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Published in:
RESNA'87 meeting the challenge

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RESNA '87

Meeting the Challenge

Proceedings of the 10th Annual Conference on Rehabilitation Technology

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June 19-23, 1987 • San Jose, California

Published by
RESNA–Association for the Advancement of Rehabilitation Technology

Proceedings of the 10th Annual Conference on Rehabilitation Technology
San Jose, California, June 19-23, 1987

Volume 7
ISSN 0883-4741

RESNA—Association for the Advancement of Rehabilitation Technology
Suite 700, 1101 Connecticut Avenue, N.W., Washington, D.C. 20036 202/857-1199

Printed in the United States of America
Dependable Printing Company, Inc.

SPEED REGULATION IN HAND RIM WHEELCHAIR PROPULSION

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ABSTRACT

Adaptation to different velocities in hand rim wheelchair ambulation was studied in terms of timing, work per cycle and push angle. Speed regulation is achieved both through adapting cycle frequency as well as the amount of work per cycle. Moreover a higher cycle frequency is mainly attained by adjusting push time. No systematic changes in push angle are seen. These findings most likely imply adaptation in the pattern of torque generation. The results hold for a group of trained wheelchair sportsmen at a daily-use speed level (.56 - 1.39 m/s) as well as racing speeds up to 3.33m/s. The results were confirmed for wheelchair propulsion in a basketball wheelchair and a racing wheelchair, the latter with different hand rim diameters.

INTRODUCTION

Propulsion technique of hand rim wheelchair ambulation is badly understood. To our knowledge no systematic research has been conducted into timing pattern, work per cycle and push angle with respect to power output, velocity and overall resistance. This rather complicates interpretation of parameters on timing and movement technique with respect to other experimental conditions, such as seat position.

Few studies have incorporated timing parameters. Only cycle frequency was determined rather frequently (1,2,3,4,5, 6). Brubaker and McLaurin (2) studied push angle, cycle time and torque applied to the hand rims in relation to seat position at V=2.5km/hr. Walsh et al. (5) analysed cycle time in wheelchair sprinting, with respect to seat position. Sanderson and Sommer (4) studied timing and movement pattern of the upper limb and trunk in the sagittal plane.

Moreover in wheelchair racing several propulsion techniques are used. It is not feasible to advise a suitable technique in wheelchair ambulation for a given subject or condition, until a detailed description and analysis of wheelchair propulsion technique is available.

Results of two current projects, in which propulsion parameters were studied next to physiological parameters, will be discussed below.

METHODS

Two hand rim wheelchair experiments (EXP) were conducted on a motor driven treadmill (MDT). Parameters of propulsion technique were determined in relation to mean wheelchair speed. The mean amount of work per cycle (A) for both arms was derived from the external power (P) and Cycle Time (CT), according to:

$$A = P \times CT \quad (= \int M.dQ)$$

P was determined in a drag test on the MDT (7), according to:

$$P = F \times V$$

in which F is the mean drag force and V the mean wheelchair velocity of a subject wheelchair combination. CT was calculated from cycle frequency (CF(Hz)). From film data the Push Angle (PA) of the left hand with respect to the wheel axis, Push Time (PT:"time on hand rim") and Recovery Time (RT = CT - PT) were determined. Relative values (%CT) for PT and RT were derived from mean values.

In EXP-1 N=6 male wheelchair sportsmen (mean age:35.6; s.d.:+/-6; mean body weight: 78.5 +/-7) conducted four 12 minute exercise tests in their basketball wheelchair. In each test, the belt speed increased with .28m/s every third minute, from .56m/s to 1.39 m/s. The slope of the treadmill was kept constant in each of the four tests at respectively 0,1,2 and 3 degrees. The tests were assigned randomly per subject.

In EXP-2 N=6 male marathon wheelchair racers (mean age:28.2 +/-6; mean body weight:70.5 +/-16.5) conducted five 12-minute exercise tests in a "Speedy Wheely" racing wheelchair. Different hand rim diameters were mounted to the spokes in the five tests (.3m,.35,38,.47,.56m). Speed increased with .83m/s every third minute, from .83m/s to 3.33 m/s. The slope of the MDT was constant (.5 degrees).

Data were statistically analysed with a multi-factor analysis of variance for repeated measures ($P \leq 0.05$), with the exception of PT,RT and PA in EXP-1. The latter was due to incomplete data and the parameters were analysed qualitatively.

RESULTS

The results for both experiments show a similar trend: an increasing speed (and subsequently P) is generated through a definite decrease in CT, as is shown for EXP-2 in Figure 1.

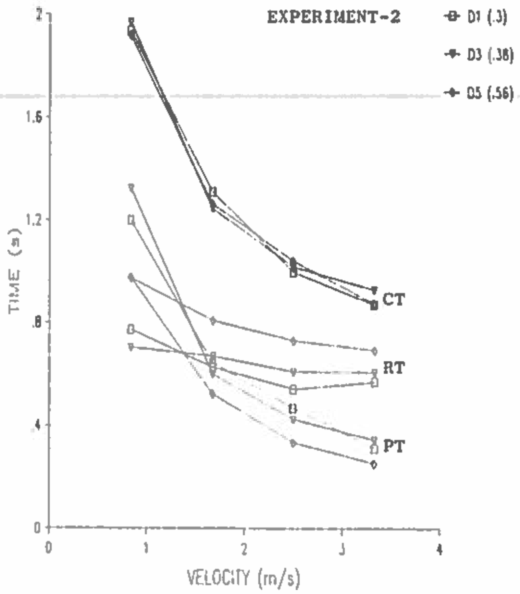

Figure 1. Mean CT,PT and RT for 3 hand rims (EXP-2).

In conjunction with a decrease in CT a definite increase in the amount of work per cycle is seen in both experiments (Fig.2.).

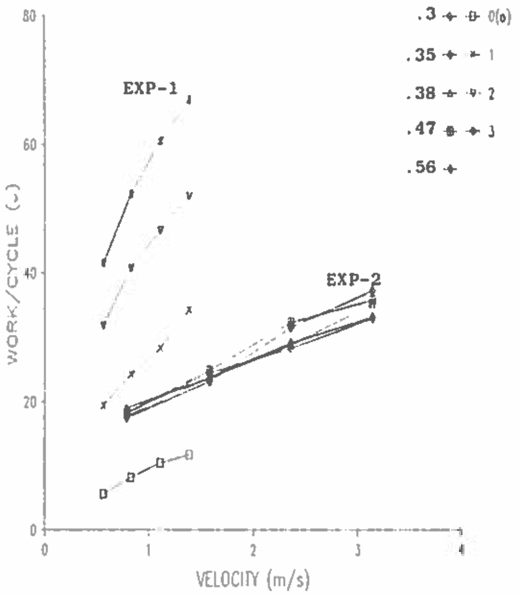

Figure 2. Mean A for EXP-1 and EXP-2.

PA ranged at a more or less constant level. (EXP-1: 65-80, EXP-2: 110-160 deg.) and showed no significant relation with propelling velocity (Table 1).

	EXP-1			EXP-2		
	Velocity	Slope	VxS	Velocity	Diameter	VxD
CT	*	*	*	*	ns	ns
A	*	*	*	*	ns	ns
PT	-	-	-	*	ns	ns
RT	-	-	-	*	ns	ns
PA	-	-	-	ns	ns	ns

(*): p≦0.05; -: not tested
ns: not significant

TABLE 1.

A lower CT with increasing wheelchair velocity is predominantly attained through a decrease in PT (Fig.1.), although a significant decrease in RT is seen as well (Table 1). Moreover a decrease in relative PT (%CT) and an increase in RT (%CT) is seen in both experiments (Fig.3.).

Contrary to our expectations no significant variation with respect to hand rim diameter was seen for any of the parameters in EXP-2 (CT,A,PA, RT and PT; Table 1.). A clear effect of slope level was however confirmed for CT and A in EXP-1 (Table 1.). This leads to an increased PT (%CT) and a decreased RT (%CT) with increasing slope (Figure 3a.).

DISCUSSION

Our data on CT agree well with previous studies (1,3,6). However in contrast with the linear relations described in these studies, a clear curvi-linear relation is evident in our data (Fig.1). Moreover the trend in the "time on hand rim" (PT) agrees with (5) and shows a similar dominant trend with increasing velocity as was described for the period of force-transmission (FT) by Lesser (3). This implies that both parameters (PT, FT) are more or less congruent.

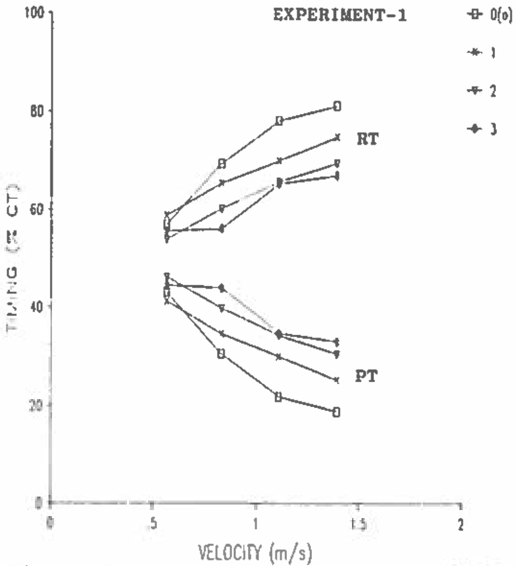

Figure 3a. PT and RT in %CT for EXP-1

Speed adaptation is also evident in A. Since no speed adaptation in PA is apparent and a shorter PT is seen, the increase in A implies a change in the pattern of force generation. An increase in torque (M) and instantaneous power is likely. This will be verified in near future with a wheelchair simulator with force registration.

Both absolute and relative values of PT show its prevailing speed-regulating characteristic. The declining pattern in PT(s) seems closely related to the required acceleration of the hand in the phase of force generation.

The small but significant diminishing trend in RT (Figure 1.) stresses the dominant declining curvature of PT in relation to CT. Whether this trend in PT is cause or effect of the CT pattern is unclear.

The findings in EXP-1 with respect to velocity and slope, indicate that timing (CT,A) is relevant in power generation in general. This can be seen in the slopes of the lines in EXP-1 in Figure 2. and may be reflected as well by the significant statistical interaction between slope and speed (Table 1.).

For a given slope (EXP-1) and hand rim diameter (EXP-2) no clear changes are seen in PA with increasing speed. This indicates a trajectory of the hand, independent of wheelchair velocity. Between different slopes and hand rim sizes no changes were seen in PA for a given speed as well. The latter indicates an increasing hand-trajectory for a larger hand rim diameter (EXP-2).

Adaptation to different hand rim sizes is clearly independent of timing. Movement analysis of arm and trunk might indicate other speed-regulating mechanisms in this respect.

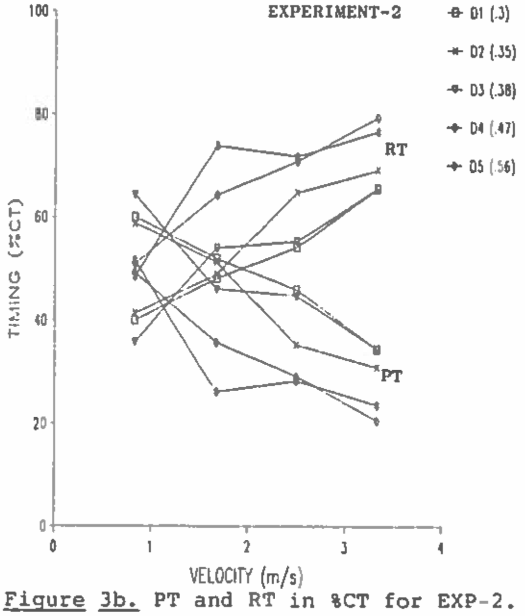

Figure 3b. PT and RT in %CT for EXP-2.

The differences in relative PT and RT between EXP-1 and EXP-2 (Figure 3.) may be due to the difference in wheelchair configuration which leads to a differentiation in the distance between shoulder and wheel axis.

CONCLUSIONS

For a large velocity-range, two wheelchair configurations and a group of wheelchair sportsmen, the speed-regulating character of several propulsion technique parameters (CT,PT,RT,A) was clearly shown. No PA changes were found. A predominance is seen for PT in adapting CT to a given velocity. This holds for wheelchair sportsmen, propelling a basketball and racing wheelchair with different rim sizes.

Timing parameters appear relevant in adapatation to slope increments as well. This implies a depence on external power output in general.

The results of EXP-2 show the independence of timing parameters in the adaptation to different rim diameter. The impetus of these findings on force generation and movement technique must be studied in more detail.

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A SPATIAL MUSCULOSKELETAL MODEL FOR WHEELCHAIR LEVER PROPULSION

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ABSTRACT

The development process for a dynamic, spatial musculoskeletal system model for simulating the wheelchair lever propulsion function is described. A 3-Dimensional model of the skeletal system and its correlation with experimental data are presented.

INTRODUCTION

A comprehensive musculoskeletal model which simulates the dynamics of the wheelchair propulsion function can provide a variety of benefits, including:

- Optimization of the wheelchair mechanical system parameters such that these parameters are customized to a specific operator;
- Determination of the joint forces and the propulsion effort required to propel the wheelchair;
- Development of an understanding of the function of individual muscles during the propulsion cycle.

A research project at the University of Virginia Rehabilitation Engineering Center (REC) and the Center for Computer Aided Engineering (CCAE) is currently developing such a model with the longer term goals of creating a wheelchair prescription software system and quantification of muscle functions.

MODELING ISSUES & APPROACHES

The modeling considerations include:

__Modeling of the Skeletal/Joint System__ - The geometric constraints and the force compliance of the upper extremity musculoskeletal system must be appropriately represented in the model to reflect the various motion and joint force patterns which are known to occur during the wheelchair propulsion process. The motion in each joint in the musculoskeletal system can, in general, be represented by two contacting surfaces undergoing relative rolling and sliding motions in 3-dimensions. Kinematically, these joints are higher pairs, i.e., cam-like pairs. The initial modeling process in the current project has concentrated on modeling these joints with lower pair representations, such as the spherical and the revolute joints; the resulting gross motion behavior is then compared with the gross motion behavior measured on the computerized test data acquisition system built at the REC to iteratively refine the model. This test data acquisition system is shown in Figure 1.

__Individual Muscle Forces__ - The force exerted by a muscle on its points of attachment depends upon a number of factors, including the length and cross-section of the aggregate fibers, the rate of contraction, the geometric orientation of fibers with respect to their tendon plates, the geometric orientation of muscle axis with respect to the joint axis and the state of neural activation of the muscle. The modeling process described in this paper is directed toward synthesizing the appropriate published research results and modeling procedures for the force generating capabilities of individual musculotendon elements into the simulation software. The dimensionless model of (1) and the quantitative model for muscles (2) are likely candidates for these modeling procedures. The selected modeling procedure for individual musculotendon elements will be applied to the muscle parameters - i.e., muscle fiber lengths, muscle length to fiber length ratios, number of sarcomeres per fiber (at both ends and at middle of the muscle belly), pennation angle, and volume. For correlation and validation of the musculoskeletal system model, the subjects utilized for tests at the wheelchair experimental facility will have Magnetic Resonance Imaging (MRI) scans from which specific muscle parameters for the musculotendon model will be extracted. Figure 2 shows the overall procedure planned for this data extraction process, in conjunction with a force model for individual musculotendon element. In order to confirm the validity of the procedure of Figure 2, the MRI scans on one cadaver have been obtained, and the cadaver has been dissected to obtain the actual muscle parameters for comparison with the data extracted from the geometric models.

__Muscle Coordination Algorithms__ - In addition to the issue involved in modeling the individual musculotendon element, the modeling of the load sharing between the various muscles at each instantaneous configuration of the musculoskeletal system requires consideration of the complex interactions of the neurological, the muscular, and the skeletal subsystems. A large body of literature already exists on the methods to solve the redundancy problem of muscular load sharing and the combined dynamic solution of the skeletal-link-mechanical and the musculo-mechanical parts of the total model. The model development process is directed to synthesizing existing approaches as appropriate for the wheelchair propulsion function.