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Kinematics of sport wheelchair propulsion

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Abstract—Eight international caliber wheelchair male athletes (3 basketball, 5 distance track) performed an all-out propulsion effort from a standing start for 10 seconds on a wheelchair ergometer. Comparisons between the basketball and track athletes on linear wheelchair and push rim velocity during the first 3 pushes and the peak value indicated that the basketball players had a significantly ($p<.05$) higher push rim velocity throughout the effort and a higher wheelchair velocity only at the end of the first push. The track athletes attained a significantly higher peak wheelchair velocity. Graphical comparison of the best individual basketball and track athletes' performances indicated that the track athletes caught up to the basketball players after about 3.7 seconds or 12 meters and travelled 49 meters in the 10 seconds, compared to 37 meters for the basketball players. Differences in push rim and wheel diameter are considered the major factor in the noted differences in propulsion kinematics of basketball and track wheelchairs.

Key words: *paraplegic, wheelchair basketball, wheelchair track, elite athletes.*

INTRODUCTION

The purpose of this paper is to describe the distance, velocity, and acceleration versus time of international caliber wheelchair basketball and track athletes during an all-out 10-second effort from a standing start on a wheelchair ergometer. A comparison between the basketball and track athletes' performances in their sport-specific wheelchairs was also carried out to quantify the differences in the initial acceleration and peak velocity characteristics of the two man-machine systems.

Three previous reports have examined some of the kinematic features of wheelchair propulsion by elite athletes. Higgs (3) compared the time and hand placement of sprinters versus distance track athletes during actual competition. His data collection and analysis, however, was limited to periods when wheelchair velocity was relatively constant, and actual velocity could not be determined due to technical difficulties. A more recent kinematic analysis of wheelchair propulsion during national level 800-meter races by Ridgway, Pope, and Wilkerson (4) determined the actual velocity during the races, and made comparisons between different classes of competitors in terms of the propulsive cycle and movement of body parts during a complete cycle. Sanderson and Sommer III (5) reported the kinematics of various body segments during wheeling on a treadmill at submaximal velocities for three paraplegic athletes. More recently, Van der Woude, *et al.* (6) have looked at physiologic and body kinematic differences in wheelchair athletes who wheeled on a treadmill at four different submaximal velocities using five different diameter push rims. Thus, previous investigations have focused on the kinematics of the athlete's body segments during constant and usually submaximal wheelchair velocity perfor-

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mances. The emphasis in the present study was to describe the kinematics of the wheelchair during an initial acceleration phase as performed by elite wheelchair track and basketball athletes.

METHODS

Eight male paraplegic athletes (3 basketball players, 5 distance track athletes) provided written informed consent to participate in this study on a form approved by the University of British Columbia's ethics committee. The three basketball players had been selected to attend the national team tryout camp, and two were chosen to be on the team representing Canada at the 1988 Paralympics in Seoul, Korea. The five track athletes were in training for the same or similar international games, and all qualified to compete at a 1500 m or longer distance at national level trials. **Table 1** presents some basic characteristics of these subjects. In order to provide comparison between the athletes, the classification system used for wheelchair track athletes was used for all subjects in designating their competitive class in **Table 1**.

After each athlete completed their normal warm-up, they were asked to perform an all-out 10-second propulsion effort on a wheelchair ergometer, which has previously been described (1). The two rollers of the ergometer had a combined moment of inertia of 0.12 $Kg.m^2$, and the athletes had their own sport wheelchairs anchored on the rollers. The athletes were all skilled users of the ergometer since they have used the same model for indoor training purposes, and felt that the ergometer provided only slightly more resistance than wheeling on a level surface. The peak velocities attained by the track athletes are similar to those achieved during racing (4); therefore, the ergometer appeared to provide a reasonable simulation of actual wheelchair propulsion. A proximity switch was positioned to generate a voltage signal once during each revolution (0.32 m linear distance) of the rear ergometer roller, and a personal computer sampling at a rate of 1000 Hz was used to record the time of the voltage signal. Standard kinematic equations were used to calculate the linear distance, velocity, and acceleration over the 10-second effort from the recorded time to the nearest 0.001 second for the wheelchair to "travel" each 0.32 m. The equations used assumed that each velocity calculated from the measured time interval for one roller revolution ($v = 0.32\ m/t2 - t1$) represented the instantaneous velocity at the mid-point of the time interval, and that the acceleration was constant between successive velocity determinations.

Selected variables from this output were analyzed to compare basketball versus track athlete data, and complete kinematic data for the best basketball and best track athlete performances were graphed to present the results of this study. Multivariate and between group t-tests were used to statistically compare the basketball and track athletes on the selected variables (BMDP statistical software, Program 3D), and the level of significance was set at 0.05.

Table 1.
Subject characteristics.

Subject	Sport	Competitive classification	Push rim diameter (cm)	Wheel diameter (cm)
1	Basketball	3	59.0	63.0
2	Basketball	3	53.0	61.0
3	Basketball	3	53.0	60.0
4	Track	2	32.0	67.0
5	Track	4	33.5	67.0
6	Track	5	33.0	67.0
7	Track	5	32.5	67.0
8	Track	4	32.0	65.5
Basketball avg. (S.E.M.)			55.0 (2.0)	61.3 (0.9)
Track avg. (S.E.M.)			32.6 (0.3)	66.7 (0.3)

RESULTS

An analysis (t-test) of the differences in push rim and wheel diameter between basketball and track athlete wheelchairs indicated that the track athletes had significantly smaller diameter push rims and larger wheels. Using the average values of the ratio of push rim diameter to wheel diameter, the basketball players had a mechanical advantage of 0.90 and the track athletes a value of 0.49.

The linear wheelchair and push rim velocities were determined during the first three propulsion efforts as well as the peak value. **Table 2** presents the values for the basketball and track athletes for these variables. The multivariate Hotelling T-square value was significant for the between group comparison. Basketball players had a significantly faster wheelchair velocity during the first push, but the track athletes achieved similar speeds during the second and third pushes and attained a higher peak speed during the 10-second effort. Push rim velocity, however, was significantly higher for the basketball players during the first three pushes and at the peak. In relative terms, the basketball players achieved 80 percent of their peak speed during the third push while the track athletes had attained only 55 percent of their peak value.

Figures 1, 2, and 3 graphically present the distance, velocity, and acceleration versus time curves, respectively, over the entire 10-second propulsion effort for the individual basketball (Subject 3) and track (Subject 4) athletes who had the highest velocities during the first three pushes and at their peak level. A cubic spline function was used to connect the individual data points in drawing these figures, which eliminated the unrealistic sawtooth appearance when straight lines were used to connect the data points. No other discernible effects on the figures were apparent in using this curve smoothing technique.

The distance versus time plot **(Figure 1)** indicates an advantage for the basketball player in rapidly covering short distances, with the advantage shifting to the track athlete after both had travelled about 12 meters in 3.7 seconds. At the end of 10 seconds, the track athlete had covered 49 meters while the basketball player went 37 meters.

Figure 2 illustrates the velocity pattern of the two athletes with each push cycle usually discernible from the major periodic velocity changes. Thus, both athletes had close to 20 pushes on the hand rims during the 10-second effort. This converts to a stroke frequency of 2 per second, which is slightly higher than the 1.77 and 1.72 cycles-per-second values observed during actual 800-meter races (4). The values attained during the first three pushes and at peak level are in general agreement with the analysis of the total sample. It can be noted, however, that the track athlete takes a longer time to complete the first three pushes, and the curve for each push tends to become bimodal at higher speeds for both athletes.

The acceleration curves **(Figure 3)** demonstrate a much greater positive acceleration for the basketball player during the first push, while the track athlete exhibits higher positive and negative values after several pushes. The occasional, extremely high negative accelerations of this track athlete were noted in the other track athletes' data and, therefore, do not represent abnormal events.

DISCUSSION

The data presented provide a description of the kinematics of wheelchair propulsion for elite basket-

Table 2.
Linear velocities for basketball and track athletes (m/s).

		Wheelchair				Push rim			
		Push 1	Push 2	Push 3	Peak	Push 1	Push 2	Push 3	Peak
Basketball (n = 3)	Avg.	2.47	2.94	3.21	4.02	2.21	2.63	2.88	3.60
	(S.E.M.)	(.14)	(.17)	(.14)	(.06)	(.08)	(.10)	(.09)	(.09)
Track (n = 5)	Avg.	1.91	2.70	3.27	5.93	0.93	1.32	1.60	2.90
	(S.E.M.)	(.11)	(.11)	(.13)	(.25)	(.05)	(.05)	(.06)	(.12)

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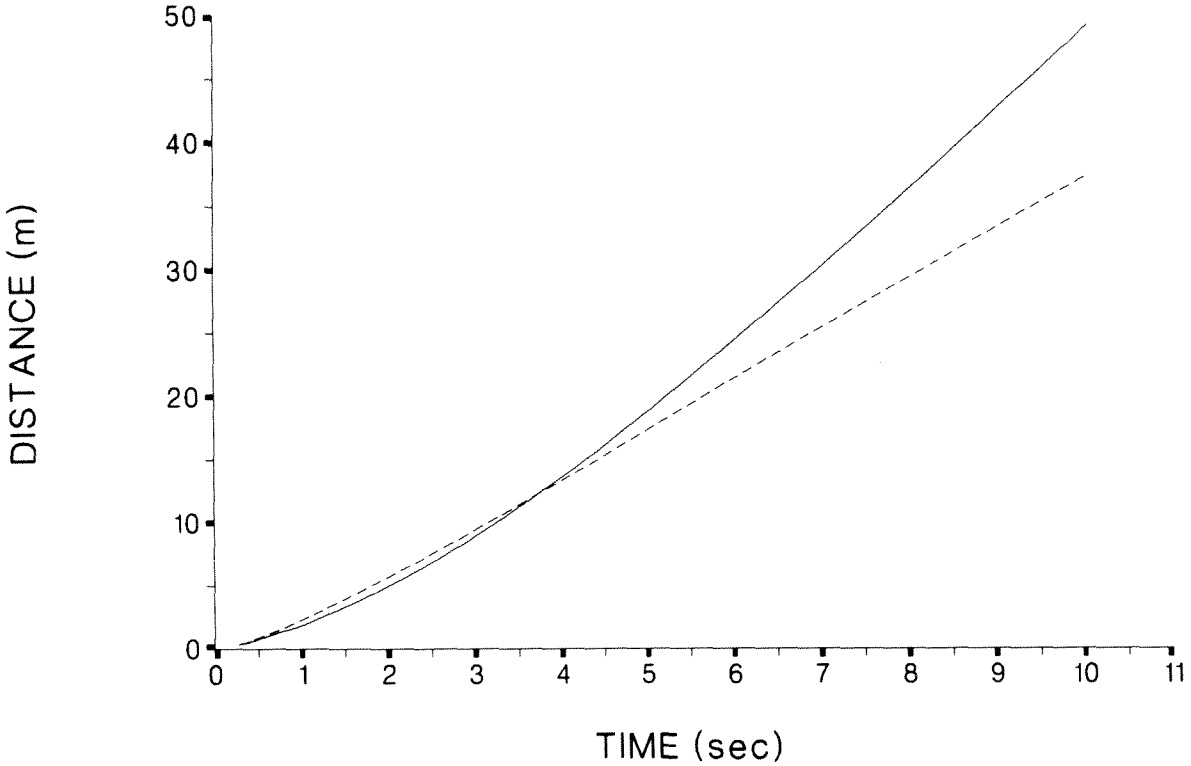

Figure 1.
Wheelchair distance versus time plot of a basketball player (dashed line) and a distance track athlete (solid line).

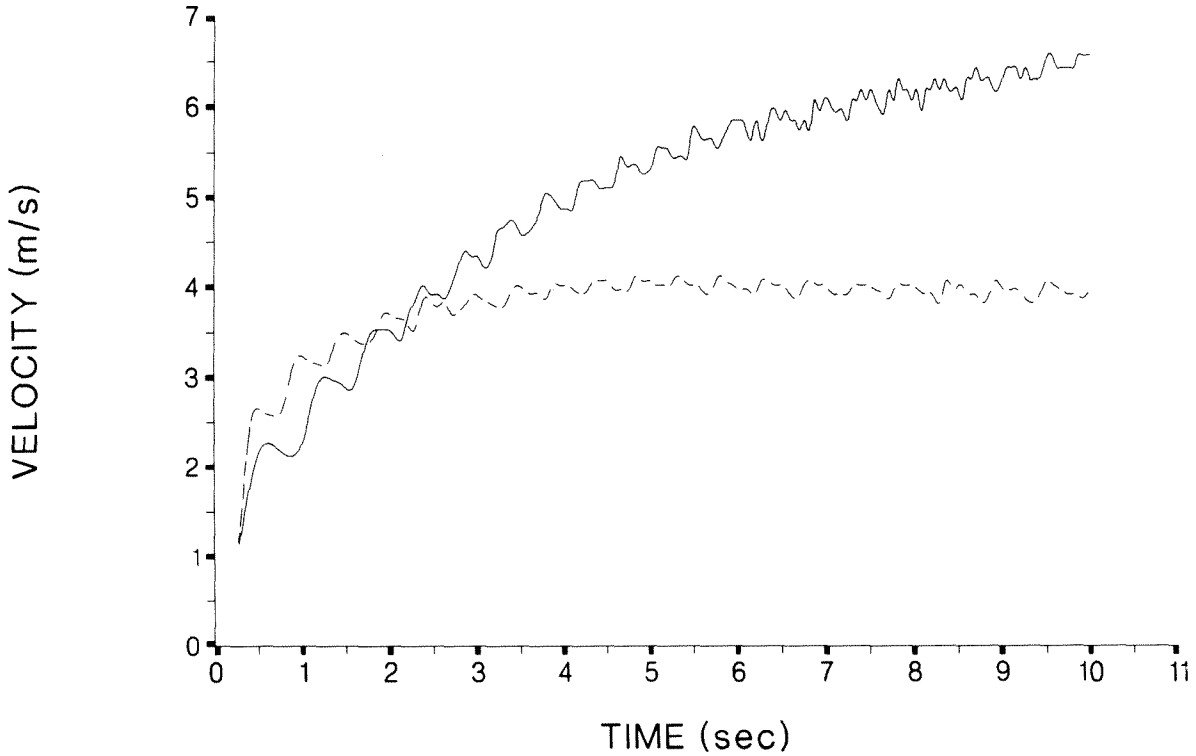

Figure 2.
Wheelchair velocity versus time plot of a basketball player (dashed line) and a distance track athlete (solid line).

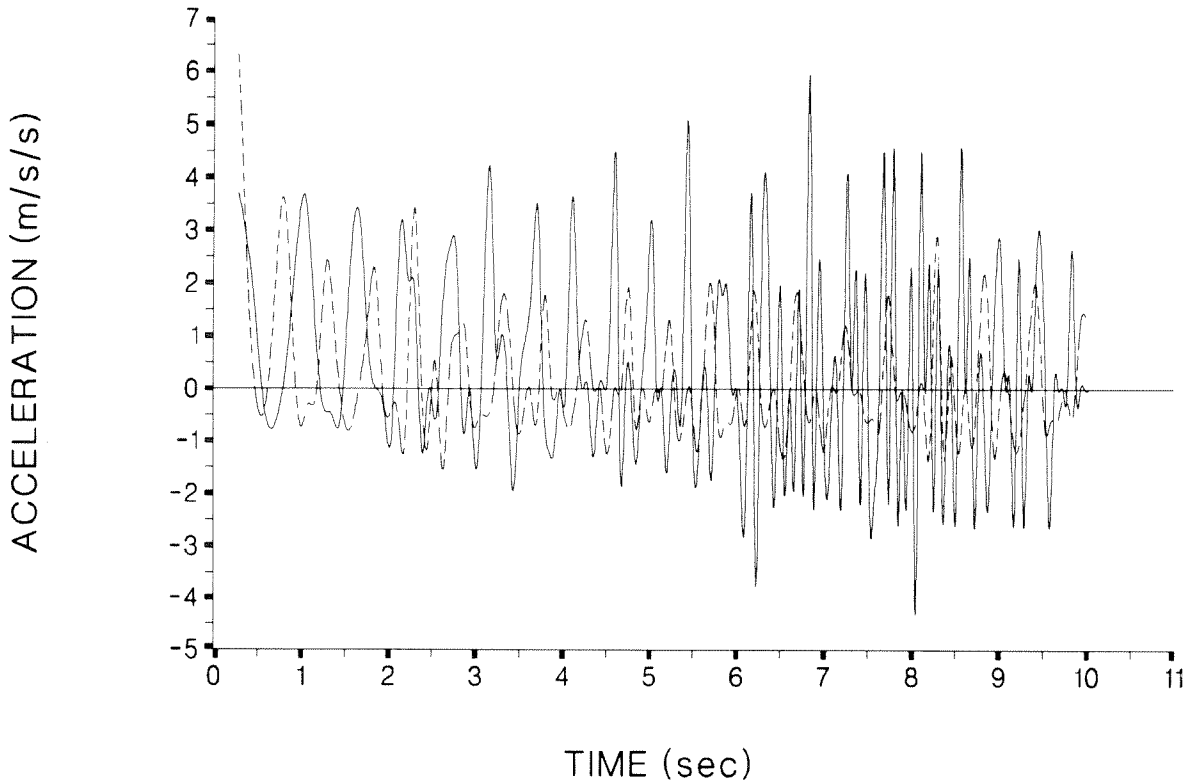

Figure 3.
Wheelchair acceleration versus time plot of a basketball player (dashed line) and a distance track athlete (solid line).

ball and distance track athletes during a 10-second all-out effort. While many other factors, such as seat placement in relation to the wheel axle and push rim, or structural difference between athletes, may influence the noted differences between the propulsion of basketball and track chairs, the measured differences in push rim and wheel diameter plus the unquantified differences in the surface contact between the hands and push rim surface were apparent reasons for the between sport differences.

The differences in push rim and wheel diameter of the basketball and track chairs provide an advantage for the basketball players, especially during the first push in accelerating their chairs. That is, for any given muscular force applied to the push rims, the turning moment will be higher for the larger diameter push rims. Similarly, a smaller diameter wheel will create a smaller resistance moment for any given linear resistive force. This is consistent with the noted slower initial pushes of the track athlete. The initial acceleration of the wheelchair, or in this simulation the ergometer's rollers, involves a greater change in momentum during each push cycle than when maximal velocity is achieved, as reflected in the greater changes in velocity. The larger diameter push rims of the basketball chairs seem to permit generation of a more effective force-time impulse with a consequent greater increase in velocity and momentum when the initial velocity of the chair is zero or close to zero.

The track chair, however, has an advantage in achieving higher maximal velocities when relatively small changes in velocity and momentum are noted during each push cycle. Thus, relatively small force-time impulses are needed during each push cycle to maintain a given average velocity, and the lower linear velocity of the track chair push rim, even at a higher peak wheelchair velocity, provides an apparent advantage over the larger push rims of the basketball chairs. This means that the linear speed of the hands during the propulsive phase of a push cycle is lower in the track athletes at a higher peak wheelchair velocity. Van der Woude, *et al.* (6), have reported a greater efficiency in wheelchair propulsion at submaximal speeds using 30 cm diameter push rims in comparison to 56 cm rims.

They also noted that 5 of their 8 subjects could not propel a wheelchair with 56 cm rims at a velocity of 4.17 m/s, while all subjects in this study attained that speed with smaller push rims. The higher linear hand speed required by the larger diameter push rims at a given wheelchair velocity may be the main factor determining maximal wheelchair velocity, and that push rim diameters of about 55 cm seem to limit that velocity to approximately 4 m/s. That is, the higher muscle contraction velocity needed to produce the desired hand speed would reduce the force-generating capacity of the muscle, as is known from standard muscle force-velocity curves. The generally higher positive acceleration values of the track athletes after the first few seconds **(Figure 3)** is consistent with the ability to apply a greater propulsive force on a push rim travelling at a lower linear velocity.

After the initial overall acceleration phase, the generally bimodal nature of each push cycle reflected in the velocity curves **(Figure 2)** is consistent with the athletes' descriptions of their technique. They attempt to have their hands going faster than the push rims at initial contact to accelerate the wheels and then "snap" their wrists to increase hand speed again as they release from the push rims. There is considerable variation, however, in the propulsive techniques of wheelchair athletes, and this data merely reflect the patterns used by the athletes in this study.

The greater positive and negative accelerations of the track athlete exhibited in **Figure 3** may also be partly due to differences in hand-to-push rim surface friction. The basketball players used bare hands to push on uncoated push rims. The track athletes wore gloves and used push rims that were coated with tape and/or adhesive compounds to increase the coefficient of friction between the contact surfaces. While this improved friction for the track athlete may be a factor in the noted greater positive accelerations at higher velocities, it may also contribute to the generally larger negative accelerations and the occasional abnormally high negative values during any accidental contact with the push rim or a technically poor push. The higher speeds of the track chair would also contribute to the slightly larger negative accelerations due to increases in frictional and rolling resistance with speed.

Basketball and track wheelchair athletes have selected and modified their wheelchairs to aid them in achieving the best performance in the tasks involved in their sport. The larger push rims used by basketball players have an obvious advantage in quick acceleration and, therefore, in covering a short distance as rapidly as possible. The fact that a track athlete may catch up to a basketball player at about 12 meters and that a basketball court is about 30 meters in length suggests that a basketball team might want to have one or two players with slightly smaller push rims who specialize in fast break offense and defense.

The practice of some track athletes, especially in the sprints, of initially pushing on the wheels for one or more pushes at the start of a race and then switching to the push rims or using larger push rims (2) provides for an initially faster acceleration similar to that noted in the basketball players in this study. Determination of the optimal number of wheel pushes at the start of a sprint race is beyond the scope of this study, but the data suggest that only one or two pushes on the wheels would provide the maximal benefit of this starting technique.

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