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METABOLISM AND PULSE RATE IN PHYSICALLY HANDICAPPED WHEN PROPELLING A WHEEL CHAIR UP AN INCLINE

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ABSTRACT. Spiroergometric studies, together with pulse rate measurements, were carried out on 29 physically handicapped wheel chair drivers ranging in age from 11–22 years during active driving up a 2° incline at velocities from 1–4 km/h. A nomogram was set up, which permits direct reading off of the necessary energy output on the basis of the degree of inclination, speed of the conveyor belt, and the body weight. Metabolic rates and load of the circulatory system showed no correlation with age. By a mean work load of 40 watts, the O_2-consumption was within the same range as has been determined for healthy persons while turning a crank. In contrast, the mean pulse rate was 20 beats/min higher than in healthy persons of the same age. The test persons with additionally handicapped arm and shoulder girdle muscles had significantly higher pulse rates than the control group by the same O_2-consumption. As a practical consequence the question must be raised to what extent the circulatory systems of such patients are conditionable at all.

The number of illnesses and especially of accidents, in consequence of which patients are confined to a wheel chair for long periods of time or just temporarily, is increasing steadily. Nonetheless, at present only little is known about the effects of propelling a wheel chair upon the rate of metabolism or upon the circulatory system. Peitzer (9) and Voigt, Berendes & Hildebrandt (10) reported on investigations of driving on level ground, but no reports on propelling a wheel chair up an incline could be found in the literature. Since knowledge of the dimensions of this burden and its effects upon the circulation can be necessary for a successful rehabilitation, especially in connection with job counselling and training for new occupation, metabolism and behavior of the circulatory system of wheel chair drivers while propelling themselves up a grade will be described. A preliminary summary of this work was presented by Hildebrandt at the 5th International Congress of Physical Medicine (3).

METHODS

The investigations were carried out on 29 pupils of hte orthopedic rehabilitation center "Lichtenau", who were unable to walk. They concerned 17 girls aged 11–19 years and 12 boys aged 13–22 years. 70% of these persons had had poliomyelitis and some were handicapped in the use of shoulder girdle and arm musculature as well as in the lower limbs. In Table I data on the individual test persons are presented.

The test persons were required to ride under their own power up a conveyor belt inclined at 2° for 4 min at each speed of 1, 2, 3 and 4 km/h. Following the second speed a pause of 4 min was made, so that the test persons would not have to stop because of muscular fatigue. In a preliminary experiment, designed to accustom the test persons to the experimental situation grades of 0°, 1°, 2° and 3° were tested at the same speeds. Here, however, the subjects had to drive for only 3 min at each speed, and only the pulse rate was considered.

Spirometric values were measured with the pulmonary function measuring system "Pneumorex" from Dr Fenyves & Gut, Basel. and pulse frequency with a photoelectric pulse counter from W. Himmelmann, Dortmund. The level of the pulse counter was read and recorded at the end of each minute.

The determination of the effective work had to be performed at each chosen speed and inclination of the conveyor belt was carried out as follows: A factory-new wheel chair (Model: Everest & Jennings, for young persons, weight 18 kg) was held on to the conveyor belt with a cable. The forces developed with loads of 30, 50 an 70 kg resp. were determined by laying the cable across a pulley and weighting down the free end so that the system was balanced at each of the various slopes and speeds. Each force was multiplied by the speed so as to arrive at the power in mkp/sec, which can be converted into watts. Fig. 1 shows as an example the effective burden of a load of 70 kg plotted against inclination and speed. All results have been summarized in a nomogram

Table I

Number	Name	Age (years)	Weight (kg)	Cause of handicap	Degree of shoulder girdle handicap
Female					
1	U. R.	11	47	Polio (1958)	Medium
2	C. M.	12	38	Polio (1957)	Medium
3	B. R.	13	22	Polio (1954)	Large
4	K. W.	13	56	Paraplegia (1964)	None
5	P. R.	14	49	Polio (1958)	Medium
6	G. S.	14	63	Spast. parapl.	Medium
7	A. B.	15	40	Polio (1953)	Medium
8	L. H.	15	46	Polio (1952)	None
9	C. B.	15	51	Progress. musc. dystr.	Large
10	I. G.	15	53	Polio (1961)	Medium
11	E. B.	15	62	Polio (1955)	None
12	D. M.	16	49	Polio (1956)	Medium
13	M. D.	16	62	Femur amp. (1961)	None
14	C. K.	17	42	Polio (1952)	Medium
15	H. B.	17	52	Polio (1951)	None
16	H. F.	17	63	Polio (1955)	None
17	M. F.	19	72	Polio (1954)	Medium
Male					
18	G. T.	13	43	Paraplegia (1959)	None
19	V. S.	14	38	Polio (1960)	Medium
20	J. S.	14	64	Polio (1961)	Medium
21	M. E.	15	48	PCP (1962)	Medium
22	M. K.	15	69	Polio (1957)	Large
23	W. S.	15	89	Polio (1956)	Medium
24	M. H.	16	66	Hemophilia	None
25	K. K.	17	54	Polio (1957)	None
26	S. S.	20	63	Polio (1960)	Medium
27	H. S.	22	54	Polio (1945)	None
28	G. S.	22	64	Paraplegia Th 9 (1958)	None
29	R. S.	22	35	Osteopsatrosis	None

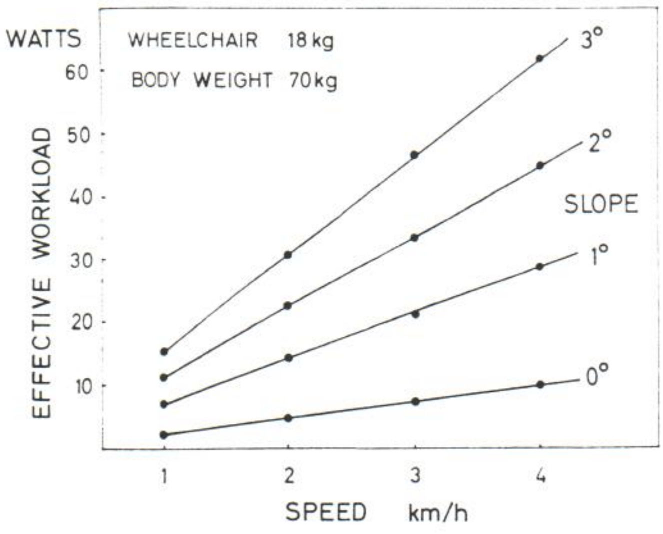

Fig. 1. Power requirements while propelling an 18 kg wheel chair with a load of 70 kg as a function of incline and speed.

in such a way, that by determination of the starting values, the power can be read off directly. These entries must be made in the following order: body weight, inclination, and speed. Fig. 2 depicts the procedure for an example with the following data: body weight 70 kg, inclination 2°, and a speed of 4 km/h. The required energy output is read to be 45 watts.

The net metabolic rate was determined as follows: On the basis of the O_2-consumption, the total metabolic rate was calculated with the help of a constant from a conversion table which takes into consideration the measured respiratory quotient. The resting metabolic rate was calculated in the same way and subtracted from the total metabolic rate.

RESULTS

The preliminary experiment with 3 min of work at each level of exertion served first of all to determine the influence of the inclination as shown by a characteristic variable of the circulatory system. As shown in Fig. 3, the pulse frequency in-

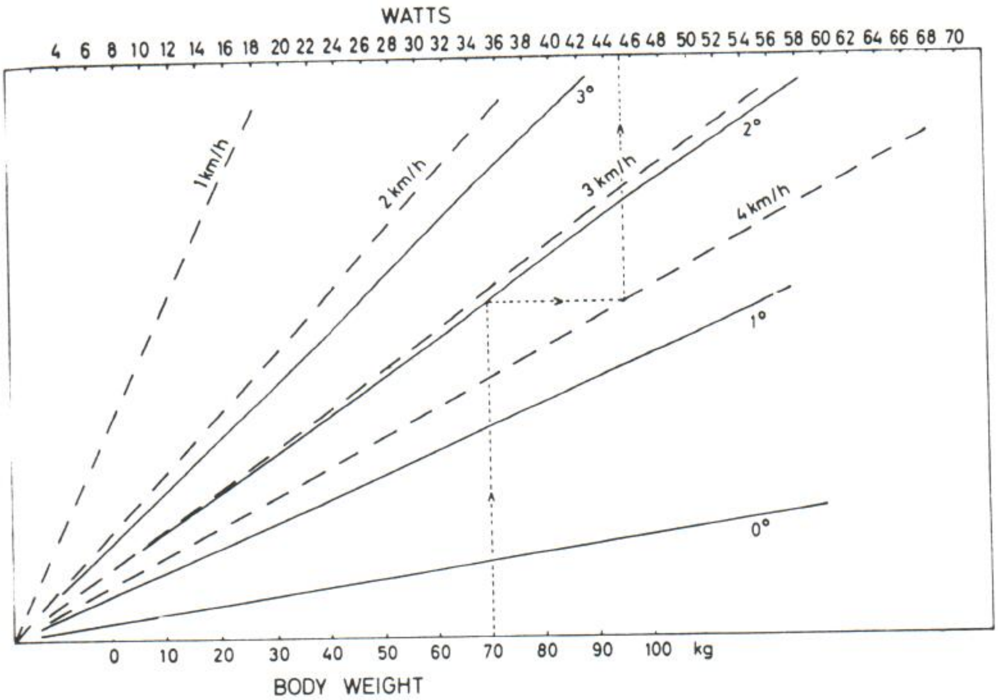

Fig. 2. Nomogram for the determination of the work load imposed by propelling a wheel chair. The required energy in watts was calculated from the values for body weight, inclination of the track (in degrees), and speed (km/h). In the example shown, by 70 kg body weight, 2° slope and a speed of 4 km/h, 45 watts can be read off. The wheel chair weighed 18 kg.

creased at all speeds almost linearly with the inclination; however, only a few of the test persons were able to negotiate the most difficult runs. For this reason we chose for the main experiment an inclination of 2°, which represented a considerable load on the one hand, but on the other hand could still be negotiated even by the most severely handicapped test persons.

Fig. 4 shows the increase in net metabolic rate during propulsion of an indoor wheel chair as a function of the speed at 0° and 2° inclination. The test persons were separated here into the age groups 11–14, 15–16, and 17–22 years. The mean ages in these groups were 13.1, 15.3, and 19.2 years, the mean body weights 46.6, 57.7, and 55.5 kg, resp. Since in our experiment the body weight was considered in calculating the energy output, the youngest age group had a lower net rate of metabolism, corresponding to the smaller body weight. However, the mean values in the various age groups did not differ significantly from one another and when body weight was considered they lay even closer together. The metabolism increased in all groups linearly with the speed.

The behavior of the pulse frequency is depicted in Fig. 5. While the means for both older age groups coincided almost exactly at every speed, the mean frequency for our younger test persons while riding on level ground was somewhat higher. The increase in pulse rate was the same; however, the resting values at the start were somewhat higher, probably due to incompletely subsided excitement generated by the experimental situation and preparations. In contrast to the behavior by greater burdens, the pulse rate at higher loads was somewhat influenced by the resting rate, that is, by the vegetative starting conditions. At 4 km/h, however, this effect could no longer be demonstrated; here all 3 age groups had the same mean pulse frequency.

In contrast, the body weight figures strongly in the power required to surmount a slope of 2°. For this reason the pulse rates of the youngest

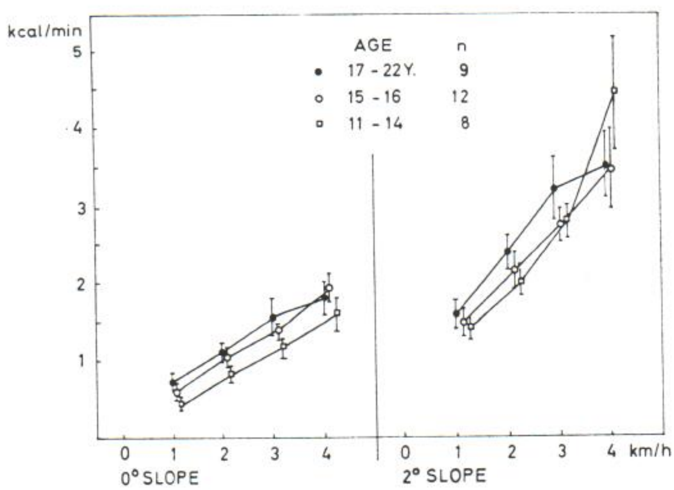

Fig. 3. Behavior of the net metabolic rate while propelling a wheel chair up 0° and 2° slopes as a function of the speed, shown for 3 different age groups. The brackets indicate the range of mean error.

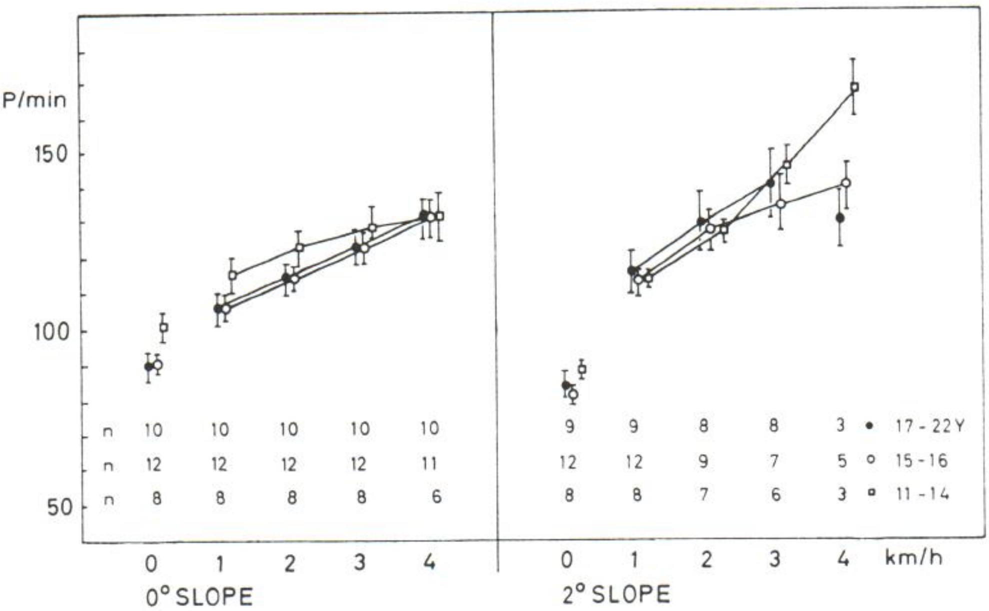

Fig. 4. Behavior of the pulse rate while propelling a wheel chair up slopes of 0° and 2° as a function of the speed, shown for 3 different age groups. The brackets indicate the range of mean errror.

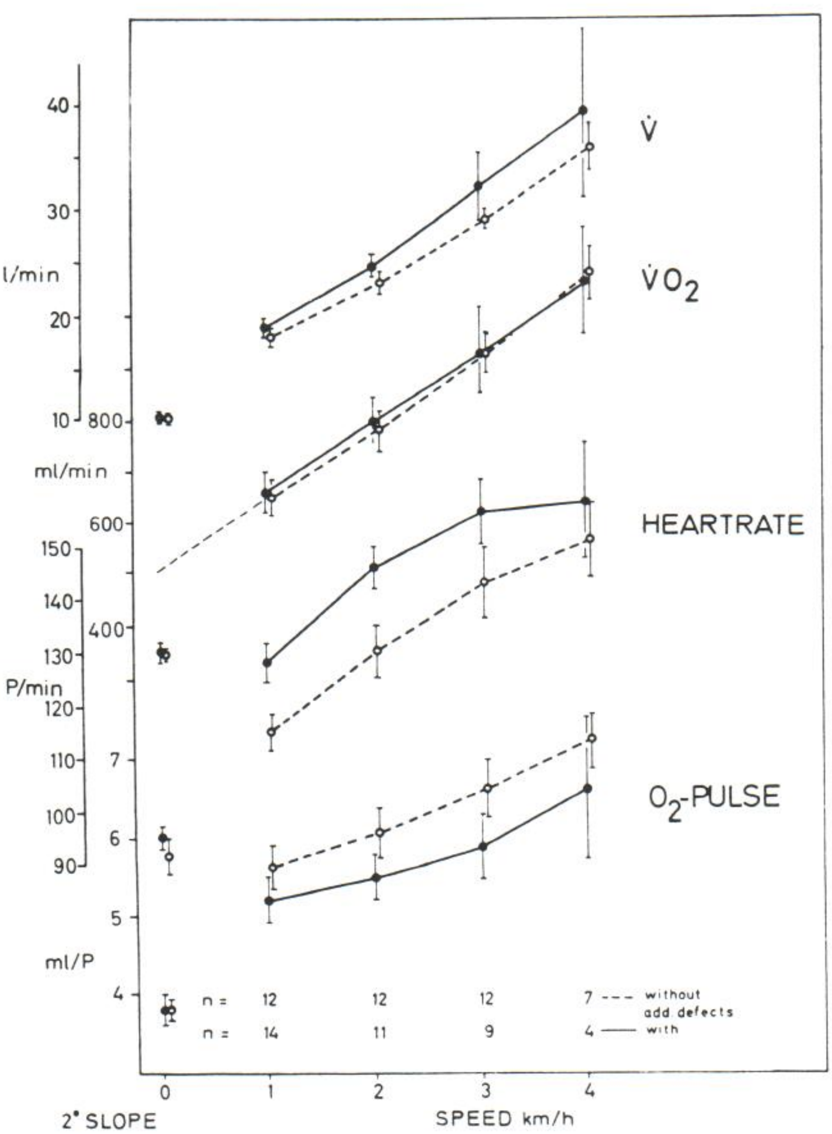

Fig. 5. Behavior of total ventilation, O_2-consumption, pulse rate, and O_2-pulse during active wheel chair driving up a 2° slope at a speed of 1–4 km h. Mean and error for handicapped persons with (●——●) and without (○- - -○) additional handicaps in the arm and shoulder girdle musculature.

test persons, who were also an average of 10 kg lighter, were initially lower, but under tiring loads exceeded the pulse rates of the older test persons. These differences appear only as a tendency; they are not statistically significant and are smaller if the weight influence is neglected. The pulse rate curve for the highest speed was not perfectly linear, due to the fact that only 36% of the test persons reached this stage.

If the whole group is divided up according to another criterion, namely that of an additional handicap in the shoulder girdle and arm musculature, significant differences can be established for several important circulatory parameters.

Fig. 6 shows for both groups with and without additional handicaps on the 2° slope the velocity-dependent changes in total ventilation, O_2-consumption, pulse rate and O_2-pulse. As was to be expected, the additionally handicapped had to break off the experiment after shorter periods and at lower performance levels. Three test persons with especially great additional handicaps were not considered. While out of the 12 test persons without additional handicaps none had to quit before reaching the highest speed level, when 5 dropped out, among the 14 additionally handicapped some were eliminated at every stage, and only 4 were able to follow the program to completion. The reason for breaking off the experiment was in every case muscular fatigue and not that of the circulatory system. Although the number of test persons decreased in the course of the experiment until under the heaviest load and only those test persons who had been better right from the start, were still taking part, the oxygen consumption increased linearly with the speed, and the mean values for both groups differed only very little.

In contrast to this, the pulse rates of the additionally handicapped test persons were significantly higher in some cases. Moreover, there was a nonlinear curve with a clear leveling off at the highest speeds, traceable to the great individual variations in pulse rate level and to the fact that the number of test persons decreased in the course of the experiment. The O_2-pulse, being derived from the other values, behaved correspondingly.

The mean values for total ventilation at various speeds did not vary significantly, but here again the increase was linear and remained unchanged as the weaker persons dropped out.

DISCUSSION

As we have already shown (10), propelling a wheel chair on a level surface represents a considerable burden for the circulatory system of handicapped young persons, although the external physical power required is very small, hardly exceeding 10 watts. The large proportion of unproductive work in the total metabolism can be explained by the ergonomically ineffective movements, including much static work. Our young test persons had been without exception handicapped for several years and had always propelled their wheel chairs themselves. Because of the difficult landscape at Lichtenau, including several long slopes which had to be climbed several times during a typical day, it can be assumed that all test persons were in as good condition as possible and accustomed to propelling a wheel chair. Studies on driving on level ground have shown not only the required work to be relatively small, but also the net caloric consumption. The latter is, in spite of inefficiency, even lower than that for walking at the same speed (3, 10). It is especially for this reason that the discrepancy between the low metabolic rate while working and the large load on the circulatory system is so conspicuous.

A 2° slope requires an energy output which, even at a speed of 4 km/h with a mean of 40 watts, is not excessive. Under this load the mean oxygen consumption was 1070 ml/min. Dressler & Mellerowicz (1) found an oxygen consumption of 1000 ml min for 7–18 years old healthy test persons while turning a crank at a power output of 40 watts. The results of our investigations are still within the reliability range of this value, the difference not being statistically significant. Oxygen and caloric consumption are seen to be closely correlated to the work performed; age and sex, as well as the existence of an additional handicap, had no demonstrable influence in our group of physically handicapped test persons. A comparison with healthy persons revealed that as long as the same muscle groups are used, the type of work has likewise no influence on the oxygen consumption.

The amount of static work in propelling a wheel chair can be estimated from Fig. 6 as follows: The backward extrapolation of the curve for oxygen consumption crosses the ordinate above the measured resting metabolism at velocity =0 km h. Since the amount of static work is independent of the speed, it can be assumed that these 120 ml O_2 are mainly due to the static work, amounting to up to 0.58 kcal/min.

In contrast to the metabolism, which corresponds approximately to that of normal persons for the same amount of work, there were clear differences in the pulse rates. While our test persons reached a pulse frequency of about 150/min on a slope of 2° at 3 km/h, corresponding to about 30 watts, the pulse rate of normal persons of the same age group while turning a crank was about 130/min (6). No age correlation could be demonstrated among our test persons, but the pulse rates of the group with additional handicaps were significantly higher than those of the other group. This can be attributed to local muscular fatigue, for in all cases in which the test persons had to quit before the end of the experiment, they gave symptoms of muscular exhaustion as the reason. This had begun, however, during the later stages of the immediately preceding test and had already affected the measurements. Karrasch & Müller (4) and Müller (7) observed in detailed studies that during tiring even of small muscle groups, so called fatigue pulses arise, which are triggered by local afferences and not by the requirements of a more burdened circulatory system (5).

Thereby wheel chair driving is seen to be an activity which certainly requires relatively little exertion, even on an upward slope, but which leads quickly to localized muscular fatigue due to the use of small groups of muscles and a high percentage of wasted energy. Although it may be assumed, as has been shown, that our test persons were in as good condition as possible and were used to propelling wheel chairs, the muscle mass at their disposal is too small and tires too quickly for the circulatory system to be loaded heavily enough. Therefore the heart is not exposed to the type of conditioning stimulus which would be necessary to improve its performance capacity. On the other hand, a relatively unconditioned heart reacts to nervous stimulation from fatigued muscles sooner and more strongly with an increase in frequency (2). This inconvenient situation hinders an increase in stroke volume, which is so eminently important for increasing the performance capacity of the circulatory system, and applies especially to patients with additional handicaps in the working muscles. Due to the physical load, severely handicapped persons may possibly be more fatigued than exercised. Thereby the question of how the performance capacity of these patients can be increased becomes a special problem.

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