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SPIROERGOMETRIC AND TELEMETRIC INVESTIGATIONS DURING THE XXI INTERNATIONAL STOKE MANDEVILLE GAMES 1972 IN HEIDELBERG

By K.-D. HÜLLEMANN, M. LIST, D. MATTHES, G. WIESE and D. ZIKA

The Heidelberg University Medical School (Ludolf-Krehl-Klinik) II Institute and Department for General Clinical Medicine (Director: Professor Dr. P. Christian)

Abstract. This paper deals with spiroergometric and telemetric studies which were carried out on 100 paraplegic athletes during the XXI International Stoke Mandeville Games, 1972 in Heidelberg.

IN the literature (Guttmann, 1956; Jung, Gottheiner & Brunner, 1971; Rolf & Witt, 1972; Schiile, 1972) there is little data on the cardiopulmonary efficiency of paralysed persons. Circulatory regulation was measured spirometrically in handicapped subjects for the first time in 1968 during the International Stoke Mandeville Games in Israel (Jung, Gottheiner & Brunner, 1971). The present study was suggested by the National Olympic Stoke Mandeville Committee. The preparations had to be completed within five months.

METHODS

1. **The Problem.** To determine the cardiovascular and pulmonary efficiency in different classes of disability and various kinds of sport. Regulation of circulation during training and competition.

2. **Investigative Procedure.** Ergospirometry and exercise electrocardiography with a triangular exercise test (Cherchi, 1968). Long-term ECG tape recording (Hüllemann, 1973) and ECG telemetry (Hüllemann & Mayer, 1971; Hüllemann, 1973; Hüllemann *et al.*, 1974).

3. **Documentation and Statistics.** Data-recording system appropriate for electronic data processing (Hüllemann, 1970; Hüllemann *et al.*, 1971; Hüllemann *et al.*, 1972). Storage and evaluation of the data was carried out at the Documentation, Information and Statistics Institute at the German Cancer Research Centre, Heidelberg (Director, Prof. Dr. G. Wagner).

4. **Investigating Personnel.** Twelve persons: five doctors, two medical students, two bioengineers, one medical laboratory technician.

5. **Apparatus.** Spiroergometric measurement unit according to the 'open system'. Two telemetry systems, one of which had six transmitters. Long-term ECG recorder with six cassettes. Digital reading of heart rate. Two-track

TABLE I

Number of TS in the disability classes and in the events. Weight-lifting (Wt.), basketball (B.b), ball/discus/javelin (B.D.J.), archery, wheelchair dash and slalom (D.S.), (*a*) men, (*b*) women, (*c*) all the TS in the two investigation procedures spiroergometry/telemetry and in the various events

	Spiroergometry				Telemetry						
Class	Wt.	B.b.	B.D.J.	Σ	B.D.J.	Archery	D.S.	Swimming	Other	Σ	$\Sigma\Sigma$
(*a*) Men											
II	4	—	—	4	—	—	1	1	—	2	6
III	15	—	1	16	3	3	7	—	2	15	31
IV	9	1	3	13	2	5	6	—	3	16	29
V	7	2	1	10	—	1	2	—	—	3	13
VI	4	1	—	5	—	—	—	1	—	2	7
Σ	39	4	5	48	6	9	16	2	5	38	86
(*b*) Women											
Ib	—	—	—	—	2	—	1	—	1	4	4
II	—	—	1	1	1	—	1	—	—	3	4
III	—	—	—	—	1	—	2	1	1	5	5
IV	—	—	1	1	—	—	—	—	—	—	1
Σ	—	—	2	2	4	—	4	1	3	12	14
(*c*) Men and women											
	39	4	7	50	10	9	20	3	8	50	100

stereo magnetic tape unit for simultaneous recording of ECG and verbal information. Sphygmomanometer. Two radiotelephones. Three pocket cassette recorders. Three one-channel electrocardiographs. Underwater arrangement for telemetry. Out-patient kit with medicines for emergencies, intubation set and a resuscitation mask.

The test subjects (TS) were selected on the basis of their availability. The investigators were in direct contact with the athletes and their coaches. Those approached showed themselves cooperative. Major organisational difficulties with the TS gave rise to a rush and other psychological problems before the competition. A great deal of time and staff were required to meet simple human needs such as transport to and from meals and locating the toilet. The athletes lost interest in the study by the final days of the Games.

There were varying numbers of subjects in the individual kinds of sport and classes of disability (Table I).

TABLE II

Heart rate f_h (beats/min.) in the different kinds of sport and classes of bodily disabilities in men (*a*) and women (*b*). Resting = lowest heart rate registered in the observation period of varying length. Exercise = maximum heart rate during sporting activity. n = no. of TS. $\bar{x}/x$ = average or single value. s = standard deviation. min./max. = minimum value/maximum value. B.D.J. = ball, discus, javelin

(*a*)

f_h—Resting						f_h—Exercise		
Kind of sport	Class	n	$\bar{x}/x$	s	min./max.	$\bar{x}/x$	s	min./max.
Archery	III	3	98	12	85/110	123	14	100/140
	IV	5	108	17	87/130	131	10	112/185
	V	1	120			120		
		9	109	10		127	5	
Wheelchair dash and slalom	II	1	109			190		
	III	7	92	4	75/110	175	11	145/185
	IV	6	97	2	77/120	187	7	190/205
	V	2	87		85/89	190		187/192
		16	95	10		185	6	
B.D.J.	III	3	102	19	65/125	121	16	110/140
	IV	2	83		81/85	107		105/110
	VI	1	72			87		
		6	85	12		105	14	
Swimming	II	1	125			192		
	VI	1	105			180		

(*b*)

Archery	III	2	103		102/105	114		99/130
Wheelchair dash and slalom	Ib	1	109			202		
	II	1	93			185		
	III	2	125			190		
		4	109	16		192	8	
B.D.J.	Ib	2	74		67/82	112		105/120
	II	1	90			128		
	III	1	90			130		
		4	82	10		120	11	
Swimming	III	1	115			180		

FIG. 1

Spiroergometric measurement unit.

Of the 50 spiroergometric measurements, the largest group was that of the weight-lifters with 39 subjects. They had to produce the results of a circulatory investigation (at least an ECG) in order to get a starting permit. Because of this one-sided loading of the investigative capacity, only 12 further athletes were given an examination at the Games, two of them being women.

The frequency distribution in the 50 telemetry and recording studies (Table II*a* and *b*) is largely attributable to the technical conditions.

The ratio of the crankhandle movement had to be reduced for the ergometric exercise position. This modification was taken into account in the work calculation. There were further technical difficulties due to differences in the height of the different types of wheelchair and severe wobbling of the wheelchairs with rubber wheels. The gain in time and the more 'true-to-life' conditions attained by the TS in their own wheelchairs (fig. 1) had to be purchased with a non-optimal degree of effectiveness.

TABLE III

Number of TS and number of participants of the various nationalities

Nation	Participants	TS
Australia	37	3
Belgium	31	4
Brazil	20	1
FRG	100	22
CSSR	24	10
Denmark	28	1
Finland	28	3
France	90	4
United Kingdom	94	7
India	15	1
Jamaica	24	1
Japan	34	5
Yugoslavia	29	6
Malaysia	4	3
Norway	40	3
Poland	27	3
Switzerland	47	14
Hungary	7	1
U.S.A.	83	8
Nations	767	100

Total of 44 nations. Total of 1351 participants

RESULTS AND DISCUSSION

A total of 100 participants from 19 nations were investigated (Table III).

1. **Spiroergometry.** *Vital Capacity (VC) and Maximal Expiratory Flow Rate (MEFR).* The VC increases from 3913 ml. in disability class II to 4858 ml. in disability class V (Table IV). The MEFR shows the same tendency to rise within the disability classes. The increase of the MEFR from disability class II to III is statistically significant ($P < 0{\cdot}02$).

Efficiencies. The rise in the maximum work of 74 watts in disability class II to 127 watts in disability class VI (Table V) was not statistically significant. However, if one compares the total work expressed as the sum of the watts expended during the whole of the loading phase, a statistically significant ($P < 0{\cdot}02$) increase in working capacity with decrease in the degree of disability is demonstrable (Table V, fig. 2).

Heart Rate. Under resting conditions the heart rate was 87 ± 13 beats per minute; in maximum loading the heart rate reached 153 ± 18 beats per minute. If

TABLE IV

Average values and standard deviation of VC and MEFR of male disabled athletes

Disability class	Number	VC	MEFR
II	4	3913 ± 773	5·97 ± 1·63
III	15	4352 ± 1054	8·21 ± 1·35
IV	12	4454 ± 853	8·16 ± 1·97
V	9	4858 ± 977	8·26 ± 2·13
VI	5	4640 ± 509	8·86 ± 1·86
Sum	45	4449 ± 939	8·08 ± 1·83

TABLE V

Average values and standard deviation of the male disabled athletes

Disability class	Number	Age (years)	Weight (kg.)	Max. loading (watts)	Total work (watts)
II	4	27·0 ± 5·92	59·3 ± 11·5	74 ± 43	285 ± 169
III	16	30·8 ± 6·27	71·1 ± 20·8	104 ± 27	423 ± 127
IV	13	28·8 ± 8·4	63·0 ± 12·0	95 ± 30	384 ± 127
V	10	29·7 ± 6·5	70·2 ± 14·0	113 ± 32	503 ± 130
VI	5	27·8 ± 5·6	77·2 ± 7·9	127 ± 32	522 ± 105
Sum	48	29·4 ± 6·7	68·4 ± 1·6	103 ± 32	430 ± 142

the disability classes are compared with one another, there is practically no difference in the behaviour of the pulse frequency.

Blood Pressure. Systolic and diastolic blood pressure had approximately the same values in all the disability classes: at rest 141 ± 19/96 ± 9 mm. Hg and during maximum exercise 165 ± 10/93 ± 11 mm. Hg.

Maximum Oxygen Uptake ($\dot{V}_{O_2}$max.). The $\dot{V}_{O_2}$max. increases from 691 ml. (class II) to 1541 ml. (class VI) (Table VI). The maximum oxygen/pulse increases in a similar way. The difference for $\dot{V}_{O_2}$max. and $\dot{V}_{O_2}$max./f_h between classes II and VI are statistically significant (P < 0·5).

Ventilation Equivalent. There were no consistent differences in the ventilation equivalent between the performance classes.

Electrocardiogram. No pathological changes were observed.

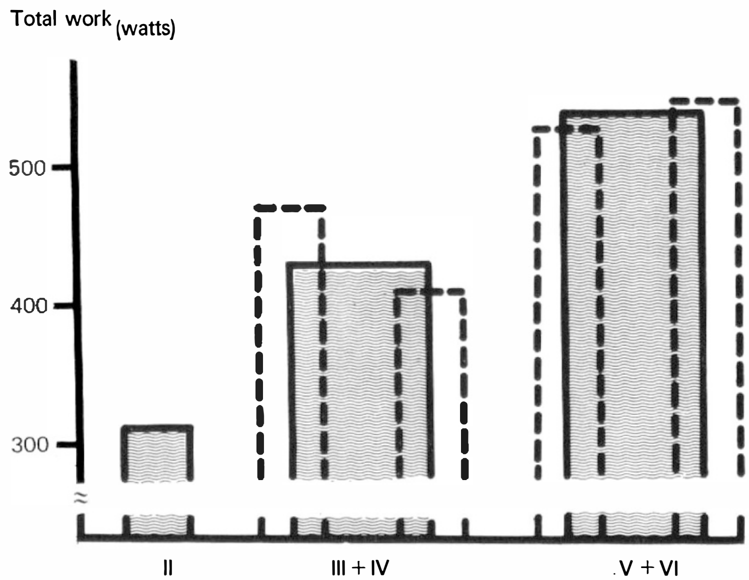

FIG. 2

Average values of total work (sum of watts) within the disability classes II-IV. The differences between the disability classes II, III + IV, and V + VI are significant ($P < 0{\cdot}02$).

TABLE VI

Average values and standard deviation of the maximum values of oxygen uptake and oxygen/pulse in disabled athletes

Disability class	Number	Max. O_2uptake (ml.)	Max. O_2pulse
II	4	961 ± 365	6·38 ± 2·26
III	13	1272 ± 435	8·25 ± 2·65
IV	10	1409 ± 535	9·00 ± 2·70
V	5	1283 ± 276	8·75 ± 2·10
VI	4	1541 ± 165	9·75 ± 1·04
Sum	36	1302 ± 436	8·48 ± 2·52

DISCUSSION

The VC of 4449 ± 939 ml. found in the handicapped agree with the values determined by Jung *et al.* (1971), who found a VC of 4500 ml. in 24 paraplegic athletes. These values are substantially higher than those obtained by Voigt *et al.* (1968) in 13 non-trained male paraplegics (3000). According to Baldwin *et al.* (1948) VC values in comparable non-disabled subjects is 4480 ml. The values for our disabled subjects are 500 to 1000 ml. less than those given by Bühlmann and Scherrer (1973), which were 5000 to 5500 ml. If one takes into account that VC in a sitting position is ten per cent lower than when standing (Hollmann, 1972), then the difference from the non-disabled comparison collective is only slight. Within the disability classes the VC increases the lower the transverse lesion is located in the spinal cord. It can be assumed that these differences would also be statistically demonstrable with a larger sample of subjects. The MEFR lies within the normal range in disability classes III to IV (Fabel & Hamm, 1962). The significantly lower MEFR in disability class II is attributable to the localisation of the injury (Th1-Th5), in which only a part of the rump musculature can be innervated actively. With increasing possibility of activating the musculature, *i.e.* localisation of the transverse injury lower in the spinal cord, a larger total physical work (sum of watts) and maximum work (watts) can be achieved. Since their total work is the same, disability classes III and IV and also V and VI can be lumped together (fig. 2). The resting heart rate is 17 beats higher than that stated by Jung *et al.* (70 ± 14 beats/min.). The difference may be attributable to the crankhandle's being moved at freewheel during the rest phase in the present study and to a higher level of mental excitation of the athletes due to the competition frequently impending on the same day. The maximum heart rate was 153 ± 18 beats per minute. Comparable non-disabled subjects have a heart rate almost 30 beats per minute lower at the same exercise if this was determined with foot crankhandle work in the lying position. According to Mellerovicz (1975) more oxygen, a larger minute volume and higher respiratory rate is necessary for the same physical performance with hand crankhandle work than in foot crankhandle work in the sitting or lying position. The effectiveness of the crankhandle work is substantially more unfavourable. This was also demonstrated by Jung *et al.* (1971) in a group of sport students who showed 56 per cent less than maximal exercise when tested by crankhandle ergometry as compared to bicycle ergometry.

Despite different exercise within the disability classes, the maximum heart rate is almost the same. Maximum performance for individuals with differing degrees of disability entails almost the same psychophysical effort; 74 watts work is just as difficult to produce for disabled subjects of class II as is 127 watts work for subjects of class VI.

The values of the indirectly measured blood pressure (141 ± 19/96 ± 12 mm. Hg) at rest are markedly higher than the norm for elderly subjects (Meesmann *et al.*, 1970). This elevation is to be viewed as a result of the generally larger arm size of the disabled, especially since the 32 TS trained either exclusively with weight-lifting or additionally with other kinds of sport. In four disabled subjects who engaged exclusively in light athletics, the blood pressure is markedly lower (136 ± 10/89 ± 10 mm Hg). Since the size of the upper arm was not measured, the blood-pressure values could not be corrected as suggested by Pickering (1969).

The increase of systolic blood pressure from 25 mm. Hg with moderate work of 103 ± 32 watts is slight. As could be shown by Jung *et al.* (1971), the comparatively lower increase in systolic pressure is not a characteristic of disabled athletes, but is attributable to the kind of exercise (crankhandle work in the sitting position).

The maximum increase in oxygen uptake (1302 ml.) is markedly less than the comparable value in the non-disabled, which was stated by Valentin *et al.* (1955) to be 3200 ml. with rotating crank work in the standing position. This $\dot{V}_{O_2}$max. of the disabled subjects relative to the comparison value was also depressed if one takes into account that exercise in a sitting position is associated with a lower uptake of oxygen (Mellerovicz & Nowacki, 1961). Voigt *et al.* (1968) and Jung *et al* (1971) also found a lowered maximum oxygen uptake in wheelchair patients. This results from the disabled musculature not carrying out any work.

The dynamic changes of the ventilation equivalent which were recorded indicated an economically favourable operation (Hollmann, 1963, 1972).

2. **Telemetry.** The highest pulse frequencies (more than 180 to 205 beats per minute) were reached in dashes and slaloms (Table VII, figs 3 and 4) and in

TABLE VII

Heart rate (beats/min.) in short-distance and slalom races. Above 14 men. In addition, the values of the Gold Medal winner in Slalom (1*) are given. Below 4 women. Resting = lowest heart rate during the period of observation. Training, pre-start, competition = maximum frequency. Pre-start = directly before the starting shot

n		Age (years)	Resting	Training	Pre-start	Competition
14	$\bar{x}$	26	95	159	131	186
	s	6	10	15	18	10
	min./max.	18/41	75/120	135/180	96/170	160/205
1*		23	95	150	125	182
4	$\bar{x}$	31	104	—	128	191
	s	3	16		12	10
	min./max.	24/32	90/125		111/140	182/202

swimming (fig. 5). Weight-lifting also led to a comparable tachycardia (fig. 6). It was possible to record the ECG continuously during the crucial competition in which a 23-year-old sportsman won the Gold Medal in the slalom (Table VIII, fig. 7).

It was not possible to show an influence of sex and disability class on regulation of heart rate. Figure 4 shows the effect of age; the 41-year-old-athlete (*a*) has about 20 beats less than his 16 to 23 years younger opponents. On the other hand, the influence of psychogenic factors is clear. Even the start situation accelerated the pulse by 30 beats (Table VII). The peak heart rates in competition are on average 25 beats higher than in training (Table VII). During the prize-giving the heart rate of a 21-year-old gold-medal winner (female) rose from 95 to 120 at the time her name was called out. In a similar situation a 17-year-old athlete (also female) developed a 4 : 1 extrasystole with an increase of heart rate from 82 to 93. This disturbance of rhythm could not be demonstrated in an exercise test

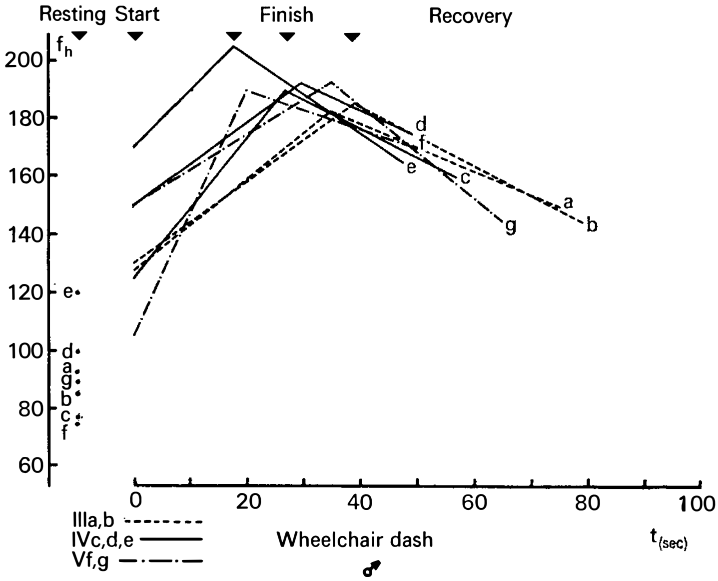

FIG. 3
Course of changes in heart rate during the men's dashes. Resting = lowest value during the observation period (which varied in length). Start = directly before the starting shot. Finish = situation in which the participants *a* to *g* pass the finishing line. The highest heart rate largely coincides with reaching the finish.

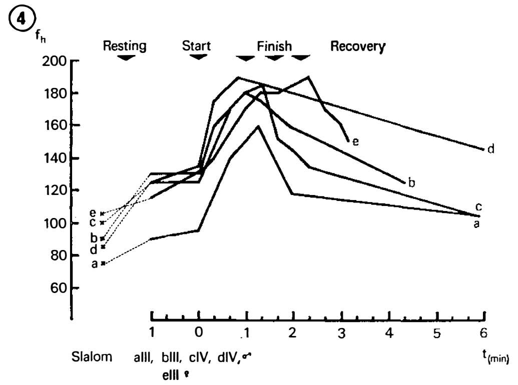

FIG. 4
Heart rate f_h (beats/min.) during slalom competitive races. The values on the left (outside the abscissa) correspond to the lowest values of heart rate recorded during the observation period (which was of varying length). Finish = time interval in which all five participants pass the finishing line. *a* = 41 years. *b* = 22 years, *c* = 25 years. *d* = 23 years; values measured during the Gold Medal competition. *e* = 31-year-old woman.

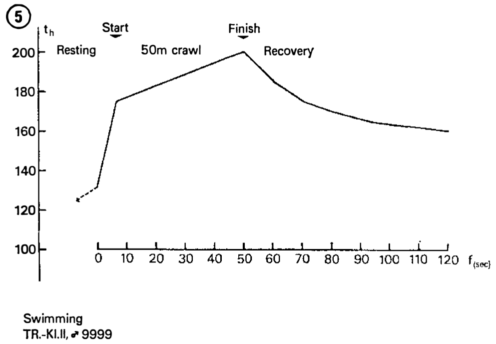

FIG. 5

Course of changes in heart rate during swimming training. Resting = lowest heart rate during the period of observation.

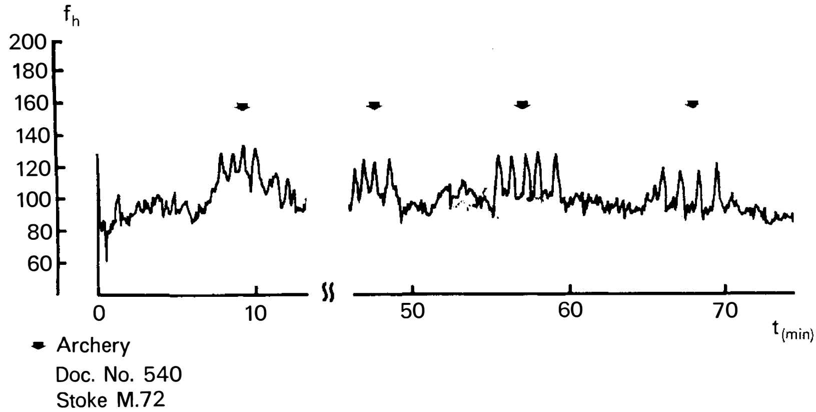

FIG. 6

Course of changes in heart rate during archery. The arrows mark a series of shots. The course of the pulse frequency from the 70th to the 120th minute corresponds to the curve shown.

with continuous ECG monitoring. During a Eurovision programme two weight-lifters had tachycardias up to more than 120 beats/min. even at rest (fig. 8). Filming the situation or speaking to the TS accelerated the pulse rate by 20 beats.

There were no pathological findings in any TS.

DISCUSSION

The peak values of heart rate reached by the wheelchair subjects are of the same order as those reached by healthy sportsmen in similar events (Bassan, 1967; Kastner *et al.*, Vogler & Glasing, 1970). The different strength of the circulatory reaction to largely static exercises with only very short dynamic intervals as

FIG. 7
Gold Medal winner in the slalom, 23-year-old medical student.

opposed to purely dynamic strenuous exercise is comparable with healthy subjects (Hollmann, 1963, 1972; Hollmann & Heck, 1971).

A dependence of the acceleration of heart rate on sex and disability class could not be demonstrated. This is based (apart from the small sample number) on the fact that all the bodily activities studied are too short in duration for one to assume that the cardiovascular system is the factor limiting performance (Reindell *et al.*, 1967; Mellerovicz, 1975). In the Olympic situation, the mental involvement illustrated above plays a particular role. The high peak frequencies of 200 were also reached in formula and touring car drivers (Hüllemann & List, 1973); with the low level of bodily activity during the race, this is mainly due to the extreme mental tension. These motor racing drivers show a tachycardiac pre-start reaction like that of the disabled sportsmen. There is further agreement in the higher rise in heart rate during the competition compared to training. Disturbances of the heart rhythm such as appeared at the prize-giving occur similarly in television viewers during live transmissions of sports programmes (Hüllemann & Mayes, 1971).

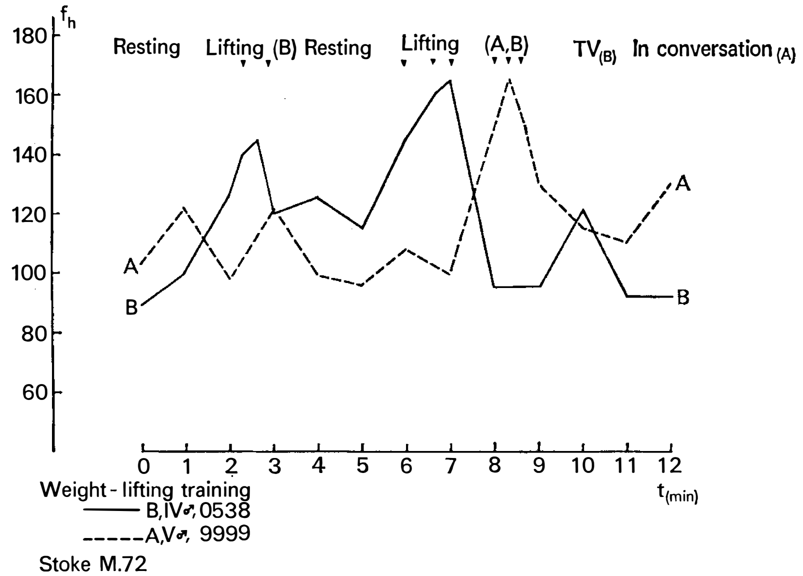

FIG. 8

Course of changes in heart rate of two weight-lifters during a Eurovision transmission. $TV_{(B)}$ = television camera on subject B. In conversation$_{(A)}$ = (A) talks to the doctor.

SUMMARY

Spiroergometric and telemetric investigations were carried out on 100 paralysed athletes during the XXI International Stoke Mandeville Games in Heidelberg, 1972. The technical and organisational difficulties in carrying out these measurements were engendered by the disabilities of subjects. The maximum oxygen uptake observed and the oxygen pulse were lower than in non-disabled persons. There were no differences in the peak heart rates (180-200 beats/min.) as compared with non-disabled athletes during particular competition situations. Sports characterised by quickness, dexterity and strength are not able to train the cardiopulmonary system substantially. Swimming is recommended as beneficial.

Psychological and training physiological considerations suggest that long-distance wheelchair races should be adopted as a Stoke Mandeville event.

RÉSUMÉ

Les investigations spiro-ergométriques et télémétriques ont été effectuées chez 100 athlètes paralysés pendant les XXIè Jeux Internationaux de Stoke Mandeville qui se sont tenus à Heidelberg en 1972. L'invalidité des sujets a occasionné des difficultés techniques et d'organisation pour étudier les paramètres. La consommation maximale d'oxygène observée ainsi que le pouls d'oxygène était plus bas que chez les personnes non paralysées. Il n'y avait pas de différence en ce qui concerne le rythme cardiaque maximal, (180 à 200/minute) en comparaison avec les athlètes non handicapés pendant les situations particulières de compétition. Les sports caractérisés par la rapidité, la dextérité et la force ne sont pas capables d'entraîner le système cardio-pulmonaire de façon substantielle. La natation est recommandée comme étant bénéfique. Les considérations psychologiques et les aspects physiologiques de l'entraîenment suggèrent que les courses en fauteuil roulant sur de longues distances devraient être adoptées dans les compétitions des Jeux de Stoke Mandeville.

ZUSAMMENFASSUNG

Spiroergometrische und telemetrische Untersuchungen wurden bei 100 gelähmten Athleten während der XXI. Internationalen Stoke Mandeville Spiele in Heidelberg, 1972 ausgeführt. Technische und organisatorische Schwierigkeiten während der Messungen waren bedingt durch die Disabilität der Untersuchten. Der maximale Sauerstoffverbrauch und der Oxygenpuls war geringer als bei Nichtgelähmten. Kein Unterschied wurde im der maximalen Herzrate (180-200 per Minute) im Vergleich mit nicht-gelähmten Athleten während speziellen Wettkampf-Situationen gefunden. Sportarten charakteristisch für Schnelligkeit, Geschicklichkeit und Kraft sind nicht geeignet, das kardio-pulmonale System erheblich zu trainieren. Schwimmen wird als vorteilhaft empfohlen. Aus psychologischen und training physiologischen Erwägungen werden Lang-Strecken Rollstuhl-Wettfahren für die Stoke Mandeville Spiele emphfohlen.

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