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ARM CYCLOERGOMETRY AND KINETICS OF OXYGEN CONSUMPTION IN PARAPLEGICS

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Abstract. A report is given on studies to determine the best methodological approach in exercise testing of paraplegics. Arm cyclometry was found to be very suitable for wheelchair users with normal upper limbs. Oxygen consumption during exercise was studied and analysed by computer.

Key words: Cycloergometry; oxygen consumption.

Introduction

THE purpose of this study was to determine the best method of evaluating the work of lower limb disabled persons in regard to cardiopulmonary efficiency. Exercise testing procedures like step tests, bicycle leg ergometers and treadmills were developed for well-trained people and are used with modifications for normal population. They are not suitable for wheelchair patients, with normal upper limbs. From different points of view there is a great need to determine ergonomic test standards for spinal cord injury patients. It is desirable that the test procedure involves natural movements, without requiring special skill or co-ordination for its performance.

Some Fields of the Application of Arm Cycloergometry

1. In hospitals, for periodic follow-up during medical rehabilitation when one of its goals is the increase of the patient's physical fitness and the amount of work which can be performed. This information would provide important data at the time of the patient's discharge from the hospital.

2. During vocational counselling procedures in order to get information about the disabled person's working capacity.

Owing to a lack of sufficient information about arm cycloergometry, in general, the pilot study was necessary to get the best methodological approach.

Oxygen consumption is considered to be the best exercise testing parameter, better than heart frequency, minute ventilation or blood pressure.

By recording the oxygen consumption continuously during rest, work, and after the cessation of exercise, it was possible to study both the adaptation and the recovery phases. Their duration is a function of the intensity of exercise, age, sex, and of the state of physical training (Andersen *et al.*, 1971).

It has been found in man that, in submaximal exercise not involving lactic acid production, the O_2 consumption during the transition from rest to work and during the immediate recovery period changes as an exponential function of time (Di Prampero *et al.*, 1970).

However, at higher work rates the steady state time is greatly delayed and the rate of O_2 transport increases more slowly and can be described by a second exponential process (Whipp & Wasserman, 1972).

Determinating the time rate constants which we considered as characteristic for exponential curve shape it was our purpose to get some preliminary data about kinetics of oxygen consumption in paraplegics during arm cycloergometry exercise testing procedure.

Methods and Results

Pilot study: The conventional leg bicycle ergometer was adapted for arm work performance so that (alternate) mode of propelling was possible. The prefixed external work load level was maintained independent of minor variations in propelling speed due to an electrically braked servo system. During the test all subjects were seated in wheelchairs. The method of continuous increasing loads (20 Watts every 3 min) with an almost steady state reached at each level was used. A telemetric three-channel system was used for ECG control and heart frequency determination. Expired air was collected in Douglas plastic bags during the last minute of highest work load and samples were analysed with a Scholander gas analyser.

Five young paraplegics took part in pilot study. Personal characteristics of subjects and the results of the pilot study are given in Tables I and II.

The experience from the pilot study was essential for the second group of experiments where continuous measuring of oxygen consumption was introduced with modified closed circuit system in connection with the 120 litres Collins chain-compensated gasometer containing pure oxygen and kymograph recording.

TABLE I

Personal characteristics of subjects (pilot study)

No.	Sex	Age (years)	Height (cm)	Weight (kg)	Level of injury	Years after injury
1. O.J.	m	24	182	75	Th 3	5·5
2. K.T.	m	21	172	69	Th 12	1·0
3. S.P.	f	30	168	54	Th 5	13·0
4. Z.M.	m	26	180	71	Th 12	0·5
5. V.Z.	f	20	160	57	Th 12	0·5

TABLE II

Results of pilot study

No.	Loading in W	Heart rate	Oxygen consumption	RQ	Mechanical efficiency %
1	100	186	1530 ml/min	0·96	20·7
2	100	176	1870	1·00	17·0
3	60	158	1190	0·97	16·1
4	100	177	1925	0·99	16·9
5	60	164	1045	0·97	18·4

Soda lime was used as carbon dioxide absorbent and all precautions to maintain its action as reliable as possible were followed.

The pulse rate meter with ear lobe pick-up (photoelectric system) was found to be satisfactory for every minute recording of regular heart rhythm.

Test Procedure

The method of discontinuous series of increasing work loads was used with 5 min rest in the beginning, 5 min work (at 25, 50 and 75 watts) with intermittent rest periods of 3 min. The test was finished with 6 min recovery. During the entire test (32 min) the subject's oxygen utilisation was continuously monitored. All tests were carried out between 10 a.m. and 12 noon on subjects in a post-absorptive state after a light breakfast early in the morning.

The investigation included eight persons, five normals and three spinal cord injury subjects. Table III shows their personal characteristics. The normals were considered to be of an average physical fitness.

All subjects were tested with a synchronous and alternate (reciprocal) mode of propelling. Between them no significant difference in any recorded parameter

TABLE III

Personal characteristics of subjects

No.	Sex	Age (years)	Height (cm)	Weight (kg)	Level of injury	Years after injury
1. R.A.	m	30	178	94	healthy	healthy
2. J.P.	m	29	166	67		
3. C.M.	m	28	180	75		
4. B.F.	m	41	175	69		
5. H.R.	m	52	165	63		
6. B.C.	m	36	172	90	Th 10	17
7. A.N.	m	45	173	74	L 1	28
8. J.J.	m	25	170	81	Th 12	7

TABLE IV

Results of increasing work loading

No.	Heart rate				Oxygen consumption (ml/min)			
	M	25 W	50 W	75 W	M	25 W	50 W	75 W
1	70	102	125	145	280	800	1200	1540
2	60	79	92	117	330	880	1200	1800
3	61	87	108	140	250	700	1080	1520
4	73	96	115	142	320	1000	1250	1900
5	75	93	117	141	280	600	1000	1620
6	65	85	97	110	270	860	1120	1800
7	77	102	125	158	250	700	880	1860
8	75	97	113	145	280	820	1150	1830

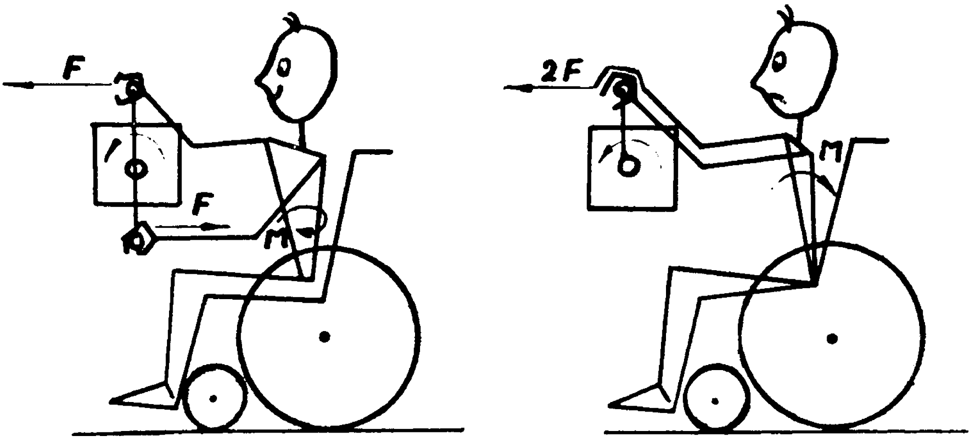

FIG. 1

was found. The average values are given in Table IV. Subjectively all subjects preferred the alternate mode of propelling (Fig. 1).

So the alternate (reciprocal) mode was used in the last part of study with the intention to get some preliminary data about the kinetics of oxygen consumption during arm cycloergometry exercise testing procedure. It was our conclusion from previous experiments that the closed circuit method which was primarily constructed for basal metabolic rate measurements, is not reliable for exercise testing procedure. We agree with Margaria *et al.* (1954) about its inconveniences as it requires from the subject a very regular and steady respiration; the drawing of the line on the respiratory tracing, the slope of which represents the oxygen consumption, is always somewhat subjective (an error of about ± 3 per cent): it is difficult to ascertain the complete absorption of CO_2 by soda lime.

Figure 2 shows the modern Siemens equipment for permanent determination (every 12 sec) of heart rate, minute ventilation, oxygen consumption and CO_2 production. The oxygen meter is constructed on the principle of oxygen paramagnetic properties and open circuit method has been used.

For off-line data processing we use the computerised system consisting of Hewlett-Packard 2100 S processor with 24K word memory, disc mass storage, Tektronic 4012 terminal with hard copy unit, display for interactive graphic, analogue to digital converters, and standard paper tape units. The operating system is HP RTE, and the programmes are written in assembler and fortran.

The oxygen consumption curve was determined before, during and after exercise (70 W), which duration depended on achievement of steady state.

Figure 3, made by the graphic display unit of our computerised system, shows the oxygen consumption curve of a Th V paraplegic subject. Mathematical characteristics of the curve in Figure 3 can be seen in Figure 4. The oxygen consumption during rest is given as the average start value with standard deviation.

With graphical presentation on the semilogarithmic scale it was possible to recognise two component exponential systems for the ascending and descending part of curves. The mathematical model of ascending part can be described by:

$$Y = a_1 (1 - e^{-k_1 t}) + a_2 (1 - e^{-k_2 t})$$

and for descending part:

$$Y = a_3 e^{-k_3 t} + a_4 e^{-k_4 t}$$

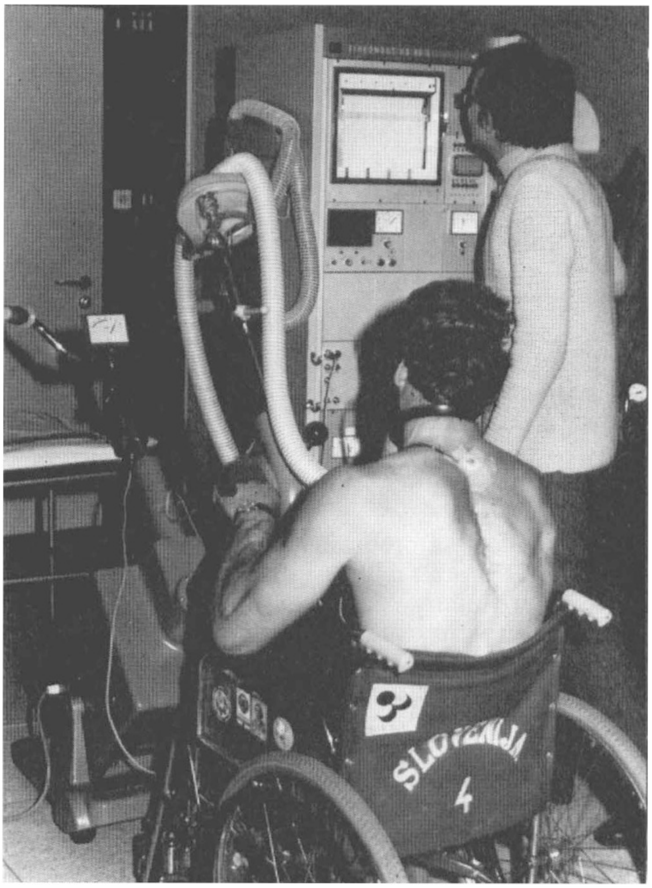

FIG. 2

Velocity constants (k) or time constants (reciprocal of velocity constant) control the rate of oxygen consumption and are characteristics for exponential curve shape.

Discussion

Upon inspecting the data there seems to be no real difference between synchronous *v.* alternate mode of propelling neither among normals nor paraplegics. It should be stressed that all paraplegics were of lower spinal cord injury level. They shared the opinion of normals about preference for the alternate mode of cycling in regard to better stability in the wheelchair. The possible explanation (Marinček, 1976) would be as follows (wheelchair has to be braked):

(1) In the alternate mode, there is a force coupled with opposite direction and only the axial movement of the trunk in the horizontal plane appears as the end result.

(2) In the synchronous mode, the direction of the forces is the same, they sum themselves so that they cause a significant bending movement of the trunk in the sagittal plane.

Our findings on heart rate response to increased work loads were as expected

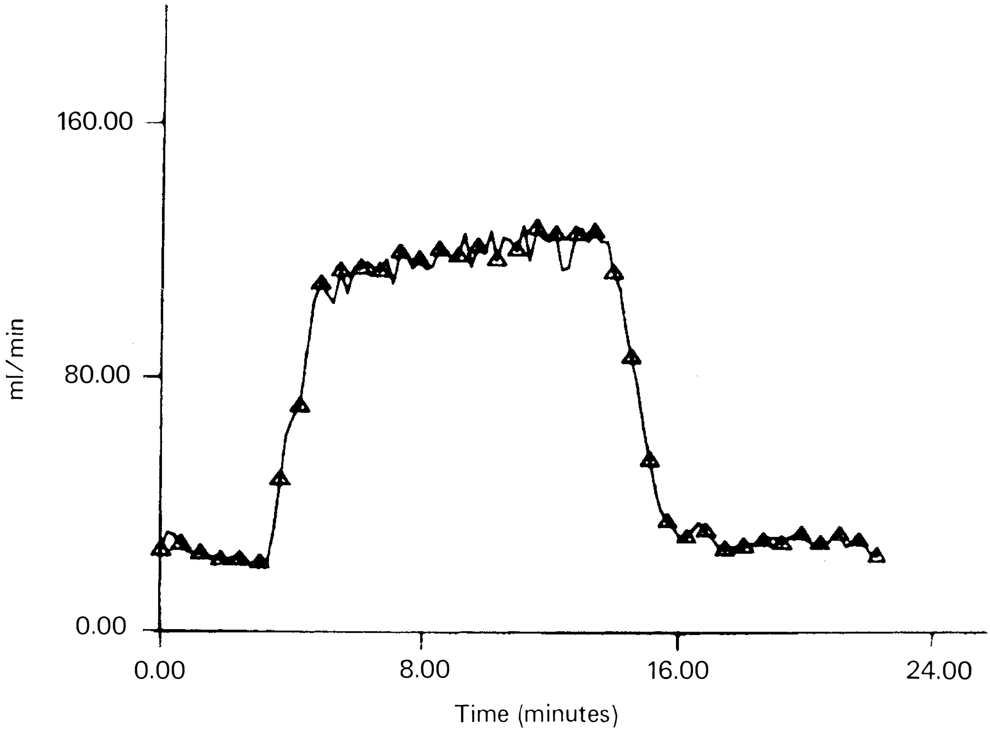

FIG. 3

SEGMENT	VEL. CONST. (1/MIN)	TIME CONST. (MIN)	HALF TIME (MIN)
1	.589	1.70	1.17
2	.049	20.21	13.94
3	.656	1.52	1.05
4	.033	29.93	20.65

AVER. ST. VALUE-O2- 324.4 (ML/MIN) ST. DEV. 33.2

FIG. 4

—higher values compared to the same work load performed with lower limbs. This is in accordance with the thesis that a given percentage of muscle maximum force contraction, regardless of muscle size, has approximately the same effect on the cardiovascular system. So for the same work performance more marked contraction of upper than lower limb muscles is necessary (Corcoran, 1971).

Arm exercise in comparison with leg exercise is accompanied by a larger rise in heart rate, blood pressure, pulmonary ventilation, and arterial lactate concentration. This difference has mainly been ascribed to a more dominating sympathetic vasoconstrictor tone during arm exercise (Astrand & Saltin, 1961; Astrand *et al.*, 1968).

When a healthy subject exercised by cranking a bicycle with the arms, the arterial blood pressure, heart rate, and pulmonary ventilation was higher than during leg exercise of approximately the same oxygen uptake (Bevegard *et al.*, 1966).

Maximal work with the arms gives an oxygen uptake about 70 per cent of maximal uptake when cycling with legs (Astrand & Saltin, 1961) or 66 per cent as found by Stenberg *et al.* (1967). Secher *et al.* (1974) disagrees with those data stressing that the arm-trained subjects can reach higher values of maximal oxygen uptake.

There are very interesting findings of Nilsson *et al.* (1975) with results showing that the paraplegics with lower thoracic or upper lumbar lesions with unaffected muscles of the arms and trunk can reach a relatively high maximal oxygen uptake if they ambulate with crutches and long legbraces.

Our results of mechanical efficiency (Table II) are in accordance with previous findings of Bevegard *et al.* (1966) who report about 18 per cent arm exercise mechanical efficiency compared to 23 per cent for legs. Stenberg *et al.* (1967) explain this difference by a larger fraction of stabilising and stabilising effort as the exercising is performed in the sitting position. Paraplegics can be only slightly helped by their trunk muscles and cannot be aided by their leg muscles, depending on the site of injury.

The oxygen uptake curve has been described as a single exponential function with rate constants being the same for all work intensities (Margaria *et al.*, 1965; Di Prampero *et al.*, 1970). As their exercise periods lasted only 2 min or less, this may not be of sufficient duration to elicit the second component. A more recent study (Whipp & Wasserman, 1972) has shown that the time to steady state oxygen consumption is progressively delayed at higher work loads and that the non-steady state part of the curve is made up of two components, a fast and a slow one. They are also of exponential function type and they appear as the work load approaches the anaerobic threshold at about 50-60 per cent of aerobic capacity (Bason *et al.*, 1973). Their different order of magnitude shows clearly for different adaptation mechanisms.

Our cases (Figs. 3 and 4) demonstrate distinctly two component processes. After observations from other measurements, we can conclude that arm work load of 70 W is of such an intensity that it demands two different mechanisms of adaptation. The slope of the second component of the paraplegic oxygen consumption curve is much closer to steady state as the subject becomes more adapted to permanent arm work (wheelchair user).

Owing to lack of sufficient information, more measurements should be performed on the paraplegic population.

Summary

The report of investigation is given to determine the best methodological approach in exercise testing of paraplegics. Arm cycloergometry was found to be very suitable for wheelchair users with normal upper limbs. Alternate (reciprocal) mode of propelling was found to be more convenient than synchronous.

The kinetics of oxygen consumption during exercise was studied with com-

puterised analysis. For work load of 70 W, two exponential components, a fast and a slow one, are required to describe accurately the rate of change in oxygen consumption.

RÉSUMÉ

On donne le compte-rendu d'une étude en vue de déterminer la meilleure approche méthodologique à adopter dans l'examen des paraplégiques pendant l'exercice. On a trouvé que la cycloergométrie du bras convient très bien aux handicapés en chaise ayant des membres supérieurs normaux. Un mode de propulsion alternée convient mieux que le mode synchrone. On a étudié, par ordinateur, la cinétique de la consommation d'oxygéne pendant l'exercice. Pour un travail de 70 W, deux composantes exponentielles, une lente et une rapide, sont nécessaires pour décrire avec exactitude le taux de changement de la consommation d'oxygène.

ZUSAMMENFASSUNG

Untersuchungen zur methodischen Bestimmung von Übungen von Paraplegikern werden berichtet. Arm Cycloergometrie wurde für Rollstuhlfahrer mit normalen Armen als sehr zweckmässig gefunden. Die Oxygenverbrauch wurde während der Übungen untersucht.

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