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A WHEELCHAIR ERGOMETER WITH A DEVICE FOR ISOKINETIC TORQUE MEASUREMENT

Kersti Samuelsson,[1] Harriet Larsson[1] and Hans Tropp[2]

From the Department of [1]Rehabilitation Medicine and the Sports Medicine Unit and the [2]Department of Orthopaedic Surgery, University Hospital, Linköping, Sweden

ABSTRACT. A wheelchair ergometer has been developed for the study of wheelchair work. At each propulsion the peak torque can be examined, and there is an opportunity to directly study angular amplitude, power output, work etc. The physical capacity of the subject as well as the importance of chair adjustments upon performance can be evaluated.

Key words: wheelchair ergometer, isokinetical dynamometer.

Several reports exist in which physiological data concerning wheelchair work are presented (1, 2, 3, 6, 10). Various methods have been used for this purpose; (A) treadmill testing (5, 9, 12), (B) stationary wheelchairs connected to bicycle ergometers (1, 4), (C) stationary wheelchairs connected to fly-wheel (11), and (D) wheelchairs on rollers (8). These methods are insufficient since the single propulsions cannot be examined.

A factor of importance when evaluating different wheelchairs is the actual power output. This factor can be calculated using the equation:

$$P_o = F_d \cdot v$$

where

P_o = actual power output
F_d = resistance force
v = velocity
$F_d = F_{if} + F_a + F_{acc} + F_r + F_{incl}$
F_{if} = internal friction
F_a = air resistance
F_{acc} = acceleration force
F_r = rolling resistance
F_{incl} = gravitational component

If a fly-wheel is used, resistance force F_d can be provided by a gravitational force acting as friction and if v is the peripheral velocity of the wheel, the relation can be written;

$$P_o = F_d \cdot v$$

Power output can also be expressed as the work per propulsion cycle multiplied by the frequency.

$$P_o = A_d \cdot f$$

where

A_d = mean work per cycle
f = cycle frequency

$$A_d = \int M \cdot d(Q)$$

where

M = effective torque exerted on the propulsion system
Q = the angle of the system

Previous studies have given the result that power output during wheelchair work is less than power output during arm cranking ergometry (11).

The estimation of physical work performance is usually done using maximal ergometry tests. The most common principle is based upon power output, oxygen uptake and changes in heart rate, i.e. physiological parameters. For patients needing a wheelchair for ambulation it is of importance to study their ability to maintain short term activity as well as submaximal performance. Likewise it is of importance to evaluate the patient's capacity at short periods of wheelchair work, e.g. to overcome a slope or accelerate a heavy chair. The power output required can be calculated according to the equations shown above. Work in conditions non-steady-state is difficult to study with conventional physiological methods.

The aim of the present study was to describe a wheelchair ergometer suitable for the intermittent character of wheelchair work.

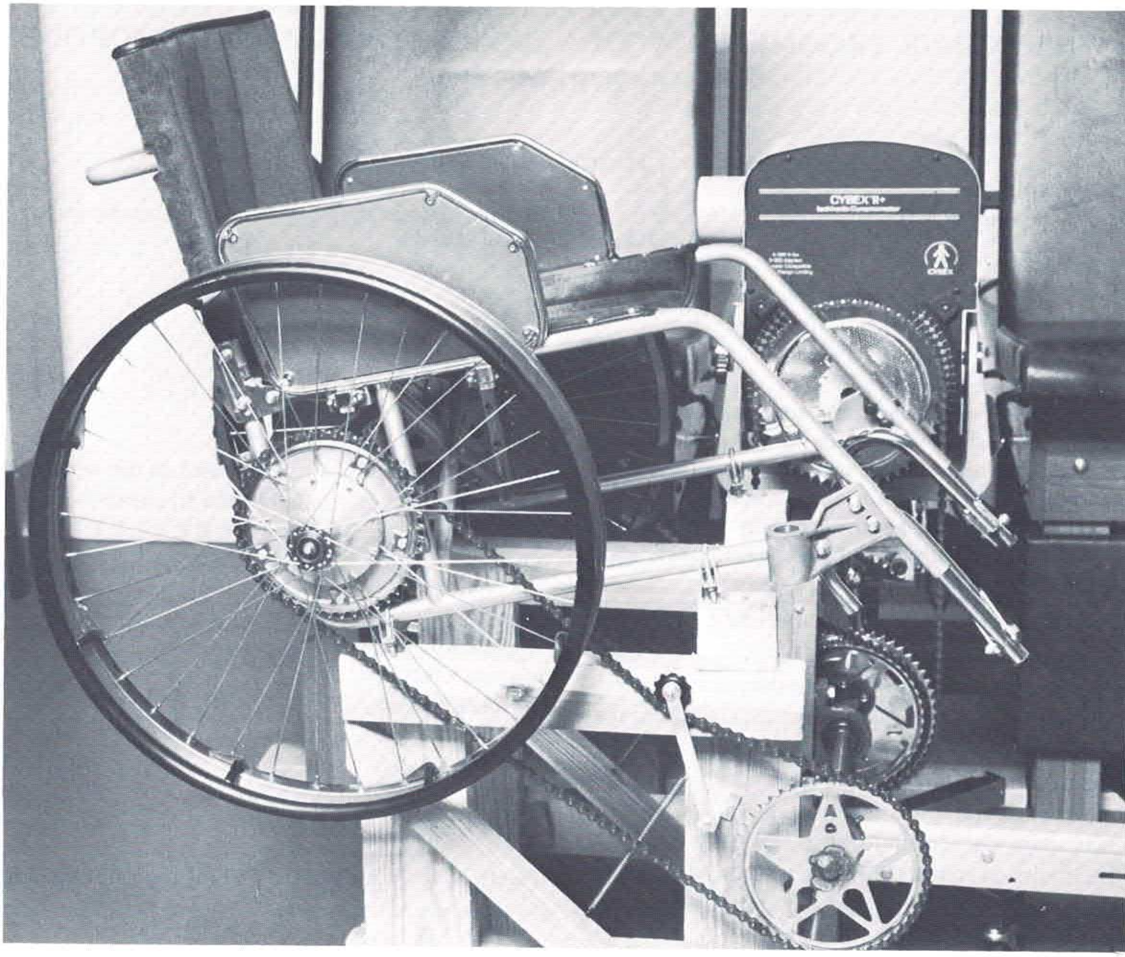

Fig. 1. The wheelchair ergometer adjusted to the dynamometer.

METHODS AND MATERIAL

The current wheelchair is set up on the frame and attached firmly (Fig. 1). The wheels are connected to a common axis. This axis is connected to the axis of an isokinetic dynamometer (Cybex II). Chains and cog-wheels are used for power transfer. The gear ratio between drive-wheel and dynamometer axis is 1/1.

The recordings are made at different dynamometer angular velocities. We can adjust instruments from 15°/s to 300°/s. If the wheelchair drive wheel diameter is 24 inches these angular velocities correlate to 0.08–1.60 m/s chair velocities.

The common axis can be disconnected from the dynamometer and connected to a fly-wheel. The power output when driving the wheelchair is then calculated as

$$P_O = F_d \cdot v$$

where

F_d=breaking force
v=fly-wheel peripheral speed

The torque and the angle is displayed as a function of time (Fig. 2). The variables which might be interesting are

- peak torque
- mean torque
- angular displacement at propulsion
- peak power
- mean power
- total work of each propulsion
- time for withdrawal of hands for a new propulsion

In this study 5 disabled men and 4 male controls were examined. They were all recorded sitting in the same chair (Spinner, Maratonprodukter, Sweden). Recordings were also made of isokinetic extension and flexion at the elbow at 30°/s and 180°/s angular velocity. This method was taken from the instructions given by the manufacturer (7).

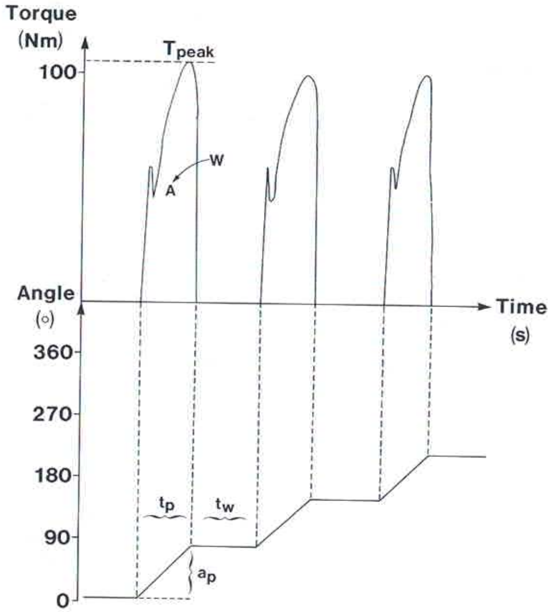

Fig. 2. An example of intermittent wheelchair work. T_{peak} = peak torque, W = work, A = area beneath the graph, t_p = time for propulsion, t_w = time for withdrawal of hands, a_p = angular displacement of the wheels during propulsion.

Table I. *The results from the pilot study*
The figures are all peak torques (Nm)

		Controls	
Disabled	$n=5$	$n=4$	
Isokinetic arm muscle-strength (Nm)			
Flexion			
30°/s	62±13	54±15	
180°/s	51±11	40±15	
Extension			
30°/s	66±18	56±10	(NS)
180°/s	51±11	43±15	
Isokinetic wheelchair torque (Nm)			
120°/s	65±20	81±28	(NS)

RESULTS

The subjects had no difficulties in accomplishing the test. Some important objections were found. The drive wheel has no inertia and stops immediately when the driver's hand leaves the rim. The hands then grip the rim which has no velocity. An impact thrust shows at the beginning at the isokinetically recorded propulsion (Fig. 2). All 5 disabled men complained that they were not used to the test wheelchair. However, it is possible to use the subject's own chair. The coefficient of variation was less than 10%. There was a tendency towards a greater angular displacement with each propulsion and a shorter withdrawal time for the trained disabled men. There was no difference regarding arm strength and peak torque between the two groups studied (Table I).

DISCUSSION

It is known that the gross mechanical efficiency of conventional hand rim wheelchairs rarely exceeds 10% (1). This is low when compared with for instance, the bicycle, suggesting a high internal waste of mechanical energy. Improvement of wheelchair energy utilization can be accomplished in three ways: (A) by improving the compatibility between the wheelchair and the subject by optimizing the "interface" between them; (B) by reducing power loss due to resistance to roll, internal friction, air resistance and gravitation; and by (C) increasing the physical work capacity through training and technique.

This method provides the means to study every propulsion at different times. Since different chairs can be attached and adjusted it is possible to study the effects directly.

We belive that this type of wheelchair ergometer can provide further information concerning wheelchair ergometry. It can be a tool for feed-back information to patients doing wheelchair exercise.

REFERENCES

1. Brattgård, S., Grimby, G. & Höök, O.: Energy expenditure and heart rate in driving a wheelchair ergometer. Scand J Rehab Med *2*: 143–148, 1970.
2. Coutts, K., Rhodes, E. & McKenzie D.: Maximal exercise response of tetraplegics and paraplegics. J Appl Physiol *55*: 479–481, 1983.
3. Dreissinger, T. E. & Londeree, B. R.: Wheelchair exercise: a review. Paraplegia *20*: 20–34, 1986.
4. Forcheimer, F. & Lundberg, Å.: Wheelchair ergometer. Scand J Rehab Med *18*: 59–63, 1986.
5. Gass, G. C. & Camp, E. M.: The maximum physiological responses during incremental wheelchair and arm cranking exercise in male paraplegics. Med Sci Sports Exerc *16*: 355–359, 1984.
6. Glaser, R. M., Sawka, M. N., Durbin, R. J., Foley, D. M. & Suryaprasad, A.: Exercise program for wheelchair activity. Am J Phys Med *60*: 67–75, 1981.

7. Isolated Joint Testing & Exercise. A Handbook for Using Cybex II and U.B.X.T. Lumex Inc., New York, 1980.
8. Motloch, W. M. & Brearley, M. N.: Technical note—a wheelchair ergometer for assessing patients in their own wheelchairs. Prosthetics and Orthotics International *7*: 50–51, 1983.
9. Sanderson, D. J. & Sommer III, H. J.: Kinematic features of wheelchair propulsion. J Biomech *18*: 423–429, 1985.
10. Voight, E.-D. & Bahn, D.: Metabolism and pulse rate in physically handicapped when propelling a wheelchair up an incline. Scand J Rehab Med *1*: 101–106, 1969.
11. Wicks, J. R., Oldridge, N. B., Cameron, B. J. & Jones, N. L.: Arm cranking and wheelchair ergometry in elite spinal cord-injured athletes. Med Sci Sports Exerc *15*: 224–231, 1983.
12. Woude, L. H. V. van der, Groot, G. de, Hollander, A. P., Ingen Schenau G. I. van & Rozendal, R. H.: Wheelchair ergonomics and physiological testing of prototypes. Ergonomics *29*: 1561–1573, 1986.

Address for reprints:

H. Tropp
Department of Orthopaedic Surgery
University Hospital
S-581 85 Linköping
Sweden