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CARDIOVASCULAR AND METABOLIC RESPONSES TO ISOMETRIC EXERCISE OF ATHLETES AND NON -ATHLETES

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SUMMARY

Seven non-anthletes [21 - 26 yrs] and five athletes [23 - 29 yrs] have participated in the study of cardiovascular and metabolic responses to 15 minutes isometric leg exercise at 15% of each of their maximal voluntary contraction force [MVC]. Oxygen consumption [VO_2], heart rate [HR] and blood pressure [BP], were measured during resting, exercise and recovery periods. The results show that there were a significant increase in VO_2, HR and BP of the two groups studied during exercise, but no significant difference between groups has been found. This study indicates that although cardiovascular response between the two groups was not significantly different, 15 minutes isometric leg exercise at 15% MVC has challenged this system in a such a way to fulfill the metabolic requirement of the working muscle in both groups. This finding was discussed in light of the available literatures.

INTRODUCTION

NUMEROUS works have been done by many workers on the cardiovascular responses to isometric exercise. However, comparative studies among non-athletes and athletes on their cardiovascular and metabolic responses to such an exercise were lacking.

Maintenance of isometric tension of 15% or more of maximal voluntary contraction force (MVC) was found to be time-limited, and this has been attributed to the insufficient rise of the blood flow to meet the metabolic requirement of the working muscle (Lind *et al,* 1964). By analysing the collected expired air during exercise, it is possible to determine the oxygen requirement of a subject, and exercised at a tension of 15% MVC not only allows a sufficient time for us to measure this parameter, as well as heart rate and blood pressure, but this also sufficiently stressed the cardiovascular system (Lind *et al,* 1964). The aim of the present cross-sectional study was to obtain a preliminary data on the oxygen uptake of the athletes and non-athletes during isometric leg exercise of 15% MVC.

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MATERIALS AND METHODS

Twelve male healthy subjects were used in the study. They were divided into two groups (7 non-athletes and 5 athletes) on the basis of their physical activities (Table I). The anthropometric data for the subject were shown in Table I.

During exercise, subjects worked isometrically with the knee extensors, mainly the quadriceps femoris muscle, on an isometric chair. The subject was placed in the sitting position on the chair with the knee flexed at 90 . The subject was fastened on the chair by means of a waistband and the arms were held positioned at elbow flexon. The force generated in the knee extensors were measured by means of strain gauge secured at the level of the lateral malleolus. The force generated over the work period was recorded on the potentiometer and simultaneously shown on an oscilloscope. This enabled the subject to maintain a predetermined contraction force required. A clock was placed in front of the subject

TABLE I

ANTHROPOMETRIC DATA AND PHYSICAL ACTIVITIES OF NON-ATHLETES AND ATHLETES

Name of subjects*	Age (yrs)	Weight (Kg)	Height (cm)	Physical activity Non-athletes	athletes
J.K	26	68.2	170.0	Student	
M.A	21	58.8	188.0	"	
S.H	24	68.3	171.5	"	
I.C	27	65.7	177.5	"	
S.R	26	69.0	164.5	"	
M.A.A	23	46.5	159.5	"	
K.L.L.	26	62.9	165.0	"	
R.M.	25	68.4	174.5		Endurance runner
B.G.	28	69.0	179.0		"
A.L.S	29	73.6	173.0		"
M.R	24	75.2	175.0		Skier
H	33	74.7	165.5		"

*Name of the subjects are written in short form.

to enable him to note the time required to be maintained i.e. 15 mins. at 15% MVC.

After coming into the laboratory, the measurement of the anthropometric data for each subject was taken. The subject was then asked to perform his MVC, that is the greatest force he could sustain for a period of 2 seconds or more. After resting for 10 - 15 minutes, both physically and mentally, a baseline recording (used as a control) was carried out by which the subject's expired air was collected through the Douglas bag for 5 minutes. At the same time his heart rate (HR) and blood pressure (BP) were also monitored. Then on command, the subject extended his leg against work load up to 15% MVC for 15 minutes and the expired air was collected in the last 5 minutes of the exercise. The HR and BP were also measured.

The HR was calculated from the R peak of Electrocardiogram (ECG), began with the first minute of contraction, and continued for 5 minutes of recovery periods.

The BP was measured by sphygmomanometer on the right arm. Measurement was made for every 2 minutes, began with the first minute of contraction, and continued for 5 minutes of recovery period.

The collected expired air was analysed: O_2 was measured by means of O_2 analyser, servomex type OA 101 MK II, and CO_2 by means of Llyod & Haldane gas analyser. Respiratory exchange ratio (R) was determined by calculating the ratio of CO_2 volume produced/O_2 volume utilized.

Ordinary statistical methods were used to

TABLE II

OXYGEN UPTAKE (VO_2), MINUTE VENTILATION (V_E) AND GAS EXCHANGE RATIO (R) IN NON-ATHLETES AFTER 15 MINUTES ISOMETRIC LEG EXERCISE OF 15% MVC

Name of* Subjects	Condition	VO_2 (L./min)	VO_2 (ml./min./kg.)	V_E (L./min.)	R
Non-athletes	Resting				
J.K		0.22	3.2	5.0	0.83
M.A		0.18	3.1	4.8	0.89
S.H.		0.28	4.0	7.5	0.85
I.C		0.27	4.2	8.7	0.81
S.R		0.22	3.2	8.9	0.92
M.A.A		0.20	4.4	6.9	0.97
K.L.L		0.23	3.6	7.9	0.85
X ± S.E		0.23 ± 0.01	3.7 ± 0.2	7.1 ± 0.6	0.87 ± 0.02
	Exercise				
J.K		0.36	5.1	9.4	0.90
M.A		0.43	7.3	13.4	1.10
S.H		0.41	6.0	11.4	0.91
I.C		0.46	7.0	13.0	0.88
S.R		0.42	6.1	14.8	0.89
M.A.A		0.28	6.0	9.1	0.99
K.L.L		0.30	4.8	8.5	0.82
X ± S.E		0.38 ± 0.02	6.05 ± 0.34	11.4 ± 0.9	0.93 ± 0.03

*Names of subject are written in the short form
X ± S.E; mean ± standard error of the mean

calculate means and standard error of the means (S.E.). Comparison between the two means was tested with the Student's t-test.

RESULT

The result were summarised in Tables II and III. 15 minutes isometric exercise of 15% MVC has been found to increase oxygen consumption (VO_2) as much as 64% ($P < 0.002$) in non-athletes and 68% ($P < 0.01$) in athletes. There was no difference in the mean VO_2 between the two groups.

During resting, the mean HR of the non-athletes was 72 ± 2 beats/min, and as the subject perform 15% MVC force, it gradually increased, reaching a mean peak value of 109 - 11 beats/min. The mean HR then dropped immediately as the exercise stopped and almost returned to the normal value at the 5th minute of recovery period (82 ± 5 beats/min). The mean resting HR for athletes (59 ± 2 beats/min) was significantly lower than that of non-athletes (76 ± 2 beats/min) ($P < 0.02$); and the HR of the former group reached a peak value of 96 beats/min at the eleventh minute of exercise. The HR of the athletes throughout exercise were lower but not

TABLE III

OXYGEN UPTAKE (VO_2), MINUTE VENTILATION (V_E) AND GAS EXCHANGE RATIO (R) IN ATHLETES AFTER 15 MINUTES ISOMETRIC LEG EXERCISE OF 15% MVC

Name of* Subject	Condition	VO_2 (L./min)	VO_2 (ml./min./kg.)	V_E (L./min.)	R
Athletes					
Resting					
R.M		0.22	3.2	5.0	0.83
B.G		0.31	4.6	7.3	0.74
A.L.S		0.22	2.9	5.1	0.69
M.R		0.26	3.5	8.4	0.83
H		0.34	4.6	8.7	0.95
X ± S.E		0.27 ± 0.02	3.8 ± 0.36	7.0 ± 0.72	0.81 ± 0.04
	Exercise				
R.M		0.48	7.1	12.6	0.89
B.G		0.54	7.8	13.8	0.90
A.L.S		0.39	5.4	12.5	0.95
M.R		0.48	6.4	14.9	0.97
H		0.40	5.4	9.1	0.91
X ± S.E		0.46 ± 0.06	6.4 ± 0.8	12.6 ± 1.0	0.92 ± 0.02

*Names of subject are written in the short form
X ± S.E; mean ± standard error of the mean

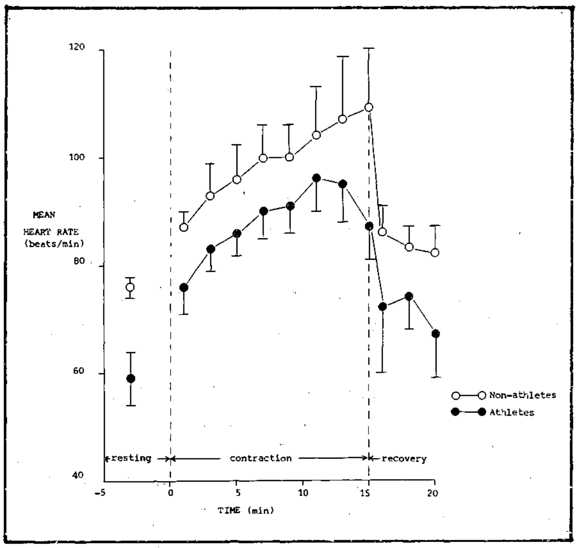

Fig. 1. Effects of 15% MVC of isometric exercise on heart rate in non-athletes and athletes. Bars indicate standard error of the mean.

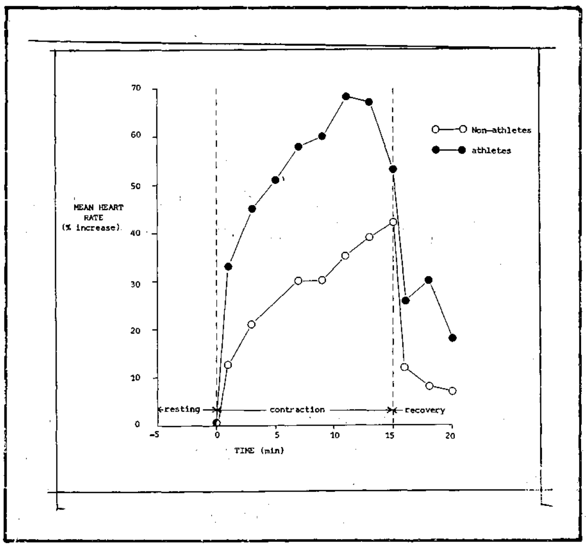

Fig. 2. The percentage increase in heart rate during 15% MVC of isometric exercise in non-athletes and athletes.

significantly different from that of non-athletes (Fig. 1). However, compared to the non-athletes, the percentage increase of HR in the athletes during exercise was markedly shown (Fig. 2).

In non-athletes, there was a 44% increases in the mean systolic pressure during exercise ($P < 0.001$), whereas, for the athletes the percentage increase was 32% ($P < 0.01$). On the other hand, the percentage increase in the diastolic pressures in non-athletes and atheletes during exercise were 52% and 50% respectively ($P < 0.001$) for both cases). There were no statistical difference in both systolic and diastolic pressure between groups (Fig. 3).

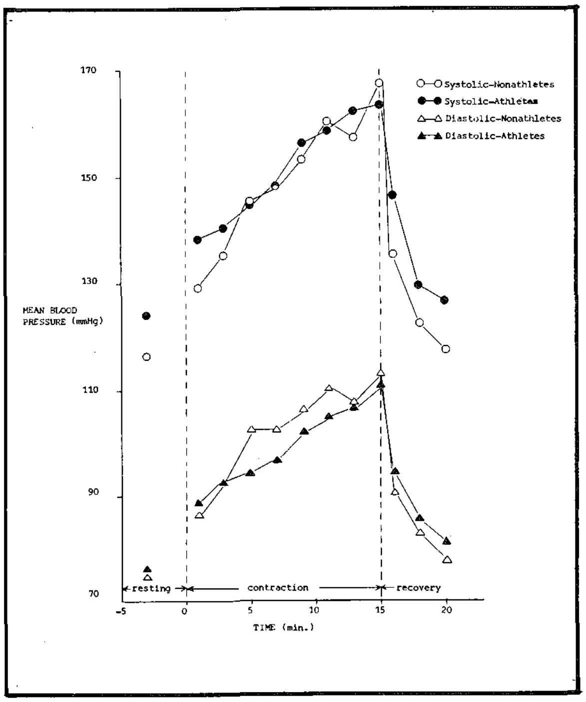

Fig. 3. Effects of 15% MVC of isometric exercise on blood pressure in non-athletes and athletes. Bars were omitted for clarification.

The mean R value for non-athletes during exercise was not significantly greater than that during resting period ($P > 0.10$), but in athletes the difference was statistically significant ($P < 0.05$). There was no statistical difference in the mean R values between groups ($P > 0.10$ both during resting and exercise periods).

DISCUSSION

The feasibility of the present study was based on the fact that a subject should be able to perform the longest exercise at a given tension which is not too low that the cardiovascular system is not sufficiently stressed, but not too high that the blood flow is occluded. Preliminary study shows that 15% MVC is the tension by which a subject can maintain for a period of maximum 15 minutes, and such a relatively long period for a performance of isometric exercise provides us a sufficient time for a measurement of the cardiovascular parameters to be made. Furthermore, Lind *et al* (1964) shows that 15% MVC is the critical tension beyond which the blood flow is occluded.

From this investigation it is evident that, during 15 minutes isometric work of 15% MVC, there was a pronounce increased in the cadio-vascular and metabolic responses within each group of subjects studied. Clark (1960) shows that during isometric exercise, there was a linear increase in the volume of oxygen income, the oxygen debt and the total oxygen requirement. However, there was a smaller oxygen income and a larger oxygen debt when static is compared to dynamic exercise at a comparable metabolic work load. This is attributed to the fact that in isometric exercise, mechanical impedence in the active muscle as a result of muscle tension occludes blood circulation (Donald *et al,* 1967; Lind *et al* 1966; Barcroft *et al,* 1939). Such a decrease in blood flow occurs in spite of the local vasodilator effects of the metabolites. If some of these muscles have their vessels occluded, then their contributions to the overall metabolic rate will not be represented in measurement made from collection of expired gas and this may partially account for the low VO_2 for the isometric work (Whipp and Phillips, 1970). Thus, in short period of work, Adenosin triphosphate (ATP) and Creatine phosphate (CP) can yield energy and the O_2 presents in the muscle (bound to the myoglobin) also makes an energy delivery from aerobic process possible. On the other hand, a prolonged activity period with reduced blood flow may cause the O_2 need to exceed the

O_2 supply, and the energy yield will be contributed by anaerobic process.

The present study indicated that the VO_2 of athletes was not significantly different from that of non-athletes. This is in an apparent contrast with the finding by Astrand (1955) who shows that men with very high work capacities (athletes) have very high VO_2 mae than those who have low capacities non-athletes), and this could be due to the inability of the tissues to extract more O_2 in the case of the latter group. The apparent difference between the present finding and that of Astrand's (1955) is unknown, although it could be due to the difference in the type and severity of exercise being studied: Astrand (1955) measured VO_2 max of subject performing dynamic exercise, whereas in the present study VO_2 was measured in an isometric exercise of relatively low tension.

The increase in HR and BP during isometric work was in a good agreement with that of previous workers (Goodwin *et al,* 1972; Tuttle and Hovarth, 1957). Although the HR of the athletes throughout exercise was not significantly different from that of non-athletes, the percentage increase in the former was greater than that of the latter group (Fig. 2). This finding is in an agreement with a well established fact that individual known to have considerable endurance usually have a slow resting HR. Training enables a person to achieve a certain cardiac output at rest, as well as during work, with a slow HR and a large stroke volume (SV) (Astrand and Rodahl, 1970). One of the interesting findings from the present study was that the HR of the athletes reached maximum at the eleventh minutes of the exercise period, whereas in the non-athletse group there was no indication of any stabilisation of HR even at the 15th minute of contraction. The mechanism for such a fast-reaching maximal HR for the athletes was unknown. However, this again, could be an indication of the bodily adjustment in a physically trained subject, in particular, his ability to have a greater SV during working.

The present data on the diastolic pressure substantiated the finding by Whipp and Phillips (1969) who showed that this pressure increases to value above 100 mmHg during isometric exercise, although they did not mention the severity of exercise being studied. The increase in resistance to blood flow, secondary to mechanical constriction of the blood vessel in a large muscle mass, may account for this high pressure (Whipp and Phillips, 1969). Our study also indicates that there was no difference in the pattern of BP between the two groups. The possible explanation for this is that during isometric work, the peripheral vasodilatation in itself is insufficient to allow blood flow. Since this impedence depends on the percentage of tension exerted, so the degree of increase in BP is experted to be the same in both athletes and non-athletes because both broups have the same relative tension.

It is impossible from the present study to conclude the percentage participation of carbohydrate and fat in the energy metabolism of the exercising individuals. However, on the basis of a greater value of R during exercise, particularly in athletes, it can be suggested that there was an increased in the use of carbohydrate as a fuel during this period. This is in accordance with the idea that the utilization of carbohydrates depend on the oxygen supply of the working muscle; the more inadequate the oxygen supply, the higher the carbohydrate utilization Astrand and Rodhal, 1970).

The present study, therfore, shows that 15 minutes sustained isometric contraction of 15% MVC could stress cardiovascular system in such a way as to meet the metabolic requirement of the exercising subjects. The fact that the cardiovascular adjustment in athletes and non-athletes was not distinguishable from this study, should not undermined the above findings. This is because the athletes participated were endurance runners and skiers, and not really trained with isometric exercise, and also that this study was conducted on a cross-sectional basis. A question remains to be answered whether subjects trained in this exercise at a given duration and intensity, manifest any difference in their cardiovascular performances compared to that of untrained subject undergone the same test.

It should be mentioned that the response of an individual towards physical exercise is also determined by the proportions of fibre types in the working muscle itself. It has been shown that at tension of 20% MVC or lower, only slow twitch fibres were recruited, whereas fast twitch fibres were recruited at higher tension (Gollnick *et al.* 1974). Thus, analysis of histochemical fibre pattern form muscle biopsy specimen of these subjects would hopefully give additional informations on their response towards exercise.

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REFERENCES

Astrand, P-O, (1955). New records in human power. *Nature,* **176**:922

Astrand, P-O, and Rodahl, K. (1970). Textbook of work Physiology McGraw-Hill, Kogakusha Ltd., Japan

Barcroft, H. and Miller,J.(1939). Blood flow through muscle during sustained contraction. *J.Physiol.* (London) **97**: 17-31

Clark, D.H. (1960). Energy cost of isometric exercise. *Res. Quart.* **31**: 3-6.

Donald,K.W., Lind, A.R. McNicol, C.W., Humphreys, P.W., Taylor, S.H. and Staunton, H.P. (1967). Cardiovascular response to sustained (static) contractions. *In: Amer. Heart Ass. No 15 by Chapman, B. [Ed]. 15-32*

Gollnick, P.D., Karlsson, J., Piehl, K. and Saltin, B. (1974). Selective glycogen depletion in skeletal muscle fibres of man following sustained contraction. *J.Physiol.* **241**: 59-67

Goodwin, G.M., McClusky, D.I. and Mitchell, J.H. (1972). Cardiovascular and respiratory response in change to central command during isometric exercise at constant muscle tension. *J.Physiol.* **126**: 173-190

Lind, A.R., Taylor, S.H. Humphreys, P.W., Kennelly, B.M. and Donald, K.W. (1974). The circulatory effect of sustained voluntary muscle contraction. *Clin. Sci.* **27**: 229-244

Lind, A.R. and McNicol, G.W. (1966). Muscular factors which determine the cardiovascular responses to sustained and rhythmic exercise. *Canad. Med. Ass. J.* **96**: 706-713

Tuttle, W.W. and Horvath, S.M. (1967). Comparison of effect of static and dynamic work on blood pressure and heart rate. *J. Appl. Physiol.* **10**: 294-296

Whipp, B.J. and Phillips, E.E. (1970). Cardio-pulmonary and metabolic responses to sustained isometric exercise. *Arch. Phys. Med. Rehan.* **51.** 398-402