Cardiovascular Responses in Upper and Lower Extremities Exercises

Khin Nwe Kyi[1], Ye Tint Lwin[2], Khin Sein Win[1], Molly Chit[3] & Ba Kyaing[3]

[1]Physiology Department
Defense Services Medical Academy
[2]Physiology Research Division
Department of Medical Research (Lower Myanmar)
[3]Medical Unit, Institute of Sports and Physical Education
Department of Sports and Physical Education

This randomized controlled study was done to determine the cardiovascular responses in upper (arm) and lower (leg) extremities exercises. The study was conducted on thirty male soccer players, aged from 16 to 20 years from the Institute of Sports and Physical Education, Yangon. The subjects participated in both arm cranking and leg cycling tests at three different workloads (25±1, 50±1 and 75±1 watts) with bicycle ergometer on different days in the same environmental conditions. The heart rate and blood pressure of the subjects were determined before, during and after the exercise. The significant increases in heart rate from 61.2±9.1 beats.min^{-1} to 89.3±10 beats.min^{-1} at load I to 108.9±14 beats. min^{-1} at load II and to 136.2±19 beats.min^{-1} at load III ($p<0.001$) in arm exercise and from 62.3±8 beats.min^{-1} to 80.6±8.2 beats.min^{-1} at load II and to 105.3±9.3 beats.min^{-1} at load III ($p<0.001$) in leg exercise were noted. Systolic blood pressure increased significantly from basal level of 104.3±7.2 mmHg to 112.5±7.2 mmHg at load I, to 127.3±7.4 mmHg at load II and to 135.1±8.3 mmHg at load III ($p<0.001$) in arm exercise and from basal level 103.0±7.5 mmHg to 110.3 ±8.9 mmHg at load I, to 114.0±21.4 mmHg at load II and to 130.3±11.2 mmHg at load III ($p<0.01$) in leg exercise. The increment in heart rate due to arm exercise was significantly greater than that due to leg exercise (28.1±8.5 beats.min^{-1} *vs.* 18.3±6 beats.min^{-1} at load I, 47.7±12.4 beats.min^{-1} *vs.* 29.8±7.0. beats.min^{-1} at load II and 75.0±17.3 beats.min^{-1} *vs.* 43.0 ±8.9 beats.min^{-1} at load III, respectively). The study clearly pointed out that upper extremity exercise elicited greater cardiovascular response than lower, extremity exercise.

INTRODUCTION

Exercise is synonymous with physical activity. Although exercise is defined ultimately in terms of muscular contraction, exercise affects every organ in the body. Furthermore, different forms of exercise evoke quite different responses in various organ systems. These responses depend on whether exercise involves small or large muscle mass, rhythmic or isometric, acute or chronic (training), intense or mild and of long or short duration.

Cardiorespiratory fitness was defined as "the ability to continue or persist in strenuous task involving large muscle groups for an extended period of time".[1] By attaining aerobic fitness, the circulatory and respiratory systems are able to adjust quickly to and recover from moderate to vigorous activities, such as running, swimming, cycling and brisk walking. Cardio-respiratory fitness also offers protection from a myriad of health disorders, including cardiovascular disease, stroke, hypertension, diabetes mellitus and obesity.[2]

The role of circulatory system in exercise is to augment the delivery of metabolic substrates and oxygen required for ATP generation. Continuous removal of the carbondioxide and hydrogen ions generated by aerobic and anaerobic metabolism also is necessary to maintain an intracellular pH for muscle contraction and glycolytic enzyme functions. These are achieved by increasing cardiac output and altering the distribution of blood flow to various vascular beds.[3] They also revealed that in the performance of dynamic exercise, cardiac output increases from resting level of 4-6 L/min to maximal levels as high as 36 L/min in well-trained athletes.

The difference in circulatory response to arm and leg exercises was pointed out by Christensen in 1931.[4] In larger groups of subjects the higher heart rate in arm work than in leg work at a given level of oxygen uptake and the lower mechanical efficiency in arm work have been documented since then. Upper body exercise is common and is often a predominant activity for many individuals.

For example, wheelchair users use the upper body musculature for locomotion. In addition, within the past several years, arm-crank exercise that predominantly activates the upper body musculature has been recommended for the rehabilitation of individuals who have suffered a myocardial infarction or undergone bypass surgery.[5, 6]

Upper body exercise however, causes a greater strain on the cardiovascular system compared to exercise with the lower body.[7, 8] A greater maximal oxygen uptake (VO_2 max) response is found at a given constant power output utilizing an arm crank than leg cycling.[9] Upper extremity exercise also elicits higher systolic and mean arterial blood pressures, equal or lower cardiac output and lower stroke volume at a given sub-maximal power output as compared to lower extremity exercise.[9, 10.]

At a given sub-maximal workload, arm exercise is performed at a greater physiological cost than leg exercise. At a given power output heart rate, systolic and diastolic pressure, oxygen consumption, respiratory exchange ratio and blood lactate concentration are higher while stroke volume and anaerobic threshold are lower during leg exercise.[11] Sub-maximum arm exercise produced higher heart rate, blood pressure and pulmonary ventilation than comparable intensities of leg exercise.[12]

By understanding the differences in physiological response between arm and leg exercises, professionals can formulate exercise programmes for specific diagnosis and/or training.[13] Thus, the present study aimed at determining cardiovascular responses in the same person for exercises of upper and lower extremities.

MATERIALS AND METHODS

Thirty apparently healthy male soccer players aged from 16 to 20 years were recruited randomly from Institute of Sports and Physical Education, Yangon. The subjects underwent medical examination including history taking, physical examination and ECG recording. Those with acute illness and ECG abnormalities were excluded from the study.

Experimental procedure

Written informed consent was obtained from each subject after explaining about the procedure. The experiment was performed at 08:00 a.m. The subjects were asked to wear shorts and short sweat shirt in order to have free movement when they were exercising. They were instructed not to make any other physical activity on that day and not to take coffee or tea for 2 hours before the test.

All subjects, participated in both arm cranking and leg cycling tests, performed 3 loads of discontinuous test on different days. Monark bicycle-ergometer was used for both arm cranking and leg cycling. All studies were performed in a comfortable laboratory environment with a mean temperature of 21°C and within the range of 18-23°C.

Each test was preceded by a 10-minute rest in seated position, after which baseline measurements of heart rate and blood pressure were made. Three workloads selected were 25±1 watts as the first load, 50±1 watts as the second load, and 75±1 watts as the third load for all subjects. For an arm cranking, the bicycle-ergometer was placed and secured on the table. The subject sat in front and the axle was placed at shoulder level. The position was adjusted to be the same for all subjects.

Then, the subject was instructed to crank 50 rpm and the workload was raised to 0.5 kg (25 watts). The subject worked for 3 minutes. During this period, the heart rate was recorded every minute with polar heart rate monitor. Blood pressure was measured immediately at the end of 3 minutes and the subject was allowed to take rest for 5 minutes.

Then, the subject was asked to crank again at 5 rpm and workload was raised to 1 kg (50 watts). The subject worked for 3 minutes, and heart rate was recorded every minute with polar heart rate monitor. Blood pressure was measured immediately at the end of 3 minutes and the subject was allowed to rest for 5 minutes.

The same procedure was repeated again with the workload of 1.5 kg as 3rd workload (75 watts). From beginning to end of the experiment, the subject was not allowed to take food and water.

For leg cycling exercise, appropriate seat, height was selected for each subject and position was standardized. The same work-load and the procedure were followed as in arm cranking, but on a separate day.

Heart rate was measured by Polar Heart Rate Monitor. Transmitter was wrapped around the chest at nipple line and receiver was attached to the wrist. Heart rate was directly read as digital number from screen of receiver. The instrument was standardized with the measurement of the radial pulse by palpation method for sixty seconds. Blood pressure was measured over the right brachial artery using mercury sphygmoma-nometer according to WHO method (1978).

RESULTS

Table 1 shows general characteristics of the subjects. Mean age, height and weight of the subjects were more or less similar. Cardiovascular status such as resting heart rate, systolic and diastolic blood pressure were more or less comparable.

Table 1. General characteristics of the subjects (Mean±SD)

Characteristics	Test group (n=30)
Age (yrs)	17.43±1.25
Height (cm)	167.91±4.65
Weight (kg)	57.27±4.37
Resting heart rate (beats/min)	61.20±9.17
Blood pressure (mmHg)	
SBP	104.33±7.27
DBP	68.00±5.50

SBP=Systolic blood pressure
DBP=Diastolic blood pressure
n=Number of subjects

Table 2 shows cardiovascular responses to arm and leg exercises. The heart rate and the systolic blood pressure increased significantly from basal level in all 3 work-loads in both arm and leg exercises.

Table 2. Cardiovascular responses to arm and leg exercises (mean±SD)

	Basal	Load 1	Load 2	Load 3
Heart rate (beats/min)				
Arm	61.2±9.1	89.3±9.7***	108.8±13.9***	136.2±18.7***
Leg	62.3±7.9	80.57±8.2***	92.0±9.0***	105.3±9.3***
SBP (mmHg)				
Arm	104.3±7.2	112.5±7.2***	127.3±7.3***	135.17±8.3***
Leg	103.0±7.4	110.3±8.8***	114.0±21.4**	130.3±11.2***
DBP (mmHg)				
Arm	68.0±5.5	70.6±6.5****	70.3±9.27****	66.6±8.8****
Leg	68.6±5.0	71.6±5.9*	69.1±5.8****	67.3±7.3****
PP (mmHg)				
Arm	36.3±6.6	41.8±9.1***	57.0±10.2***	68.5±10.9***
Leg	34.3±5.6	38.6±8.6**	44.8±21.4**	63.0±9.8***
MAP (mmHg)				
Arm	80.1±5.3	84.6±5.3***	89.3 ±7.2***	89.5±7.0***
Leg	80.1±5.4	84.2±5.9***	84.9±6.0***	88.3±8.0***

HR=Heart rate, SBP=Systolic blood pressure
DBP=Diastolic blood pressure, PP=Pulse pressure
MAP=Mean arterial pressure
p<0.05 means statistically significant
*indicates p<0.05 from baseline value
**indicates p<0.01 from baseline value
***indicates p<0.001 from baseline value
****indicates p>0.05 from baseline value

Although the diastolic blood pressure increased significantly in the 1st workload of leg exercise, that of arm exercise was not significantly increased. The diastolic blood pressure was not significantly increased in the 2nd and the 3rd workloads of both arm and leg exercises. In the case of pulse pressure, changes were significant in both arm and leg exercises. Mean arterial pressure changes were statistically significant in all 3 workloads of both arm and leg exercises.

Heart rate changes of both arm and leg exercises showed significant increase from basal level. The greater the increment of the workload, the larger the changes in the heart rate were noted. The increment in the heart rate due to arm exercise was significantly greater than that of leg exercise.

A significant increase in the systolic blood pressure was observed in all 3 work sessions in both arm and leg exercises. In addition, the change of the systolic blood pressure due to arm exercise after the 2nd workload was found to be significantly greater than that of leg exercise.

There were no significant changes in the diastolic blood pressure in all 3 work sessions of arm exercise. In leg exercise, a significant increase in the diastolic blood pressure in the 1st workload was observed but no significant changes of diastolic blood pressure were found in the 2nd and the 3rd workloads. There were no significant differences in the diastolic blood pressure changes between arm and leg exercises.

DISCUSSION

In this study, the heart rate increased in all 3 workloads of both arm and leg exercises; the greater the increment of the workload, the larger the changes in the heart rate. The heart rate initially increased at any given workload and if the exercise was sustained, it remained more or less steady at the raised values. When this steady state, value for the heart rate was measured at several workloads, interrupted by rest periods, there was a linear relation between the heart rate and given workload.[14] The heart rate increment due to arm exercise was significantly greater than that of leg exercise. These findings were in agreement with previous observations.[15]

They explained that exercise with the arm evoked higher heart rate than the leg exercise at a given workload. This could be due to the increased sympathetic tone resulting from static contraction of the muscles which stabilize posture. However, the differences in physiological variables remained between arm and leg exercises even when the light workloads were used to minimize the effect of the static component during arm exercises.[16]

In the present study, the same workload was given in both arm and leg exercises. The legs have greater muscle mass than arms, so that at the same level of comparable load, arm exercise may induce much higher metabolic workload as well as muscle spindle activity and consequently stimulation of chemoreceptors and mechemoreceptors than does leg exercise. The lactate concentration in arterial blood was higher during arm work, reflecting a more pronounced metabolic acidosis, and evoked higher pulmonary ventilation, which in turn had an effect on heart rate and cardiac output.[17]

During arm cranking, the afterload on the heart is greater than that of leg cycling because area of vascular bed dilation is lesser than that of constriction in arm cranking leading to increased total peripheral resistance. In addition, during arm cranking the venous return is less facilitated which may result in relatively low stroke volume.

During upper extremity exercise, increased sympathetic output elevates the peripheral resistance and heart rate. An elevated heart rate may maintain a high level of cardiac output.[9, 10] The mean arterial pressure (MAP) was increased with increased work load. The changes were statistically significant in both arm leg exercises.

There was significant increase in the systolic blood pressure (SBP) observed in all 3 work sessions in both arm and leg exercises.

Increased systolic blood pressure generally reflects increased cardiac output. The increase in cardiac output is due to an increase in heart rate or stroke volume or both. In the present study, increased heart rate in both arm and leg exercises were noted. There might also be increased stroke volume because arm cranking and leg cycling exercise were isotonic in nature and the heart rate was below 180 beats/min. Increase in stroke volume contributes to increase in cardiac output up to 40-45% of VO_2 max. Further increases in cardiac output were due to increase in the heart rate.[18]

In both arm and leg exercises, the diastolic blood pressure increased in the 1st workload but decreased in the 2nd and the 3rd workloads. The diastolic blood pressure generally reflects the total peripheral resistance. There was a generalized sympathetically mediated vasoconstriction in exercise that is opposed in active tissue by a metabolically induced vasodilatation.[19] This can be observed in the changes of diastolic blood pressure in this study. At the 1st workload, it increased probably because of a generalized vasoconstriction of exercise stress but when exercise was continued with the 2nd and the 3rd workloads, decrease in the diastolic blood pressure was noted probably due to accumulation of vasodilator metabolites in the active muscle.

The changes in mean arterial pressure of arm exercise were greater than those of leg exercise although statistically significant change was found only at the 2nd workload. This finding was in agreement with the previous studies.[20] They described that at a given maximal oxygen uptake, the systolic and diastolic blood pressures are considerably higher when work is performed with upper extremities than that with the lower extremities. [20] Another study stated that with exercise, the resistant vessels dilate in the active muscles by a local mechanism, and constriction in the inactive muscles was due to an increase in sympathetic vasoconstrictor activity. [21] It is, therefore, possible that a higher arterial pressure will ensure if the work is performed with small muscle groups when only a small part of the vascular bed dilates compared to the large remaining vascular bed in which a constriction of the resistance vessels will occur.[21] On the other hand, the higher blood pressure for a given oxygen uptake during arm exercise compared to leg exercise indicates a higher sympathetic outflow.[15]

The changes of systolic blood pressure due to arm exercise after the 2nd workload was found to be significantly greater than that of leg exercise. Although there were not statistically significant differences of systolic blood pressure after the 1st and the 3rd workloads, exercise indicated a higher sympathetic outflow.

The changes of systolic blood pressure in arm exercise after the 2nd workload was found to be significantly greater than that of leg exercise. Although there were not statistically significant differences of systolic blood pressure after the 1st and the 3rd workloads, systolic blood pressure in arm exercise was found to be greater than that of leg exercise. When compared between arm and leg exercises, the increment of the heart rate was significantly greater in arm exercise, so systolic blood pressure in arm exercise was also greater than that in leg exercise.

Conclusion

Heart rate increased significantly from the basal level in both arm and leg exercise. The greater the increment of the workload, the larger the changes in heart rate were noted. The increment in heart rate changes due to arm exercise was significantly greater than that of leg exercise.

A significant increase in systolic blood pressure, pulse pressure and mean arterial blood pressure was observed in all 3 work sessions in both arm and leg exercises. There was no significant change in diastolic blood pressure in all three work sessions of arm exercise. In leg exercise, a significant increase in diastolic blood pressure was observed in the 1st workload but not in the 2nd and the 3rd workloads. There were no significant differences in diastolic blood pressure changes between arm and leg exercises.

Recommendations

Since the study in agreement with previous studies, clearly pointed out that upper extremity exercise elicited greater cardio-vascular response than lower extremity exercise;

- Exercise regimen prescribed to patient with ischaemic heart diseases should be based on leg exercise rather than arm exercise.
- In cases of lower body injuries requiring prolonged rest, arm exercise should be prescribed to maintain cardiovascular fitness of the patients. This is very important for athletes.

REFERENCES

1. Nieman DC. Immune response to heavy exertion. *Journal of Applied Physiology* 1998; 82: 1385-1394.
2. Blair SN, Kohl HW, Gordon NF & Paffenbarger RS. Flow much physical activity is good for health. *Annual Review of Public Health* 1992; 13: 19-26.
3. Kremser CB & Rajfer SI. The normal cardio-vascular response to exercise. *Cardio-pulmonary Exercise Testing* 1986; 107-121.
4. Stengberg J, Astrand PO, Ekblom B, Royce J & Saltin B. Heamodynamic response to work with different muscle groups, sitting and supine. *Journal of Applied Physiology* 1967; 22(1): 61-70.
5. Toner MM, Glickman EL & McArdle WD. Cardiovascular adjustment to exercise distri-buted between the upper and lower body. *Medicine and Science in Sport and Exercise* 1990; 22(6): 773-778.
6. Franklin BA, Scherf J, Pamatmat A & Rubenfire M. Arm-exercise testing and training. *Cardio-logy* 1982; 8: 43-70.
7. Astrand PO, Ekblom B, Messin R, Saltin B & Stenberg J. Intraarterial blood perssure during exercise with different muscle groups. *Journal of Applied Physiology* 1965; 20: 253-256.
8. Schwade J, Blomqvist CG & Shapiro W. A comparison of the response to arm and leg work in patients with ischemic heart disease. *American Heart Journal* 1977; 94: 203-208.
9. Toner MM, Sawka MN, Levine L & Pandolf KB. Cardio-respiratory responses to exercise distributed between the upper and lower body. *Journal of Applied Physiology* 1983; 54: 1403-1407.
10. Sawka MN. Physiology of upper body exercise. *Exercise and Sports Science Review* 1986; 14: 175-211.
11. Franklin BA. Exercise testing, training and arm ergometry. *Sports Medicine* 1985; 2: 100-119.
12. McArdle WD, Katch FI & Katch VKL. Functional capacity of the cardiovascular system. In: *Exercise Physiology Textbook*, 5th ed. Philadelphia 2001; 344-357.
13. McArdle WD, Katch FI & Katch VL. Energy, nutrition and human performance. In: *Exercise Physiology Texbook*, 4th ed. Baltiomore Williams Wilkins Co, 1996.
14. Astrand PO & Rodahl K. In: *Work Physiology Textbook.* McGraw Hill, New York. 1970; 147-183,
15. Bevegard S. Freyschuss U & Strandell T. Circulatory adaptation to arm and leg exercise in supine and sitting position. *Journal of Applied Physiology* 1966; 21: 37-46.
16. Taguchi S & Horvath SM. Metabolic responses to light arm and leg exercise when sitting. *European Journal of Applied Physiology* 1987; 56: 53-57.
17. Stenberg J, Astrand PO, Ekblon D, Royce J & Saltin B. Haemodynamic response to work with different muscle groups, sitting and supine. *Journal of Applied Physiology* 1967; 22: 61-70.
18. Patil RD, Karve SV & DiCardo SE. Integrated cardiovascular physiology: A laboratory exercise. *American Journal of Physiology* 1993; 265: 520-531.
19. Shephard JT, Blomqvist CG, Lind AR, Mitchell JH & Saltin B. Static (Isometric) exercise. Retrospection and introspection. *Circulation Research* 1981; 48(6 pt 2): 179-188.
20. Bloomfield J, Fricker PA & Fitch KD (Editors). In: *Science and Medicine in Sport Textbook.* Melbourne. Blackwell Scientific Publications.
21. Blair DA, Glover WE & Roddie IC. Vasomotor responses in the human arm during exercise. *Circulation Research* 1961; 9: 264-274.