with this, the Japan Industrial Safety and Health Association (JISHA) drew up a contract with the Ministry of Health, Labor and Welfare, to perform examinations. The Safety and Health Committee within each enterprise, which is composed of employers, industrial physicians and representatives of employees, and set up according to the Industrial Safety and Health Law, also gave approval.

In line with this, 4,936 male and 2,147 female workers who were 20 to 69-year old underwent medical examination, investigation of life-style, and assessment of physical fitness for the THP at Fukui Health Service Association in 1998. Subjects meeting the following 2 criteria were selected from these: free from the contraindications for exercise test and capable of undergoing the exercise test without any problems, and receiving no medication or therapy. This produced 3,679 male and 1,593 female workers remaining for study.

The management staff of the companies fully explained THP to all subjects. The staff of Fukui Health Service Association also fully explained all subjects the details of measurements and obtained oral consent on the occasion of the examination.

On the assumption that physical strength level among these workers was in the normal range, those whose $\dot{V}O_2$max were separated by 3 σ or more from the means of the distribution of $\dot{V}O_2$max in each gender and age group (10 yr) were excluded. Finally there were 3,648 males (average age, 38.3 ± 12.1 yr) and 1,575 females (average age, 35.6 ± 11.1 yr) subjects.

Method

The seven factors, which may affect $\dot{V}O_2$max were chosen for analysis: age, SBP (mmHg) as a physiological factors, BMI as one of the physical factors that is the physique index computed from height and weight, work form as intensity, i.e. sedentary, standing or ambulatory, exercise habits and exercise histories as physical activity factors, and smoking as a life-style factor. $\dot{V}O_2$max was measured using a bicycle ergo-meter (Aerobic Capacity System, ML-1400, Fukuda Electronic, Japan) by the indirect method which presumed $\dot{V}O_2$max (ml/min/kg) from the primary regression equation (pulse/min) of work load (watt) with pulse rates[7, 32]. Blood pressure was measured using automatic blood pressure equipment for movement loads of circulation (STBP-780, Nippon Korin, Japan)[7, 20].

Categorization for exercise habits, exercise histories, work form, and smoking were based on individual answers to the self-administration questionnaire which were quoted from Japan Industrial Safety and Health Association Guideline as shown below: "exercise habit" was assessed on a 5-point scale based on frequency: 1) almost every day, 2) 3 or 4 times for the week, 3) 1 or 2 times in the week, 4) 1 or 2 times in the month, 5) only occassional exercise.

The responses were dichotomized: the scaling of 1) to 3) defines as having "exercise habit", and 4) and 5) as "no exercise habit".

"Exercise history" was assessed as exercise experiences: 1) walking, 2) jogging and running, 3) cycling, 4) swimming, 5) gymnastics, 6) healthy gymnastics and stretching, 7) ball games, such as tennis and volleyball, 8) ball games, such as baseball and softball, 9) mountain climbing and hiking, 10) golf.

The participants chose a maximum of three items from these ten.

These responses were dichotomized: if one or more items were chose individuals were defined as having "exercise history"; if no items were chosen "no exercise history" was assigned.

Work form was assessed on a 3-point scale of main physical posture during work time: 1) sitting down in almost all work-shift, 2) standing in almost all work-shift, 3) walking in turns in almost all work-shift. These responses were trichotomized as they were: "sedentary", "standing", and "ambulatory".

Smoking was assessed by present smoking status: 1) smoker, 2) non-smoker including ex-smoking. These responses were dichotomized as they were: “smoker”, and “non-smoker”.

Statistics Analysis

Bivariate analyses among work form, exercise habits, and smoking were performed by the chi-square test in each gender group.

Average values of age, $\dot{V}O_2$max, SBP, and BMI were compared for work form by one-way layout ANOVA in each gender group.

Simple correlation analysis of $\dot{V}O_2$max with each of seven factors were performed, for each gender group.

The correlation analyses with these quantitative variables, namely age, SBP, and BMI were performed using Pearson’s correlation analyses. When at least one of the variables was categorical, correlation coefficient was calculated by Spearman’s method.

Multiple regression analyses of $\dot{V}O_2$max as dependent variable with seven factors as independent variables were performed for each gender. For the analysis, a dummy variable was used for work form, and a variable of work form was forced into the regression equation. The other six factors were applied by the stepwise method. A variable was adopted when F value was 2.00 or more, and it was excepted when F value was less than 2.00.

All statistical analyses were performed using the 7.5J release version of SPSS statistical package for personal computers (SPSS Inc., Chicago, IL, USA).

Statistical differences were judged to be significant at $P < 0.05$.

Results

Characteristics of subjects

Table 1 shows average values and standard deviations, $\dot{V}O_2$max (ml/min/kg), SBP (mmHg), and BMI, and distributions of work form, exercise habits, exercise histories, and smoking for each gender. As shown in Table 1, as to work form, the “ambulatory” group was in the most as 46.7% in males, and the percentages of the “sedentary” group and the “standing” group were almost equivalent. In females, the percentages were in the following order: the “sedentary” group (56.1%), the “ambulatory” group, and the “standing” group. Those with exercise habits were less than 50% in both males and females. Smokers attained 62.6% in males and 12.9% in females.

Table 2 shows average values of age, $\dot{V}O_2$max, SBP, and BMI stratified by work form for each gender. As for all physical factors, namely, age, $\dot{V}O_2$max, SBP, and BMI, there were significantly differences among work form subgroups in males.

As to age, there was the following high order: the “standing” group, the “sedentary” group, and the “ambulatory” group. As for $\dot{V}O_2$max, there was the following high order: the “ambulatory” group, the “standing” group, and the “sedentary” group. As for SBP, there was the following high order: the “standing” group, the “ambulatory” group, and the “sedentary” group. As for BMI, there was the following high order: the “sedentary” group, the “standing” group, and the “ambulatory” group. As for age, SBP, and BMI, there were significantly differences among work form, but $\dot{V}O_2$max was not significantly differences in females. As for age, there were in the following high order: the “standing” group, the “ambulatory” group, and the “sedentary” group. As for

Table 1. Characteristics of subjects by gender

	male	female	total
Number	3,648	1,575	5,223
Age (years)	38.3 (12.1)	35.6(11.1)	37.5(11.8)
$\dot{V}O_2$max (ml/kg/min)[a]	37.2 (6.0)	31.2(5.3)	35.4(5.8)
SBP (mmHg)[b]	125.3 (12.6)	116.2(12.8)	122.6 (12.7)
BMI[c]	22.9 (2.9)	21.2(2.6)	22.4 (2.8)
Sedentary (%)[d]	28.5	56.1	36.8
Standing (%)[e]	24.8	15.9	22.2
Ambulatory (%)[f]	46.7	27.9	41.0
Exercise habits (%)[g]	48.1	36.4	44.6
Exercise histories (%)	44.0	49.7	45.7
Smoking (%)	62.6	12.9	47.6

Physical Characteristics: mean and standard deviation, Other Characteristics: percentage,
[a]$\dot{V}O_2$max: maximum oxygen uptake, [b]SBP: systolic blood pressure, [c]BMI: body mass index,
[d]Work form by sedentary, [e]Work form by standing, [f]Work form by ambulatory,
[g]Exercise habits (%): Regular Exercise (%).

Table 2. Characteristics of subjects by work form

male	Work form			P values
	Sedentary	Standing	Ambulatory	
Number	1,039	906	1,703	
Age (years)	39.5 (11.3)	41.0 (13.3)	38.3 (12.5)	<0.001*
$\dot{V}O_2max$ (ml/kg/min)[a]	36.6 (6.2)	37.5 (6.2)	38.2 (6.0)	<0.001*
SBP (mmHg)[b]	121.2 (20.8)	125.1 (13.2)	124.1 (14.2)	<0.001*
BMI[c]	23.3 (2.9)	22.7 (2.9)	22.6 (2.9)	<0.001*
Exercise habits (%)[d]	53.1	39.8	49.5	<0.001*
Smoking (%)	53.7	62.7	67.9	<0.001*

female	Work form			P values
	Sedentary	Standing	Ambulatory	
Number	884	251	440	
Age (years)	36.9 (11.2)	43.0 (12.6)	39.1 (12.4)	<0.001*
$\dot{V}O_2max$ (ml/kg/min)[a]	31.0 (5.7)	30.2 (5.9)	31.1 (5.5)	0.061
SBP (mmHg)[b]	116.2 (15.4)	121.4 (14.0)	117.5 (16.2)	<0.001*
BMI[c]	21.2 (2.8)	22.6 (3.1)	21.9 (2.9)	<0.001*
Exercise habits (%)[d]	34.8	30.7	42.7	0.002*
Smoking (%)	11.4	13.9	15.2	0.130

Physical Characteristics: mean and standard deviation, Other Characteristics: percentage,
*Significant difference at P<0.05, Physical Characteristics: P values obtained from One-way layout ANOVA, Other Characteristics: P values obtained from Chi square test,
[a]$\dot{V}O_2max$: maximum oxygen uptake, [b]SBP: systolic blood pressure, [c]BMI: body mass index,
[d]Exercise habits (%): Regular Exercise (%).

SBP, there were in the following high order: the "standing" group, the "ambulatory" group, and the "sedentary" group. As for BMI, there was the following high order: the "standing" group, the "ambulatory" group, and the "sedentary" group.

And Table 2 shows relationships between work form, exercise habits, and smoking.

The "sedentary" group in males had the most frequent exercise habits amongst the groups, and in females the "ambulatory" group had most frequency of exercise habits amongst the groups. The groups for work form differed greatly in exercise habit frequency among the two gender groups.

The prevalence of smokers was highest in the "ambulatory" group, less in the "standing" group, and least in the "sedentary" group in both males and females. The differences in percentages of smokers was remarkable especially in males.

Simple correlation analysis to factors of $\dot{V}O_2max$

Table 3 shows significant negative correlations between $\dot{V}O_2max$, age, SBP, and BMI for both males and females.

Significant positive correlations between $\dot{V}O_2max$ and exercise habits were observed for both males and females. Significant correlations between $\dot{V}O_2max$ and exercise histories were neither observed in males nor females. A significant positive correlation between $\dot{V}O_2max$ and work form was observed in males only.

A significant positive correlation between $\dot{V}O_2max$ and smoking was observed for both males and females.

Table 3. Correlations analysis of maximum oxygen uptake with age, systolic blood pressure, body mass index, exercise habits, exercise histories, work form and smoking by gender

Variables	Male	Female
	Simple correlation coefficient	Simple correlation coefficient
Age (yr)	−0.249*	−0.233*
SBP (mmHg)[a]	−0.266*	−0.253*
BMI[b]	−0.568*	−0.412*
Exercise habits[c]	0.033*	0.085*
Exercise histories	−0.016	0.011
Work form	0.135*	0.004
Smoking	0.061*	0.122*

[a]SBP: systolic blood pressure, [b]BMI: body mass index,
[c]Exercise habits: Regular Exercise.

Multiple regression analysis of $\dot{V}O_2max$ with the factors

Table 4 shows that the factors with significant positive

Table 4. Multiple regression analysis of maximum oxygen uptake with age, systolic blood pressure, body mass index exercise habits, work form and smoking by gender

Variables	Male			Female		
	Standardized regression coefficient	T values	P values	Standardized regression coefficient	T values	P values
Age (yr)	−0.165	−12.320	<0.001*	−0.085	−3.474	<0.001*
SBP (mmHg)[a]	−0.126	−9.293	<0.001*	−0.140	−5.882	<0.001*
BMI[b]	−0.526	−38.913	<0.001*	−0.364	−15.316	<0.001*
Exercise habits[c]	0.017	5.370	<0.001*	0.115	5.106	<0.001*
standing[d]	0.057	3.684	<0.001*	0.039	1.637	0.102
ambulatory[e]	0.098	6.245	<0.001*	0.038	1.634	0.103
Smoking	−0.021	−1.598	0.110	0.066	2.924	0.004*
	Adjusted for R square	0.384*		Adjusted for R square	0.219*	

*Significant difference at P<0.05,
[a]SBP: systolic blood pressure, [b]BMI: body mass index, [c]Exercise habits: Regular Exercise, [d]Work form by standing,
[e]Work form by ambulatory.

standardized regression coefficients to $\dot{V}O_2$max were "ambulatory" (SRC as 0.098), "standing" (SRC as 0.057) as work form, and exercise habits (SRC as 0.017). in order with a strong influence in males The factors that attained significant negative standardized regression coefficients in decreasing strength of association were BMI (SRC as −0.526), age (SRC as −0.165), and SBP (SRC as −0.126). Although smoking showed a negative standardized regression coefficient, significance was not attained.

The factors with significant positive standardized regression coefficients to $\dot{V}O_2$max were exercise habits (SRC as 0.115), and smoking (SRC as 0.066) in order of decreasing strength of association in females, and the factors with significant negative standardized regression coefficients were BMI (SRC as −0.364), SBP (SRC as −0.140), and age (SRC as −0.085) in order of decreasing strength of association.

Although the factors of "standing" and "ambulatory" for work form showed positive standardized regression coefficients, significance was not observed for females. Exercise history was not adopted as an independent variable in either males or females.

Discussions

Validity of objects

With regard to physiological characteristics (age, SBP) and physical characteristics (BMI), the averages were equivalent to the average values of the workers sampled from all over the Japanese nation[19]. The age of the present subjects were 38.7 ± 9.9 yr for male, 38.0 ± 8.9 yr for female; SBP were 117.2 ± 15.0 mmHg for male, 107.4 ± 15.0 mmHg for female, and BMI were 23.1 ± 3.0 for male, 21.6 ± 3.2 for female.

Since these values were similar to those of the general population studied for epidemiological purposes relating to vascular disease[19], our object group can be considered to represent workers generally.

Categorization of physical activities and of physical exercise

There are some published researches on the relationship between labor load and $\dot{V}O_2$max. Kishida *et al.*[25] demonstrated a significant positive partial correlation coefficient of 0.193 in the males in their 30's, between physical activity including work and $\dot{V}O_2$max. According to a report of Suenaga[27], $\dot{V}O_2$max of active middle-aged males was significantly higher than those largely sitting down during work.

Naito[31] reported that $\dot{V}O_2$max was higher among standing workers. By measuring METs, he attributed the large amount of energy expended in standing to the increase in $\dot{V}O_2$max. In these researches, exercise and work load were summed up to the amount of physical activities.

In our present study, exercise and work load were used as independent factors.

There are some reports of physical activities increasing $\dot{V}O_2$max.

The amount of physical activities usually converts into the amount of energy consumption in kcal units, $\dot{V}O_2$max is so high that the amount of energy consumption is high[18, 23, 31]. Daily exercise habits can also be quantified. There is also a report showing a positive relationship between daily exercise habits and $\dot{V}O_2$max.

The American College of Sports Medicine (ACSM) shows the intensity of the various kinds of exercise in

METs. As to an exercise factor, habitual physical activity for one week is calculated and summed by the following equation: exercise intensity (METs) × exercise time (min) × exercise frequency (times per a week)[7, 24]. In Japan developed for such exercise calculations[28, 29] Generally, either of the two methods are now used in Japan. Neither of them covers all of the various kinds of exercises.

Even for the same exercise item, the exercise intensity differs between individuals or countries (nations). In order to acquire records on METs or RMR for individuals, it is necessary to study an individual object. In our present study for a large number of workers for a purpose of public health, it is very difficult to get this information. Therefore, information obtained by using self-administered questionnaire on exercise were confined to two categories "having exercise habits" and "having no exercise habits".

In order to take the influence of exercise histories into consideration, exercise histories were also dichotomized into "without exercise histories" and "with exercise histories". Since $\dot{V}O_2max$ is said to decrease without period exercise[9, 27], the absence of exercise histories may be critical.

Multiple regression model as a mathematical model

In the multiple regression model, it is a premise that the type of independent variables are interval variables with normal or dichotomous distribution, and the relationships of independent variables to each other must be independent. Therefore, we chose age and blood pressure as physiological factors, and chose BMI as physical factors[10–15, 17, 33].

As is well-known for blood pressure, there is a strong correlation between SBP and DBP. If both of them are used in the regression model, multicollinearity occurs. Therefore, only SBP was utilised in our multiple regression model[22].

Relationship of $\dot{V}O_2max$ to the seven factors

Various factors of life-style influence $\dot{V}O_2max$. Previous studies have reported that ageing, being overweight, and hypertension reduce $\dot{V}O_2max$, whilst exercise, increases $\dot{V}O_2max$[7, 21–23, 30]. Again in our present research, age, BMI, and SBP had significant relationships to $\dot{V}O_2max$ as seen in the correlation analysis.

Suenaga[27] reported that, five years or more after stopping an exercise habit, there was significant negative partial regression coefficient between $\dot{V}O_2max$ and years stopped exercising. We found no significant relation between $\dot{V}O_2max$ and exercise history by simple correlation analysis, therefore it was not adopted as an independent variable for multiple regression analysis.

Previous researches reported that smoking decreases $\dot{V}O_2max$[30, 33]. According to

the cross-sectional study by Yamaji[32], there was no significant difference in $\dot{V}O_2max$ between smokers and non-smokers. In our present cross-sectional study, however, from the simple correlation analysis a significant positive relationship was found between smoking and $\dot{V}O_2max$ in both males and females. In the multiple regression analysis no significant correlation between these was detected in males. However in females a positive standardized regression coefficient was detected and thereafter smoking was adopted as an independent variable. Our results on smoking for females need further consideration. According to the study by Tobita *et al*.[7, 33], although the factor of smoking was not shown to be related $\dot{V}O_2max$ by the preceding cross-sectional study, decrease in $\dot{V}O_2max$ was shown by the longitudinal study to be significant among smoking for females.

In order to consider the relation between smoking and $\dot{V}O_2max$, a longitudinal study is desirable for our population.

Physical work load

The most popular reference for the categorization of the life activity intensity is the 4-point classification involved in the guideline developed by the present authors[29] and Nagaya[26], quoting this 4-scale categorization, used self-judged 3-point work activity level (weak, moderate, strong). He revealed a strong relevance of work activity with serum lipids. By means of modifying the Japan Ministry 4-point classification, Kishida *et al*.[25] considered duration, combined with walk and work form and categorized the work load intensity into 3 categories (light, moderate, heavy. They then showed a significant effect of work load intensity on $\dot{V}O_2max$. Suenaga[27] for the purpose of assessing the pattern of physical activity more precisely, further classified the Japan Government 4-point classification, into 6 groups: 1) sedentary, 2) sedentary and walking, 3) sedentary and brisk walking, 4) sedentary and exercise, 5) active with no regular job but spending spare life time activity, 6) active with no regular job but spending spare life time activity and exercise. In the study of Suenaga[27] all the groups showed significantly higher values of $\dot{V}O_2max$ than the sedentary group.

We categorized the variable of work form levels into "sedentary", "standing", and "ambulatory", in order of increasing work load intensity.

Our present study is similar to these three preceding studies on terminology for categorizing work load. Although there have been only a two studies addressing work load intensity with regard to $\dot{V}O_2max$, our study, showing a relationship between work form and $\dot{V}O_2max$

using the 3-scale category of the work intensity, is comparable with these studies.

In our multiple regression model, work form was an independent explanatory variable for the $\dot{V}O_2$max in males after adjusting for age, SBP, BMI, exercise habits, exercise histories, and smoking habit. The factors of “standing” and “ambulatory” for physical work load levels appeared to increase $\dot{V}O_2$max.

In addition, in our research on $\dot{V}O_2$max, the influence of work form was stronger among males than exercise habits, a finding that is meaningful for health promotion and industrial health.

Although, the factors of “standing” and “ambulatory” for work form showed positive standardized regression coefficients, significance was not observed for females.

The reason for this may be that the working duration time and the intensity of “ambulatory”, “standing” as work form are different between the male and female. For instance, working time of more than 8 h for one day and heavily loaded labor are seen among males, on this point as well, there is room for further investigation.

Health promotion

Although the sedentary workers in this research had the highest rate of exercise habits compared to the standing or ambulatory workers, $\dot{V}O_2$max may decrease more among those who do not take exercise. Therefore, health education should necessarily include instructions on exercise, especially to sedentary workers who do not exercise.

Moreover, we recommend exercise to standing workers who do not exercise. Generally Japanese workers do not have good exercise habits. It cannot be overemphasized that $\dot{V}O_2$max is increased by exercise.

Study prospectives

To overcome the limitative nature of this cross-sectional study, a longitudinal study is required. Work intensity also needs to be quantitatively examined to further test the hypothesis that it contributes to improvement of $\dot{V}O_2$max.

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