Department of Veterans Affairs

Journal of Rehabilitation Research and Development
Vol. 39 No. 1, January/February 2002
Pages 63–71

# A kinematic study of the upper-limb motion of wheelchair basketball shooting in tetraplegic adults

**Hiroyuki Nunome, MS; Wataru Doyo, MS; Shinji Sakurai, PhD; Yasuo Ikegmai, BS; Kyonosuke Yabe, PhD**
*Research Center of Health, Physical Fitness and Sports, Nagoya University, Nagoya, Japan*

**Abstract—**Kinematic aspects of the reduced shooting ability of tetraplegic (TP) wheelchair basketball players were investigated and compared with those of able-bodied (AB) basketball players. TP showed significantly smaller values for the vertical component of ball release velocity (4.26 (°/s) versus 5.45 (°/s)) and maximum wrist flexion angular velocity (878.4 (°/s) versus 1445.9°) than AB. Moreover, for a specific shoulder horizontal adduction motion, a larger range of shoulder abduction motion and larger displacements of the right shoulder were observed in TP. The reduced ball velocity of TP subjects with lesions at the C7 to C8 levels depended on an insufficient wrist flexion angular velocity, where dysfunction of available musculature may be a causal determinant. Further, the specific motions observed in TP subjects most likely maximize the function of available musculature, thereby partially compensating for the dysfunction of the wrist flexor muscles and contributing to resultant ball release velocity.

**Key words:** *angular velocity, reduced ball velocity, tetraplegia, wrist flexion.*

**This material is based on work supported by the Research Center of Health, Physical Fitness and Sports, Nagoya University. Part of this study was financially supported by the Ministry of Education, Science, Sports and Culture of Japan, grant No. 07458016.**

Address all correspondence and requests for reprints to Hiroyuki Nunome, MS; Research Center of Health, Physical Fitness and Sports, Nagoya University, Nagoya, 464-8601, Japan; e-mail: nunome@htc.nagoya-u.ac.jp.

## INTRODUCTION

Sport for people with a disability has become very popular during the past decade. Persons with a disability can now participate in a variety of able-bodied and disability-based sporting events in which various arm motions, other than wheelchair propulsive motion, are required. However, most previous research studies have focused on physical capacity (1–3) and measure either the wheelchair propulsive task or the wheelchair propulsive motion itself (4–7).

For wheelchair basketball, in particular, shooting ability is a major factor for successful performance. In general, persons with paraplegia have been very successful in wheelchair basketball. Persons with tetraplegia, by contrast, because of higher spinal cord lesion levels and resulting arm dysfunction, have some difficulty joining and playing in this sport. Although some studies have been conducted regarding able-bodied basketball shooting (8–10), wheelchair basketball shooting has not been well documented.

Therefore, the purpose of this study was to investigate the kinematic factors affecting ball release velocity and the individual shooting mechanics of tetraplegic adults, via a comparison with those of able-bodied adults.

## METHODS

Informed consent was obtained from six adult (including one female) wheelchair basketball players with tetraplegia (TP) and six adult, (AB) able-bodied male basketball players. All subjects were right-handed. The AB subjects were university-level basketball players and had not sustained previous injury of the shooting arm. The TP subjects were the members of organized and competitive wheelchair basketball teams under the modified rules for tetraplegics called ‘‘twin basketball’’ (11). The demographic variables for both subject groups are summarized in **Table 1**. The functional level of each TP subject was assessed by both the Zancolli clinical classification system (12), as is formally done in twin basketball, and the American Spinal Injury Association (ASIA) scale (13) for motor scores.

After stretching and warm-up, all subjects were instructed to perform 10 one-handed shots to the official height goal using a regulation basketball (diameter = 24.5 cm; mass = 587 g) from a seated position in a wheelchair. All instructions were conveyed to the subjects by an experienced researcher. TP subjects used their own wheelchairs (for wheelchair basketball use), to which their trunks were tightly fixed using straps and pads to ensure stability. The AB subjects used regular-sized wheelchairs to minimize the difference in sitting height between the two groups. Horizontal distance to the basket (2.16 m) used for this study corresponded to the distance for free-throw shooting in the modified rules of twin basketball (14). For 3-D video analysis, two electrically synchronized, high-speed video cameras (NAC Inc., Tokyo, Japan) were used to sample the shooting motion at 200 Hz (shutter speed was 1/1000 s), positioned at the rear and shooting arm (right) side. To calibrate the 3-D performance area, we videotaped a calibration frame (1 m × 1 m × 1.8 m) with 16 control points before the trials.

**Table 1.**
Demographic variables of subjects.

| Variables | TP (n = 6) | | AB (n = 6) | |
|---|---|---|---|---|
| | Mean | (SD) | Mean | (SD) |
| Age (y) | 32.60 | (2.40)* | 21.50 | (5.00) |
| Sitting height (m)† | 1.23 | (0.37) | 1.25 | (0.24) |
| Weight (kg) | 51.30 | (2.80)* | 64.60 | (5.00) |
| Time since injury (y)‡ | 9–21 | | — | |
| ASIA score‡ | 28–39 | | — | |
| Functional level | | | | |
| No. subjects at C7 | 5 | | — | |
| No. subjects at C8 | 1 | | — | |

*Shows significant difference ($p < 0.01$).
†Height is measured at a distance from floor to top of head in a seated condition (seated in a wheelchair).
‡Values are range.
ASIA = American Spinal Injury Association
SD = standard deviation
TP = tetraplegia
AB = able-bodied

Prior to videotaping, we placed reflective markers at anatomical landmarks, including right and left acromion process, right lateral epicondyle, right ulnar styloid, right third metacarpal head, and the lowest thoracic spinous process that was visible from the back-view. According to a method described first by Sakurai et al. (15) and later applied by Feltner and Nelson (16), a wooden stick (25 cm in length, 20 g in mass) was affixed to the dorsal surface of the forearm just proximal to the wrist, to quantify forearm and wrist motions. An experienced researcher placed all markers and the stick and fixed them as firmly as possible using double- and single-sided adhesive tape.

None of the TP subjects could propel the regulation ball above the official height of the goal, whereas all the AB subjects could make 3 to 5 of the 10 baskets attempted. The shot with the largest release ball velocity was selected for each TP subject, and one successful shot was selected for each AB subject.

An experienced researcher manually digitized the body landmarks, two ends of the wooden stick, and the center of the ball in each image using a personal computer (Sharp Inc., Osaka, Japan) (**Figure 1(a)**). Each trial was digitized from 350 ms before to 50 ms after ball release. The moment of release was determined from the back-view videotape records as the first frame in which the ball was no longer in contact with the hand. The marker on the left shoulder was hidden momentarily from the right-side camera view, whereas the other markers were clearly visible from both camera views. Although the experienced researcher carefully interpolated the hidden location of that marker, its coordinate data might be prone to rather large random error. The direct linear transformation (DLT) method (17) was used to obtain the 3-D coordinates of each landmark. The 3-D performance area (1 m × 1 m × 1.8 m) was calibrated with a net root mean square (rms) error term of 3 mm.

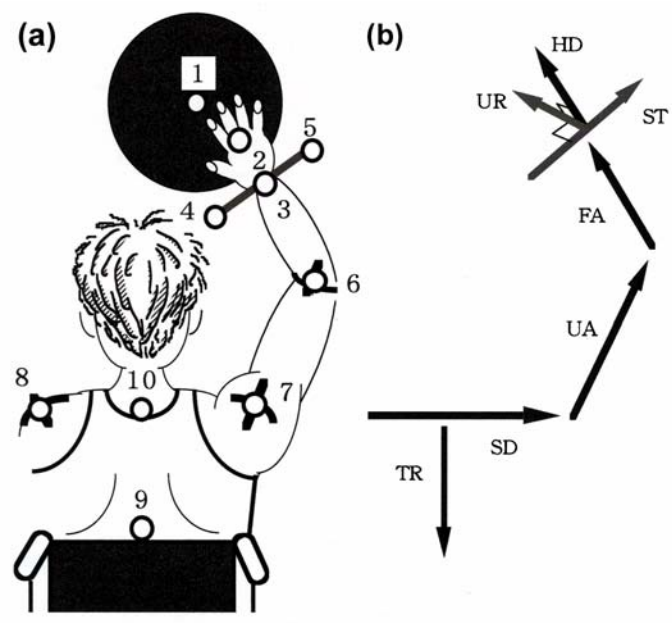


**Figure 1.**
(a) Digitized landmarks (1 to 10). Mid-point of shoulder landmark (No. 10) was computed from coordinate data. (b) Vectors used to detect upper limb motion. Vectors are **SD:** left to right shoulder; **TR**: mid-point of right and left shoulders to center of trunk; **UA**, **FA,** and **HD**: longitudinal axis of right upper arm, right forearm, and right hand segment, respectively; **ST**: radial to ulnar edges of wooden stick; **UR**: vector product of **ST** and **FA**.

The time-dependent coordinates of the landmarks were digitally smoothed with the use of a second-order, zero-lag, Butterworth-type low-pass filter (18) at 12.5 Hz. The first and last 50 ms of the coordinate data were removed to exclude the effect of filter distortion. Thus, analysis of all trials began 300 ms before (–300 ms) and concluded at ball release (0 ms).

Seven vectors were defined to obtain seven joint angles of the upper limb (**Figure 1(b)**). **SD** was defined as the vector from the left to right shoulder. **TR** was defined as the vector from the mid-point of the right and left shoulders to the center of the trunk. **UA**, **FA,** and **HD** were defined as the vectors along the longitudinal axis of the right upper arm, right forearm, and right hand segment, respectively. **ST** was defined as the vector from the radial edge to ulnar edge of the wooden stick. **UR** was defined as the vector determined by the vector product of **ST** and **FA** (**ST** × **FA**).

The definitions of the angles are shown in **Figure 2**, panels **(a)** to **(g)**. The shoulder abduction angle (**Figure 2(c)**) was defined as the angle between **TR** and **UA**. Full shoulder abduction corresponded to 180°.

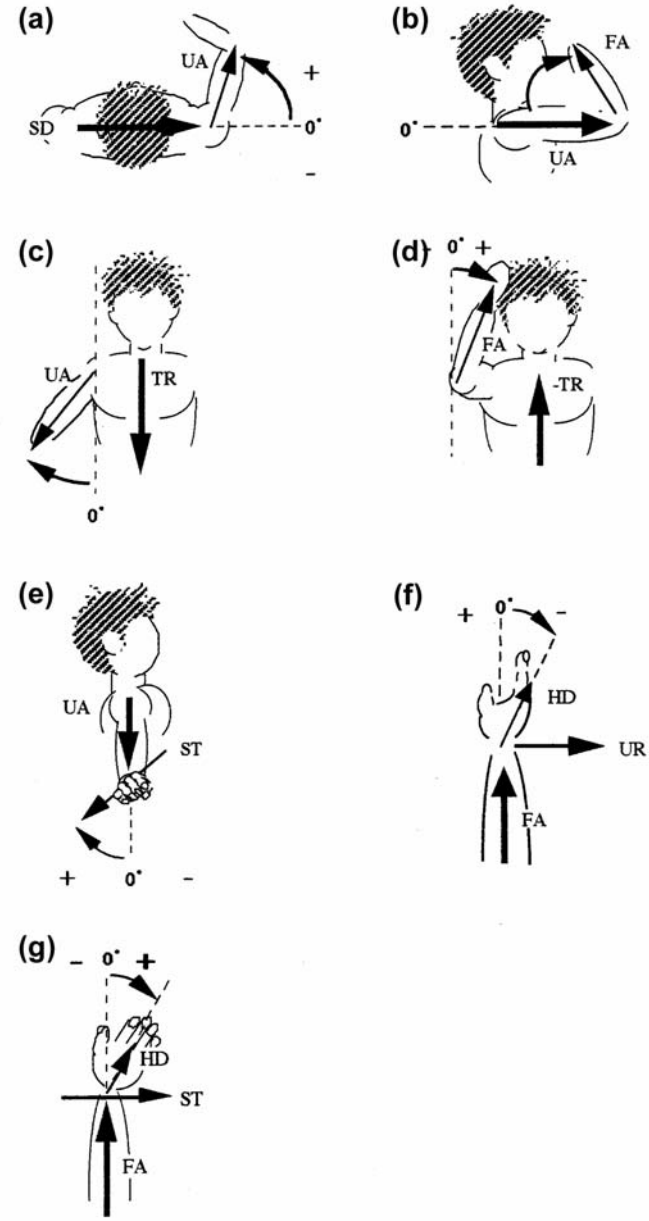


**Figure 2.**
Pictorial definitions of seven joint angles used to detect upper-limb motions during basketball shooting: (a) Shoulder horizontal adduction (+)/ horizontal abduction (–), (b) elbow extension, (c) shoulder abduction, (d) shoulder internal rotation (+)/external rotation (–), (e) forearm pronation (+)/ supination (–), (f) wrist flexion (+)/extension (–), and (g) wrist ulnar flexion (+)/radial flexion (–).

The elbow extension angle (**Figure 2(b)**) was defined as the angle between **UA** and **FA**, with full elbow extension corresponding to 180°.

The shoulder horizontal adduction/abduction, shoulder internal/external rotation, forearm pronation/supination,

wrist flexion/extension, and wrist ulnar/radial flexion angles were computed as projected angles.

The shoulder horizontal adduction/abduction angle (**Figure 2(a)**) was defined as the angle between the projections of **SD** and **UA** on the plane perpendicular to the **TR** vector. The position of **UA** parallel to **SD** was defined as a neutral position (0°), where positive and negative values corresponded to shoulder horizontal adduction and horizontal abduction, respectively.

The angle between the projections of **FA** and –**TR** on the plane perpendicular to the **UA** vector was used to define the shoulder internal/external rotation angle (**Figure 2(d)**). The position of **FA** parallel to –**TR** was defined as a neutral position (0°), where positive and negative values corresponded to shoulder internal and external rotation, respectively.

The forearm pronation/supination angle (**Figure 2(e)**) was defined as the angle between the projections of **ST** and **UA** on the plane perpendicular to the **FA** vector. The position of **ST** parallel to **UA** was defined as a neutral position (0°), where positive and negative values corresponded to forearm pronation and supination, respectively.

The angle between the projections of **HD** and **FA** on the plane perpendicular to the **ST** vector defined the wrist flexion/extension angle (**Figure 2(f)**). The position of **HD** parallel to **FA** was defined as a neutral position (0°), where positive and negative values corresponded to wrist flexion and extension, respectively.

The last angle, the ulnar/radial flexion angle (**Figure 2(g)**), was defined as the angle between the projections of **HD** and **FA** of on the plane perpendicular to the **UR** vector. The position of **HD** parallel to **FA** was defined as a neutral position (0°), where positive and negative values corresponded to wrist ulnar and radial flexion, respectively.

Displacement of the right shoulder was calculated as an index of the trunk motion. This was done because the lower part of the trunk was hidden by the backrest of the wheelchair and, thus, could not be defined properly. The displacements in the horizontal and frontal planes were defined as forward and upward displacements, respectively.

We calculated ball and angular velocities as first derivatives of the ball and angular positions using a finite difference method. Projected angle of the ball was calculated as the angle between the 3-D ball velocity vector and the horizontal plane.

Since the one female TP subject showed a performance comparable to those of the male TP subjects, data from the female subject were included for statistics. We compared between the two groups all kinematic variables using two-tailed Student t-tests. The criterion for statistical significance was $p < 0.01$ for all analyses.

## RESULTS

Ball release parameters are presented in **Table 2**. The TP subjects showed a significantly smaller vertical component of ball release velocity ($p < 0.01$) and release height ($p < 0.01$) than those of the AB subjects.

**Figure 3**, panels **(a)** to **(g)**, shows the changes in average (±**SD**) values for seven joint angles of the shooting arm, synchronized with the moment of release ($t = 0$ ms). As shown, at the beginning of the shooting motion ($t = -300$ ms), the TP subjects showed significantly ($p < 0.01$) smaller angles of shoulder horizontal adduction, shoulder abduction and elbow extension than those of the AB subjects. Moreover, although all the AB subjects were in an internally rotated shoulder position and pronated forearm position, those of the TP subjects were varied—four of the TP subjects had an externally rotated shoulder position and three had a supinated forearm position.

From this point, the elbow extension (**Figure 3(b)**) and shoulder abduction motions (**Figure 3(c)**) occurred continuously in both groups and reached their maximum abducted and extended positions at ball release, respectively. Although the TP subjects maintained a significantly smaller shoulder abduction angle throughout the shooting motion, the range of motion was significantly larger than that of the AB subjects (see **Table 3**). The shoulder joint of the TP subjects was horizontally adducted prior to its horizontal abduction motion (**Figure 3(a)**). Although the beginning of the horizontal abduction

**Table 2.**
Selected ball release parameters.

| Ball Velocity (m/s) | TP | | AB | |
|---|---|---|---|---|
| | Mean | (SD) | Mean | (SD) |
| Horizontal component | 3.47 | (0.73) | 3.14 | (0.37) |
| Vertical component | 4.26 | (0.67)* | 5.45 | (0.25) |
| Release height (m) | 1.66 | (0.10)* | 1.83 | (0.06) |
| Projected angle (°) | 50.30 | (7.70) | 59.20 | (2.50) |

*Shows significant difference ($p < 0.01$).

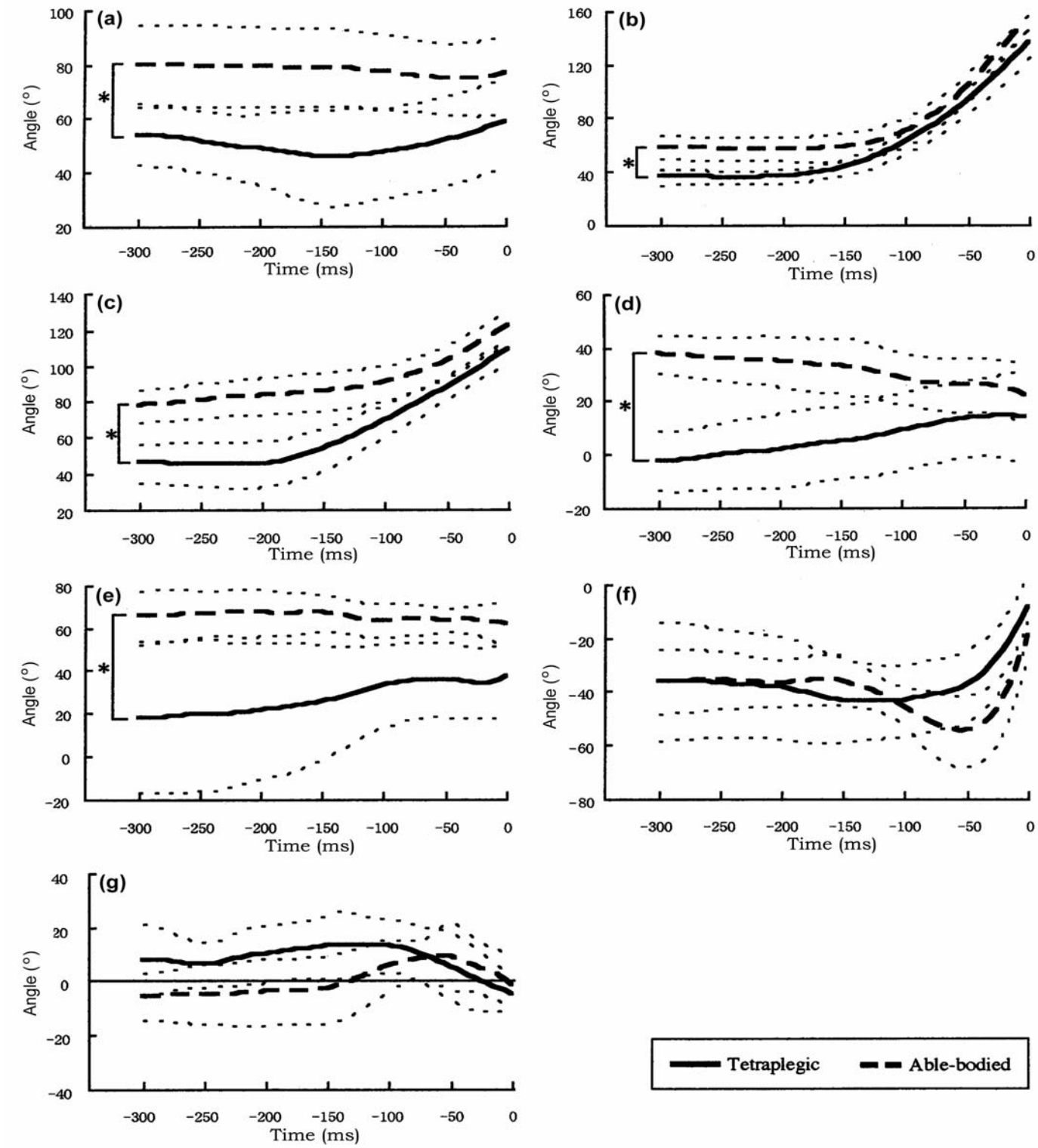


**Figure 3.**

Average (±SD) angular changes of seven joint angles of upper limb during shooting: (a) Shoulder horizontal adduction (+)/horizontal abduction (–), (b) elbow extension, (c) shoulder abduction, (d) shoulder internal rotation (+)/external rotation (–), (e) forearm pronation (+)/supination (–), (f) wrist flexion (+)/extension (–), and (g) wrist ulnar flexion (+)/radial flexion (–). Two thick lines (solid and broken), synchronized with moment of release ($t$ = 0 ms), show changes of average values for tetraplegic and able-bodied subjects, and * indicates significant difference ($p < 0.01$) between two groups.

motion was somewhat varied among the TP subjects (mean $t = -150.0 \pm 63.8$ ms), from near to ball release (about $t = -60$ ms), the horizontal abduction motion was consistently observed until ball release. In contrast, no motion was observed in the AB subjects for the shoulder horizontal adduction/abduction motion. Moreover, the forearm motion (pronation/supination; **Figure 3(e)**) varied among the TP subjects, whereas no motion was observed in the AB subjects.

The wrist joint of the AB subjects (**Figure 3(f)**) was gradually extended prior to its flexion motion (about $t = -60$ ms), with the flexion motion occurring continuously until ball release. Although a similar pattern of wrist flexion motion was observed for all TP subjects, the wrist extension motion was not apparent for three of the TP subjects. For the other joints, no patterned motions were observed for either group.

**Figure 4** shows the change in average (±SD) angular velocity for three joint motions: shoulder abduction, elbow extension, and wrist flexion/extension. As shown, the maximum values of angular velocity of shoulder abduction and elbow extension were found to occur prior to ball release, whereas that of the wrist joint occurred at ball release. The TP subjects showed a significantly ($p < 0.01$) smaller maximum angular velocity of wrist flexion, whereas no significant differences were found in angular velocities of shoulder abduction and elbow extension between the two groups (see **Table 3**).

Changes in average angular velocity values for the shoulder horizontal adduction/abduction motion could not be compared and were relatively small (data not shown) for the other joint motions. No significant differences were found between the two groups.

The TP subjects showed significantly larger ($p < 0.01$) forward and upward displacements of the right shoulder than those of the AB subjects (see **Table 3**).

## DISCUSSION

Minimal information is available regarding wheelchair basketball shooting. Malone et al. (19) is the only study that reported ball release parameters for successful free-throw shooting in wheelchair basketball. In their report, players having less functional ability (Classes 1 and 2, whose typical disabilities include level L1 and upper paraplegia) tended to release the ball from a lower release height using a greater ball release velocity. Since a somewhat shorter horizontal distance was used in the present study, the absolute ball velocity reported by Malone et al. could not be compared directly with that of the present study. Therefore, the vertical component of the ball velocity should be used for an equitable comparison between the two studies. Using the average ball velocities and projected angles reported by Malone et al., we calculated the vertical component of ball velocity. The vertical component of ball velocity and release height of the AB subjects (5.45 m/s and 1.83 m, respectively) were quite similar to those reported for the Class 4 players (5.73 m/s and 1.84 m, respectively) whose typical disabilities included level L5 and lower paraplegia. On the other hand, the TP subjects showed a remarkably smaller vertical component of ball velocity (4.26 m/s) and a similar release height (1.66 m) when compared to those

**Table 3.**
Selected values of angular displacement, range of motion, angular velocity, and right shoulder displacement.

| Joint | Motion | Mean | | Mean | |
|---|---|---|---|---|---|
| | | TP | (SD) | AB | (SD) |
| Shoulder | Min. abduction angle (°) | 43.8 | (12.4)* | 77.3 | (9.0) |
| | Range of abduction motion (°) | 64.6 | (12.9)* | 44.4 | (8.2) |
| | Max. abduction angular velocity (°/s) | 447.7 | (59.2) | 431.7 | (74.1) |
| Elbow | Min. extension angle (°) | 34.3 | (5.3)* | 55.3 | (8.9) |
| | Max. extension angular velocity (°/s) | 948.4 | (155.6) | 1,072.1 | (139.2) |
| Wrist | Max. flexion angular velocity (°/s) | 878.4 | (174.7)* | 1,445.9 | (358.5) |
| Right Shoulder | Forward displacement (m) | 0.08 | (0.06)* | –0.01 | (0.02) |
| | Upward displacement (m) | 0.14 | (0.02)* | 0.03 | (0.02) |

*Shows significant difference ($p < 0.01$).

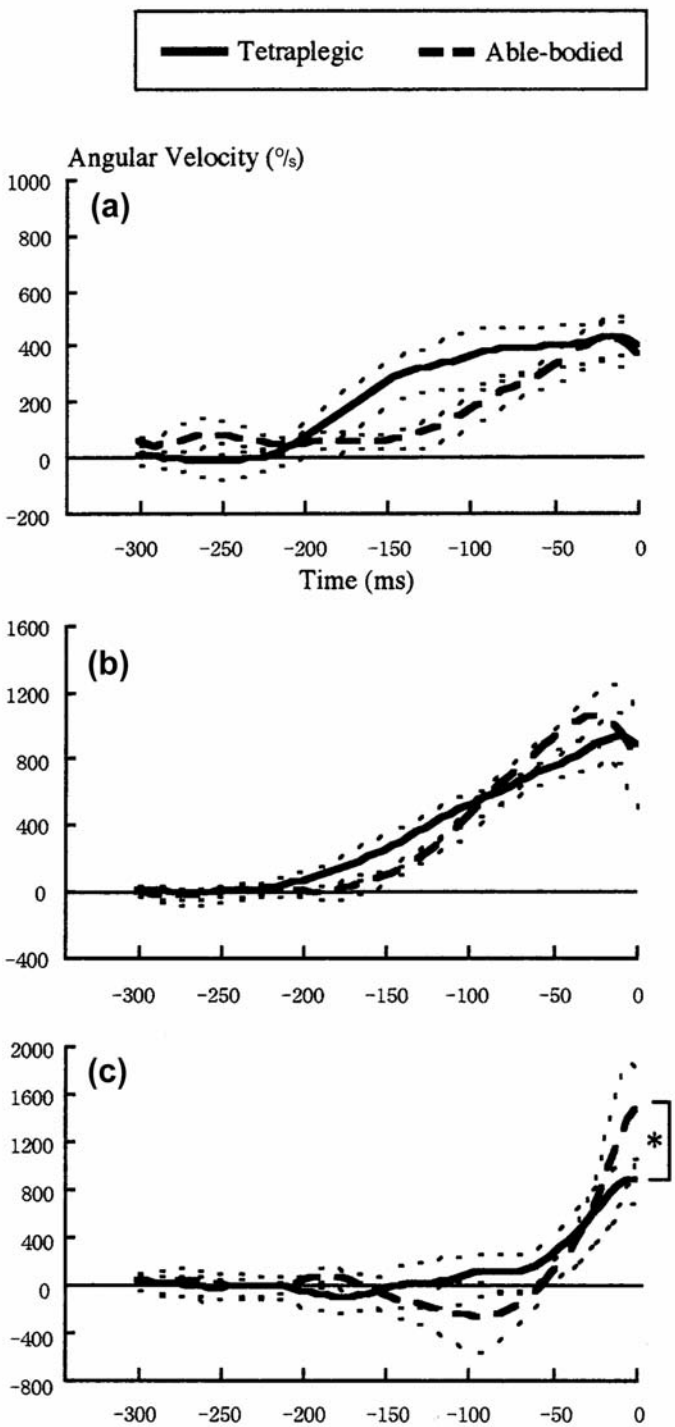


**Figure 4.**
Average (±SD) angular velocity changes for three joints: shoulder abduction/adduction (a), elbow extension/flexion (b) and wrist extension/flexion (c). Two thick lines (solid and broken) synchronized with moment of release ($t$ = 0 ms) show changes of average values for tetraplegic and able-bodied subjects, and *shows significant difference ($p < 0.01$) between the two groups.

reported for the Class 1 players (6.37 m/s and 1.62 m, respectively), whose typical disabilities included level T7 and upper paraplegia. These results suggest that the TP subjects may achieve an adequately high release point but are unable to generate a sufficient ball release velocity.

No study results can be compared directly to the angular motions quantified in this study because previous research (8–10) did not account for non-planar motion. An attempt was made, here, to understand the kinematic features of wheelchair basketball shooting motion by the TP subjects (C7–C8 level) through a comparison with that of the AB subjects. The general patterns of joint angular motion indicated that the shoulder abduction, elbow extension and wrist flexion motions were consistently dominant in both groups. Thus, it is reasonable to suppose that these motions are mostly responsible for ball release velocity in both groups.

Among the various kinematic variables related to these motions, the most dominant factor that affected the reduced ball velocity of the TP subjects was the slower wrist flexion angular velocity. To better clarify the contribution of wrist flexion motion, the vertical component of ball velocity at the beginning of wrist flexion was also calculated and compared for the two groups (**Table 4**). The vertical components of ball velocities at this moment were 4.36 ± 0.55 m/s and 3.48 ± 0.90 m/s (see **Table 4**), for the AB and TP groups, respectively. No significant difference was observed between the two groups until this moment. Moreover, one TP subject could not accelerate the ball from the beginning of wrist flexion to ball release (3.93 to 3.42 m/s, respectively; data not shown). These findings indicated that the TP subjects could not accelerate the ball sufficiently during the wrist flexion motion. The interpretation is that the reduced ball release velocity (vertical component) of the TP subjects depends primarily on an insufficient wrist angular velocity in

**Table 4.**
Vertical component of ball velocity at beginning of wrist flexon (BWF) and at ball release.

| Ball Velocity (m/s) | TP | | AB | |
|---|---|---|---|---|
| | Mean | (SD) | Mean | (SD) |
| At BWF | 3.48 | (0.90) | 4.36 | (0.55) |
| At ball release | 4.26 | (0.67)* | 5.45 | (0.25) |

*Shows significant difference ($p < 0.01$).

which dysfunction of the wrist flexor muscles may be a causal determinant.

On the other hand, some characteristic motions were observed for the TP subjects. From near ball release (about $t$ = –60 ms), the shoulder horizontal adduction motion occurred continuously until ball release (**Figure 3(a)**). Moreover, a larger range of shoulder abduction motion and larger forward and upward displacements of the right shoulder were observed for the TP subjects (see **Table 3**). These motions, typically considered unapparent for the AB subjects, most likely serve to maximize the function of available musculature around the shoulder, thereby partially compensating for the dysfunction of wrist flexor muscles. However, as the TP subjects had little trunk musculature control, the larger forward and upward displacements of the right shoulder were aided possibly by the actions of the nonthrowing (left) arm.

These findings suggest a possibility that shooting performance (ball release velocity) in tetraplegic individuals may be improved through acquisition of specific shooting mechanics that require somewhat different moves from those used by able-bodied individuals. However, it is emphasized that this study dealt only with small sample sizes and with the kinematic aspects of the shooting motion, in which the joint torque actually generated by the wrist flexors could not be inferred. It is doubtful that only the wrist flexor muscles contributed to such high angular velocities observed in the AB subjects. Most likely, joint torques derived from larger muscles (e.g., the elbow extensor and/or the shoulder abductor muscles) were used in the wrist flexion motion as well.

In most cases, inertial properties of body segments are calculated as functions of total body weight and are generalized for able-bodied individuals. However, atrophy of the lower part of the body, occurring typically in disabled individuals, changes the mass distribution of body segments and thereby affects the estimated inertial properties. Consequently, without additional kinetic analysis the results of this study are still insufficient to determine the role of specific muscles related to the shooting motion. Further investigations using kinetic analysis and a larger number of subjects will lead to a more definitive interpretation of the shooting style of tetraplegic individuals.

## CONCLUSIONS

The basketball shooting motion of tetraplegic wheelchair basketball players with spinal cord lesions at the C7–C8 level was quantified and their kinematic features were compared with those of able-bodied basketball players. The reduced ball release velocity observed for the tetraplegic players depended on an insufficient angular velocity of the wrist flexion motion, which may be restrained by dysfunction of available musculature. Moreover, for shoulder horizontal adduction motion near the time of ball release, a larger range of shoulder abduction motion and larger displacements of the right shoulder were observed selectively in the tetraplegic players. These motions most likely served to maximize the function of available musculature around the elbow and shoulder joints, thereby compensating for dysfunction of the wrist flexor muscles and contributing to the resultant ball release velocity.

## ACKNOWLEDGMENT

We would like to thank Dr. Laurie Malone of the Division of Health, Physical Education and Recreation at Virginia Commonwealth University, United States, for her great help in preparing this manuscript. A part of this study was presented at 16th Congress of International Society of Biomechanics, Tokyo, 1997.

## REFERENCES

1. Coutts, KD. Aerobic and anaerobic power of Canadian wheelchair track athletes. Med Sci Sports Exerc 1987;19:62–5.
2. Schmid A, Huonker M, Stober P, Barturen JM, Schmidt-Trucksaess A, Duerr H, Voelpel HJ, Keul J. Physical performance and cardiovascular and metabolic adaptation of elite female wheelchair basketball players in wheelchair ergometry and in competition. Am J Phys Med Rehabil 1998;77:527–33.
3. Van der Wonde LHV, Bakker WH, Elkhuizen JW, Veeger HEJ, Gwinn T. Anaerobic work capacity in elite wheelchair athletes. Am J Phys Med Rehabil 1997;76:355–65.
4. Cooper RA, Boninger ML, Shimada SD, Lawrence BM. Glenohumeral joint kinematics and kinetics for three coordinate system representations during wheelchair propulsion. Am J Phys Med Rehabil 1999;78:435–446.

5. Davis JL, Growney ES, Johnson ME, Iuliano BA, An KN. Three-dimensional kinematics of the shoulder complex during wheelchair propulsion: A technical report. J Rehabil Res Dev 1994;31:138–43.
6. Rao SS, Bontrager EL, Gronley JK, Newsam CJ, Perry J. Three-dimensional kinematics of wheelchair propulsion. IEEE Trans Biomed Eng 1996;41:152–60.
7. Sanderson DJ, Sommer III HJ. Kinematic features of wheelchair propulsion. J Biomech 1985;18:423–9.
8. Elliott B. A kinematic comparison of the male and female two-point and three-point jump shots in basketball. Aust J Sci Med Sport 1992;24:111–8.
9. Elliott B, White E. A kinematic and kinetic analysis of the female two and three point jump shots in basketball. Aust J Sci Med Sport 1989;21:7–11.
10. Miller S, Bartlett RM. The effects of increased shooting distance in the basketball jump shot. J Sports Sci 1993;11:285–93.
11. Uchida A, Yamaguchi S, Hayashi T, Inasaka R, Fukuda J, Hasegawa T, Hashitani T, Owasi M. Tetraplegic wheelchair basketball. Paraplegia 1994;32:59–62.
12. Zancolli E: Surgery for the quadriplegic hand with active, strong wrist extension preserved. Clin Orthop 1975;112:101–13.
13. Ditunno JF, Young W, Donovan, WH, Greasey G. The international standards booklet for neurological and functional classification of spinal cord injury. Paraplegia 1994;32:70–80.
14. Japan Wheelchair Twin Basketball Federation. Wheelchair twin basketball regulations. 1993 (in Japanese).
15. Sakurai S, Ikegami Y, Okamoto A, Yabe K, Toyoshima S. A three-dimensional cinematographic analysis of upper limb movement during fastball and curveball baseball pitches. J Appl Biomech 1993;9:47–65.
16. Feltner ME, Nelson ST. Three-dimensional kinematics of the throwing arm during the penalty throw in water polo. J Appl Biomech 1996;12:359–82.
17. Abdel-Azis, Y I, Karara, H M. Direct linear transformation from comparator coordinates into object space coordinates in close-range photogrammetry. Proceedings of the American Society of Photogrammetry Symposium on Close-Range Photogrammetry; 1971 January 26–29; Urbana, IL. Falls Church (VA): American Society of Photogrammetry; 1971. p. 1–18.
18. Winter DA. Biomechanics of Human Movement. 2nd ed. New York (NY): John Wiley & Sons; 1990.
19. Malone LA, Gervais PL, Steadward RD. Parameters of ball release in wheelchair basketball free throw shooting. Proceedings of the International Symposium of Biomechanics in Sports; 1999 June 30–July 6; Perth, Western Australia. Perth: Edith Cowan University; 1999. p. 29–32.

Submitted for publication January 17, 2001. Accepted in revised form August 8, 2001.