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Relationship between physical characteristics and physiological responses during maximal arm cranking in paraplegics

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The purpose of this study was to elucidate the main physical factor(s) affecting cardiorespiratory responses during maximal arm cranking exercise in patients with paraplegia. Peak oxygen uptake (peak V_{O_2}), peak pulmonary ventilation (peak VE) and peak heart rate (peak HR) were measured during maximal arm cranking exercise in 28 Japanese male patients. A cluster analysis was applied to the data for peak V_{O_2}, peak HR and peak VE, and then the subjects were classified into four groups (A, B, C and D). Group A showed high peak VE and peak HR and low peak V_{O_2}, Group B low peak V_{O_2} and high values for other parameters, Group C the greatest physiological values for all measurements among the groups and, in contrast, Group D showed low peak V_{O_2} and the lowest peak VE and peak HR among the groups. The subjects in Group C had low level of spinal cord injury and were sports participants. On the other hand, duration since injury was not related to the cardiorespiratory responses during maximal arm cranking. These findings indicate that the effects on these responses of years since injury are subordinate to those of the level of spinal cord injury and training.

Keywords: arm cranking exercise; peak oxygen uptake; wheelchair sport; paraplegics; spinal cord injury

Introduction

It is well known that the cardiorespiratory responses in able-bodied people during maximal work are dependent on many physical factors including age, sex, and training level.[1] In addition to these, in patients with paraplegia the level of spinal cord injury (SCI) and years since SCI should be taken into consideration. To study the cardiorespiratory responses during maximal work in these subjects, many investigators have divided them into several groups according to the level of SCI[2–6] or physical training,[7–10] because of the great effect that these factors are considered to have on these responses.

By using such methods in which the subjects are grouped in advance, one can identify the relationship between the cardiorespiratory responses and the level of SCI or physical training. However, these methods may mask the effects of individual differences in other characteristics such as age, body size and years since injury.

One method of examining the effects of physical characteristics on the cardiorespiratory responses during maximal work is to group the subjects according to their cardiorespiratory responses. By this method, data can be obtained for a group with homogenous response pattern, and by subsequently analyzing the characteristics of each group, the physical factor(s) that influence the cardiorespiratory responses during maximal work can be identified. Such an investigation has apparently not been carried out in patients with paraplegia.

The aim of this study, therefore, was to classify the subjects according to their cardiorespiratory responses during maximal arm cranking and to elucidate the main physical factor(s) affecting these responses. For this purpose, we applied a cluster analysis to the data for oxygen uptake (V_{O_2}), and pulmonary ventilation (VE) and heart rate (HR) during maximal work. In this study, we focused upon the effects of the number of years since injury, the level of SCI, and physical training.

Materials and methods

Subjects

The subjects were 28 Japanese males with paraplegia whose physical characteristics are summarized in Table

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1 in descending order of injury level. The 16 subjects who participated in wheelchair sports, such as basketball, distance running, or tennis, more than three times a week were defined as sports participants. All had paralyzed legs and were wheelchair users due to SCI but were otherwise healthy. Prior to his participation in the study, written informed consent was obtained from each subject.

Testing protocols

Each subject performed arm cranking exercise on a mechanically braked arm cranking ergometer (Monark Rehab Trainer model 881E) while seated in his immobilized wheelchair. The arm cranking ergometer was operated at the rate of 50 revolutions per minute, beginning at 0-W power output and increasing by 5 W every minute until the subject could no longer keep pace with the metronome. More tests were terminated after 11–15 min of exercise. Before the experimental testing to obtain physiological variables during maximal arm cranking, each subject was allowed to complete several practice sessions on the arm cranking ergometer to become accustomed to the testing procedure. The room temperature was controlled at within the range from 24–26°C.

Table 1 Physical characteristics of the subjects

Subject	*Age (years)*	*Weight (kg)*	*Height (cm)*	*Injury level*	*Years since injury*	*Sports participation*
1	46	57.7	172	T3	26	Marathon
2	27	51.0	168	T4	7	
3	44	48.8	172	T4,5	16	Marathon
4	29	42.2	172	T5*	6	
5	32	54.5	173	T5	14	
6	26	45.7	157	T6,7	8	Basketball
7	25	54.0	170	T7	2	Marathon
8	47	45.0	160	T8	20	
9	36	67.7	173	T9	6	Marathon
10	39	62.5	165	T10*	16	
11	30	53.6	175	T11*	8	Tennis
12	49	58.0	170	T11	22	Tennis
13	51	57.0	162	T12	25	Basketball
14	52	61.0	163	T12	17	
15	39	45.7	165	T12	18	
16	42	67.0	170	T12	25	
17	27	48.5	160	T12	3	Basketball
18	35	58.0	175	T12,L1	7	Tennis
19	45	58.5	173	T12,L1*	25	Tennis
20	44	78.8	176	L1	20	
21	41	77.0	183	L1	4	Basketball
22	48	67.1	158	L1*	13	
23	32	46.0	164	L1	9	Marathon
24	38	62.0	166	L1,2*	9	Tennis
25	37	56.5	174	L2	12	
26	28	46.0	164	L2	5	Marathon
27	21	60.1	165	L3	1	Basketball
28	41	51.9	158	L3	9	

*incomplete injury

Physiological variables

During each exercise test, V_{O_2} and VE were measured both with a computerized system and by the Douglas bag method. The computerized system provides on-line measurement using an automated gas and flow analzyer with a computer, Aeromonitor AE-280 (Minato Medical Science Co., Ltd., Japan). In the Douglas bag method, VE was measured with a dry gas meter and the O_2 and CO_2 concentrations of samples of expired air were analyzed using an electrochemical O_2 and CO_2 analyzer (Respina 1H26, NEC-Sanei, Japan). V_{O_2} and VE were recorded at 30-s intervals throughout the exercise. HR was continuously monitored from chest electrodes (modified CM5 placement). The peak V_{O_2}, peak VE and peak HR were utilized for analysis, with the peak VE and peak HR defined as the VE and HR at the time of peak V_{O_2}, respectively. Peak V_{O_2} was determined as the greatest V_{O_2} during each test.

Statistical analysis

The cluster analysis by Ward's method was applied to the data for peak V_{O_2}, peak VE and peak HR, transformed into standardized values (Z scores), to classify the subjects into several groups. The means and standard deviations (SD) of physical characteristics, peak V_{O_2}, peak VE and peak HR were then calculated for each group. The one-way Kruskal-Wallis analysis of variance (ANOVA) was used for statistical comparison among the groups. When a significant difference was found in the ANOVA, the difference between means was tested with Mann-Whitney test. All P values less than 0.05 were considered significant.

Results

Figure 1 shows a dendrogram identified by the cluster analysis applied to the data for peak V_{O_2}, peak HR and peak VE in Table 2 as measures of the subjects' physiological response during the maximal arm cranking exercise. As a result, the subjects could be apparently divided into four groups (A, B, C and D).

The peak V_{O_2}, peak HR and peak VE in each group are illustrated in Figures 2, 3 and 4, respectively. Because the Kruskal-Wallis ANOVA indicated significant differences among groups for each measurement ($P<0.01$), the differences between means were compared for all measurements using the Mann-Whitney test. The test revealed significant differences for peak V_{O_2} between groups ($P<0.05$ or $P<0.01$). On the other hand, significant differences of peak HR were recognized only between Group D and the other groups ($P<0.01$). Groups B and C showed significantly greater peak VE than Groups A and D ($P<0.01$).

Table 3 shows the physical characteristics of each group. The ANOVA applied to the data for age, weight, height and years since injury revealed significant differences found only in weight ($P<0.05$),

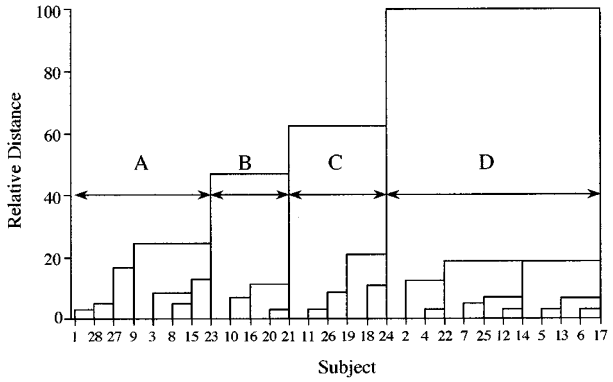

Figure 1 A dendrogram obtained from the cluster analysis applied to the data for peak V_{O_2}, peak HR and peak VE. In this Figure, the closer is the relationship between the profiles of the subjects, the shorter is the relative distance between branches. Four clusteres could be obtained; Group A, B, C and D

Table 2 Physiological responses during maximal arm cranking in the subjects

Subject	*Peak V_{O_2} ($l.min^{-1}$)*	*Peak V_{O_2} ($l.min^{-1}$ kg^{-1})*	*Peak HR (beats. min^{-1})*	*Peak VE (BTPS) ($l.min^{-1}$)*
1	1.428	24.7	182	61.7
2	1.010	19.8	144	43.5
3	1.470	30.1	163	47.6
4	1.050	24.9	141	53.3
5	1.230	22.6	161	49.2
6	1.150	25.2	157	47.2
7	1.290	23.9	157	60.5
8	1.126	25.0	166	55.4
9	1.742	25.7	201	71.6
10	1.220	19.5	165	81.5
11	1.700	31.7	187	73.6
12	1.235	21.3	147	59.3
13	1.304	22.9	156	52.4
14	1.286	21.1	152	64.9
15	1.240	27.1	169	58.7
16	1.180	17.6	178	75.5
17	1.210	24.9	156	47.1
18	2.110	36.4	183	100.9
19	1.946	33.3	174	75.3
20	1.585	20.1	184	86.2
21	1.724	22.4	182	85.0
22	1.680	25.0	136	57.5
23	1.300	28.3	155	71.7
24	1.909	30.8	168	98.9
25	1.190	21.1	160	65.6
26	1.421	30.9	187	78.0
27	1.400	23.3	174	56.6
28	1.270	24.5	178	60.8

with the mean weight being significantly greater in Group B than in the other groups ($P<0.05$). Groups A and D included subjects with lesions from the high thoracic level to the lumbar region. In contrast, there were none with a high thoracic lesion level in Group B or C. The proportion of sports participants was five of eight (63%) in Group A, one of four (25%) in Group B, all five (100%) in Group C, and five of 11 (45%) in Group D. Subjects with incomplete lesion were included in all groups.

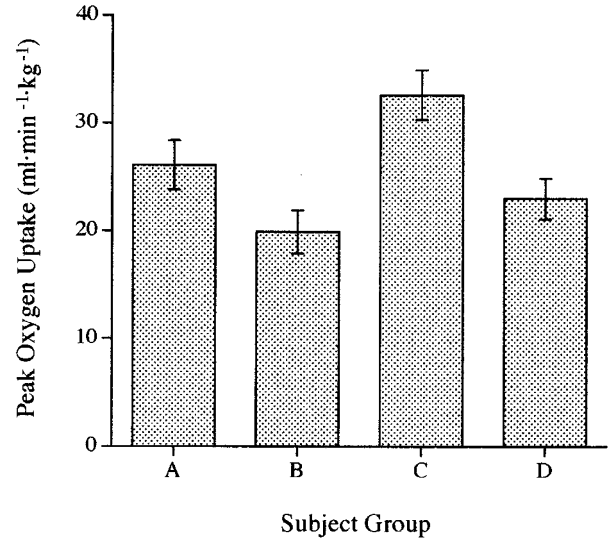

Figure 2 Peak V_{O_2} in each group. Significant differences were found between the groups ($P<0.05$)

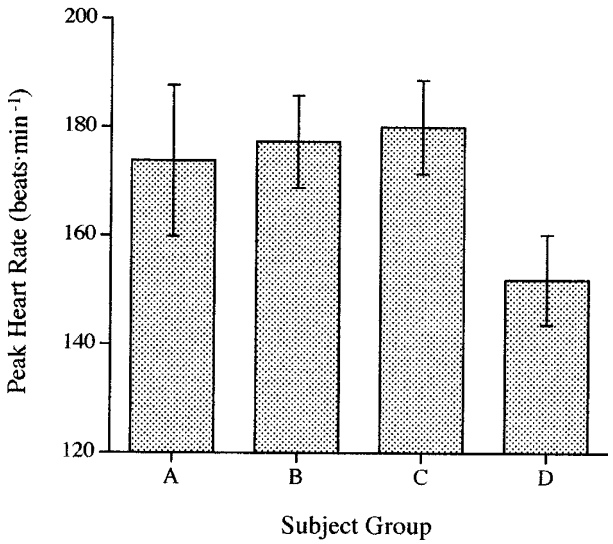

Figure 3 Peak HR in each group. Significant differences were found between Group D and other groups ($P<0.01$)

Discussion

In the present study, by applying a cluster analysis to the data for peak V_{O_2}, peak VE and peak HR, we classified the subjects into four groups. Group A

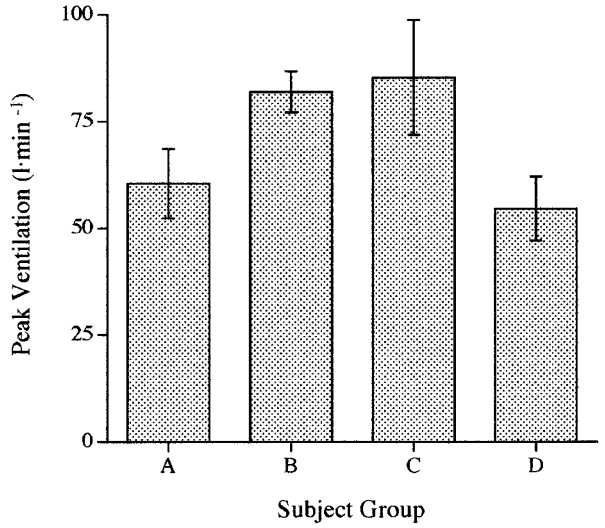

Figure 4 Peak VE in each group. The HR values in Groups B and C were significantly greater than those in Groups A and D ($P<0.01$)

Table 3 Physical characteristics of each subject group

Group (N)	*Age (year)*	*Weight (kg)*	*Height (cm)*	*Injury level*	*Years since injury*
A	38.3	52.9	166.1	T3–L3	13.1
(8)	8.6	8.2	5.6		8.3
B	41.5	71.3	173.5	T10–L1	16.3
(4)	2.1	7.8	7.8		9.0
C	35.2	55.6	170.6	T11–L2	10.8
(5)	6.8	6.1	5.2		8.1
D	36.6	54.1	166.1	T4–L2	11.7
(11)	11.1	7.1	6.2		7.5

Group B showed significantly greater weight than the other groups ($P<0.05$)

showed high peak VE and peak HR and low peak V_{O_2}, Group B low peaks V_{O_2} and high peak VE and peak HR, Group C the greatest values among the groups for all of peak V_{O_2}, peak VE and peak HR. In contrast to Group C, Group D showed low peak V_{O_2} and the lowest peak VE and peak HR among the groups. Thus, the subjects could be grouped according to their cardiorespiratory responses during the maximal arm cranking exercise. Cluster analysis seems a useful method of identifying the subject groups with distinctive characteristics.

It is well established that physically trained subjects show higher peak V_{O_2} and peak HR than their physically untrained counterparts. It has also been demonstrated that the peak V_{O_2} is related to the level of SCI. Hooker and Wells[11] reviewed the peak physiological responses recorded in trained paraplegic athletes in their studies conducted since 1986 and indicated that physical training involving wheelchair propulsion can markedly enhance upper body cardiorespiratory fitness. In the present study, the subjects in Group C, who showed the greatest peak V_{O_2} and peak HR, were all sports participants, and their level of SCI was relatively low (below T11). The peak V_{O_2} and peak HR in this group are comparable to those reported for physically well-trained subjects with paraplegia with a low level of SCI.[5,12] On the other hand, the subjects in Group D, even though five of them were sports participants, showed low values for all physiological measurements, and their peak HR and peak VE were the lowest among the groups. The proportion of the subjects with high lesion (above Th7) was the highest (about 45%) in this group. Thus, one might expect that the low physiological values were attributable to the high level of the lesion in these subjects.

We found that the cardiorespiratory responses during maximal work in these subjects were independent of their age or the number of years since the injury. It is established that peak V_{O_2} decreases gradually with aging in able-bodied persons.[13–15] In addition, Sawka *et al*[16] found that peak V_{O_2} decreased linearly with advancing age in 18 wheelchair-dependent subjects including five patients with paraplegia. In the present study, we failed to find a significant effect of age on maximal respiratory responses in spite of the wide range of the subjects' ages (from 21 to 52 years). It may be that age has less effect than does either the level of SCI or physical training; otherwise the sample size might be too small to demonstrate the effect of age. One unexpected finding of the present investigation is that there were significant differences in weight between Group B and the other groups. Although the subjects in this group showed high peak HR and peak VE, the peak V_{O_2} expressed as a function of body weight was relatively low.

In conclusion, the present findings indicate that these subjects could be grouped according to their cardiorespiratory responses during the maximal arm cranking exercise. The group that showed the highest peak V_{O_2} was recognized as showing low level of SCI and high level of physical activity. On the other hand, durations since the SCI was not related to the cardiorespiratory responses during maximal arm cranking. In patients with paraplegia, the effect of duration since the injury on these responses seems to be subordinate to those of the level of SCI and physical training.

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