A Description of Stroke Dynamics in 100 Meter Wheelchair Racing

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INTRODUCTION

Since wheelchair racing was introduced in the United States over thirty years ago, wheelchair sports have been experiencing a growing popularity. An ever increasing number of national, and international competitions are being held for the disabled athlete; and record times in racing events are being set on an almost routine basis. Much interest by coaches, athletes, and researchers exists in identifying optimal performance factors in wheelchair propulsion. Three major areas of interest relating to performance have been the topics of recent research, symposia, and conferences. These include the following: (1) designing effective training programs; (2) improving chair design; and (3) optimizing technique.

Elite disabled athletes are being profiled by researchers from both physiological and biomechanical perspectives. All wheelchair users stand to benefit from wheelchair sports and research. Where many everyday chair users once were in a heavy, awkward «hospital-type» chair that fitted no one and certainly wasn't designed for sports use, now light weight, easily maneuverable chairs are in use. As equipment is improved and propulsion techniques become more efficient, all chair users can benefit from such knowledge.

The United States Olympic Committee sponsored their first Sports Medicine and Sports Science Conference for the Disabled Athlete in the United States in March of 1987. This conference provided the opportunity for coaches, athletes, researchers, and other persons interested in sports for the disabled athlete to come together to share knowledge and ideas, and to examine the unique needs of the disabled performer. While physical limitations may influence the disabled athlete's perfomance, today's athletes are vitally interested in learning how to maximize their individual physical abilities.

Although the major thrust of a great many of the research studies investigating wheelchair athletes has often been of a physiologic nature, a growing body of biomechanic research on wheelchair propulsion has been identified (Ridgwaw, Pope & Wilkerson, 1987; Siler, Martin & Mungiole, 1987; Higgs, 1986; Sanderson & Sommer, 1985; Cerquiglini, Figura, Marchetti & Ricci, 1981; King, 1981; and Perry, 1981). Many of these investigations have included small sample sizes, have been limited to male subjects, and have included relatively few classes of wheelchair athletes. Additionally, few have studied the elite wheelchair athlete during commpetition.

The purpose of this study was to develop a kinematic model of wheelchair propulsion during 100-meter racing as performed by three classes of elite male wheelchair athletes.

METHODOLOGY

Subjects

Twenty-seven elite male wheelchair athletes served as subjects for this investigation. Subjects were semi-finalists in the 100-meter racing event at the 1986 National Wheelchair Track and Field Championships held at the University of Illinois. Subjects included 8 males in class IB, 9 in class II, and 10 in class III. The medical classification system of the National Wheelchair Athletic Association was used in classifying athletes for competition. According to Weiss and Curtis (1986) class IB athletes are quadriplegics with generalized trunk and lower extremity weakness; normal or good triceps. Class II are paraplegics with abdominal paralysis or poor abdominal strength; no useful trunk sitting balance. Class III are paraplegics with upper abdominal and spinal extensor musculature; poor to fair trunk sitting balance.

Procedures

Data were collected using a 16-mm Locam high speed motion camera operating at a frame rate of 100 Hz. The camera was positioned perpendicular to the straight-away of the track which was approximately 60 meters into the race. Sagittal plane views were obtained of the performers as they moved past the camera during competition. Time was ascertained with an LED timing light inside the camera.

Film data were analyzed using a Sonic digitizer interfaced to an Apple IIe microcomputer and software written by Richards and Wilkerson (1984). Alternate frames were digitized for one complete stroke cycle including propulsion and recovery. The raw data were smoothed with a second order low pass digital filter set at 6 Hz (Winter, 1979).

Computer stored data were then analyzed to produce measures of head, trunk, upper arm, and thigh inclination measured from the vertical. The relative elbow angle was also reviewed. Ranges of motion at the head, trunk, shoulder, and elbow during each part of the propulsion and recovery phases of the stroke were analyzed in addition to angular positioning of the various segments during specific events of the stroke cycle.

Temporal data included chair velocity, stroke distance, stroke time, and stroke rate. Stroke time was subdivided into percentage of time spent in propulsion and recovery.

RESULTS

Temporal data mean values are presented in Figures 1, 2 and 3. Generally, classes II and III were quite similar in stroke dynamics while class IB athletes tended to take a longer time to complete a stroke cycle, travelled less distance per stroke, and achieved lower chair velocities.

Analysis of mean stroke velocity and stroke rate (Figure 1) indicated that class III athletes reached higher chair velocities (5.26 m/s) than either class II (4.94 m/s) or class IB (3.64 m/s). However, all classes were quite similar in stroke rate with approximately 2 stroke cycles completed per second. Because time and distance are functions of velocity, stroke distance and stroke time (Figure 2) were also better in classes II and III than in class IB. Interestingly, the percent of time spent in the propulsive phase and the recovery phase (Figure 3) were very similar for all classes with approximately 1/3 of the stroke cycle spent in propulsion and 2/3 spent in recovery.

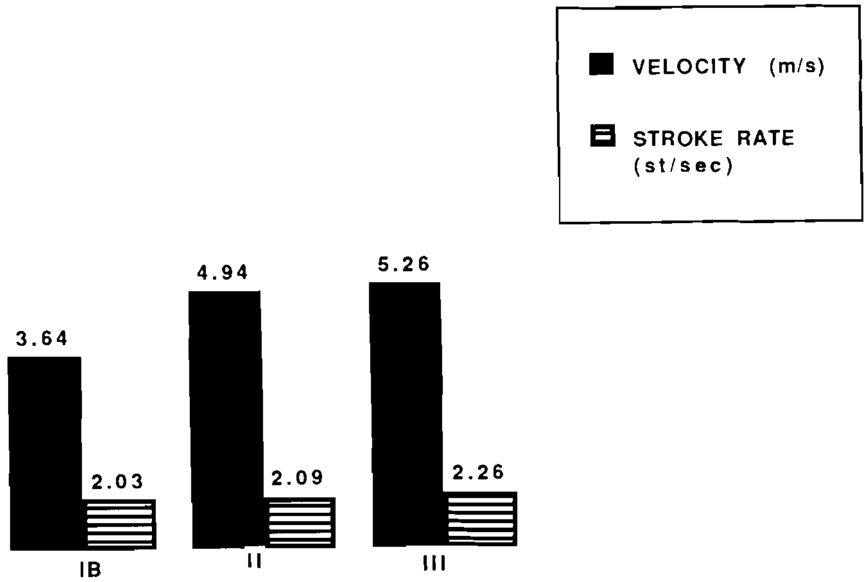

Fig. 1 Velocity and Stroke Rate by Class.

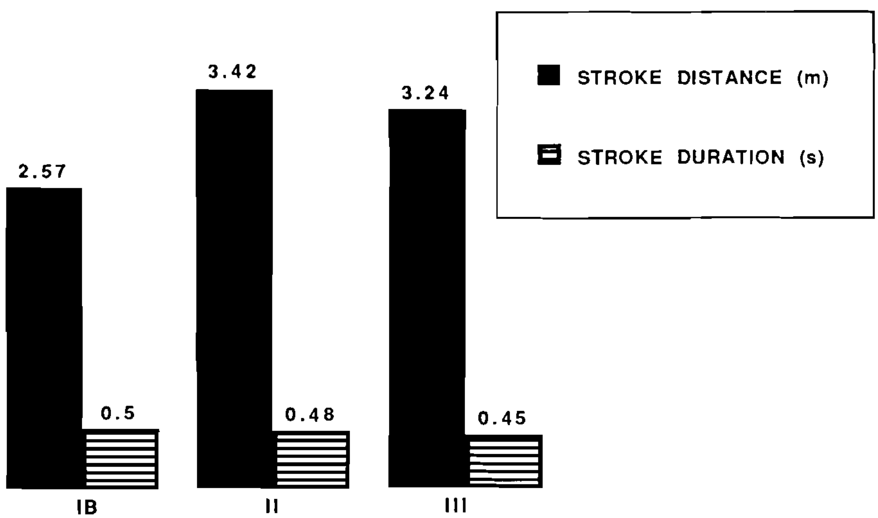

Fig. 2 Stroke Distance and Duration by Class.

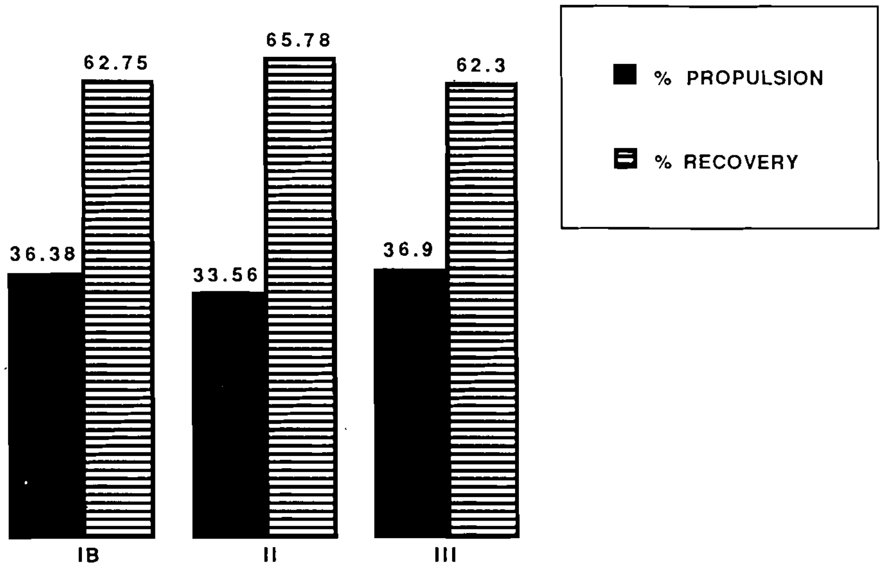

Fig. 3 % Propulsion & Recovery by Class.

Two aspects of head and trunk motion were quantified: range of motion and relative amount of forward inclination. Figure 4 displays the mean head and trunk ranges of motion during propulsion. Head and trunk excursions were comparable in the three classes with head excursion considerably greater than trunk excursion. The «neck» flexed prior to and at the start of propulsion while trunk flexion occurred during propulsion.

The mean shoulder and elbow ranges of motion during propulsion are presented in Figure 5. The higher classes went through greater ranges of motion at the shoulder and the elbow with the most observable differences occurring at the elbow. Class III athletes flexed through a mean range of 82.26° at the shoulder and extended through a mean range of 69.60° at the elbow. In comparison class IB athletes had 72.72° range of flexion at the shoulder and an elbow excursion of only 43.25° of extension.

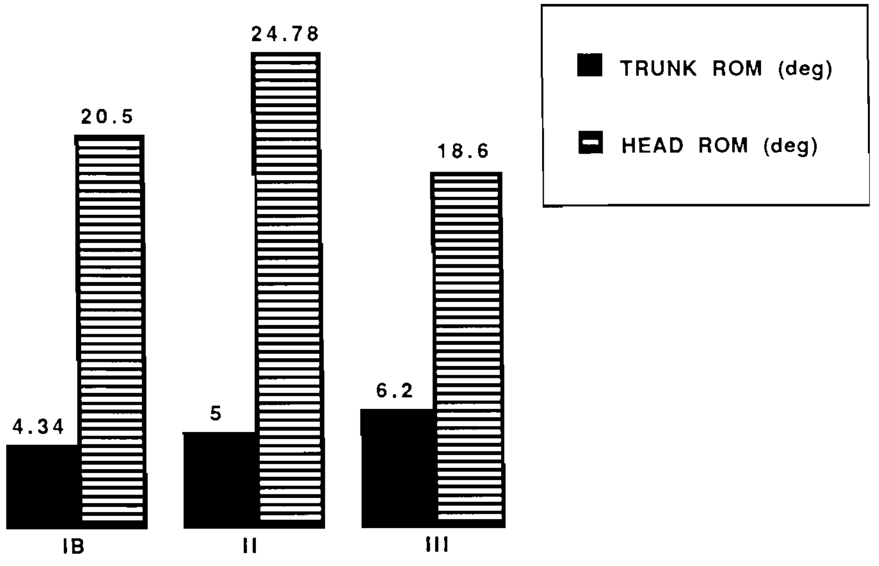

Fig. 4 Trunk and Head Range of Motion During Propulsion by Class.

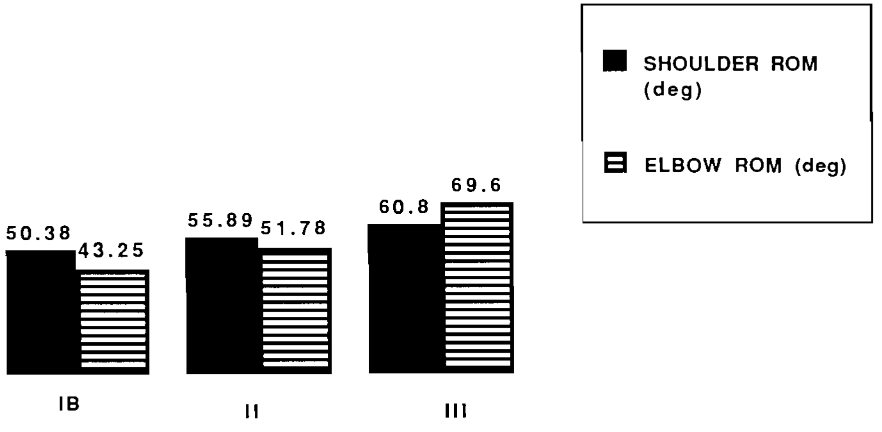

Fig. 5 Shoulder and Elbow Range of Motion During Propulsion by Class.

Table 1 summarizes mean angular data for the various body segments at the start and end of propulsion for the three classes of wheelchair athletes. Fig. 6 provides an illustration of a «typical» start position assumed by a 100-meter wheelchair racer immediately prior to the start of propulsion. Fig. 7 depicts the athlete at the end of propulsion and prior to the start of the recovery phase.

TABLE 1

Joint Kinematics

Variable[a]		Start - Propulsion		Start - Recovery		ROM - Propulsion	
Head		Mean	sd	Mean	sd	Mean	sd
	IB	63.40	(8.92)	42.73	(10.66)	20.5	(13.35)
	II	67.47	(14.52)	42.62	(11.32)	24.78	(12.17)
	III	67.58	(14.29)	48.93	(13.26)	18.60	(5.82)
Trunk							
	IB	16.83	(8.75)	21.44	(8.40)	4.38	(3.16)
	II	20.31	(7.45)	24.89	(6.88)	5.00	(4.66)
	III	18.00	(7.39)	21.52	(5.26)	6.20	(4.37)
Upper Arm							
	IB	72.72	(13.94)	22.53	(12.61)	50.38	(12.43)
	II	83.26	(12.26)	27.31	(12.26)	55.89	(8.39)
	III	82.26	(10.56)	21.34	(8.48)	60.80	(9.53)
Elbow							
	IB	86.09	(5.08)	129.47	(16.87)		
	II	83.03	(6.22)	134.94	(11.22)		
	III	84.36	(13.12)	154.13	(20.41)		
Thigh							
	IB	38.00	(5.09)				
	II	40.22	(9.99)				
	III	39.05	(7.48)				

[a] Mean values in degrees (standard deviation).

Fig. 6 Start of Propulsion.

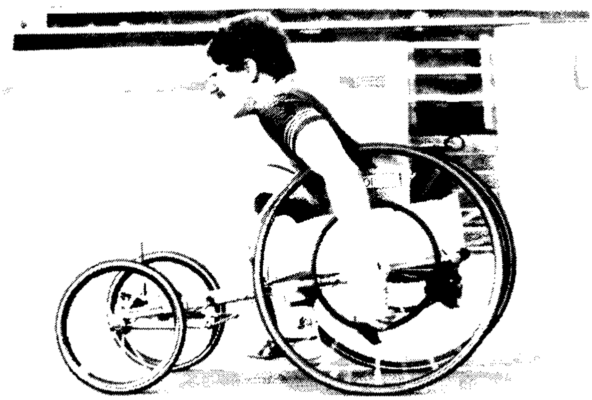

Fig. 7 End of Propulsion.

Analysis of mean angular kinematic data of class IB athletes during the propulsion phase revealed that the «neck» was flexed so that the head was in a position of 63.40°, the trunk had a forward lean of 16.83°, the upper arm was positioned behind the body nearly horizontal in the sagittal plane (72.72°) with the elbow flexed (86.09°). The thigh was positioned at a 38.00° angle.

At the end of the propulsive phase the mean head inclination for class IB performers was 42.73° indicating the «neck» extended (approximately 20°) during propulsion. The mean trunk position was 21.44° at the end of propulsion which meant the trunk flexed slightly (approximately 5°) during propulsion. The shoulder flexed throughout propulsion and the upper arm reached a position of 22.53°, just short of vertical alignment. Extension occurred at the elbow with a maximum angle of 129.47° reached at the end of propulsion.

Similar kinds of observations relating to angular positioning during propulsion can be made for classes II and III. If subject differences were related to level of injury, they became more apparent when studying joint excursions at the shoulder and elbow, and the temporal data.

CONCLUSIONS

Based on the findings of this study, basic segmental movement patterns typifying a wheelchair athlete during propulsion and recovery during one stroke cycle in the middle of a 100-meter racing event may be characterized by the following observations:

(1) At the start, the hip is flexed so that the thigh is in a position approximately halfway between the vertical and the horizontal; the trunk is upright; the head is inclined forward slightly; the shoulder joint is extended so that the upper arm is in a position behind the body; the elbow joint is flexed.

(2) Prior to the start of propulsion, body movement is initiated by the head, which is flexed at the «neck»; this is followed immediately by a small amount of trunk flexion which increases the forward lean of the body during propulsion.

(3) During propulsion, the shoulder joint flexes so that the upper arm starts from an almost horizontal position behind the body and finishes approximately in line with the body; the elbow joint extends from approximately a 90° angle to a moderately extended position.

DISCUSSION

In evaluating wheelchair performance one cannot neglect an athlete's strength, flexibility, stroking technique, and chair design. Also it is important to keep in mind the level of disability of the athlete in designing an appropriate training program and developing an effective stroking pattern.

In an attempt to identify variables which may be linked to attaining optimmal stroking velocities, it is evident from this investigation that increased excursion of the arm at the shoulder and elbow are characteristics of increased velocity and better performance in 100-meter racing. The higher velocities attained by the higher classes of wheelchair athletes in this study may be a function of greater extensor forces exerted during propulsion.

It is interesting to note that these three performance classes of elite wheelchair racers did not differ markedly on many aspects of stroke dynamics. The small variation in head and trunk movement is indicative of how similar the movement patterns of the different classes were. However, it is apparent that while classes IB, II and III used a similar arm action to propel their wheelchairs, upper arm axcursions varied markedly as did resulting chair velocities.

Several considerations should be kept in mind in future studies of wheelchair athletes. There is a need to better estimate the influence of trunk motion. Future studies should consider how to measure trunk positions in such a way that if mid-trunk flexion occurs, it will be accurately evaluated.

Also, it would be valuable to measure forces applied to the handrim. Analyzing film data results in an arbitrary decision being made regarding when the hand is on or off the rim. Quite possibly there are times when the athlete is grasping the handrim but no force is being applied. Only if force output for each arm can be determined can one indicate the advantages of a particular stroking technique.

Three dimensional analyses are necessary to fully understand stroking patterns in wheelchair athletes. Qualitative analysis of videotapes taken of frontal views of wheelchair racers during performance revealed that many athletes showed signs of asymmetry during the stroke cycle.

It can be inferred from the pattern of head and trunk movement that a more effective transfer of momentum results when the head initiates upper body movement. Some of the literature (Sanderson & Sommer, 1985) indicates that forward lean, although a function of disability level, may enhance aerodynamic positioning, application of force on the handrim and overall stroking efficiency. In this study the trunk movement, though difficult to assess, appeared similar for all classes.

The data for thigh positioning suggest that all three classes positioned them similarly. Much speculation exists regarding the appropriate thigh positioning. Chair customizing which positions the racer close to the ground with knees flexed to the chest allows the athlete to compensate for the disadvantage of poor sitting balance. The athlete can press against the thighs without losing sitting balance which apparently allows for a more effective propulsive action. In a recent study by Ridway, Pope & Wilkerson (1987), findings indicate that the higher classes (III, IV and V) of athletes positioned their thighs farther from the body than the lower classes. Whether this allows the athlete a greater range of force application or a better, more streamlined position is open to speculation and should be examined.

The stroke cycle includes a propelling and a gliding or recovery phase. Too long a gliding (recovery) phase leads to a drop in the chair's velocity and a high energy output to reaccelerate. As suggested by Siler, Martin & Mungiole (1987), the arm flexion during the recovery phase allows for a more rapid recovery because of an increase in angular velocity of the rotating segment. The wheelchair athlete must develop a kinesthetic feel for his/her movements in an effort to maintain motion of the chair and keep it moving smoothly.

In the present study, while propulsion and recovery times were similar for the three classes of athletes, force production and resulting chair velocities were quite dissimilar in the three classes. Further investigation is needed to identify other kinematic variables as well as kinetic variables which characterize high performance in wheelchair racing.

IMPLICATIONS

As a result of the findings of other studies as well as the findings of this study of three classes of 100-meter elite wheelchair racers, the following suggestions for coaches, athletes, and researchers are offered:

1. Medical and physical differences within the classes influence performance techniques, chair positioning, chair design, and training methods.
2. Flexibility is an important component of wheelchair racing; especially in the shoulder, elbow, head and trunk.
3. Shoulder strength and mobility play an important part in efficient stroking. The development of strength and power in the shoulder and shoulder girdle muscles should be a part of the 100-meter racer's training program.
4. Head, trunk, elbow and wrist muscles should be developed within the physical limitations of the athlete.

5. The sequencing of active head and trunk flexion may provide an increase in momentum transferred to the handim.
6. Increased forward lean during the stroke cycle may be helpful in positioning the racer for a more effective stroking action and optimizing body position.
7. The percentage of stroke time involved in propulsion should be increased with possibly a 1:1 ratio between propulsion and recovery being more efficient than the 1:2 mean ratio used by subjects in this study.
8. Depending on level of ability experimenting with thigh positioning may lead to a more effective stroking action.

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