Relationship between Heart Rate and Oxygen Uptake during Submaximal Arm Cranking in Paraplegics and Quadriplegics

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The purpose of this study was to clarify the effect of the level of spinal cord injury (SCI) and of daily exercise on the relationship between heart rate (HR) and oxygen uptake (Vo_2) in persons with SCI (PSCI) during an arm cranking exercise. Eighteen PSCI were divided into three groups according to the level of SCI; 4 quadriplegics (C6-C8), 7 high-level paraplegics (T3-T8), and 7 low-level paraplegics (T10-L2). In the relationship between HR and Vo_2 , the higher the level of SCI, the smaller the slope of regression line, that means the HR at a given Vo_2 become larger as level of SCI was higher. Significant differences were found among these regression lines ($P < 0.01$). In addition, the regression lines between HR and Vo_2 in active persons tended to shift toward upper in comparison with those in inactive persons. The present investigation clearly shows that the HR- Vo_2 relationship in PSCI is remarkably influenced by the level SCI and physical training. (Ann. Physiol. Anthropol. 13(5) : 275-280, 1994)

Key words : Heart rate, Oxygen uptake, Paraplegics, Quadriplegics, Arm cranking exercise

It has been well established that persons with spinal cord injury (PSCI) have higher heart rate (HR) responses for a given work rate or oxygen uptake (Vo_2) level than able-bodied persons (ABP) (Hjeltnes, 1977; Jehl et al., 1991). The higher HR response during submaximal exercise could be attributed to venous blood pooling in paralyzed lower limbs that resulted in lower stroke volume. Thus, in PSCI, the relationship between HR and Vo_2 is expected to be different from that in ABP.

Furthermore, as the level of spinal cord injury (SCI) is higher, haemodynamic adaptation to exercise will be strongly affected. Drory et al. (1990) pointed out that in exercising at similar work loads, HR was significantly higher in quadriplegics and upper paraplegics (T1-T) than in ABP, and no significant differences were found between lower

paraplegics (below T6) and ABP. Even in everyday life, persons with the high level of SCI showed the higher HR (Yamasaki et al., 1992). In the relationship between HR and Vo_2 , the level of SCI should be taken into consideration.

As is true with ABP, physically active PSCI have a higher capacity for aerobic exercise compared to inactive PSCI (Nilsson et al., 1975; Davis and Shephard, 1988; Yamasaki et al., 1994). It has been widely confirmed that in trained ABP, HR responses for given work load are lower than in untrained ABP. Accordingly, training level is one of the most important factors in the relationship between HR and Vo_2 . However, there are few studies of training effect on this relationship in PSCI.

Therefore, the purpose of this investigation was

to clarify the influences of the level of SCI and of daily exercise on the relationship between HR and Vo_2 in PSCI during arm cranking exercise.

METHODS

Subjects. The subjects of this study were 18 males with SCI who had resumed their familial or social activities. Of the 18 PSCI, 4 were quadriplegics and 14 were paraplegics. Table 1 shows the physical characteristics of PSCI in relation to the level of SCI (4 quadriplegics, C6-C8, 7 high-level paraplegics, T3-T8, and 7 low-level paraplegics, T10-L2). Ten PSCI comprising of two quadriplegics, four high-level paraplegics, and four low-level paraplegics had regularly engaged in sports (marathon, tennis, weight training, archery, or basketball) at least three times a week. These subjects were defined here as active subjects, and others as inactive subjects.

In addition, 8 male ABP served as control subjects, ranging in age from 20 to 42 years, in body mass from 55 to 75kg, and in height from 165 to 183cm. The ABP were also divided into active and inactive group according to their daily lifestyle. None had any cardiopulmonary or metabolic disease. Each subject was informed previous to testing as to the purpose of the study, their extent of involvement, and any known risks. Each expressed understanding by signing a statement of informed consent.

Experimental Protocol. Before exercise, the subjects kept resting in supine position for 30 min and sitting position on his wheelchair for 15 min. A mechanically braked arm cranking ergometer (Monark Rehab Trainer model 881E) was used at 6 levels of exercise (50 rpm at 0 watts, and 20, 30, 40, 50 and 60 rpm at 30 watts). For quadriplegics, the level of exercise was set at 10 watts instead of 30 watts, taking into account their muscle power. Exercise at each load was 4 min in duration interspersed by at least 10 min rest periods. The sequence of the exercises in each subject was randomized. PSCI tended to move the upper half of the body vigorously during exercise. Then, a simple head rest (Fig. 1) was prepared, and its effect was also assessed. The subjects were instructed to fast

Fig. 1 Subject in position using an arm cranking ergometer with head rest.

Table 1 Physical Characteristics of Subjects

Level of Injury	n	Age (yrs)	Weight (kg)	Years in Wheelchair	Skinfold Thickness (mm)				Girth (cm)		Grip Strength (kg)	
					B	T	S	C	U	C	Right	Left
C6 - C8	4	27.0	53.5	7.0	3.7	4.5	7.5	7.1	23.8	85.8	15.6	12.4
		± 6.8	± 7.8	± 7.2	± 1.1	± 2.3	± 2	± 3.2	± 3.4	± 5.2	± 18.7	± 17.5
T3 - T8	7	38.4	61.2	9.2	4.4	8.2	14.1	13.5	28.9	92.4	54.6	50.9
		± 13.3	± 12.6	± 7.8	± 2.3	± 4.2	± 5.7	± 8.6	± 3.9	± 10.6	± 5.6	± 8.2
T10 - L2	7	38.9	60.2	10.7	4.2	7.4	13.0	12.4	30.9	96.8	54.7	50.2
		± 6.8	± 7.8	± 8.2	± 2.6	± 2.1	± 4.2	± 4.5	± 1.7	± 8.4	± 8.5	± 6.3
Total	18	36.1	59.1	9.3	4.2	7.0	12.2	11.7	28.5	92.7	46.0	42.1
		± 10.6	± 9.9	± 7.5	± 2.1	± 3.3	± 5	± 6.5	± 4	± 9.3	± 19.4	± 18.9

Mean $\pm$ standard deviation

B, Biceps; T, Triceps; S, Subscapular; C, Chest; U, Upper arm

for at least 2 hours before a test. Room temperatures were controlled to the range of 24 to 26°C.

Physiological Variables. HR and Vo_2 were determined during the last 5 minutes in both the supine position and the sitting position on his wheelchair and during the last minute of arm cranking exercise. Expired gas was collected using a Douglas bag. The volume of expired gas was measured with a dry gas meter. Oxygen and carbon dioxide concentrations in the expired gas were measured with an instantaneous gas analyzer (Respina, NEC-Sanei). The gas analyzer was calibrated before and during testing with room air and reference gases of known concentrations. HR was measured with a telemetric electrocardiograph using the chest lead method.

Statistical Analysis. Regression techniques were employed to examine the relationship between HR and Vo_2 . Analysis of covariance was used for statistical comparison of regression lines. The unpaired t-test was utilized to test for differences in the responses of the measured variables between active and inactive subjects. All P values less than 0.05 were considered significant.

RESULTS

To clarify the relationship between HR and Vo_2 , we analyzed regression lines of these two parameters determined in the two resting positions. In most subjects, the coefficient of correlation between the two parameters tended to be higher in the supine position than in the sitting position. The values of these parameters in the supine position, therefore, were used as the resting values of the parameters in subsequent analyses.

The influence of the head rest on the relationship between HR and Vo_2 was examined (Fig. 1). Fig. 2 compares the regression line using a head rest to that without a head rest in one subject. The movement of the upper half of the body during a given level of exercise became smaller by using a head rest. However, the relationship between HR and Vo_2 was hardly affected by the use of this head rest.

Fig. 2 Example of regression lines for heart rate and oxygen uptake for one subject with and without head rest.

Fig. 3 Relationships between heart rate and oxygen uptake for three groups: quadriplegics ($\blacktriangle$), high-level paraplegics ($\times$) and low-level paraplegics ($\circ$).

Even when differences in the level of SCI and the muscle power differences were taken into consideration, the regression line remained almost unchanged irrespective of the use of the head rest. In subsequent analyses, therefore, the data using a head rest were analyzed together with the data obtained without a head rest.

Fig. 3 shows the relationship between HR and Vo_2 in each of three groups. In each group, the HR- Vo_2 relationship was linear, resembling the relationship observed in ABP. The higher the level of SCI, the smaller the slope of regression line. That is, the percent of increase in HR following a given increase of Vo_2 become larger as level of SCI was higher. Statistically, there were significant differences among these regression lines ($P < 0.01$). In compari-

son to ABP, HR at same Vo_2 was significantly higher in quadriplegics and high-level paraplegics, while no differences were found between ABP and low-level paraplegics.

In general, the regression lines between HR and Vo_2 in active persons tended to shift toward upper in comparison with those in inactive persons. Thus, Vo_2 at a level of HR will become larger in active persons than inactive persons. Fig. 4 compares the Vo_2 at a HR of 120 beats·min⁻¹ between active and inactive persons. At this HR level, Vo_2 increased in both active and inactive persons as the level of SCI became lower. There were significant differences between the Vo_2 at a HR of 120 beats/min in active and inactive persons. Fig. 5 schematically compares the HR- Vo_2 relationship for active and for inactive subjects in each of four groups. In all groups, the gradient of the regression line was higher for active subjects than for inactive subjects. Namely, the percent of increase in HR following a given increase in Vo_2 was smaller for active subjects in all groups, although the magnitude of this tendency slightly differed among the four groups.

DISCUSSION

The HR- Vo_2 relationship in ABP has been regarded as a useful index in assessing the respiratory and cardiovascular function and the endurance of individuals. In PSCI, the HR- Vo_2 relationship has been also widely utilized for prediction of energy expenditure (Mollinger et al., 1985; Yamasaki et al., 1992), exercise prescription (Hooker et al., 1993), and prediction of physical work capacity (Irizawa et al., 1991). Consequently, it is significant to clarify characteristics of the HR- Vo_2 relationship in PSCI.

As the level of SCI became higher, the slope of the regression line between HR and Vo_2 decreased, indicating that the percent increase in Vo_2 for a given increase in HR was suppressed as the level of SCI. This may be explained by the view that, as the level of SCI becomes higher, the oxygen-consuming active muscles and the muscular pumping action

decrease, which leads to a reduction in blood return and to an increase in HR (Bevegard et al., 1966, Pollock et al., Bar-Or et al., 1978). More recently, Hooker et al. (1994) showed that the relationship between percent peak HR and percent Vo_2 during arm cranking exercise was not altered in persons with either high or low paraplegics. On the other hand, McLean et al. (1992) reported a complete dissociation of the percent peak HR and percent Vo_2 relationship due to the lack of HR increase during arm cranking exercise in quadriplegics. These studies indicated that even when HR and Vo_2 were expressed as percent to respective peak value, this relationship in quadriplegics differ from that in paraplegics. Droy et al. (1990) pointed out that HR at similar workloads was significantly higher in quadriplegics and higher PSCI than in controls, whereas no differences were observed between lower PSCI and controls. These findings were in good agreement with ours. Droy et al. (1990) considered that the higher HR was compensatory mechanism of the low systolic blood pressure in quadriplegics and high-level paraplegics.

The degree of physical training is an important factor in the relationship between the HR- Vo_2 relationship in not only ABP but also PSCI. The present investigation clearly shows how the HR- Vo_2 relationship is influenced by physical training. In general, physically active PSCI showed higher peak oxygen uptake than inactive subjects due to training effect (Nilsson et al., 1975; Yamasaki et al., 1993, 1994). However, the training effects in PSCI are especially reflected in a drop in HR during submaximal arm exercise (Ekblom and Lundberg, 1968; Zweiren and Bar-Or, 1975). This finding is a remarkably good agreement with our data illustrated in Fig. 4 and 5.

In summary, this study indicates that the HR- Vo_2 relationship in PSCI is affected greatly by the level of SCI and daily habit of exercise, and that the aerobic ability of PSCI at any level can be improved by arm exercise.

Fig. 4 Relationships between level of spinal cord injury and oxygen uptake (Vo_2) at 120 beats of heart rate. The trend lines are illustrated. Open circle: active subject. Closed circle: inactive subject.

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Fig. 5 Schematic illustration of extent of regression lines between active and inactive subjects.

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- (Received March 28, 1994)*
(Accepted May 10, 1994)

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