KINEMATIC COMPARISON OF TWO RACING WHEELCHAIR PROPULSION TECHNIQUES

John Chow, Tim Millikan[1], Les Carlton, Woen-sik Chae, and Marty Morse[1]
Department of Kinesiology and [1]Division of Rehabilitation Education,
University of Illinois, Urbana, Illinois, USA

The purpose of this study was to quantify selected 3-D kinematic characteristics of the upper body during racing wheelchair stroking over a roller system using the conventional technique (CVT) and para-backhand technique (PBT). Eight CVT and seven PBT users served as the subjects. Each subject performed maximum effort stroking for 30 s at two loads and was recorded by two S-VHS camcorders (60 Hz). The CVT was found to have significant shorter push time, smaller relative push time, and greater relative recovery time than the PBT. Significant difference in arm position at the instant of hand release was found between the two techniques and the difference may have implications for the stress placed on the structures around the shoulder joint. When compared to each other, the CVT is a more compact stroke and the PBT has a faster overall movement speed.

KEY WORDS: kinematics, wheelchair sports, disability.

INTRODUCTION: Two stroking techniques are commonly used by wheelchair racers. With the conventional technique (CVT, also called the thumb technique), initial contact with the push rim occurs between the first joint and knuckle of the thumb (gripping). As the thumb rotates around the outside of the push rim, the tops of the forefinger and middle finger between the middle joint and knuckle begin to make contact with the outside of the push rim. Tape preparations with heavy padding over the contact areas of the hand are required. On the other hand, using a specialized glove designed for the para-backhand technique (PBT), the hand makes initial contact with the push rim with the back of the middle finger and the back of the index finger rather than the thumb (Morse et al., 1994). After the initial contact, the hand rides around the outside of the push rim and the contact point is switched to the base of the thumb and index and middle finger cuticles. Originally, the PBT was developed with an aim to reduce upper extremity injuries among wheelchair racers. Theoretically, the PBT enables an athlete to keep the elbows close to the body during stroking. This may help to decrease the stress placed on the rotator cuff muscles. To test this hypothesis, it was the purpose of this study to quantify the kinematic characteristics of the trunk and upper arms during racing wheelchair stroking over a roller system using the PBT and CVT at two different resistance loads.

METHODS: The CVT group consisted of eight males (33±5 yrs, injury level ranged from T5 to L1). The PBT group consisted of six males and one female (26±3 yrs, T8 to T12). All subjects were highly-trained experienced racers (track classification T3 - T4) and several of them represented the United States in the 1992 and/or 1996 Paralympic Games. A female whose performance level was similar to the male subjects was included.
Experimental Setup: All stroking trials were performed on a computerized drum roller system with a maximum braking resistance of 15 Nm (Eagle Sports Chair). The system consisted of a metal roller (diameter = 17.8 cm) mounted on the rear end of a metal base. The front wheel of the wheelchair was fixed to the front end of the base and the rear wheels were supported by the roller. The axle of the rear wheels were aligned vertically with the axis of rotation of the roller. Two S-VHS camcorders (60 Hz) were located in front and behind, and to the left of the subject (camera-subject distance = 3 m). A calibration frame (17 control points, 1.3 x 1.1 x 0.9 m^3), a plumb line, and two markers were used for spatial reference and defining a global reference frame, respectively.
Trials: All subjects used their own racing wheelchairs and gloves during the data collection. Each subject was asked to perform a maximum effort trial for each of the two resistance loads – 30% (light) and 50% (heavy) of the maximum resistance offered by the roller system.

In each trial, the subject stroked for 30 s and was videotaped. To synchronize the video recordings from the two cameras, a large light emitting diode (LED) which was visible in both camera views was activated during the trials.

Data Reduction: The average calibration error (i.e., the root-mean-square error between the computed locations of the control points and their known locations) for different data collection sessions was 2.55 mm. For the purpose of this study, a stroke cycle starts at the instant of initial hand contact with the push rim and ends at the instant of the next initial hand contact. For each subject, three consecutive stroke cycles occurring in the middle of each trial were analyzed. A manual digitizing Peak Motion Measurement System (Englewood, CO) was used to extract two-dimensional coordinates of the supra-sternal notch, midpoint between two hips, left shoulder, elbow, wrist, and third knuckle from the video recordings. The direct linear transformation (DLT) procedure (Abdel-Aziz and Karara, 1971) was used to obtain three-dimensional coordinates. Coordinate transformation aligned the principal axes of the global reference frame with the antero-posterior, vertical, and medio-lateral directions (positive for forward, upward, and medial).

For each stroke cycle, selected kinematic parameters of the body landmarks (range of motion and velocity) and body segments (inclination) and the orientation of a plane formed by the upper arm and forearm at the instants of initial hand contact (HC), hand release (the instant the hand breaks contact with the push rim (HR), and maximum elbow height (MEH) were determined. The inclination of a segment is the smallest angle between a segment and the horizontal plane, the angle is positive if the distal endpoint is higher than the proximal endpoint. The orientation of the arm plane is represented by a unit vector perpendicular to the plane and was obtained by the cross product of two vectors representing the upper arm and forearm, respectively. Time durations, both in seconds and as a fraction of the stroke time, were determined for the push (from HC to HR), ascending recovery (HR to MEH), descending recovery (MEH to HR), and recovery (HR to HC) phases. For each kinematic parameter in each trial, the average value over the three stroke cycles was used for subsequent analysis.

Statistical Analysis: For each parameter, mean and standard deviation were computed for each technique and resistance load. A two-way ANOVA was used to test for significant differences between the two techniques and two resistance loads ($p < .05$).

RESULTS AND DISCUSSION: No significant difference was found between the two techniques in stroking speed (speedometer reading) for both loads. No interaction was found in any of the ANOVA tests performed. The focus of the discussion of this paper will be restricted to differences between the techniques displayed by the two subject groups.

Temporal Characteristics: No significant difference was found in the stroke time and stroke frequency. However, the CVT had significantly shorter push time, smaller relative push time, and greater relative recovery time than the PBT (Table 1). In other words, the PBT spent greater percentage of the stroke time in contact with the push rim. For both techniques, the subjects maintained the same stroke frequency at different loads by varying the push and recovery times.

Segment Inclinations and Arm Planes: In terms of arm positions at critical instants, major differences between the two techniques were found at HR but not at HC or MEH (Table 2). For both techniques, the unit vector representing the arm plane at HC was directed approximately half way between forward and sideward, and slightly downward. The arm inclinations at HR indicated that the arm was not fully extended at HR. For the PBT, the arm plane at HR was at a vertical orientation (a horizontal unit vector) and faced more sideward than the CVT. Therefore, the upper arm in the CVT was more internally rotated at HR than in PBT. This may place more stress on structures of the shoulder joint.

Ranges of Motion: The PBT had significantly greater ROMs in the shoulder (vertical), elbow (vertical and medio-lateral) and wrist (antero-posterior and medio-lateral) joints than the CVT (Table 3). Because there was no significant difference in stroke time between the two techniques (Table 1), the joint ROM values suggest that the CVT is a more compact stroke and the PBT has a faster overall movement speed.

Table 1 Mean (SD) of Temporal Characteristics

	CVT/Light	CVT/Heavy	PBT/Light	PBT/Heavy
Stroke Time (s)	0.539 (0.063)	0.538 (0.059)	0.533 (0.032)	0.524 (0.053)
Stroke Frequency (Hz)	1.879 (0.222)	1.879 (0.210)	1.884 (0.109)	1.926 (0.187)
Push Time (s) *#	0.088 (0.013)	0.111 (0.015)	0.106 (0.019)	0.132 (0.027)
Rel. Push Time (%) *#	16.62 (4.00)	20.83 (4.21)	19.94 (3.00)	25.09 (4.10)
Recovery Time (s)	0.451 (0.071)	0.428 (0.065)	0.426 (0.027)	0.392 (0.040)
Relative Recovery Time (%) *#	83.38 (4.00)	79.17 (4.21)	80.06 (3.00)	74.91 (4.10)
Asc. Recy Time (s) #	0.346 (0.053)	0.339 (0.052)	0.297 (0.061)	0.288 (0.053)
Rel. Asc. Recy Time (%) #	64.09 (3.48)	62.82 (3.54)	55.54 (10.44)	54.80 (7.31)
Desc. Recy Time (s)	0.105 (0.029)	0.088 (0.022)	0.129 (0.042)	0.104 (0.023)
Rel. Desc. Recy Time (%) #	19.30 (4.09)	16.33 (3.43)	24.49 (9.01)	20.14 (5.46)

Note: Significant difference in technique (*) or load (#).
Rel = Relative; Asc = Ascending; Desc = Descending; Recy = Recovery

Table 2 Mean (SD) Segment Inclination and Arm Plane Values

	CVT/Light	CVT/Heavy	PBT/Light	PBT/Heavy
Inclination at HC (°)				
Trunk	14.6 (8.6)	16.9 (8.9)	14.2 (8.4)	17.1 (6.3)
Upper Arm*	9.0 (8.3)	8.0 (7.1)	0.2 (7.3)	-0.8 (4.4)
Forearm	-74.5 (5.2)	-73.4 (7.9)	-72.2 (6.2)	-73.2 (4.4)
Arm Plane at HC (unit v)				
Antero-posterior	0.67 (0.07)	0.66 (0.07)	0.69 (0.06)	0.70 (0.06)
Vertical	-0.25 (0.09)	-0.26 (0.13)	-0.16 (0.18)	-0.17 (0.14)
Medio-lateral	-0.69 (0.07)	-0.69 (0.07)	-0.68 (0.09)	-0.68 (0.08)
Inclination at HR (°)				
Trunk	7.3 (8.5)	8.0 (8.9)	7.1 (10.2)	8.9 (8.1)
Upper Arm *	-34.0 (6.6)	-33.3 (6.0)	-40.4 (6.9)	-40.8 (6.8)
Forearm *	-74.9 (6.7)	-75.6 (7.2)	-68.2 (4.1)	-72.9 (4.8)
Arm Plane at HR (unit v)				
Antero-posterior *	0.61 (0.11)	0.61 (0.10)	0.49 (0.08)	0.52 (0.11)
Vertical *	-0.12 (0.13)	-0.11 (0.13)	0.00 (0.08)	-0.04 (0.12)
Medio-lateral *	-0.76 (0.11)	-0.77 (0.10)	-0.85 (0.04)	-0.84 (0.06)
Inclination at MEH (°)				
Trunk	24.5 (9.0)	23.0 (9.4)	24.4 (6.0)	24.1 (4.6)
Upper Arm *	38.7 (9.5)	31.0 (9.7)	29.0 (16.2)	21.6 (14.3)
Forearm #	-27.0 (14.3)	-41.8 (10.4)	-29.9 (15.8)	-48.6 (12.0)
Arm Plane at ME (unit v)				
Antero-posterior	0.39 (0.18)	0.44 (0.09)	0.41 (0.18)	0.47 (0.13)
Vertical	-0.43 (0.17)	-0.44 (0.18)	-0.37 (0.23)	-0.43 (0.17)
Medio-lateral	-0.78 (0.05)	-0.76 (0.07)	-0.78 (0.07)	-0.74 (0.08)

Note: Significant difference in technique (*) or load (#).

Joint Velocities: No significant difference between the two techniques was found in any joint velocities at HC and MEH. Significant differences were found in the velocities of the shoulder (antero-posterior), elbow (vertical and medio-lateral), and wrist (vertical and medio-lateral) at HR between the two techniques (Table 4). The CVT had greater speeds than the PBT in all cases except the medio-lateral velocity of the wrist at HR. It is interesting to note that the wrist was moving downward for the CVT and upward for the PBT at HR. The average locations of the wrist and the axle of the rear wheels at HR confirm that the wrist was located slightly in front of the axle at HR for the CVT and the opposite was true for the PBT.

CORICLUSION: Because there was no significant difference in the stroke speed and stroke time (i.e., same work done per stroke) the differences in push time and push distance suggest that less power is required during the push phase in the PBT (completed the same amount of work over a longer period of time) than the CVT. It was suggested in a previous study that the two techniques emphasized different muscles during the descending recovery and push phases at different loads (Chow et al, 1996). These findings suggest that the two techniques should be applied to athletes of different physical and physiological attributes. For example, the PBT may be more suitable for endurance athletes who are less explosive in their pushing strokes. The greater time spent on the push rim is an advantage for these athletes, allowing them the opportunity to transmit more force to the wheel. An area for further investigation is the orientation of the wrist at HC.

Table 3 Mean (SD) Linear Joint Center Range of Motion (m) Values

		CVT/Light	CVT/Heavy	PBT/Light	PBT/Heavy
Shoulder	Antero-posterior	0.067 (0.032)	0.065 (0.032)	0.062 (0.021)	0.063 (0.017)
	Vertical #	0.179 (0.048)	0.153 (0.045)	0.188 (0.032)	0.152 (0.039)
	Medio-lateral	0.056 (0.016)	0.047 (0.019)	0.050 (0.016)	0.040 (0.012)
Elbow	Antero-posterior	0.168 (0.038)	0.139 (0.041)	0.179 (0.055)	0.151 (0.039)
	Vertical *#	0.552 (0.060)	0.492 (0.065)	0.606 (0.045)	0.533 (0.055)
	Medio-lateral *	0.088 (0.032)	0.081 (0.025)	0.130 (0.033)	0.128 (0.028)
Wrist	Antero-posterior *	0.346 (0.064)	0.344 (0.064)	0.416 (0.082)	0.402 (0.052)
	Vertical #	0.721 (0.105)	0.598 (0.090)	0.775 (0.112)	0.613 (0.092)
	Medio-lateral *	0.109 (0.032)	0.089 (0.023)	0.188 (0.083)	0.140 (0.075)

Note: Significant difference in technique (*) or load (#).

Table 4 Mean (SD) Joint Velocity **(m/s)** Values at HR

		CVT/Light	CVT/Heavy	PBT/Light	PBT/Heavy
Shoulder	Antero-posterior	-0.13 (0.19)	-0.08 (0.19)	-0.14 (0.16)	-0.14 (0.20)
	Vertical *	-0.51 (0.35)	-0.33 (0.38)	-0.03 (0.24)	0.13 (0.34)
	Medio-lateral	0.00 (0.11)	0.08 (0.15)	0.02 (0.06)	0.05 (0.14)
Elbow	Antero-posterior	0.04 (0.34)	0.00 (0.34)	-0.18 (0.41)	0.02 (0.30)
	Vertical *	-1.26 (1.02)	-0.90 (0.79)	-0.13 (0.63)	-0.09 (0.48)
	Medio-lateral *	0.72 (0.20)	0.65 (0.25)	0.25 (0.41)	0.53 (0.51)
Wrist	Antero-posterior	-2.05 (0.48)	-1.82 (0.38)	-2.52 (0.74)	-2.02 (0.73)
	Vertical *	-0.61 (1.25)	-0.53 (0.94)	0.53 (0.45)	0.36 (0.51)
	Medio-lateral *	-0.43 (0.38)	-0.33 (0.34)	-0.79 (0.20)	-0.59 (0.25)

Note: Significant difference in technique (*)

REFERENCES:

Abdel-Aziz, Y.I., & Karara, H.M. (1971). Direct linear transformation from comparator coordinates into object space coordinates in close-range photogrammetry. Proceedings of the Symposium on Close-Range Photogrammetry (pp. 1-18). Falls Church, VA: American Society of Photogrammetry.

Chow, J.W., Millikan, T.A., Carlton, L.G., & Morse, M.I. (1996). Electromyographic analysis of two racing wheelchair propulsion techniques. Proceedings of the 20th Annual Meeting of the American Society of Biomechanics. (pp. 51-52)

Morse, M., Millikan, T., Hedrick, B., & Iniguez, T. (1994). The Illinois Para-backhand pushing technique. *Sports* and Spokes, **20(1)**, 58-60.

Acknowledgment

This study was supported in part by the Research Board of the University of Illinois. Thanks to Sarah Beckman, Brian Case, Dan Johnson, and Young-tae Lim for assistance.