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Cardiorespiratory Capacity of Thai Workers in Different Age and Job Categories

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Abstract The objective of this study was to assess the cardiorespiratory capacity of Thai male and female blue-collar workers in different age and occupational categories. The maximal oxygen uptake (VO_2max) of 70 men and 56 women was assessed using a submaximal bicycle-ergometer test supplemented with ventilatory gas analyses. The age of the subjects varied from 16 to 55 years. They worked in construction, manual materials handling and metal jobs. For the male subjects the VO_2 max ranged from 1.43 to 3.50 l/min and from 21.3 to 66.3 ml/min/kg. The corresponding values for the female subjects were 0.97–2.97 l/min and 16.2–42.4 ml/min/kg. According to the European fitness classifications the mean age related VO_2max of the male and female subjects can be considered moderate or poor. When compared to the European data heart rate of the subjects was 25–30% higher at submaximal levels of oxygen uptake, confirming earlier results. The low cardiorespiratory capacity of many Thai workers may be a limiting or even risk factor in physically demanding jobs. *J Physiol Anthropol 21 (2): 121-128, 2002* http://www.jstage.jst.go.jp/en/

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Introduction

The maximal oxygen uptake (VO_2max) is considered the most appropriate parameter to quantify the aerobic capacity of the cardiorespiratory system (Bassett and Howley, 2000). The VO_2max reflects the efficiency of the heart and blood circulation transporting oxygen from lungs to active muscles and the efficiency of the muscles to consume oxygen available as well as to release waste products from the body (Di Prampero, 1981). The VO_2max decreases due to age and is lower for women than men, and may be affected by the physical job demands (Lewis et al., 1983; Buskirk and Hodgson, 1987; Rowel, 1993; Tanaka et al., 1997; Astrand et al., 1997; Torgen and Kilbom, 2000).

A variety of different exercise tests are used to assess the VO_2max (Howley et al., 1995; Smith et al., 1996). The tests are mostly performed in standardized laboratory conditions and protocols. Usually incremental test protocols are used either on a bicycle-ergometer or on a treadmill (Astrand and Rodahl, 1986; McArdle et al., 1991; Smith et al., 1996).The prediction of the VO_2max can also be based on submaximal step-tests (von Döbeln et al., 1967; Fitchett, 1985). In healthy persons, the cardiorespiratory responses of VO_2 and heart rate (HR) increase linearly parallel with the increase in exercise intensity up to near maximal level. Before the maximum the linearity of the VO_2 and HR relationship becomes asymptotic when the saturation level of oxygen in blood is reached and exercise is entirely based on the anaerobic energy production (Di Prampero, 1981; Wasserman et al., 1999). However, the high correlation between VO_2 and HR justifies the estimation of VO_2max by calculating the linear regression equation of VO_2 and HR at submaximal incremental levels of exercise and by using in the prediction of the VO_2max the average age-related maximal HR (Graham and Andrew, 1973; Oja et al., 1982; Astrand and Rodahl, 1986; Nielsen and Meyer, 1987; Mesquita et al., 1996; Noonan and Dean, 2000). The accuracy of this kind of VO_2max-predictions is about ±10% (Kilbom, 1990).

Previous studies in Thailand, Indonesia and India showed 25–30% higher HRs at submaximal VO_2 levels when compared to the Western data (Vanwonterghem and Intaranont, 1993; Astrand et al., 1997; Yoopat et al., 1998). That affects cardiorespiratory strain in various physically demanding jobs and more research both in the laboratory and field conditions is needed for outlining sufficient cardiorespiratory capacity of Thai workers and their acceptable physical workload. Consequently, the objectives of this study were 1) to assess the cardiorespiratory capacity i.e., the VO_2max of Thai male and female workers in different age and blue-collar job categories based on a submaximal responses of HR and ventilatory gas exchange in the incremental bicycle-ergometer test, and 2) to compare the VO_2-HR relationship of the male and female workers in different age categories, and to confirm the dependency of submaximal VO_2 and HR responses of South East Asia workers.

Methods

Subjects

The subjects comprised 70 male and 56 female Thai industrial workers aged 16–55 years in construction, manual materials handling and metal jobs (Table 1). The mean work experience in the present jobs was 4 (SD 4) years for the male and 5 (SD 4) years for the female subjects. The subjects were voluntary and were carefully informed on the test procedure and possible health risks engaged in the test.

The subjects worked in the Bangkok metropolitan area and performed various tasks in the construction (e.g., brick-laying, providing materials, carpentry), in manual materials handling (e.g., luggage sorting, loading and unloading, cleaning air crafts), and in the steel bar production.

Test protocol

Before the submaximal exercise test on a bicycle-ergometer the subjects had a health examination supplemented with an electrocardiogram (ECG) in a supine position. Each subject's resting HR was assessed from his or her ECG recordings. During the health examination the subjects responded to the questionnaire on their occupational tasks.

The bicycle-ergometer tests were carried out in the laboratory of the Ergonomics Unit at the Rangsit University in Bangkok under standardized indoor conditions. The ambient temperature was of 22°C (SD 1.5) °C and the relative humidity was 70%. The subjects wore a cotton T-shirt and shorts.

According to the pilot study on the feasibility of various submaximal test protocols for Thai workers (Yoopat et al., unpublished results), an incremental test was selected for the use with a mechanically braked bicycle-ergometer (Monark E818, Sweden). The test was started by a rest period of 2 minutes sitting on the bicycle-ergometer, and was followed by a warm-up period of 3 minutes with a load of 25 W. Then the load was increased by 25 W every second minute until the target HR of each subject was reached. It was based on the prediction of the age-related maximal HR as follows: 220-age beats/min minus 10% for the male and 15% for the female subjects. The rate of pedaling was 50 rounds/min. The exercise was followed by a 5-min recovery period sitting on the bicycle-ergometer. At rest, during the exercise and recovery the data of the ventilatory gas exchange were collected with intervals of 30 s by the Oxycon 4 gas analyzer (Mijnhardt, The Netherlands). The data included respiratory frequency (f), tidal volume (TV), volume of ventilation (VE), oxygen consumption (VO_2), the production of carbon dioxide (VCO_2), and the respiratory exchange ratio (R). In the test HR was monitored continuously and the average of every minute was registered using the BHL6000 equipment (Bauman & Haldi, Switzerland).

The VO_2max was extrapolated according to the individual linear regression equations between VO_2 and HR (Louhevaara et al., 1980; Astrand, 1986). The statistics of the data included descriptive values such as means and standard deviations, and the regression analysis of VO_2 and HR.

Results

Submaximal ventilatory gas exchange and HR

Almost all of the male subjects could perform the work load of 100 W with a mean HR of 135 beats/minute (Table 2). The corresponding values were 75 W and 146 beats/min for the female subjects (Table 3). The number of the male subjects started to reduce rapidly at the work load levels of 125 W and 150 W, and none could accomplish the load of 200 W. For the female subjects the same phenomenon was observed at the work loads of 50 W lower than those of the male subjects. At the work load of 150 W the mean HR of the male subjects was 164 beats/min, which was close to the age-predicted target HR of the subjects. Their mean VO_2 was 2.08 l/min. With the

Table 1 Characteristics of the subjects

	Men (n=70)			Women (n=56)		
	Mean	SD	Range	Mean	SD	Range
Age (years)	31	8	16–53	31	8	16–55
Height (cm)	165	6	147–180	154	6	142–165
Weight (kg)	61	9	40–89	55	8	38–76
BMI (kg/m^2)	23	3	16–32	23	3	17–31

Table 2 Ventilatory gas exchange and heart rate for the male subjects at rest and at incremental workloads

Workload (W)	N	VE (l/min) Mean	SD	Range	VO_2 (l/min) Mean	SD	Range	VCO_2 (l/min) Mean	SD	Range	R Mean	SD	Range	HR (beats/min) Mean	SD	Range
0	69	8.8	2.1	3.6-14.8	0.26	0.06	0.10-0.43	0.21	0.05	0.07-0.36	0.83	0.07	0.59-0.98	81	12	57-109
25	68	16.9	3.3	11.1-27.1	0.64	0.09	0.41-0.85	0.53	0.09	0.33-0.75	0.84	0.09	0.67-1.18	97	13	70-127
50	68	20.7	3.5	13.3-29.1	0.83	0.11	0.44-1.14	0.70	0.09	0.44-0.94	0.85	0.07	0.71-1.07	106	12	80-137
75	68	27.9	4.5	19.3-37.1	1.12	0.12	0.77-1.41	1.02	0.13	0.73-1.28	0.91	0.07	0.77-1.08	120	14	90-160
100	66	36.3	5.8	23.9-52.9	1.40	0.14	1.03-1.86	1.38	0.15	1.11-1.79	0.99	0.07	0.83-1.15	135	15	104-171
125	54	46.6	8.4	28.4-75.5	1.75	0.14	1.42-2.03	1.80	0.18	1.38-2.18	1.03	0.06	0.88-1.17	150	14	125-180
150	27	56.0	9.4	42.4-72.9	2.08	0.14	1.78-2.41	2.22	0.20	1.78-2.60	1.07	0.06	0.92-1.20	164	13	137-185
175	6	55.3	9.6	47.1-73.3	2.33	0.11	2.17-2.52	2.41	0.22	2.26-2.85	1.03	0.05	0.97-1.13	161	8	150-172

VE = pulmonary ventilation, VO_2 = oxygen consumption, VCO_2 = the production of carbon dioxide, R = respiratory exchange ratio, HR = heart rate.

Table 3 Ventilatory gas exchange and heart rate for the female subjects at rest and at incremental workloads

Workload (W)	N	VE (l/min) Mean	SD	Range	VO_2 (l/min) Mean	SD	Range	VCO_2 (l/min) Mean	SD	Range	R Mean	SD	Range	HR (beats/min) Mean	SD	Range
0	56	7.6	1.9	3.4-13.8	0.21	0.05	0.06-0.40	0.17	0.04	0.05-0.32	0.80	0.07	0.61-0.98	86	12	57-120
25	55	15.3	2.6	9.4-22.9	0.57	0.08	0.36-0.81	0.46	0.08	0.27-0.64	0.81	0.07	0.61-1.04	109	12	73-145
50	55	20.0	3.8	12.6-36.2	0.76	0.10	0.50-1.17	0.66	0.11	0.42-1.08	0.87	0.07	0.67-1.03	125	14	90-161
75	51	27.3	4.0	17.0-37.8	1.01	0.11	0.72-1.25	0.98	0.12	0.64-1.33	0.98	0.08	0.82-1.24	146	12	116-172
100	20	37.3	5.9	28.0-52.4	1.29	0.17	0.80-1.48	1.36	0.20	0.88-1.66	1.06	0.09	0.91-1.24	156	11	133-173
125	3	38.2	9.1	32.2-48.7	1.23	0.44	0.80-1.67	1.32	0.49	0.91-1.87	1.07	0.08	0.97-1.13	167	8	160-176

VE = pulmonary ventilation, VO_2 = oxygen consumption, VCO_2 = the production of carbon dioxide, R = respiratory exchange ratio, HR = heart rate.

Table 4 Estimated maximal oxygen consumption (VO_2max) for the male subjects in different age groups and job categories. MMH= manual materials handling

Men	N	VO_2max (l/min) Mean	SD	Range	VO_2max (ml/min/kg) Mean	SD	Rang
Age (years)							
16-29	36	2.60	0.50	1.46-3.50	43.7	9.2	27.2-66.3
30-39	25	2.29	0.55	1.43-3.24	35.9	7.8	21.3-47.2
40-53	9	2.16	0.57	1.53-3.13	37.1	8.2	27.1-49.7
Job							
Construction	24	2.68	0.55	1.53-3.50	45.2	9.3	27.3-66.3
MMH	22	2.26	0.58	1.43-3.47	35.3	7.2	21.3-48.7
Steel	24	2.33	0.43	1.44-2.85	38.6	8.1	21.4-51.5
All	70	2.43	0.55	1.43-3.50	40.0	9.3	21.3-66.3

female subjects the target HR was reached at the load of 100 W with the mean VO_2 of 1.29 l/min.

Maximal oxygen uptake

The assessed mean VO_2max for both male and female subjects was the highest in the age group of 16-29 years (2.60 l/min, 43.7 ml/min/kg and 1.62 l/min, 30.5 ml/min/kg, respectively) and decreased with age (Table 4 and 5). According to the job, the highest mean VO_2max was observed for male construction workers (2.68 l/min and 45.2 ml/min/kg) (Table 4). Among the female subjects the differences of VO_2max due to job were small (Table 5).

The VO_2-HR relationship

The linear regression lines of VO_2-HR in different age groups are in Fig. 1 for the male subjects and in Fig. 2 for the female subjects.

Discussion

Submaximal ventilatory gas exchange

With both male and female subjects the measured responses of ventilatory gas exchange corresponded well to external work loads during submaximal bicycle-ergometer exercise previously reported e.g., by Astrand (1960); Vanwonterghem and Intaranont (1993); Vanwonterghem and Manuaba (1997). The obtained

Table 5 Estimated maximal oxygen consumption (VO_2max) for the female subjects in different age groups and job categories

Women	N	VO_2max (l/min) Mean	SD	Range	VO_2max (ml/min/kg) Mean	SD	Range
Age (years)							
16-29	23	1.62	0.33	1.10-2.21	30.5	5.8	16.2-42.4
30-39	22	1.48	0.29	1.10-2.20	26.0	4.1	18.2-36.4
40-55	11	1.38	0.14	1.19-1.60	25.9	3.4	22.1-32.0
Job							
Construction	24	1.56	0.35	1.01-2.14	28.4	6.3	16.2-42.4
MMH	20	1.54	0.26	1.20-2.21	29.1	3.8	23.5-37.6
Steel	12	1.39	0.21	0.97-1.71	24.5	3.5	20.6-32.0
All	56	1.52	0.30	0.97-2.21	27.8	5.2	16.2-42.4

MMH = manual materials handling.

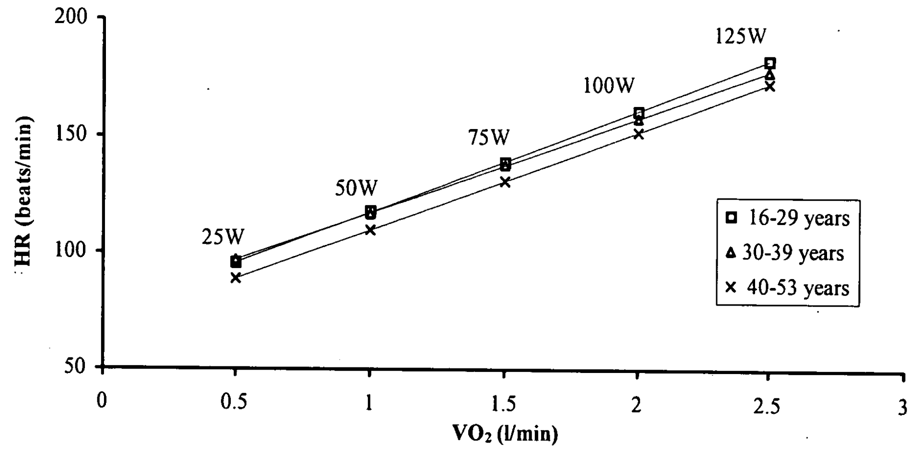

Fig. 1 Linear regression equations between oxygen consumption (VO_2) and heart rate (HR) for the male subjects in the age groups of 16-29 years (n=36), 30-39 years (n=25), and 40-53 years (n=9).

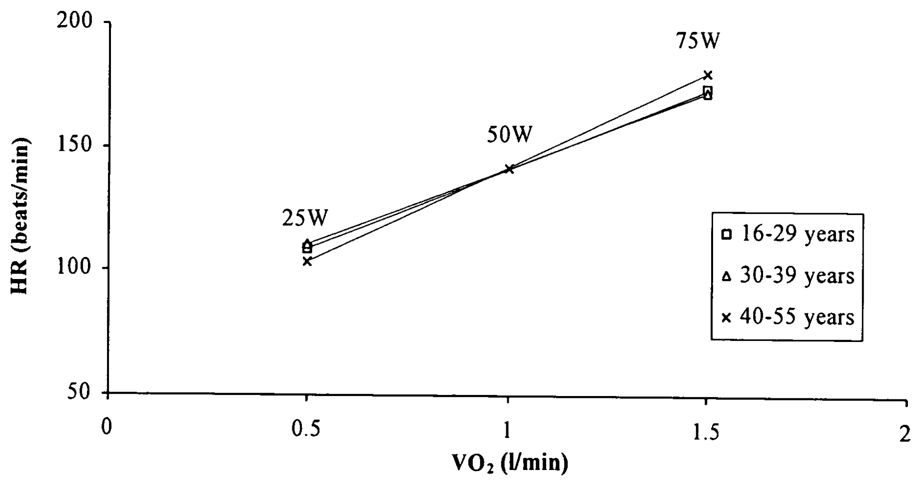

Fig. 2 Linear regression equations between oxygen consumption (VO_2) and heart rate (HR) for the female subjects in the age groups of 16-29 years (n=23), 30-39 years (n=22), and 40-55 years (n=11).

mean VO_2 values at submaximal levels of external work loads were accurately in line to the earlier well studied and documented relationships between external work load and VO_2 during submaximal bicycle exercise (Astrand, 1960; Spiro, 1977; Kilbom, 1990).

Maximal oxygen uptake

As expected the average VO_2max reduced with age. For both the male and female blue-collar workers studied, the ranges of VO_2max were quite large in each category of age and occupation. However, the male construction workers showed a higher mean VO_2max than that of steel workers and manual handlers of materials. Regarding the VO_2max related to the body mass (ml/min/kg), the average value was the lowest for the middle age category of 30–39 years, and obviously was affected by larger body mass which may be due to a slight obesity.

According to the fitness classification by Shvartz and Reibold (1990) and Vanoeteren (1995) the male workers had, on the average, a moderate VO_2max related to body mass (40.0 ml/min/kg) and that for the female workers was poor (27.8 ml/min/kg).

The submaximal cardiorespiratory capacity of the studied workers may be considered moderate or poor because their HRs were quite high for the measured submaximal VO_2 levels. The present data confirmed earlier similar findings on the submaximal VO_2-HR relationship in the South East Asia (Vanwonterghem and Intaranont, 1993; Vanwonterghem and Manuaba, 1997).

It is difficult to make reliable comparisons between the cardiorespiratory data obtained from the tropical area due to the lacking information on tests protocols, measurement equipment and occupational background of subjects. However, some data are quite equal (Saha, 1975; Varghese et al., 1995). The mean VO_2max of female workers in India was somewhat higher compared to that of industrial workers in Thailand (1.66 l/min vs. 1.52 l/min) (Varghese et al., 1995). The Indian test protocol was not identical to the Thai protocol, and the occupational background of the subjects was also different: household tasks in India and construction work, manual materials handling and jobs of steel bar production in Thailand. However, compared to the Swedish studies by Astrand (1960) and Astrand et al. (1997) the VO_2max values obtained in India and Thailand were significantly lower (on the average more than 1 l/min) than those in Sweden for both sexes in comparable age groups.

The actual training effect of the physical job demands on VO_2max is difficult to evaluate. The inter-individual differences were large in similar jobs, which suggest that, possibly due to occupational backgrounds, individual differences may mask the VO_2max values.

The low capacity of oxygen uptake affects negatively the physical performance, the productivity and efficiency, and may even create serious health risks when performing heavy physical jobs (Astrand, 1967; Grandjean, 1968). The low VO_2 capacity at submaximal work load needs to be compensated by high HRs (Vanwonterghem and Intaranont, 1993; Vanwonterghem and Manuaba, 1997).

The highest submaximal work loads of 75–100 W for the majority of the studied female workers were quite similar as found in Indian female workers (Varghese et al. 1995). Only three female workers were able to exercise at a work load of 125 W which is the equivalent of VO_2 of about 1.7 l/min. At this level the dynamic work load can be considered as moderately heavy corresponding to quite a high mean HR (167 beats/min). Most of the studied male workers were able to exercise at the load of 125–150 W. Six male workers reached the work load of 175 W with an average HR of 161 beats/min. Their HR response was reasonable high when compared with the required VO_2 of about 2.3 l/min. At the corresponding load the mean HR of Europeans was about 120 beats/min at the equal age category (Spiro, 1977; Vanoeteren and Vanwonterghem, 1995).

These results conclude that the risk for cardiorespiratory overstrain is higher in South East Asian than in Europe. This may be due to diffrences in the cardiac output, nutrition, amount of active muscle mass, and the use of stimulating drugs sometimes in combination with some tranquilizers (Vanwonterghem 1993).

VO_2-HR relationship

The slope of increasing HR at equal submaximal levels of VO_2 was steeper for the female than for male subjects. In different age categories, all linear regression lines were close to the average although the older male subjects had a slightly decreased slope compared to the younger subjects. The slope of the female subjects in the age category of over 40 years deviated most from the other age categories of the female subjects. One explanation might be that the majority of these subjects worked in steel-bar jobs consisting of lot of static muscle work.

In Fig. 3, the VO_2-HR relationship of the present subjects is compared with previous South East Asian studies (Vanwonterghem and Intaranont, 1993; Vanwonterghem and Manuaba, 1997; Yoopat et al., 1999) and the European values (Astrand, 1986). The HR of the South East Asian subjects was considerably higher at equal submaximal VO_2 levels.

The present results of high circulatory strain could possibly be related to the Sudden Death Noctural Syndrome-casualties, because of an excessive workload and fatigue whether or not associated with inadequate nutrition and socio-economical reasons (Suyasning, 1999). It can be noted that the obtained results for Thai workers between 1993 and 1999 (Vanwonterghem, 1993, Yoopat, 1999) are quite similar, and the slight differences

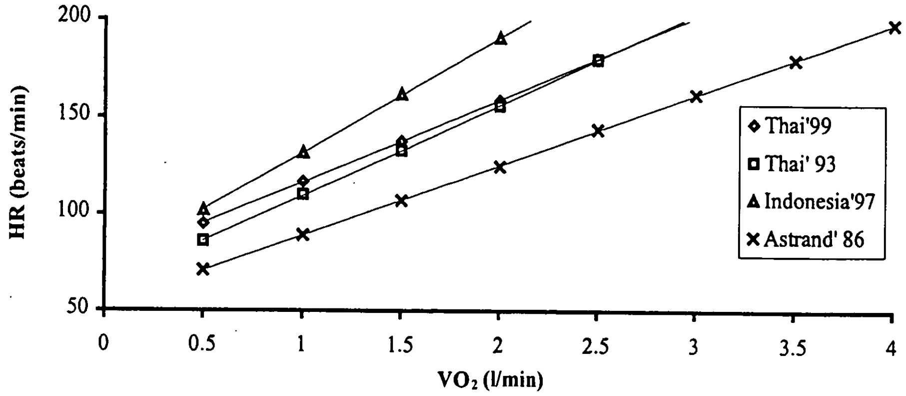

Fig. 3 VO_2-HR relationship according to linear regression lines for male subjects in different studies.

probably can be explained by the individual characteristics. The exaggerated HR response may result in the termination of the bicycle-ergometer test due to limited cardiac capacity rather than inadequate capacity of muscles to consume energy that also may have effects on the performances in physically heavy industrial work situations (Grandjean, 1968; Lewis et al. 1982; Rowell, 1993).

The cardiorespiratory capacity may become under threat in hot and humid climatic conditions because of its central role in the thermoregulation when the heat is transferred from the core to the periphery. This mechanism has also to be studied in the future since the strategy of increased vasodilatation and increased blood flow due to higher cardiac output may increase the health risks. The differences in the VO_2-HR relationship as found in the laboratory are not affected by climate because the tests were carried out under controlled conditions.

Methodological considerations

The effects of various submaximal test protocols on the estimated VO_2max values are controversial and still under discussion (Howley, 1995; Wasserman, 1999). Continuously incremental or steady state work loads can be used in exercise tests. HR and the ventilatory gas exchange can be measured and recorded in many ways. Small increases in work loads may avoid muscle fatigue in the legs and that was the main reason for selecting the present protocol as it was found that 3-min work loads were too long for Thai workers (Yoopat, unpublished results; Varghese et al. 1995). However, used incremental work loads with the length of 4 min on a bicycle-ergometer was coducted in India. These questions require further research especially in developing countries where the information on the feasibility of different exercise protocols is lacking.

The use of the linear regression equation of VO_2 and HR are also to be questioned. The linear regression up to the submaximal target HR may overestimate the VO_2max because the VO_2-HR relationship is no more linear near the maximum. On the other hand, the predicted maximal age related HR values may vary individually to about 20 beats/min. Therefore, the discussion about the use of linear or logarithmic regression equations is often not relevant. Most often the VO_2max is predicted according to the linear model (Saha, 1975; Louhevaara et al, 1980; Astrand and Rodahl, 1986; Laukkanen, 1993).

Conclusions

The present results justify the following conclusions:

- The measured VO_2 values corresponded accurately to those previously well-indicated values of VO_2 at equal submaximal external work loads with a bicycle-ergometer.
- The VO_2max of studied Thai workers is difficult to classify because of the lack of reliable gender and age specific reference values for Thai population, and the implementation of Western classifications of the VO_2max is not relevant. Reliable sex and age specific reference values for the VO_2max of the Thai and South East Asian populations should be determined.
- The VO_2-HR relationships of the Thai workers deviated from the Western workers i.e., HR of the Thai workers was considerably higher at equal VO_2 levels. The lower cardiac capacity may limit performance or be even a health risk in physically demanding jobs.

The present results confirm earlier observations. Therefore, a research project concerning the basic causal factors for the phenomenon becomes of prior importance.

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