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Relationship Between Performance Characteristics and Player Classification in Wheelchair Basketball Shooting

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A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Doctor of Philosophy

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“Few in number are those that

see with their own eyes and feel with their own hearts.”

Albert Einstein

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Faculty of Graduate Studies and Research

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled *Relationship Between Performance Characteristics and Player Classification in Wheelchair Basketball Shooting* submitted by *Laurie Ann Malone* in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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To my parents…

loving memory in death and celebration in life

ABSTRACT

Wheelchair basketball is an exciting, highly competitive sport. To gain the "competitive edge" required for success, there is a need to fully understand and develop the fundamental skills involved. The free throw (FT) is especially important as it provides an opportunity for a team to score free or uncontested points and is often the deciding factor in a close game. Unfortunately, FT success rates in wheelchair basketball tend to be quite low.

Using data collected at the 6th Men's Gold Cup World Wheelchair Basketball Championship, an in-depth, three-part investigation of the FT was conducted. Issues related to outcome characteristics, segment coordination, and shooting mechanics in performance of the FT by wheelchair basketball players were examined.

A review of game statistics confirmed the low FT shooting percentages and importance of successful FT shooting to overall success. Schematic diagrams, which recorded the systematic nature of ball action at the basket, indicated that short shots comprise the most prominent free throw error.

Utilizing 3-D video data collected at the tournament, segmental coordination of the shooting arm was examined. Variables related to the timing and sequencing of joint motion at the shoulder, elbow and wrist were assessed. It was found that players tended to perform the FT with a combination of sequential and simultaneous segment rotations.

In addition, video data was used to examine the parameters of ball release and joint kinematics associated with performance of the clean swish by each of the classes. Significant differences were identified between the classes in the FT shooting mechanics

required for a clean swish. The lower classes (1 & 2) tended to release the ball from a lower height, with greater velocity and angle of projection. In addition, they demonstrated a smaller angle of shoulder flexion at release, and greater maximum angular velocity at the shoulder and elbow.

In conclusion, the results indicate the need for specific coaching and training techniques and provide direction for such interventions. Preliminary guidelines for identifying individual outcome errors have been provided, as well as information as to the mechanics used for successful FT shooting by players in each of the classes.

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CHAPTER 1

Introduction

Wheelchair basketball is an exciting, fast paced, high-calibre sport played in over 75 countries around the world. It has grown from a means of therapy and rehabilitation into a competitive, highly athletic sport. As attitudes towards persons with a disability have changed, wheelchair basketball players have come to be recognised, first and foremost, as athletes.

The International Wheelchair Basketball Federation (IWBF) governs competition in wheelchair basketball at the international level. Previously a committee within the International Stoke Mandeville Wheelchair Sports Federation (ISMWSF), IWBF became an independent sports federation with 50 member nations in 1993. In order to encourage a strong association between wheelchair and stand-up basketball, the IWBF works closely with FIBA (Federation International de Basketball). Furthermore, in order to best serve its members, the IWBF has two main goals: 1) to organise and develop international wheelchair basketball competitions of the highest quality for its member nations and 2) to establish and develop standards of play in an increasing number of countries (IWBF on-line homepage, 1998).

The Gold Cup World Championship for men, first held in 1975, provides an opportunity for elite international wheelchair basketball competition every four years (in between years of the Paralympic Games). International wheelchair basketball is played in accordance with the rules of the IWBF and FIBA, with only minor amendments to accommodate the wheelchair. To ensure fair and equitable competition, and to include players at all levels of physical potential, the IWBF Player Classification System was adopted in 1984. Designed to give every player an equal opportunity to compete, the system is based on the functional ability of players in performing the fundamental basketball skills of shooting, passing, rebounding, pushing and dribbling. It has been observed that level of trunk function directly affects performance of these fundamental skills (Barcelona '92 Classification Guide). The player classification system, therefore, utilises level of trunk movement and sitting balance as the fundamental elements in the definition of each class. Hence, the classification system does not measure the talent or level of training of a player, but instead the functional limitations caused by physical disability.

The current player classification system consists of four classes (Class 1, 2, 3 and 4), with half point classes (Class 1.5, 2.5, 3.5, and 4.5) designated for borderline cases. Based on the level of classification, players are assigned a corresponding point value (i.e., Class 1 = 1 point, Class 2.5 = 2.5 points, etc.). During play, the points of the five players on the court are summed and must not exceed a predetermined maximum at any one time. During IWBF sanctioned international play, the total number of points on the floor must not exceed 14. For an outline of the current international player classification system see Appendix A.

For a team or individual player to gain the "competitive edge" required for success in basketball, there is a need to fully understand and develop the fundamental skills involved (i.e., shooting, passing, dribbling). Of the fundamental skills in basketball, shooting can be considered as the most important in putting points on the board and determining the outcome of a game. The free throw, in particular, is especially important as it provides an opportunity for a team to score free or uncontested points and is often the deciding factor in a close game (Miller & Horkey, 1970; Sharman, 1965) or even a championship title (Hobson, 1955). In addition, the free throw is the only shot common to all players and has been shown to account for 20-25% of a team's scoring in men's college basketball (Hays & Krause, 1987). Similarly, in a notational analysis of English National League matches played between 1984 and 1990, Miller and Bartlett (1996) found that free throws accounted for 26% of all shots attempted.

Whereas free throw shooting percentages in men's college basketball in the USA consistently average near 70% (Krause & Hayes, 1994), scoring averages of wheelchair basketball players from the free throw line typically range between 45% and 55% (Owen, 1982). Official results from the 1992 Paralympics in Barcelona revealed that of the twelve men's wheelchair basketball teams competing, only two teams had free throw percentages above 50% (Sweden 54%, Spain 52%). Across teams, only 46% of the free throw attempts were successful.

Although there are obvious disadvantages to shooting a basketball from a wheelchair (limited power from legs, increased distance to basket) as compared to standing up, it does not seem likely that the difference in success rates can be attributed solely to differences in the required shooting mechanics (Owen, 1982). Brasile and Hedrick (1996) remarked that wheelchair basketball players have become more proficient in the skills required for the game, however, the preceding statistics indicate that there may still be considerable room for improvement in the skill of free throw shooting.

Although proficiency in an activity can be attained through practice, the physical attributes and functional ability of the player will influence the technique used. Due to the wide range and complex nature of disabilities, modifications made to fundamental skills by individual players in wheelchair basketball are likely to be dependent on the degree of disability and the level of classification. In an effort to develop the skill of free throw shooting in wheelchair basketball players, players who are performing under very different conditions and limitations, it is apparent that relying on information from stand-up basketball is not an effective method for instruction. To date, little if any quantitative research has been completed with respect to wheelchair basketball. Instead, the available literature tends to be qualitative in nature, based on coaches' opinions and subjective analyses. Although the outcome of a free throw is that which will affect the score in a game, a thorough understanding of how the free throw is executed is a critical means by which improvements in performance can be made. The technique of free throw shooting by elite wheelchair basketball players in each of the classes must be investigated and further understood if performance is to be optimised.

STATEMENT OF THE PROBLEM

The objective of this original, three-part investigation was to determine the relationship between performance characteristics and player classification in wheelchair basketball free throw shooting. The investigation was comprised of three parts to examine the two aspects of free throw shooting, namely outcome and performance. No such research had previously been completed with respect to wheelchair basketball, and each portion of the investigation contributed unique and meaningful information to the fields of disability sport and biomechanics.

As a descriptive analysis, Part I looked at patterns of shooting in wheelchair basketball in an attempt to determine the characteristics of free throw shots taken by elite wheelchair basketball players performing in a competitive environment, and to provide a technique for describing free throw outcome beyond the traditional dichotomy of success or failure. The newly developed technique used for error detection provided necessary information for determining how shots were most often missed, as well as supporting data for the two biomechanically based portions of the study which followed.

The purpose of Part II was to describe the pattern of segment motion (coordination) used in free throw shooting by wheelchair basketball players and to determine the relationship between shooting style (as defined by segment motion patterns) and player classification. In conjunction with the information obtained in Part I, this data provided insight as to the influence of the selected shooting styles on ball action at the basket and free throw outcome.

Finally, the third step was to gather information that, combined with the results of the previous two studies, could eventually be used by coaches to begin an intervention program with a player from a particular class. In order to look at only those shots that would most likely reveal the desired technique for successful shooting, all shots except those resulting in clean swishes were factored out. Hence, in an analysis of clean swishes, the aim of Part III was as follows: 1) to determine the relationship between ball release parameters (height, angle and velocity of projection) and player classification, and 2) to identify the shooting technique used to achieve the release parameters required for successful shooting within each class, focusing on angular displacements and velocities of the major joints involved (shoulder, elbow, wrist).

In order to capture the performance of the best basketball players in the world, the 6th Men's Gold Cup World Wheelchair Basketball Championship was chosen as the venue for data collection. As the tournament involved only male players, investigation of women players was not possible at this time. In a competitive setting such as this the methods of data collection were limited to those which were unobtrusive to the subjects. Therefore, in addition to collection of descriptive information from statistics and schematic diagrams, cinematography provided a means by which data on free throw shooting by these highly skilled players could be obtained without interference to their performance. As the cameras were positioned in the spectator stands, away from the sides of the playing court, the players could not easily discern them. Therefore, as required by the competition committee and international governing body, and as approved by the University of Alberta Ethics Committee, players were unaware that data were being collected during the competition. Upon completion of the tournament teams were notified that data had been collected and were asked to give consent for the data to be used. Consent was received from all teams and performance of the subjects was in no way hindered, altered, or affected by the process of collecting data during the competition.

HYPOTHESES (NULL)

For the purposes of this investigation, the following hypotheses were tested:

- There is no difference in patterns of segmental coordination between the four classes
- There is no difference in patterns of segmental coordination between successful and unsuccessful free throws

- Shooting style and player classification are independent (not related)
- There is no difference in clean swish shooting mechanics (ball parameters, joint kinematics) between the four classes

LIMITATIONS

The results of this investigation were limited by the following conditions:

1. The sample for this study may not have been representative of the population of wheelchair basketball players as subjects were not randomly chosen, but were selected by virtue of having performed a free throw at one pre-determined basket on the court during World Championship competition. As a consequence, an unequal number of players in each class were analysed.
2. Although precautions were taken (see Appendix B), certain errors are inherent in cinematographical data collection and analysis (i.e., possibility of perspective errors, film graininess and distortions through the optical elements of the recording and/or projection devices).
3. Other factors possibly affecting performance during competition (e.g., motivation, levels of anxiety, personality, physical fitness) were not considered.

DELIMITATIONS

This investigation was delimited in the following ways:

1. Subjects in this study were elite level wheelchair basketball players.
2. Only right-handed shooters were analysed in the video-based portions of this study due to the nature of the camera positions.

3. Only free throws taken at one pre-determined end of the court were used for analysis.
4. IWBF player classification groups were combined for analysis as follows Class 1 = 1.0 & 1.5, Class 2 = 2.0 & 2.5, Class 3 = 3.0 & 3.5, Class 4 = 4.0 & 4.5.
5. Actual horizontal distance from point of ball release to the centre of the basket was not measured. Instead, all calculations were based on the measured horizontal distance (419.1 cm) from the free throw line to the centre of the basket.
6. Degree of trunk movement and sitting height was not measured.
7. Spin of the ball during flight and its affect on trajectory was not measured.
8. Air resistance was neglected.
9. A sampling rate of 60 Hz was used for video data collection.

DEFINITION OF TERMS

Angle of entry (θ_e) - angle formed by the tangent to the ball's centre of mass pathway and the horizontal at the moment the lowest portion of the ball approaches the rim of the basket.

Angle of projection (θ_p) - the angle formed by the tangent to the ball's centre of mass pathway and the horizontal at release.

Ball release - defined by the first frame in which the ball is no longer in contact with the hand.

Clean swish - successful shot in basketball that does not discernibly touch the rim or backboard, but goes cleanly through the hoop.

Gold Cup World Championship - elite international wheelchair basketball competition held every four years.

Height of ball release - vertical distance from the floor to the centre of mass of the ball at release.

Margin for error (E_m) - the horizontal distance (±) that the centre of the ball at approach can be away from the centre of the hoop and still go cleanly through the basket.

Minimum projection angle (θ_{mp}) - the smallest projection angle that can be used with a particular release height and distance from the basket and still go cleanly through the basket.

Minimum-speed angle (θ_{ms}) - projection angle for a shot from a given point which requires the least amount of speed, and thereby force, at release of the ball.

Paralympic Games - elite international sports competition for persons with a disability held every four years in the same years as the Olympic Games.

Player classification system - system used in disability sport to give every player an equal opportunity to compete; based on measures of functional limitation caused by the physical disability.

Schematic diagrams - diagrams recorded during free throw shooting which numerically depict movement of the ball at the basket (rim and/or backboard).

Velocity of ball release - velocity with which the ball is released from the shooter's hands.

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CHAPTER 2

Expanding the Dichotomous Outcome in Wheelchair Basketball Shooting

To determine the results of a team in free throw shooting, game statistics can be reviewed. For example, National Basketball Association (NBA) statistics from the 1990/91 season indicated that the top 10 free throw shooters had averages ranging from 89.1% to 91.8% (Sports Illustrated). During the 1997/98 NBA season, the top 10 free throw shooters had averages ranging from 86.4% to 93.9%, with percentages ranging from 81.2% to 94% during the season playoffs (CBS Sportsline). The ten teams (1991) with the highest scoring averages had free throw percentages ranging from 74.1% to 82.4%. Owen (1982) has reported that scoring averages of wheelchair basketball players from the free throw line range between 45% and 55%. More recent statistics, from the official results of the 1992 Paralympic Games in Barcelona, revealed that of the twelve men's wheelchair basketball teams competing, only 2 teams had free throw percentages above 50% (Sweden 54.2%, Spain 52.5%). On average, only 47.5% of the free throw attempts were successful. The top ten individual free throw shooters during the tournament had percentages ranging from 51.7% to 71.4%.

Championship play in wheelchair basketball tends to result in lower game scores than both the NBA and Division I college basketball. In addition, free throws typically account for slightly less of the total score in wheelchair basketball. As indicated by the 1992 Paralympics, and the Pac10 and ACC 1996/97 season games, college and wheelchair basketball tended to average close to twenty fouls per game. During the 1991 NBA Playoffs, statistics revealed that for the two final teams (Bulls and Lakers), free throws accounted for 19% and 22% of the total points scored by each team during the tournament, respectively. Statistics of the Pac10 and ACC Division I teams for the 1997/98 season (CBS Sportsline) indicated that on average free throws accounted for 21% of total points scored throughout the season. Similarly, at the 1992 Paralympic Games, free throws accounted on average for 16% of the total points scored by a team.

Brasile and Hedrick (1996) have remarked that, as the sport of wheelchair basketball has grown, players have become more proficient in the skills required for the game. The preceding statistics, however, indicate that there may still be considerable room for improvement in the skill of free throw shooting, and clearly illustrate that the importance of free throw shooting cannot be denied. The free throw is such a critical part of basketball that any improvement in this particular skill by players on a team could help produce a greater percentage of wins over the season. To improve shooting technique, the teacher or coach must provide effective instruction and appropriate feedback. The free throw is classified as a closed, discrete skill, performed in an environment that is both stable and predictable with a definite beginning and end (Schmidt, 1991). As such, free throw shooting is conducive to being highly developed and refined through the use of proper technique instruction, practice and effective feedback.

The outcome of a basketball shot is typically classified as either successful or unsuccessful. Consequently, the result of a free throw is thereby reduced to a dichotomous outcome of hit (score) or miss. Actual performance, however, occurs along a continuum ranging from clean swish to clean miss (air ball). Within each category, successful and unsuccessful, there are different shades of performance. All "hits" are not the same, ranging from clean swish to near miss, although they count the same on the scoresheet. The ball with the trajectory of a clean swish has a predictable outcome, whereas, rim or backboard shots could go either way (hit or miss) depending on the nature of other factors involved (e.g., spin on the ball, contact point, ball velocity, etc.). For effective intervention in such a skill (e.g., technique instruction), therefore, evaluation should be based on actual performance. Although the shooter can observe the outcome of the performance, additional feedback as to how the basket was actually hit or missed should also be provided. A monitoring technique to determine the systematic nature of the ball action could provide information as to the characteristics (or errors) that are typical of a player or group of players. Such information could then be used to develop a framework for effective intervention. As pointed out by Schmidt (1991), extrinsic feedback provided by the instructor is one of the most critical aspects in learning a skill, and information about the direction of errors is crucial in matching the movement to the desired goal. With such low percentages of success in free throw shooting by wheelchair basketball players, the need to gain insight as to the underlying reasons is clear.

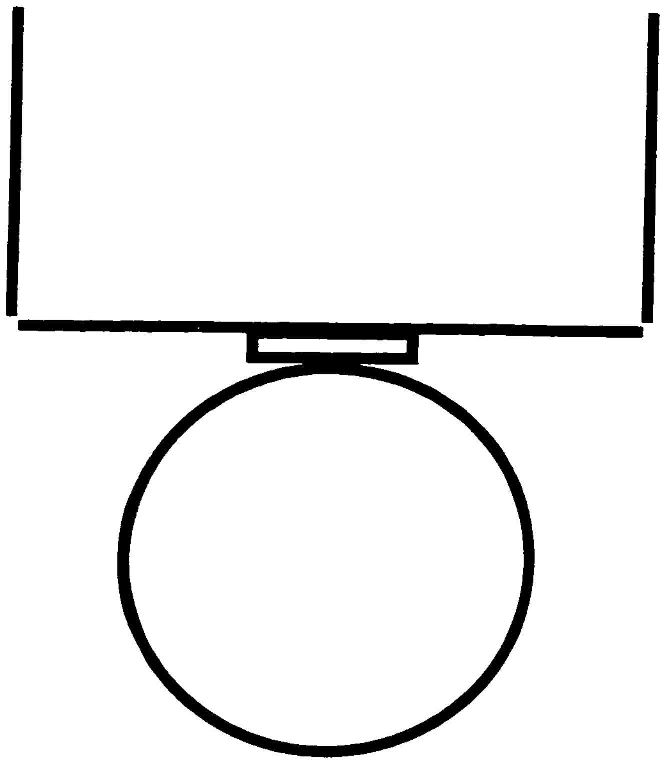
The purpose of this investigation, therefore, was twofold:

1. To determine the outcome characteristics of free throw shooting among elite wheelchair basketball players performing in a competitive environment.
2. To provide a technique for describing the free throw outcome, beyond the traditional dichotomous outcome.

METHODS

Data were collected at the 6th Men's Gold Cup World Wheelchair Basketball Championship held in Edmonton, Alberta, Canada. The top twelve teams in the world competed in a ten-day tournament during which time 1576 free throws were attempted. All free throw shots taken at one pre-determined basket were visually observed from a point parallel to the free throw line and schematic diagrams (see Figure 2-1) depicting ball movement patterns at the basket were recorded. A total of 737 free throws were attempted, observed, and recorded at that end of the court at which data collection was taking place. Within each player class, information was collected on the following number of shots: Class 1 - 60, Class 2 - 125, Class 3 - 119, Class 4 - 433. Eighty-one percent (116) of a possible 143 players who played in the tournament qualified as subjects by virtue of having attempted at least one free throw.

For interpretation of the schematic diagrams, ball pattern at the basket was tracked in a numerical sequence and later encoded for descriptive purposes (see Figure 2-2). The encoding format was comprised of clean swish (CS), backboard (BB), back rim (BR), front rim (FR), subsequent rim bounce (R), success after a sequence of events (H, i.e., hoop), and miss (M). For example, as shown in Figure 2-2, a ball which hit the backrim, hit the backboard, and then went in would be coded as - BR, BB, H. A ball which hit the front rim and went out would be coded as - FR, M. It should be noted, that initially attempts were made to record the side-to-side location (i.e., right rim, left rim) of ball hits, but through accuracy checks with records from an overhead camera that was available for two games, it was determined that the positioning of the person recording was not conducive to clearly detecting lateral movement of the ball.



Sequence # ________

☐ successful

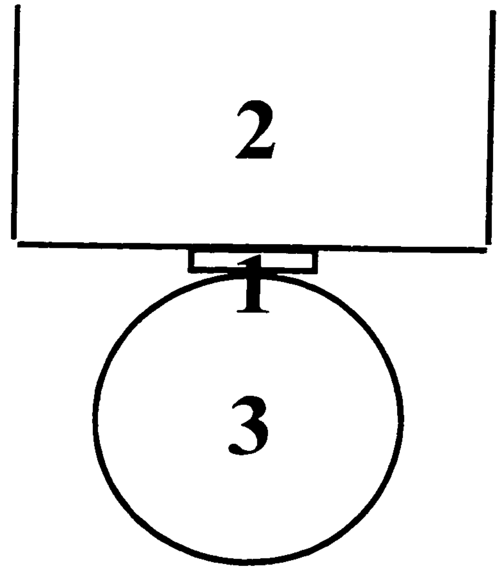
☐ missed

1st or 2nd

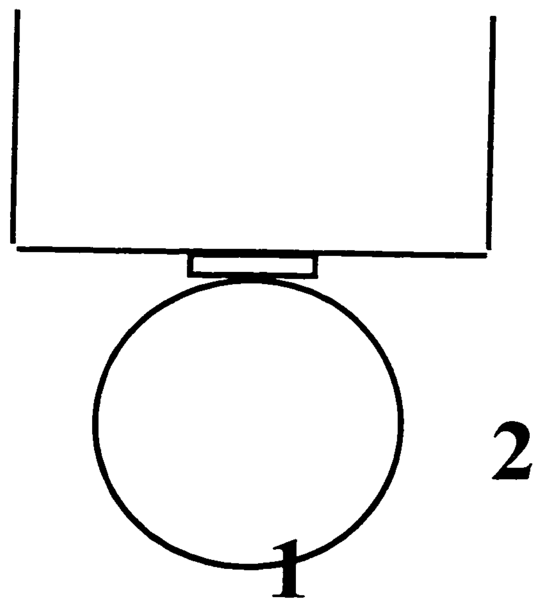
Player # ________ Team ________________ Class ________

Game # ________ Date ____________

Figure 2-1 Recording sheet



BR, BB, H = A successful shot after hitting the backrim and backboard



FR, M = An unsuccessful shot after hitting the front rim

Figure 2-2 Schematic diagramming of ball movement patterns

According to pattern of ball movement at the basket, free throws were then grouped into 5 categories or types of shots, namely: 1) clean swish, 2) long success, 3) short success, 4) long miss, 5) short miss. To determine whether a shot was short or long, the first hit of the ball was used. For example, a successful shot that hit on the backboard or back half of the rim first was considered a long success, whereas a ball that hit on the front half of the rim was considered a short success. These categories expanded the dichotic difference between successful and unsuccessful shots and described more specifically how a free throw was either missed or made. Descriptive statistics were then utilised to provide meaningful information regarding the patterns identified.

In wheelchair basketball competition, standard tournament statistics can provide information concerning not only individual player free throw shooting accuracy, but shooting percentage of each classification group as well. An in-depth examination of game statistics, therefore, was used to identify the contribution of successful free throw shooting to overall team success and to identify any differences in free throw shooting percentages between classes. Analysis of tournament statistics involved computation of several measures including the following: final game points, percentage of team points accounted for by free throws, percentage of individual points accounted for by free throws, team free throw shooting percentage, and individual free throw shooting percentage. In addition, sets in which an individual player made two successive free throw attempts were also examined.

RESULTS

The in-depth examination of the free throw statistics revealed several important trends, which illustrated the significance of the free throw in the success of a basketball team. The Gold Cup tournament consisted of 42 games, during which time 1576 free throws were attempted. Of the numerous free throws that were attempted, only 53% of them were successful. Overall, successful free throw shooting percentages were quite low: average individual player free throw percentage was only 47%, team free throw percentages ranged from 36-59%, and class free throw percentages ranged from 49-54%. The percentage of successful shots by class is shown in Figure 2-3. Of those players who attempted at least 20 free throws, the top ten had free throw percentages ranging from 58-78%. Free throw shooting percentage for the top ten overall scorers of the tournament ranged from 40-77%.

Of the 42 games played, almost one quarter (23.8%) were lost by five or less points. In each of these games a perfect free throw record by the losing team would have made them winners. On average, 17% of the total team score during a game was scored by free throws; this percentage extended as high as 47%.

The importance of all players being skillful in shooting free throws was demonstrated by the fact that of 143 players on 12 teams, 116 (81%) took at least one free throw during the tournament. On average, five players per team shot free throws each game.

Over half (56%) of all the free throw shots during the tournament were taken by Class 4 players for a total of 885. Players in Class 1 (greatest degree of disability) took the fewest number of attempts (122). A similar number of shots were taken by the two

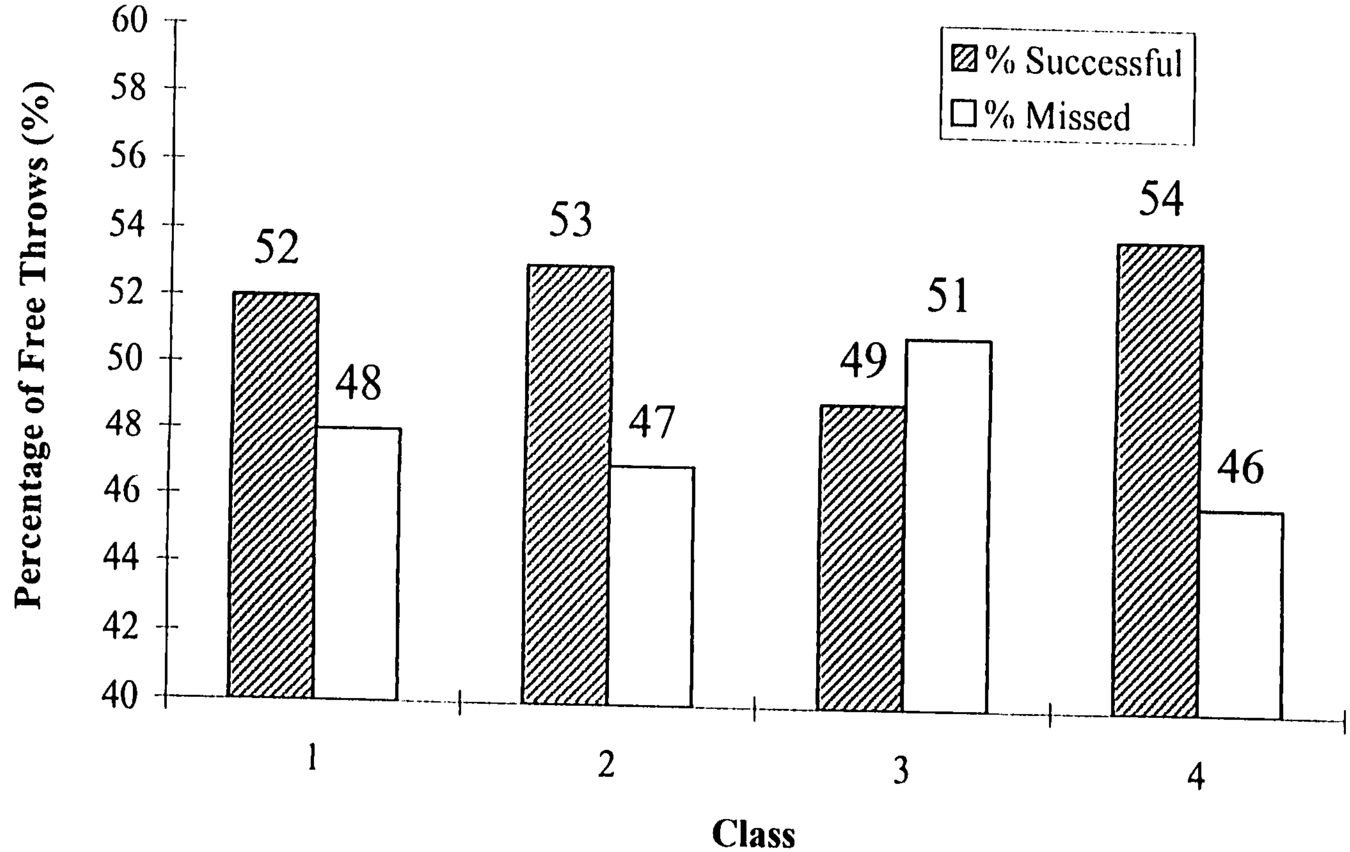


Figure 2-3 Free throw outcome by class

middle classes; Class 2 - 295 shots and Class 3 - 274 shots. These results are consistent with what would be expected relative to player class and position on the court. Typically, Class 1 players are used for picking and screening roles, thereby tending to stay outside the key. The Class 4 players, on the other hand, who are typically the taller players, are those going into the key for shots and rebounds. In this role, the Class 4 players are more likely to be fouled and therefore will take more free throws.

A review of the schematic diagrams disclosed some important information. In looking at the unsuccessful shots, it was found that 67% were thrown short. Of the successful shots, it was found that 47% were clean swishes, while 24% were initially short and 29% were initially long (see Figure 2-4).

Similarities in ball movement patterns were found between the four classification groups (see Table 2-1). In Classes 1, 3 and 4, the greatest number of shots were short misses. Whereas, the least number of shots were found to be short successes for Classes 1, 2, and 4. Players in all classes had a greater number of clean swishes than long or short successes.

In looking at sets of 2 successive free throw attempts made by individual players (273 sets examined), a greater number of first shots were made (205) than missed (68). Of the second shots, 156 were missed and 117 were made. Of the sets with a successful first shot, 129 of the second shots were missed and 76 were made. Of the sets with a missed first shot, 27 of the second shots were missed and 41 were made. Of the sets containing two successful shots, only 21 (< 8%) were clean swishes both times. Success after a first shot miss did not depend on whether it had been a long or short miss. If the first shot was a long miss (21), 62% of the second shots were made while 38% were missed. In the case

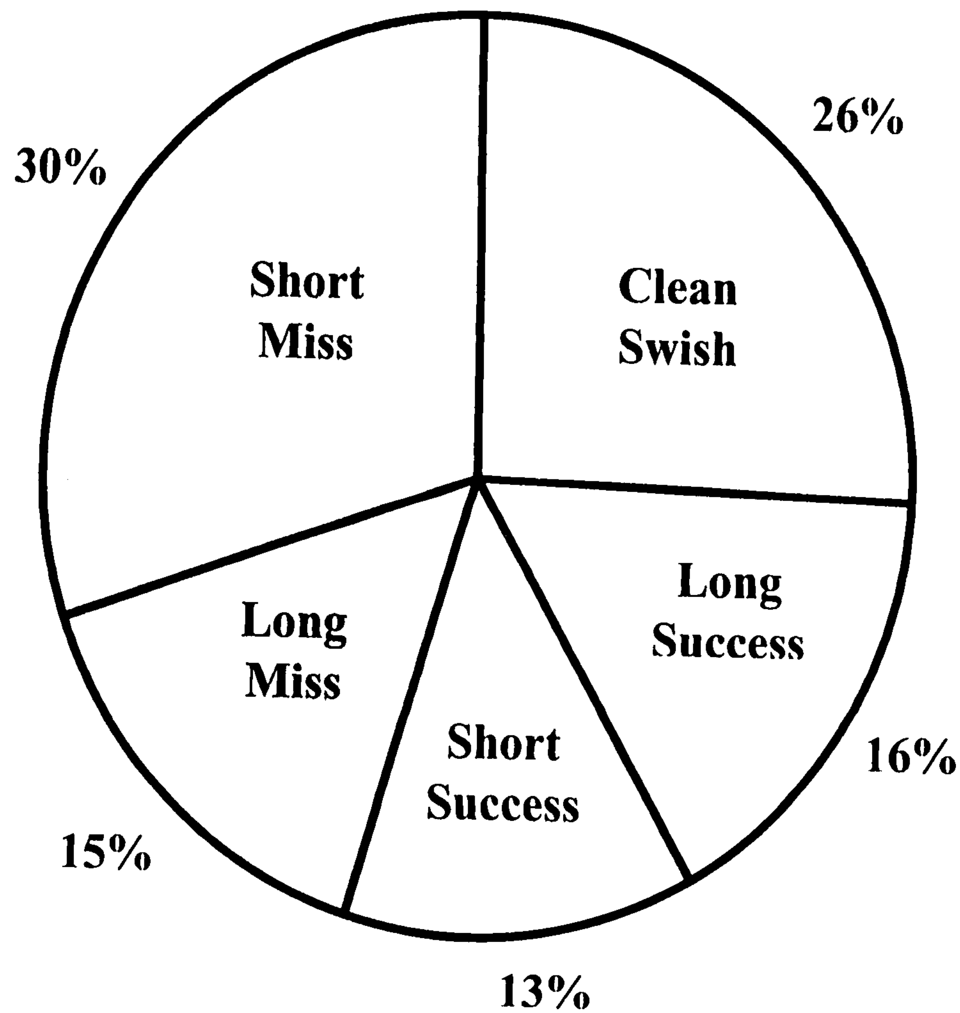


Figure 2-4 Classification of free throws (% of total attempted)

where the first shot was a short miss (47), 60% of the second shots were made while 40% were missed. If the first shot was a long success (61), 26 of the second shots were made and 35 missed, and of those missed 27 were missed short. If the first shot was a short success, 29 of the second shots were made and 13 were missed.

Table 2-1

Shot Patterns by Class

Type of Shot	All classes	Class 1	Class 2	Class 3	Class 4
Long miss	111	7	22	18	64
Short miss	222	25	28	39	130
Clean swish	190	11	31	32	116
Long success	119	10	27	12	70
Short success	95	7	17	18	53
Total	737	60	125	119	433

DISCUSSION

As witnessed, free throw shooting percentages were low among these elite wheelchair basketball players. Although just over half of the free throws attempted during the tournament were successful, individual shooting records showed a need for greater attention, as most players shot below the 50% mark. The low success rate of free throw shooting suggests that specific coaching and training techniques are needed. The information gained from the data collected in this study provides direction for such interventions. As seen, short shots comprised the most prominent free throw error. The large number of short shots may have been expected when considering the lack of available force from the lower limbs and the lowered position of players in their wheelchairs as compared to stand-up players. The results, which revealed the frequency with which free throws were thrown short, indicate the need for proper technique training combined with improved physical conditioning to maximise the strength of the upper limbs.

Considering the properties of projectile motion, it is also crucial that the wheelchair basketball player develop consistency and accuracy in his/her shot. This is especially important for the players who tend to sit lower. As indicated by Brancazio (1981), as release height of the ball is decreased, the necessary force and projection speed increase and the margins for error decrease. Therefore, given equal ability in free throw shooting, a shorter player is at a disadvantage compared to a taller player because of a decreased margin for error. This smaller margin for error helps explain to some degree why shooting percentages of wheelchair basketball players (shorter players) tend to be less than those of similar calibre stand-up players (taller players).

When considering the flight of the ball as a projectile, the low release heights used by the players and the large number of short shots indicate that either the angle or speed of projection must be increased. The low release heights used by the players result in a smaller margin for error compared to a ball released from a stand-up height with the same velocity and angle at release. For a certain release height, there will be a range of projection angle and velocity combinations that will allow the ball to go into the basket. For any increase in projection angle, the velocity must increase at a greater rate. To make the ball travel through the centre of the basket, with a given velocity, the seriousness of a one degree error in the projection angle increases as the angle increases (Mortimer, 1951).

The fact that there were more long successes than short successes is in agreement with suggestions by Hay (1993). When considering a shot that hits the rim or backboard first, Hay (1993) proposed that the three most important factors in determining the outcome are as follows: 1) where that ball contacts the rim or backboard, 2) velocity when it hits, and 3) amount of spin on the ball. In general, he suggested that a ball which hits near the back, has a relatively low speed at contact, and has some backspin would tend to favour rebound into the hoop. The results of several other studies also indicate that balls shot long, hitting the backboard with backspin, are more likely to be successful (Brancazio, 1981; Hamilton & Reinschmidt, 1997; Shibukawa, 1975).

RECOMMENDATIONS

Individual player shooting profiles may not necessarily reflect the generalised shooting trends found in this study. For instance, the objectives of a particular player may not be a clean swish, but rather a shot off the backboard. The diagram recording method, therefore, should be used to determine the actual coaching intervention appropriate for a given individual and should be consistent with the shot objectives of that player. As such, the instrument developed for this study can be used to build individual practice profiles, which systematically address particular problem trends a player may have in shooting.

To provide more detailed feedback for the players, the diagram recording method should be adapted as such to allow for assessment of lateral shot accuracy. To obtain this information, an observation perspective perpendicular to the free throw line would be required. For example, a player with a chronic tendency to shoot to the right could receive specific coaching to address this problem and could be monitored with the use of the same observational instrument. The combined assessment of all dimensions of accuracy would provide a powerful tool for effective intervention and skill development for a closed skill such as free throw shooting.

This study has investigated shooting outcomes and error trends in free throw shooting. Further study on the movement patterns most responsible for these observed outcome characteristics is warranted and will be the focus of the subsequent study.

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CHAPTER 3

Player Shooting Style as Defined by Patterns of Segment Coordination and the Relationship to Player Classification

Sport skills can be classified under four general movement patterns including underarm, sidearm, overarm and kicking (Kreighbaum & Barthels, 1996). Each pattern group will contain skills, which use a series of anatomical movements with similar spatial configurations. The basketball free throw shot, like the shot put and tennis serve, are classified as using an overarm pattern. Although these three skills involve similar movement patterns, differences can be seen in the timing and spatial characteristics of individual segment motions. Similarly, when comparing performance of the same skill under two different conditions, for example stand-up and wheelchair basketball free throw shooting, differences might be seen in the timing and spatial characteristics of segmental motion due to the different constraints under which the skill is being performed. For instance, the increased projection distance and the reduced functional ability of the players (dependent on the level of disability) in wheelchair basketball may require different patterns of segment motion as compared to stand-up basketball.

The group of segments involved in an activity can be modelled as either a closed- or open-link system (Kreighbaum & Barthels, 1996; Putnam, 1993). A closed-link system is one in which the distal segment meets with considerable resistance and is unable to move freely (e.g., arms: pushup, legs: vertical jump). An open-linked system, on the other hand, is composed of rigid segments in which the distal end moves freely through space (e.g., arms: basketball shot, legs: football punt). To achieve effective movement within an open-linked system, the combination of several individual segment movements is required in a coordinated or well-timed motion (Kreighbaum & Barthels, 1996).

According to Hudson (1986), coordination in an activity is based on the timing and sequencing of segment motion. Based on adjacent segment interactions and resulting movement patterns, skills can then be grouped according to similar coordination patterns. Two patterns clearly identified in activities and defined by Kreighbaum and Barthels (1996) include the "throwlike" and "pushlike" patterns. Throwlike patterns are characterised by movements occurring with a sequential fashion of segmental rotation (e.g., throwing a baseball) whereas those whose segmental rotations occur simultaneously are called pushlike (e.g., bench press).

As outlined by Putnam (1993), the sequencing of segmental rotations can be determined by the timing of peak segment or joint angular velocities (Putnam, 1993). Simultaneous motion is characterised by peak angular velocities occurring at the same time whereas sequential motion is that in which the peak angular velocities occur over time in a proximal to distal fashion.

Another method used to assess the simultaneity or coordination of an activity is outlined by Hudson (1986). This method used by Hudson (1986) and Ross and Hudson (1997) in assessing vertical jump performance is based on the concept of positive segmental contribution. During a selected phase of an activity, positive contribution (PC) can be determined for each segment and is defined as the initiation of extension or flexion of the limb (depending on the activity) and ending with the reaching of maximum angular velocity. Using the PC for each segment, the percentage of shared positive contribution (SPC) is then determined. The percentage of SPC between adjacent segments is the time that both segments are contributing positively divided by the time that at least one segment is contributing positively. The higher the percentage of SPC, the more simultaneous is the movement of two adjacent segments. See Appendix C for an example calculation of the SPC between adjacent segments of the arm.

Clearly, not all open-linked activities can be classified as being entirely sequential or entirely simultaneous. Instead, most activities will be a combination of the two segmental patterns, and depending on the pattern observed, activities can be placed on a continuum ranging from simultaneous (pushlike) to sequential (throwlike) (Hudson, 1986; Kreighbaum & Barthels, 1996). Movements in which light objects are manipulated and/or in which the distal segment is open will typically involve sequential segment rotations and be placed towards one end of the continuum (Hudson, 1986). Activities in which heavy objects are moved and/or in which the distal segment is closed tend to involve simultaneous segment motion and will be placed at the other end of the continuum (Hudson, 1986).

As indicated by Hudson (1986), the velocity and accuracy requirements of a movement will also influence where on the continuum a movement will fall. The expected pattern of motion is more simultaneous when accuracy is important and would tend to be more sequential when velocity is important (Hudson, 1986; Kreighbaum & Barthels, 1996). The positioning of accuracy movements and velocity movements at opposite ends of the continuum is supported by various studies in which velocity of upper extremity movements and accuracy in hitting a target during such activities as handball (Bayios & Boudolos, 1998; Eliasz, Janiak, & Wit, 1990) and other overarm throwing motions (Atwater, 1979; Hore, 1996) have been shown to be negatively correlated. Such studies support the original speed-accuracy tradeoff principle developed by Fitts (1954) which states that movement times will be faster when the accuracy demands of a task are low as compared to situations in which greater accuracy is required. In the middle of the continuum would fall those movements, which require an optimal combination of these factors, resulting in a blend between simultaneous and sequential segmental motion.

The above descriptions of segment motion stem from the summation of speed principle developed by Bunn (as cited in Putnam, 1991). This principle states that the speed of the distal end of a linked system is maximised if movement begins with the more proximal segments and moves to the more distal segments. By summing the individual speeds of all segments involved in the sequence, speed is generated at the distal end (Putnam, 1993). This proximal to distal sequencing in the production of high end point velocities has been observed in activities such as overarm throwing (Atwater, 1979), handball (Joris, van Muyen, van Ingen Schenau, & Kemper, 1985), volleyball (Luhtanen, 1988), and water polo (Elliott & Armour, 1988). Computer simulation studies of throwing have demonstrated that highest endpoint velocity of the distal segment is achieved when the onset of joint torques occurs sequentially in a proximal to distal fashion (Herring & Chapman, 1988; Chapman & Sanderson, 1990). Successive segmental rotations, sequentially timed in a proximal to distal fashion, allow for a much higher angular velocity of the distal segment than would otherwise occur (Putnam, 1991) and will produce extremely fast linear speed at the distal end of the link-system (Kreighbaum & Barthels, 1996). Conversely, segmental rotations can occur simultaneously and are most effective for skills involving accuracy or overcoming a resistive force (Hudson, 1986; Jensen & Schultz, 1977; Kreighbaum & Barthels, 1996).

Therefore, based on the nature of segmental rotations, throwlike movements are typically used to produce high end-point velocity, whereas, pushlike movements are used to produce high accuracy and/or force.

As indicated by Kreighbaum and Barthels (1996), activities involving the pushing or throwing of an object will have one of two overall performance objectives: (1) greatest possible vertical or horizontal projection or (2) accurate projection, enhanced by projection speed. In activities involving projection of an object, depending on the goal of the activity, success will therefore depend primarily upon velocity or accuracy of projection. In basketball shooting, the overall performance objective is maximum accuracy of projection (Kreighbaum & Barthels, 1996; Miller, 1998). According to Hay (1993), the need for accuracy in basketball shooting far outweighs the need to develop high velocities at release. In the case of the set shot, large segment rotations are declined in favour of a position that allows forces to act primarily in the direction of the basket (Hay, 1993). Some have described the typical basketball shot as a smooth, sequential, coordinated pattern of arm segment movements (Shaver, 1981; Skillen, 1983). In a study of jump shot action, Elliott (1991, 1992) found sequencing of arm segment motion to follow a pattern as such: simultaneous flexion of the upper arm at the shoulder and extension of the forearm at the elbow, followed by final movement of the hand at the wrist.

Another factor that must be considered in wheelchair basketball is player classification, which is dependent on degree of disability. As pointed out by Kreighbaum and Barthels (1996), the constraints of the activity or the physical attributes of the player will determine the pattern of movement used and where on the continuum the skill will be located. In the case of wheelchair basketball, this concept applies to the physical limitations and position of each player in the chair. The degree of impairment and reduced shooting height will pose a constraint on the pattern of segment motion used and how the skill is performed.

The current classification system consists of four classes (Class 1, 2, 3 and 4) defined by the elements of trunk movement and sitting balance, with half point classes (Class 1.5, 2.5, 3.5, and 4.5) designated for borderline cases. Class 1 includes those players with the greatest degree of impairment, while Class 4 includes those with the least amount of impairment. For a more detailed description of the classes as they relate to shooting see Appendix A.

Based on the information cited above, it would therefore, be expected that the free throw would require some degree of simultaneous segmental rotation. Due to the lower release height in wheelchair basketball, however, there may be a need to develop higher velocities at release. Supporting this notion, in a comparison of stand-up and wheelchair basketball shooting, Higger (1984) found that the speed of ball release was significantly greater in wheelchair basketball players.

To compensate for a lower release height and reduced functional ability, it seems that a sequential pattern of segment motion would be most effective for wheelchair basketball players in generating the necessary velocity at ball release. However, accuracy must still be considered and, as discussed previously, a push-like or simultaneous segmental movement pattern may be more effective for greater accuracy in certain performances. Hence, the question arises as to where on the continuum of segment coordination will free throw shooting by wheelchair basketball players fall?

The purpose of this investigation, therefore, was to describe the pattern of segment motion (coordination) used in free throw shooting by wheelchair basketball players and to determine the relationship between shooting style (as defined by segment motion patterns) and player classification.

METHODS

Free throws taken at one pre-determined end of the court during the course of the 6th Men's World Wheelchair Basketball Championship were recorded using the following methods for three-dimensional video data collection.

Calibration

Prior to the first day of competition, a calibration space of 150cm x 225cm x 300cm was measured. The calibration space was sized to include the complete movement of the player during a free throw and to follow the path of the ball approximately fifteen frames after release during recording. Wood and Marshall (1986) who showed that significant inaccuracies can occur in the three-dimensional reconstruction if points of interest fall outside the calibrated space demonstrated the importance of this procedure. For purposes of data collection during the wheelchair basketball competition, instrumentation was set, secured and calibrated each day prior to the first game, with all equipment ready to operate before the first free throw was shot. At the beginning of each filming day, the field was calibrated using four plumb lines and four survey poles placed within the field of view at specified locations (See Appendix D). The control points were located so as to surround the activity space, rather than be within the field, as has been shown to produce greater reconstruction accuracy by Challis and Kerwin (1992). A total of sixteen reference points (25mm diameter) on the four plumb lines, along with an extra sixteen points on the poles for assessing data collection accuracy, were carefully set at pre-specified locations (See Appendix E) using a nylon coated steel measuring tape (graduations = 1mm) and recorded to identify the spatial position of each point. Subsequently, the plumb and pole configuration was recorded on videotape by each camera and then removed prior to competition. After the last game of each day, the plumbs and poles were once again positioned in the calibration space at the appropriate locations and recorded on videotape a second time.

Camera Set-up

Two Panasonic SVHS Reporter AG-450 video cameras were used for recording of data. Each camera video recording system was composed of 4 rotary heads and a helical scanning system, with a tape speed of 33.3 mm/s. Each camera used a 1/2-inch CCD image sensor and contained a 10:1 power zoom lens with macro function and auto iris.

The two video cameras, placed at different angles to the free throw line, were securely positioned at one end of the court to record the free throws of right handed shooters. The camera parameters were fixed as follows: shutter speed 1/500, manual focus, SVHS, indoor white balance, and standard gain on. Cameras were levelled and manually zoomed-in to fill the field of view with the calibrated space. One camera (Camera A) was set parallel to the free throw line, 16.40 metres away from the origin of the calibration field, to obtain a side view of the player. The second camera (Camera B), oriented obliquely to the front line to obtain a more frontal view of the player, was located 27.20 metres from the origin. Distance between Camera A and Camera B was 26.06 metres. The entry of the ball into the basket was not recorded on video, but a manual record was kept as to whether each shot was successful or unsuccessful. To synchronise the cameras, a manually triggered light-emitting diode (LED) was visible to each camera during filming.

Data Reduction

For the process of data reduction the Ariel Performance Analysis System (APAS) produced by Ariel Life Systems, Inc. was utilised. Experimental testing by independent parties has found this system to meet clinical standards for reliability and validity (Klein & DeHaven, 1995; Wilson, Smith, & Gibson, 1997). The first step in data reduction involved grabbing the specified video images and transferring them into a file for digitising. For each shot, the number of frames grabbed included ten frames before the player began the shooting motion until ten frames after the ball left the players hands, inclusive. To assure that the same frames were grabbed from each view, the views from each of the two cameras were time-matched using the LED as the synchronising point.

Next, specified points were digitised for conversion of the video image sequences to computer image sequences. From each grabbed file, with every other frame used to define a sequence, the following points were manually digitised: 1) metacarpophalangeal joint of the right middle finger, 2) centre of the right wrist joint, 3) right elbow (between lateral epicondyle of humerus and head of radius), 4) right shoulder (greater tubercle of the humerus), 5) right hip (greater trochanter of the femur). Connections were made between specific points to create the following segments: 1) knuckle-wrist = hand, 2) wrist-elbow = forearm, 3) elbow-shoulder = arm, 4) shoulder-hip = trunk.

Next, the digitised coordinates of each point in each frame were transformed to absolute image space coordinates. The two-dimensional digitised views from each camera, containing the x and y position coordinates of each point, were then converted into a three-dimensional image sequence using the direct linear transformation (DLT) algorithm (Abdel-Aziz & Karara, 1971) implemented on the APAS system. According to the procedures of the DLT, the known image coordinates, as well as the digitised coordinates of the control points, were used by the APAS system to solve a set of simultaneous linear equations which related one set of coordinates to the other. This set of equations, being over-determined, was solved using a linear least-squares approximation, which yielded the image space coordinates of each point, given the digitised view coordinates of that point. With this method, measurement of the internal and external parameters of the cameras (e.g., location and orientation, focal length and optic centre) was not required (Allard, Blanchi, & Aissaoui, 1995; Ladin, 1995). Instead, using a calibration procedure with a known set of control points, the relationship between the image space and each of the digitised views was directly determined. For a three-dimensional analysis, at least six non-coplanar control points are required to solve the set of simultaneous equations (Abdel-Aziz & Karara, 1971). However, using more than the minimum number of control points will allow additional unknowns to be added to the equations to account for components of lens distortion and film deformation increasing the reconstruction accuracy of the transformation (Karara & Abdel-Aziz, 1974). Shapiro (1978) suggested using 12-20 control points to increase the accuracy of the three-dimensional accuracy, similar to Chen, Armstrong and Raftopoulos (1994) who recommended 16-20 control points. Accordingly, for the purposes of the present study, a total of sixteen control points were used.

Due to the inability to exactly locate the body joint centres when digitising, small random errors or "noise" enter into the digitised data. This error has a frequency on the order of the digitised film or video frequency (typically ranging from 30 - 200 Hz), while human motion exhibits significantly lower frequencies ranging from 5 to 15 Hz or less (APAS User's Manual). Since the error term is well above the frequency found in true joint motion, it can be removed or attenuated with the use of appropriate mathematical smoothing or filtering techniques (Wood, 1982). Therefore, prior to further analysis, the three-dimensional coordinate data was smoothed using a Quintic spline algorithm with a smoothing factor of 0.5 cm to 1.0 cm. As indicated by Zernicke, Caldwell, and Roberts (1976) and McLaughlin, Dillman, and Lardner (1977), spline functions are better suited for close approximation of human movement patterns than are global polynomials or finite differences techniques.

Data Analysis

To examine segmental coordination of the shooting arm, twenty free throws from each of the four classes (10 successful, 10 unsuccessful) were analysed. Free throws were randomly selected from those subjects who had both a successful and unsuccessful attempt. Using the APAS system, the angular motion of each joint was computed as the relative motion between the two adjacent segments sharing this joint as their centre of rotation (APAS User's Manual). In describing the angle at a particular joint, the relative angle was defined as the angle between the longitudinal axes of the two segments (Hamill & Knutzen, 1995). Angular motion of each joint was computed as follows: shoulder joint - relative motion between the trunk and arm; elbow joint - relative motion between the arm and forearm; wrist joint - relative motion between the forearm and hand. Relative joint angular velocities for the shoulder, elbow and wrist were calculated using central differences as implemented in the APAS system.

Calculation of Coordination Variables

All free throws were evaluated over the force phase which was defined as beginning when the shoulder initiated flexion and ending when the ball was released from the shooting hand. The selection of variables used to describe segmental coordination during the force phase was derived from methods developed by Hudson (1986). Certain variables related to the timing and sequencing of joint motion at the shoulder, elbow and wrist were obtained from the digitised data. Specifically, the time at which the following events occurred were determined for the force production phase of each shot: 1) initiation of shoulder flexion (IFsh), 2) initiation of elbow extension (IEel), 3) initiation of wrist flexion (IFwr), 4) maximum angular velocity of the shoulder (MVsh), 5) maximum angular velocity of the elbow (MVel), 6) maximum angular velocity of the wrist (MVwr).

The following variables were then computed to define the timing and sequencing of joint motion (where IM refers to the initiation of movement) during the force phase of each free throw:

- IMshel - time between IFsh and IEel
- IMelwr - time between IEel and IFwr
- MVshel - time between MVsh and MVel
- MVelwr - time between MVel and MVwr

To determine how long each joint was positively contributing during the force phase, the following variables were computed:

- PCsh - time from IFsh to MVsh
- PCel - time from IEel to MVel
- PCwr - time from IFwr to MVwr

To assess where on the continuum of simultaneous to sequential a free throw fell, the shared positive contribution (SPC) of pairs of joints, and of all three together, was determined. The SPC values of the involved segments were expressed as a percentage of the total positive contribution phase. The percentage of SPC occurring between two adjacent joints was determined as the time that both were contributing positively divided by the time that at least one was contributing positively. The percentage of SPC occurring between three joints was the time that all were contributing positively divided by the time that at least one was contributing positively. More specifically, measures of SPC between the segments were calculated as follows:

- SPCshel (%)- positive contribution of the shoulder and elbow occurring concurrently
- SPCelwr (%) - positive contribution of the elbow and wrist occurring concurrently
- SPCall (%) - positive contribution of the shoulder, elbow, and wrist occurring concurrently
- preSPCall (%) - time from start of PC of first joint until all three contributing positively
- postSPCall (%) - time from end of PC of first joint until all three stop contributing positively

Determination of Shooting Style

Free throws were then classified according to the calculated SPC values and placed into one of four shooting style categories based on the following:

- SIM - both SPCshel and SPCelwr ≥ 50%
- SimSeq - SPCshel ≥ 50% and SPCelwr < 50%
- SeqSim - SPCshel < 50% and SPCelwr ≥ 50%
- SEQ - both SPCshel and SPCelwr < 50%

Statistical Procedures

Using *SPSS for Macintosh* Version 6.1.1, statistical tests were first run to determine if overall differences existed between the four classes and between successful and unsuccessful free throws on the coordination variables. Rather than use a MANOVA procedure, separate ANOVA tests were run on each variable. This decision was based on the fact the MANOVA uses multiple regression procedures which are most effective if the variables in the prediction are unrelated to each other (Vincent, 1995). It was felt that MANOVA, therefore, was not appropriate for this data set because several of the variables were related. Instead, each of the ANOVAs were conducted with a Bonferroni adjustment ($\alpha = .01$) as suggested by Wagoner (as cited in Vincent, 1995), followed by a Tukey HSD post hoc test where needed. Furthermore, in order to examine the magnitude of differences between the groups and meaningfulness of the findings, effect size using the eta-squared index (η^2) was calculated for each variable as recommended by several authors (Keppel, 1982; Ottenbacher, 1992; Sutlive & Ulrich, 1998; Thomas, Salazar & Landers, 1991). The following variables were included in the overall analysis: IMshel, IMelwr, MVshel, MVelwr, PCsh, PCel, PCwr, SPCshel, SPCelwr, SPCall, preSPCall, and postSPCall.

The null and alternative hypotheses were stated as follows:

- H_0: There is no difference in patterns of segmental coordination between the four classes
- H_1: H_0 is false
- H_0: There is no difference in patterns of segmental coordination between successful and unsuccessful free throws
- H_1: H_0 is false

Next, to determine the relationship between shooting style and player classification, a chi-square (χ^2) test of independence was used. This test allowed inferences to be made regarding the relationship between the two categorical variables (Polit, 1996). The null and alternative hypotheses were stated as follows:

- H_0: Shooting style and player classification are independent (not related)
- H_1: H_0 is false

The test of the null hypothesis involved a 3x4 contingency table (df = 6) with player classification specified as Class 1, Class 2, Class 3 or Class 4, and shooting style as SIM, SEQ or COMBO. The categories of shooting style previously identified as SimSeq and SeqSim were combined to form the COMBO group, in order to increase the expected cell frequencies and overall test accuracy. Minimum expected cell frequencies must not be less than one (Polit, 1996; Vincent, 1995) and are often recommended to be greater than five (Hays, 1973; Vincent, 1995). Critical region for rejection was set at $\alpha = .05$. If the calculated value of χ^2 exceeded the critical χ^2 of 12.59 the null hypothesis was rejected. Upon obtaining a significant chi-square value, Cramer's V was calculated to measure the strength of the relationship.

RESULTS

Results of the ANOVA tests revealed no significant differences between successful and unsuccessful shots, along with effect sizes (η^2) of <1% for most variables. In addition, no differences were found between the four classes except on one variable (IMshel). Although, individual group data were combined for further discussion, certain variables showed medium to large effect sizes (η^2) and are therefore presented by class in Table 3-1. Means and standard deviations of the temporal and sequential (coordination) variables for the combined classes are listed in Table 3-2.

Coordination of Segments

Initiation of movement or occurrence of maximum angular velocity at the proximal joint prior to the distal joint resulted in negative IM and MV values, respectively. In all subjects, either this proximal to distal sequencing, or occurrence of events in adjacent joints at the same time, was seen for IMshel, IMelwr and MVelwr. The values for these variables, thereby, accurately reflected both the sequencing and average timing of these variables. For MVshel, however, the sequencing was distal before proximal in eight subjects with maximum velocity of the elbow reached just prior (33ms) to that of the shoulder. Therefore, to better represent the average time between occurrence of maximum angular velocity at the shoulder and maximum angular velocity at the elbow (MVshel), the absolute value of this variable is also reported in Table 3-2.

Table 3-1

Class Data and Calculated Effect Size (η^2) for Each Coordination Variable

Variable	Class 1 (n = 20) *M*	*SD*	Class 2 (n = 20) *M*	*SD*	Class 3 (n = 20) *M*	*SD*	Class 4 (n = 20) *M*	*SD*	η^2
Imshel* (ms)	-74	35	-83	61	-134	114	-149	83	15%
IMelwr (ms)	-71	25	-74	34	-76	22	-83	31	2%
MVshel (ms)	-31	36	-21	27	-7	39	-56	92	10%
|MVshel| (ms)	31	36	21	27	26	30	63	88	9%
MVelwr (ms)	-17	23	-13	17	-25	18	-30	28	9%
PCsh (ms)	153	31	170	80	239	128	206	94	13%
PCel (ms)	111	19	109	19	112	20	114	23	1%
PCwr (ms)	56	29	48	27	61	22	61	34	4%
SPCshel (%)	46	23	49	21	44	27	31	22	8%
SPCelwr (%)	33	21	31	20	27	19	24	19	4%
SPCall (%)	10	14	12	16	11	13	7	12	2%
preSPCall (%)	35	37	29	35	43	37	24	34	4%
postSPCall (%)	5	10	4	8	6	7	4	8	3%

Note for η^2: small effect size = 1%, medium effect size = 6%, large effect size = 15% (Cohen, 1977; 1988). * Significant difference between Class 1 and Class 4 ($p < .01$).

Table 3-2

Combined Group Data for the Coordination Variables in Free Throw Shooting

Variable (n = 80)	*M*	*SD*
IMshel (ms)	-110	84
IMelwr (ms)	-76	28
MVshel (ms)	-29	57
|MVshel| (ms)	35	53
MVelwr (ms)	-21	22
PCsh (ms)	192	94
PCel (ms)	111	20
PCwr (ms)	57	28
SPCshel (%)	42	24
SPCelwr (%)	29	20
SPCall (%)	10	13
preSPCall (%)	32	36
postSPCall (%)	4	8

Movement during the force phase of free throw shooting began with shoulder flexion in most subjects, followed by initiation of extension at the elbow. In three cases initiation of shoulder flexion and elbow extension occurred at the same time, as did initiation of elbow extension and wrist flexion in one case. The average delay between the shoulder and elbow (110 ms) was longer than the average delay between the elbow and wrist (76 ms). The variability of these timing measures was quite large however with IMshel ranging from 0 - 429 ms and IMelwr ranging from 0 - 132 ms.

Time delay between maximum angular velocity of the shoulder and elbow was slightly greater than the time delay between maximum angular velocity of the elbow and wrist (29 ms and 21 ms, respectively). However, MVshel showed much greater variability than did MVelwr (range: 297 ms and 99 ms respectively).

On average, positive contribution of the shoulder occurred for the longest time period, followed by the elbow and wrist respectively (Table 3-2). The range of scores for PCsh, however, was extremely large at 495 ms.

As seen in Table 3-2, movement at the shoulder and elbow, as indicated by SPCshel, was more synchronous (42%) than that at the elbow and wrist (SPCelwr - 29%). The shared positive contribution for all three joints (SPCall) was zero in 54% of the free throws analysed. The average shared positive contribution of those shots in which SPCall was not zero (37/80) was 22%. In these non-zero shots, average preSPCall was much greater (69%) than average postSPCall (8%).

Shooting Styles

Free throws were then categorised based on SPC values as previously defined. Results of the chi-square test indicated that class and shooting pattern were not related.

The distribution of shooting style by class is shown in Table 3-3. In half the shots (40/80) the SEQ pattern was used, whereas, only eight shots followed the SIM pattern. The SeqSim pattern was seen in only seven shots demonstrating a movement of shoulder flexion followed by a simultaneous push at the elbow and wrist. The SimSeq pattern, which showed a push with the shoulder and elbow followed by a flick of the wrist, was seen in 31% (25/80) of the shots.

Table 3-3

Distribution of Shooting Style by Class

Class	SIM	SimSeq	SeqSim	SEQ
1	1	9	4	6
2	3	7	1	9
3	2	5	1	12
4	2	4	1	13
Total	8	25	7	40

DISCUSSION

So where on the continuum of simultaneous to sequential does the wheelchair basketball free throw fall? In assessing the coordination characteristics of segmental motion identified in this study, it was found that for the skill of free throw shooting, players used a combination of segmental movement patterns which tended to fall closer to the sequential end of the continuum. In looking at the timing and sequencing of shoulder, elbow, and wrist joint motion it was found that initiation of movement most often occurred in a proximal to distal sequence and that the shared positive contribution of these three joints was on average only 10%. Of the total shots, 54% actually showed no shared positive contribution between the three joints. More often, two joints would act together, either preceded or followed by contribution of the third. In no cases was a shot performed with completely sequential segmental rotations as defined by the summation of speed principle (Putnam, 1991). There was always some overlap between one of the pairs of segments (shoulder & elbow or elbow & wrist) in the timing and/or sequencing variables. The patterns of coordination observed, therefore, indicate that the free throw was performed with a combination of sequential and simultaneous rotations, falling somewhere in between the two extremes of the continuum. According to the method of describing segmental rotation patterns used by Kreighbaum and Barthels (1996), the free throw as performed by wheelchair basketball players would be considered as using a blend of throw and pushlike patterns.

As previously noted, the overall performance objective and the constraints of the player and/or environment determine the type of segmental pattern used for a skill (Kreighbaum & Barthels, 1996). Furthermore, success in a skill involving the projection of an object, will depend primarily on velocity or accuracy of projection (Kreighbaum & Barthels, 1996). Clearly, accuracy is an important component in successful free throw shooting. However, in the case of wheelchair basketball, consideration must also be given to the fact that players are constrained to a shooting position from the wheelchair that is

2-6 feet lower than that of stand-up players (Owen, 1982), and as a result use greater projection velocities (Higger, 1984).

Taking these factors into account it makes sense that the free throw fell in between the two extremes of the continuum, as segmental patterns for accuracy skills and velocity skills typically fall at opposite ends of the continuum. In the wheelchair basketball free throw, which requires both accuracy and velocity, players used a technique which optimised coordination of the segments with a pattern that combined both simultaneous and sequential movement.

As indicated by Kreighbaum and Barthels (1996), the physical attributes of a player will also have an effect on the choice of pattern used. Although no statistically significant differences were found between the groups, certain trends in the data were seen that may be attributed to the physical differences between the players in each of the classes. For instance, in reviewing the classification of shots broken down by group, it was seen that in Class 4 players (those with the greatest functional ability), the SEQ pattern of coordination was used more than twice as much as in Class 1. In Classes 3 and 4 over 50% of the shots were classified as SEQ. Class 1 had the greatest number of Combo shots, more than twice as much as both Classes 3 and 4. In attempting to understand these differences between the classes, the physical differences between the players must be considered. As defined in the *1996 Atlanta Paralympic Games General and Functional Classification Guide* (1995), players in Classes 1 and 2 will have loss of stability in the trunk, affecting elevation of the arm and follow-through during shooting. Both groups are unable to move their trunks toward the basket when shooting for effective follow-through. Players in Classes 3 and 4, on the other hand, have excellent stability of the trunk and are able to move forward in the sagittal plane during shooting. This ability to move more freely while shooting, may generate sequencing of movements in a more sequential fashion by players in the upper classes. This notion is supported by the data presented in Table 3-1, in which several variables including PCsh, IMshel, MVshel and MVelwr showed a medium to large effect size. In comparing Class 1 and Class 4, a pattern of coordination was used by the upper classes in which the shoulder contributed positively for a longer time period, and in which a greater time delay was observed between initiation of movement of the shoulder and elbow and occurrence of maximum angular velocity between the shoulder and elbow and elbow and wrist. These values suggest that the Class 4 players used a more sequential pattern of motion as compared to the Class 1 players. Players in the lower classes, on the other hand, may use a technique which coordinates their movements in such a manner which reduces the chance of losing stability, thereby enhancing consistency and accuracy in their shot, by constraining the limbs to act more as a single unit.

In looking at the overall results, it must be noted that large variances were seen in many of the variables. The amount of variability observed may be attributed to the wide range in levels of functional ability between the players. Due to the numerous and complex aspects of disability, the specific limitations observed will vary from individual to individual. As such, there is a potential problem with the use of aggregate data in disability sport research, where heterogeneity of subjects is most often the case. Although the purpose of this study was to examine performance of the four player classes using aggregated measures, the results could be further expanded using a single-subject design analysis in those cases where an individualised coaching program is planned or needed for a specific player. In this manner, technique intervention by the coach could be made specific to the individual player's needs.

Lastly, the question arises as to how player shooting style in successful free throw shooting translates into those factors which ultimately determine the projectile path of the ball, namely; velocity of ball at release, angle of projection, and height of release. This question is addressed in the subsequent chapter.

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CHAPTER 4

Shooting Mechanics Related to Player Classification and Success in the Free Throw

Although a relatively constant success rate of 69% in free throw shooting has been observed in men's college basketball in the USA since the 1970's, Krause and Hayes (1994) believe that free throw shooting percentages can be improved with increased practice and development of proper technique. In comparison, Owen (1982) indicates a success rate of only 45-55% from the free throw line, and as confirmed by data collected during the Gold Cup Tournament and as outlined in Chapter 2, the skill of free throw shooting in wheelchair basketball can be described as "poor". Can these shooting percentages in wheelchair basketball be improved? Although there are obvious disadvantages to shooting a basketball from a seated position as compared to standing up, it does not seem likely that the difference in success rates can be attributed solely to differences in the required shooting mechanics (Owen, 1982). Individual players in wheelchair basketball have demonstrated consistent shooting averages beyond 70% (Owen, 1982), so what is it that they do to achieve such success?

As described by Elliott (1991), an understanding and application of movement mechanics is necessary if an athlete's potential is to be fully developed. According to several authors (Burns, 1990; Sanchez, 1982), skilled shooters are not "born", but instead can be developed with proper training using a scientific approach (Brancazio, 1984). Hudson (1985) and Burns (i990) highlight the importance of developing good shooting technique, and as noted by Ingram and Snowden (1989, p. 79), "the free-throw line is an excellent place to analyse a player's shooting mechanics". Furthermore, the free throw is an unopposed shot and can be easily replicated in practice for development of proper technique. As pointed out by Elliott (1991), only when "good technique" is used in training practices and game matches can a player reach his or her full potential. According to Owen (1982), one reason why wheelchair basketball free throw percentages are so low is that most players never learned the proper technique. Consequently, the identification of key components related to success in free throw shooting is necessary for proper training and technique development in wheelchair basketball players.

FACTORS AFFECTING PERFORMANCE OF THE FREE THROW

Conditions of Ball Release

At release, the ball becomes a projectile, and is therefore subject to the laws of projectile motion. The factors that determine the path of a projectile include height, angle and speed at release. Although air resistance during flight is a factor in projectile motion, it is typically regarded as having little effect in basketball shooting due to the relatively low speed of the ball (Hay, 1993).

For the greatest chance of a basketball passing cleanly through the hoop, it would have to approach the basket from directly above (Kreighbaum & Barthels, 1996; Miller & Bartlett, 1996). This angle of entry (90°), although not possible from a practical standpoint (Hay 1993), would allow for the greatest margin of error on all sides. A common coaching suggestion is that a ball should be shot with a large angle of projection so that the ball is "dropping" when it reaches the basket (Bunn, 1964; Rush & Mifflin, 1976). The more vertically the ball approaches the basket, the greater chance it has of being a clean swish (no contact with the rim or backboard). As the angle of entry decreases, the margin for error decreases (Brancazio, 1981; Hay, 1993). Maugh (1981) indicates that using an angle of projection that is too small, which reduces the margin for error, is the most common fault in basketball shooting. Based on the relative diameters of the ball and the basket, the smallest angle that the ball can approach the basket and still go through the hoop is 32°42' (Hay, 1993). As noted by Miller and Bartlett (1996), the angle at which the ball enters the basket is positively related to the projection angle at release. Although a high angle of entry, and therefore angle of projection, is desirable, errors in the angle of projection become more serious in their effect on the distance of the shot as the projection angle increases (Mortimer, 1951). For example, as the projection angle for a 4.57 m shot (release height 2.13 m) increases from 45° to 50°, the error due to a +1° error in the projection angle increases from -3.6 cm to -6.4 cm (Hay, 1993, p. 232). This indicates that with a one-degree error in projection angle, the horizontal distance of the 50° shot versus the 45° shot is decreased by 6.4 cm compared to 3.6 cm, respectively. The values of -3.6 cm and -6.4 cm indicate the distance from the centre of the basket that the ball falls short. Under the specified conditions for this particular shot, the -6.4 cm error is outside the margin for error and therefore results in a shot that is missed short. In other words, greater accuracy is demanded of a player when shooting with a higher angle of release because there is less room for error in performing the projection.

In a discussion of the factors related to outcome of a basketball shot, Hay (1993), suggests a projection angle between 49° and 55° for a shot taken from a distance of 4.57m (free throw line) at a release height of 2.13 m. For a large margin for error in angle, Brancazio (1981) recommends a projection angle between 49.2 ± 3.4°, where 49.2°

is the minimum speed angle. In an analysis of jump shooting kinematics and playing position, Miller and Bartlett (1996) found that release angle for a jump shot from a free throw distance was on average 52° for guards and forwards, and 54° for centres. Additional quantitative suggestions include a projection angle corresponding to an angle of entry of 45° (Mullaney, 1957), and an angle 2-3 degrees above the minimum angle which results in a successful shot (Mortimer, 1951). Qualitatively based recommendations for angle of projection in stand-up basketball have included the use of a high arch for greater chance of success (Alexander, 1988), a medium arch (Cooper & Siedentop, 1969; Wooden, 1966), and an angle between 35° and 45° (Sharman, 1965).

With regard to wheelchair basketball, Owen (1982) suggests a minimum projection angle of 45°. In comparing wheelchair basketball players and stand-up players, Higger (1984) found that wheelchair basketball players used a significantly greater angle of projection and had a significantly faster speed of release (56°, 7.2 m/s and 52°, 6.5 m/s, respectively). The angle of entry of balls projected by wheelchair basketball players was found by Higger to be slightly greater than stand-up players (46° and 43°, respectively).

The higher the angle of projection, the greater is the required projection velocity (Brancazio, 1981; Hay, 1993). As found by Hudson (1974), one of the best predictors for determining the success of a free throw is the velocity of ball projection. For any given shooting distance, there is an angle of release for which the required release speed is a minimum (Brancazio, 1981). After experimenting with different combinations of release angles and velocities (with a given release height), Mortimer (1951) determined that to achieve the most efficient shot a player should use the lowest possible projection velocity (for the given release parameters) with an angle of release about two degrees more than the minimum projection angle.

According to Maugh (1981), the chances of scoring are increased as the height of release is increased. Several authors (Brancazio, 1981; Cooper & Siedentop, 1975; Mortimer, 1951) have demonstrated that a ball released at a higher point requires a smaller projection angle, and less velocity for accuracy (Mortimer, 1951), than a shot released from a lower point. As noted by Kreighbaum and Barthels (1996), the closer the release height is to the height of the basket, the smaller the required angle and velocity of ball projection. According to Cousy and Power (1970), the range of a shot is decreased with a higher release point, thereby making it more accurate. Schaafsma (1971) and Wooden (1980) both advocate the use of a high point of release when describing the performance of skilled players, and suggest the use of a high release point to increase the margin for error. Hudson (1982a, 1985) compared three groups of women basketball players with different skill levels and found that the most skilled players released the ball 27 cm higher than the lowest skilled group and that the height ratio of the shooter (ratio of shooter's standing height to height of release) was one of the best predictors of free throw shooting success.

The physical characteristics of the performer (Martin, 1981) and the position of the player's body at release (Hay, 1993) will determine at what height the ball is released during a basketball shot. McGinnis (1975) has suggested that in shooting a basketball, the angle of ball projection is more closely related to the height of the player than to the level of skill. Since wheelchair basketball players shoot from two to six feet lower than stand-up players, a higher arch (greater projection angle) is required for success (Owen, 1982).

Suggestions for increasing release height of the ball in basketball shooting have included more flexion at the shoulder (Rush & Mifflin, 1976) and greater extension at the elbow (Mullaney, 1957). Similarly, successful jump shooters were found to use greater elbow range of motion and shoulder flexion at release, resulting in a greater angle of projection (Yates & Holt, 1982).

Joint Kinematics

Joint displacements and velocities at the time of release will determine the release parameters of the ball (Elliott, 1992) and subsequent trajectory and outcome. Movements of the upper extremity will largely determine the velocity of the ball (Elliott, 1991), and as pointed out by Miller and Bartlett (1996), the angular velocities of the shooting arm at the moment of release will, to a large extent, determine the release speed. With lack of lower limb involvement in force production during free throw shooting by wheelchair basketball players, of great importance will be the position and velocity of the shooting arm at release.

Literature regarding the action of the wrist in shooting is mostly qualitative in nature. A cocked wrist is typically recommended in both stand-up (Burns, 1990; Koryagin, 1975; Palladino, 1980; Sharman, 1965; Shaver, 1981; Smith, 1994) and wheelchair basketball (Hedrick, Byrnes & Shaver, 1989; Owen, 1982; Shaver, 1981) followed by forward motion as if to "wave good-bye to the ball" (Palladino, 1980). It is agreed upon by most (Burns, 1990; Cooper & Siedentop, 1975; Palladino, 1980; Sanchez, 1982; Sharman, 1965; Wooden, 1980), that the final motion in shooting should be a quick snap of the wrist. Wrist action is important in both the generation of force and guidance of the ball at release (Martin, 1981; Sharman, 1965). With a forward flexion and snap of the wrist, additional force is developed (Hartley & Fulton, 1971). Martin (1981) states, that for a basketball shot to be successful, the force resulting from wrist flexion must be compatible with the angle of projection and distance from the basket. Using a stepwise multiple linear regression analysis to predict shooting accuracy from selected biomechanical variables, Hudson (1974) found that velocity of wrist flexion just prior to release was one of the best predictors.

In an analysis of the basketball jump shot, Yates and Holt (1982) found that start angle of the elbow accounted for a significant portion of the variance in shooting accuracy. When compared to performers with low shooting percentages, the more successful shooters demonstrated a much smaller start angle (greater flexion) at the elbow. Elliott (1991, 1992) found mean elbow angle at release to be 153° in high performance Australian basketball players performing the jump shot and determined that a large range of motion at the elbow is important for generating the necessary velocity at ball release. Miller and Bartlett (1993), looking at the effect of increased shooting distance on the basketball jump shot, found that elbow extension angular velocity increases as shooting distance increases. The authors attributed this finding to a requirement for increased impulse needed for the ball to reach the basket with increased shooting distance. A similar finding might be expected in the shooting technique of wheelchair basketball players as a result of the increased distance to the basket due to the sitting position in the wheelchair.

Coaching suggestions outlined by Mullaney (1957) include maximum arm extension as part of proper free throw technique. In a discussion of women's basketball, Alexander (1988) suggested that the more fully the shooting arm is extended at ball release, the greater the chance for success. As the ball is released, Sharman (1965) suggested that the arm should be fully extended. In an analysis of the basketball jump shot, Yates and Holt (1982) found that shoulder angle at release accounted for a significant portion of the variance in shooting accuracy. Players with a high shooting percentage utilised a greater shoulder angle at release. In another study of jump shooters, Elliott (1991, 1992) reported mean shoulder flexion angle at release (angle formed between the trunk and upper arm) to be 146° for male shooters and 143° for female players. No significant differences were identified at release in joint displacement of the shoulder, elbow or wrist with increasing distance from the basket.

The Clean Swish

A "truly" successful free throw can be defined as one in which the ball passes cleanly through the hoop without touching the rim or backboard. Contact with the hoop or backboard would indicate that some form of error in release parameters had occurred (Miller & Bartlett, 1993). As noted by Hudson (1982b, p. 343), the "simple designation of a shot by success or failure obscures the fact that some failures are very close to being successes and some successes can result from inaccurate shots which take lucky bounces." In an investigation by Satern (1986) looking at the effect of ball size and basket height on the free throw mechanics of seventh grade boys, a system was used to code free throw attempts (Pangman, 1982 as cited by Satern, 1986) that identified successful shots as those which did not touch the backboard. When the ball contacts the hoop or backboard, any number of occurrences is possible, making it virtually impossible to predict the sequence of events leading to a particular outcome. As stated by Haase (1996, p. 21), the result of a ball bouncing off the rim "is as random as a coin toss". Based on the premise that only those shots which do not touch either the hoop or backboard are taken with appropriate release parameters for success, Miller and Bartlett (1996) used only clean swishes in their analysis of the relationship between basketball shooting kinematics, playing position and distance from the basket. Moreover, the outcome of any shot that hits the rim or backboard will be affected by the coefficient of restitution of the basketball (Hamilton & Reinschmidt, 1997), in addition to ball spin and point of contact. The coefficient may vary between balls, which make subsequent bounces after contact very hard to predict. As suggested by Hamilton and Reinschmidt (1997), the clean swish is the best shot for players to master because this is the only shot that is not affected by the coefficient of restitution of the ball. Hence, the free throw swish can be considered the gold standard shot, not only in terms of successful scoring, but also as the best example of an accurate shot.

Stand-up vs. Wheelchair Basketball

Although several characteristics of free throw shooting performance by stand-up basketball players have been discussed in the literature, little attention has been paid to wheelchair basketball. According to Skillen (1983), the fundamental skills of shooting, passing, and dribbling are basically the same in both stand-up and wheelchair basketball. It must be noted however that skill, although a result of practice, is influenced by the physical attributes and ability of a player (Thomas, 1994). With wheelchair basketball players being positioned lower and the generation of propulsive forces coming mainly from the arms and upper body, it seems reasonable to expect that some degree of skill modification would be necessary.

The wide range and complex nature of disabilities would suggest that individual modifications made to fundamental skills by wheelchair basketball players are dependent on the degree of disability. The IWBF utilises a player classification system to reflect the degree of functional ability. The capacity to perform various fundamental basketball skills such as wheeling, catching, passing, dribbling and shooting is thereby related to the player's classification level.

Upon consideration of the criteria used for player classification (Appendix A), it becomes apparent that relying on information from stand-up basketball is not an effective method for developing the skill of successful free throw shooting in wheelchair basketball players, players who are performing under these very different conditions and limitations. The technique of free throw shooting by wheelchair basketball players in each of the individual classes must be investigated if performance is to be optimised.

To date, little if any quantitative research has been completed with respect to the mechanics of wheelchair basketball. Instead, the available literature tends to be qualitative in nature, based on coaches opinions and subjective analyses. Three-dimensional cinematography, useful in the investigation of movement mechanics, has not been employed in the analysis of wheelchair basketball free throw shooting. If the shooting potential of wheelchair basketball players is to be developed, it is essential that an understanding of the mechanics of the movement be acquired. In addition, a further distinction must be made, one that identifies the differences in mechanics of movement demonstrated by each of the player classification groups.

In an attempt to determine what factors are associated with successful free throw shooting in wheelchair basketball, an analysis of clean swishes taken at the 6th Men's Gold Cup World Wheelchair Basketball Championship was undertaken. The relationship between player classification and shooting mechanics was investigated, with the objective of addressing the following question: Is there a difference between the classes in the shooting mechanics (ball parameters, joint kinematics) important for success in free throw shooting?

Based on the above question, the purpose of this investigation was: 1) To identify the relationship between ball release parameters (height, angle and velocity of projection) and player classification, and 2) To determine the shooting technique used to achieve the release parameters required for successful shooting within each class, focusing on angular displacements and velocities of the major joints involved (shoulder, elbow, wrist).

METHODS

Free throws taken at one pre-determined end of the court during the course of the 6th Men's Gold Cup World Wheelchair Basketball Championship were recorded using methods for three-dimensional video data collection and reduction as outlined in Chapter 3. The centre of the ball was included as an additional point during digitising.

Determination of Clean Swishes

At the same time that free throws were being recorded on video, the same shots were visually observed from a point parallel to the free throw line. Schematic diagrams (see Figure 2-1) depicting ball movement patterns at the basket were recorded for 737 free throws as outlined in Chapter 2.

Data Analysis

Clean swishes with acceptable video data (i.e., both camera views clear) were then compiled for kinematic analysis. Although numerous clean swishes were visually observed as discussed in Chapter 2, a large number of video recordings could not be used for three-dimensional analysis due to camera obstruction by the coach and/or referee, or cases in which a camera was not operating correctly. The total number of clean swishes identified in each class and further analysed was as follows: Class 1 (n = 7), Class 2 (n = 16), Class 3 (n = 18), Class 4 (n = 26).

To examine shooting mechanics and trajectory of the ball, the identified free throws were analysed using the APAS system. Three-dimensional joint angular displacements and velocities of the shoulder, elbow and wrist were calculated using a relative reference system. The angular motion of each joint was computed as the relative motion between the two adjacent segments sharing this joint as their centre of rotation (APAS User's Manual). In describing the angle at a particular joint, the relative angle was defined as the angle between the longitudinal axes of the two segments (Hamill & Knutzen, 1995). Angular motion of each joint was computed as follows: 1) shoulder joint - relative motion between the trunk and arm; 2) elbow joint - relative motion between the arm and forearm; 3) wrist joint - relative motion between the forearm and hand.

Release parameters of the ball were calculated using the three-dimensional displacement data of the centre of the ball. Time of ball release was defined as the first frame in which the ball was no longer in contact with the hand. Release height was measured as the vertical distance from the ground to the centre of the ball. Velocity of release was measured as the resultant of the three velocity vector components. Angle of ball projection was calculated using the following formula:

$$\theta_p = \text{Arctan}[(Y_{aft} - Y_{rel})/(X_{aft} - X_{rel})]$$

Where: θ_p = angle of projection

X_{rel} and Y_{rel} = x and y coordinates of the centre of the ball in frame of release, respectively

X_{aft} and Y_{aft} = x and y coordinates of the centre of the ball in the frame after release, respectively

To further describe the trajectory of the basketball, additional variables were calculated for each free throw, including the following: angle of entry, margin for error, minimum projection angle, and minimum-speed angle.

Angle of entry was calculated using the following formula (Brancazio, 1981):

$$\tan\theta_e = \tan\theta_p - 2h/L$$

Where: θ_e = angle of entry

θ_p = angle of projection

h = vertical distance between rim of basket and point of release

L = horizontal distance from point of release to centre of basket

Margin for error was calculated using the following formula (Hay, 1993):

$$E_m = \pm (r_h \sin\theta_e - r_b)$$

Where: E_m = margin for error

θ_e = angle of entry

r_h = radius of hoop

r_b = radius of basketball

Minimum projection angle was calculated using the following formula (Brancazio, 1981):

$$\tan\theta_{mp} = \tan 32° + 2h/L$$

Where: θ_{mp} = minimum projection angle

h = vertical distance between rim of basket and point of release

L = horizontal distance from point of release to centre of basket

Minimum-speed angle was calculated using the following formula (Brancazio, 1981):

$$\tan\theta_{ms} = h/L + (1 + h^2/L^2)^{1/2}$$

Where: θ_{ms} = minimum-speed angle

h = vertical distance between rim of basket and point of release

L = horizontal distance from point of release to centre of basket

Statistical Procedures

Using *SPSS for Macintosh* version 6.1.1, statistical tests were run to determine if differences existed between the four classes on the ball trajectory and joint kinematic variables. One-way analysis of variance (ANOVA) tests were conducted followed by Tukey HSD post hoc tests where needed. Although ANOVA is considered a robust test (Vincent, 1995), violation of *F* test assumptions, specifically homogeneity of variance, was a concern due to the unequal group sizes. However, according to Tabachnick and Fidell (1989), problems created by unequal group sizes are relatively minor in a simple one-way between subjects ANOVA. To examine this issue, a Levene Test for homogeneity of variances was conducted on the groups for each of the variables. In addition, to control for possible inflation of alpha with multiple ANOVAs, a Bonferroni adjustment ($\alpha = .01$) of the original alpha level was utilised (Wagoner as cited in Vincent, 1995). Moreover, in order to examine the magnitude of differences between the groups and meaningfulness of the findings, effect size using the eta-squared index (η^2) was calculated for each variable as recommended by several authors (Keppel, 1982; Ottenbacher, 1992; Sutlive & Ulrich, 1998; Thomas, Salazar & Landers, 1991). Tests were run using the following statistical design:

- Analysis of 67 right-handed free throws
  - 7 shots (Class 1)
  - 16 shots (Class 2)
  - 18 shots (Class 3)
  - 26 shots (Class 4)
- Independent variable
  - player classification (1 - 4)
- Dependent variables
  - height, angle and velocity of ball release
  - start angle of elbow
  - shoulder and elbow position at release
  - maximum shoulder, elbow and wrist velocity

The null and alternative hypotheses are stated as follows:

- H_0: There is no difference in clean swish shooting mechanics between the four classes
- H_1: H_0 is false

RESULTS

Ball Parameters

Results of the ANOVA tests revealed statistically significant differences between the groups on parameters of ball release and are supported by the large calculated effect sizes for each variable (see Table 4-1). Means and standard deviations of the three ball variables (height, angle, and velocity of ball release), together with the effect size for each variable, are shown in Table 4-1.

Statistically significant differences were seen in release height of the ball between the classes. The release heights of Classes 1 and 2 (162cm and 160cm, respectively) were both significantly lower than the release heights of Classes 3 and 4 (179cm and 184cm, respectively). In labelling Classes 1 and 2 as the lower classes and 3 and 4 as the upper classes, it can be said that there was a significant difference between the upper and lower classes, with the upper classes releasing the ball from a greater height (see Figure 4-1).

Statistically significant differences were also seen in release angle between the classes. The release angles of Classes 1 and 2 (59° and 58°, respectively) were both significantly different than the release angles of Classes 3 and 4 (55° for both). The upper classes were found to use a smaller angle of release as compared to the lower classes (see Figure 4-2).

In terms of velocity of the ball at release, statistically significant differences were found between Class 1 (743 cm/s) and the upper classes (Class 3 - 707 cm/s; Class 4 - 699 cm/s). As shown in Figure 4-3, release velocity tended to decrease with an increase in class.

Table 4-1

Ball Parameters at Release

Variable	Class 1 (n = 7) *M*	*SD*	Class 2 (n = 16) *M*	*SD*	Class 3 (n = 18) *M*	*SD*	Class 4 (n = 26) *M*	*SD*	η^2
Release height[a] (cm)	162	4	160	6	179	13	184	17	40%
Projection angle[a] (deg)	59	2	58	2	55	3	55	3	30%
Velocity at release[b] (cm/s)	743	22	719	32	707	30	699	21	22%

Note for η^2: small effect size = 1%, medium effect size = 6%, large effect size = 15% (Cohen, 1977; 1988). [a] Significant difference ($p < .01$) between the lower classes (1 & 2) and the upper classes (3 & 4). [b] Significant difference between Class 1 and the upper classes ($p < .01$).

In Table 4-2, descriptive statistics (mean and standard deviation values) for the additional trajectory variables are shown for the four classes. On average, the free throws approached the basket with an angle of entry of 43° for the lower classes and 40° for the upper classes. The lower classes tended to have a higher angle of entry, and therefore slightly greater margin for error, as a result of larger projection angles. The average minimum trajectory angle required for the lower classes was calculated as 53°, while that for the upper classes was determined to be 50°. On average players used a projection angle that was 5° greater than the minimum required. The minimum-speed angle was determined to be 55° for the lower classes and 53° for the upper classes. A comparison of

Tables 4-1 and 4-2 reveals that on average, players in the upper classes used a projection angle closer to their minimum-speed angle.

Table 4-2

Additional Ball Trajectory Variables

	Class 1 (n = 7)		Class 2 (n = 16)		Class 3 (n = 18)		Class 4 (n = 26)	
Variable	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Angle of entry (deg)	44	3	42	4	40	4	40	5
Margin for error (cm)	3.5	0.9	2.9	1.1	2.5	1.1	2.5	1.4
Min projection angle (deg)	52	0.4	53	1.0	51	2.0	50	2.0
Min-speed angle (deg)	54	0.2	55	0.4	53	0.8	53	1.0

Joint Kinematics

Statistically significant differences between the groups were identified on several of the joint kinematic variables. Of the variables measured, shoulder position at release, maximum shoulder velocity, and maximum elbow velocity showed a significant difference between the classes and a large effect size. Mean and standard deviation values of the upper limb joint positions and angular velocities, together with the effect size for each variable, are shown in Table 4-3 for each of the classes.

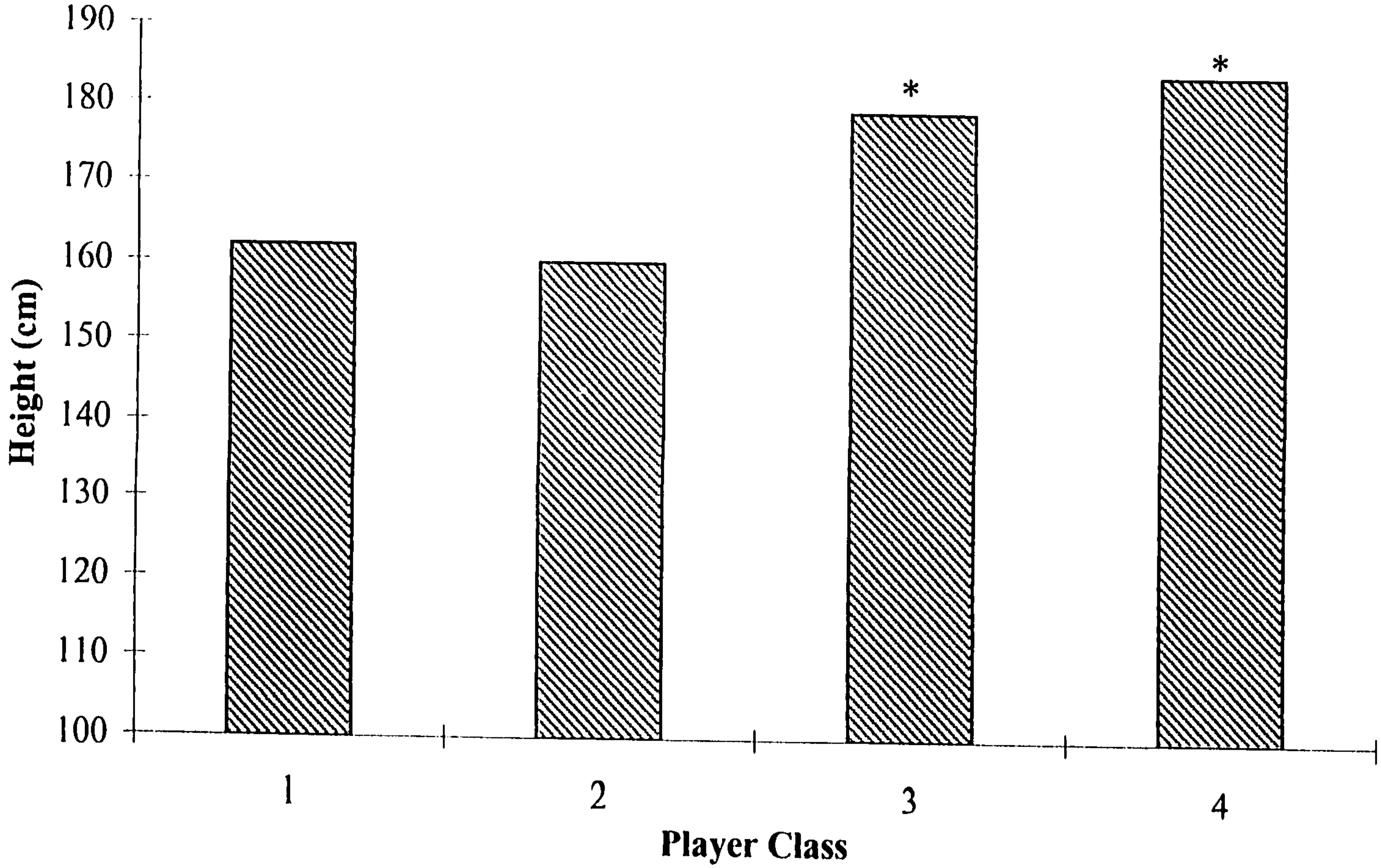

Figure 4-1 Average release height of the ball by player class. * Significant difference ($p < .01$) between the upper classes (3 & 4) and the lower classes (1 & 2).

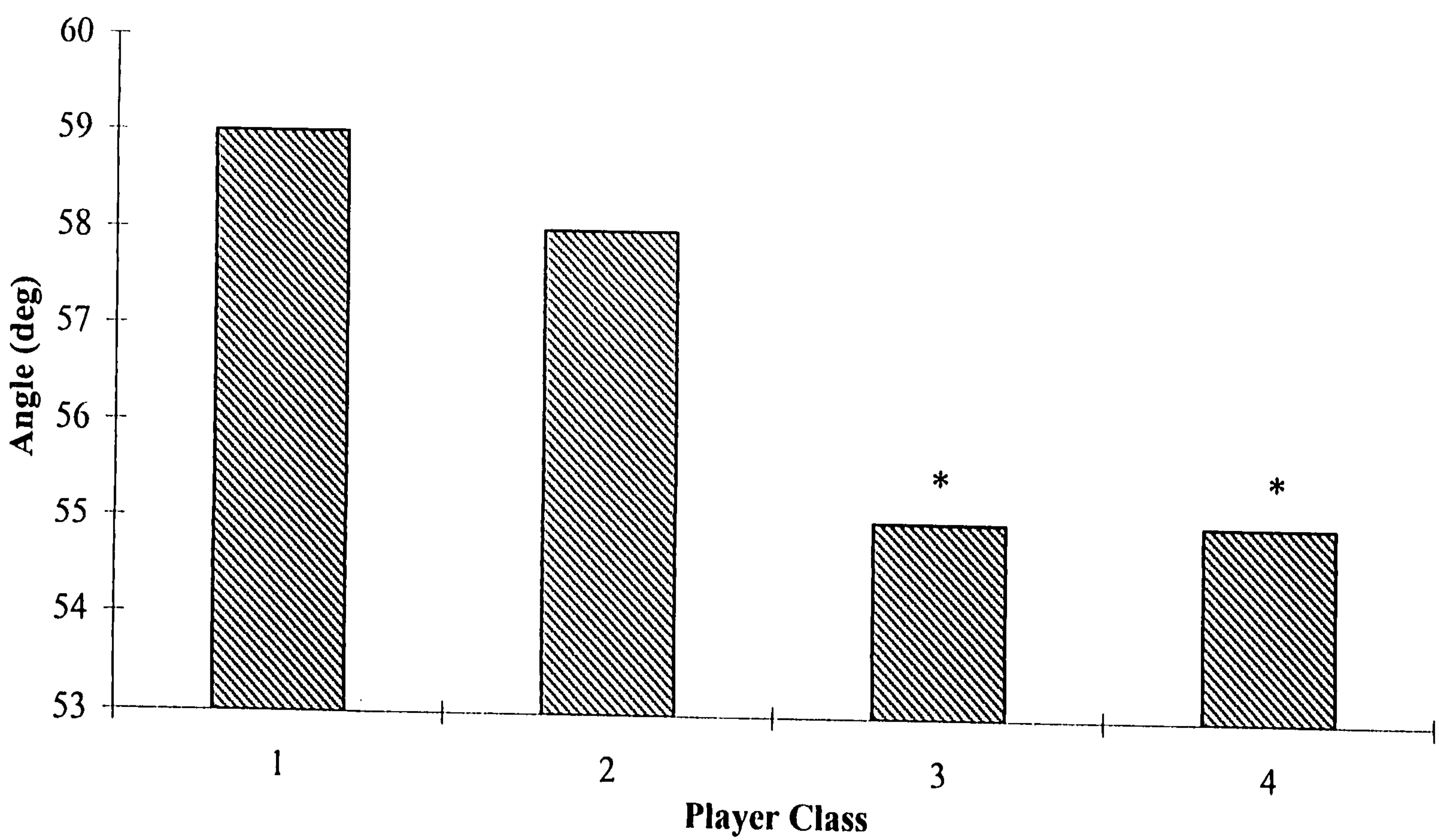

Figure 4-2 Average release angle of the ball by player class. * Significant difference ($p < .01$) between the upper classes (3 & 4) and lower classes (1 & 2).

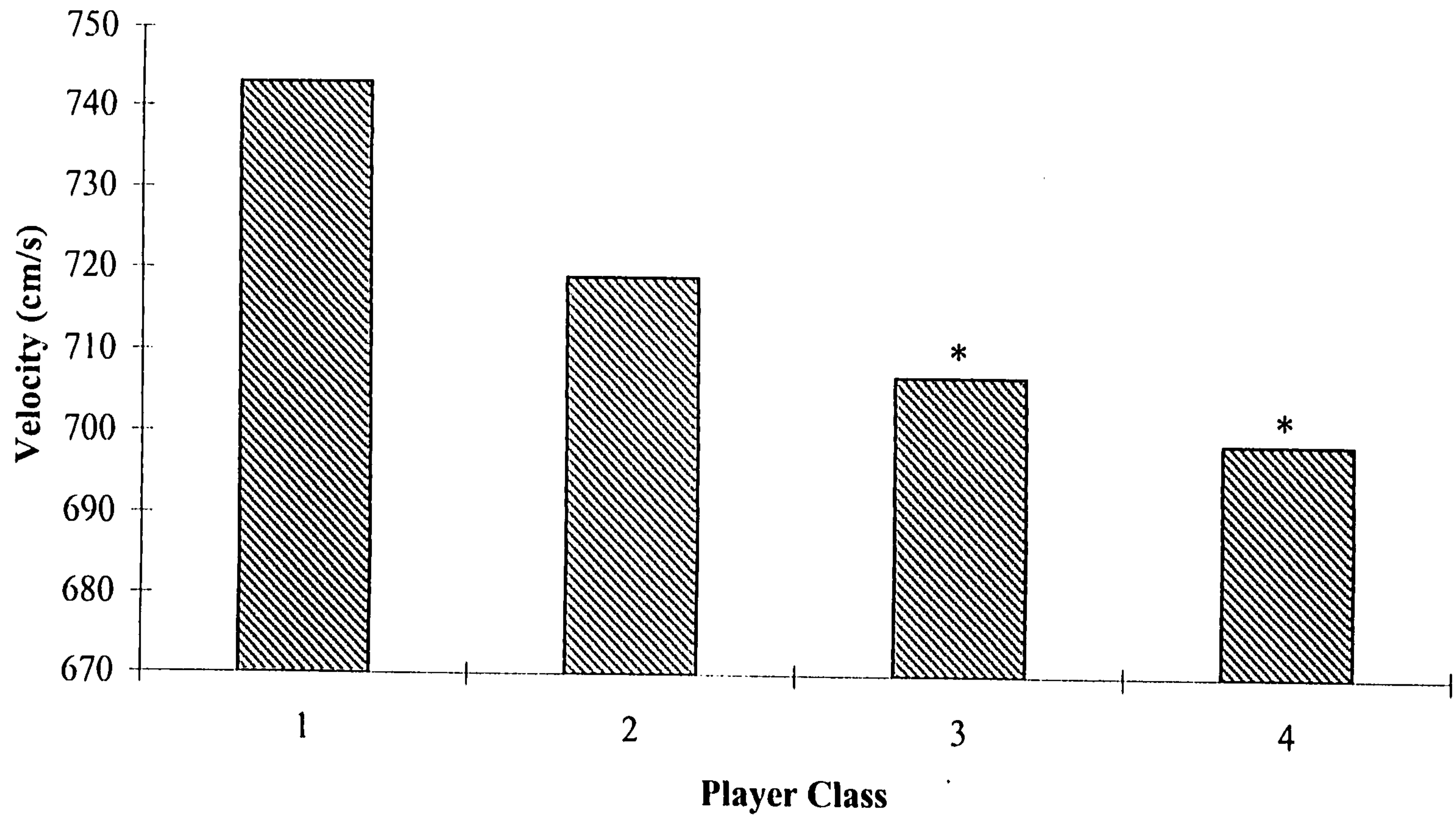

Figure 4-3 Average velocity of the ball at release by player class. * Significant difference ($p < .01$) between Class 1 and the upper classes (3 & 4).

Table 4-3

Upper Limb Joint Positions and Angular Velocities

Variable	Class 1 (n = 7) *M*	*SD*	Class 2 (n = 16) *M*	*SD*	Class 3 (n = 18) *M*	*SD*	Class 4 (n = 26) *M*	*SD*	η^2
Start angle of elbow (deg)	48	4	46	5	52	10	51	6	10%
Position at release (deg)									
Shoulder[a]	116	8	123	7	133	9	132	8	35%
Elbow	139	8	142	7	145	8	143	7	5%
Maximum angular velocity (deg/s)									
Shoulder[b]	462	61	533	75	441	128	412	89	20%
Elbow[c]	960	111	888	113	798	117	776	79	29%
Wrist	791	231	940	212	1003	175	1038	248	11%

Note for η^2: small effect size = 1%, medium effect size = 6%, large effect size = 15% (Cohen, 1977; 1988). [a] Significant difference ($p < .01$) between the upper classes (1 & 2) and the lower classes (3 & 4). [b] Significant difference ($p < .01$) between Class 2 and the upper classes. [c] Significant difference ($p < .01$) between Class 1 and the upper classes and between Class 2 and Class 4.

As shown in Table 4-3, shoulder position at release showed a significant difference between the upper (Class 3 - 133°, Class 4 - 132°) and lower (Class 1 - 116°, Class 2 - 123°) classes. On average, the upper classes demonstrated a larger angle of shoulder flexion at release (see Figure 4-4).

Class 2 had significantly faster maximum angular velocity at the shoulder than Classes 3 and 4. As shown in Table 4-3, average velocity for Class 2 was 533 deg/s, whereas Classes 3 and 4 had an average velocity of 441 deg/s and 412 deg/s, respectively (see Figure 4-5).

Maximum elbow velocity showed a significant difference between Classes 1 & 3, 1 & 4, and 2 & 4. Values of 957 deg/s, 888 deg/s, 798 deg/s and 776 deg/s were seen for Classes 1 - 4, respectively. In general, a decrease in velocity was identified with an increase in class (see Figure 4-6).

DISCUSSION

Results of this study revealed significant differences between wheelchair basketball classes in the free throw shooting mechanics required for a clean swish. It appears that different techniques, as demonstrated by several aspects of the shooting motion and ball trajectory, are used by the upper (3 & 4) and lower classes (1 & 2).

In terms of ball parameters at release a clear distinction was seen between the upper and lower classes. The lower classes tended to release the ball from a lower height, using a greater velocity and angle of projection. The technique of the lower classes in using a higher angle of release, although providing a larger margin for error, demanded greater accuracy due to the seriousness of errors as the release angle is increased (Hay, 1993). As indicated by tournament statistics (see Chapter 2), however, it appears that players in the lower classes managed to develop the required accuracy and achieve similar free throw shooting percentages (Class 1 - 52%, Class 2 - 53%) as players in the upper classes (Class 3 - 49%, Class 4 - 54%).

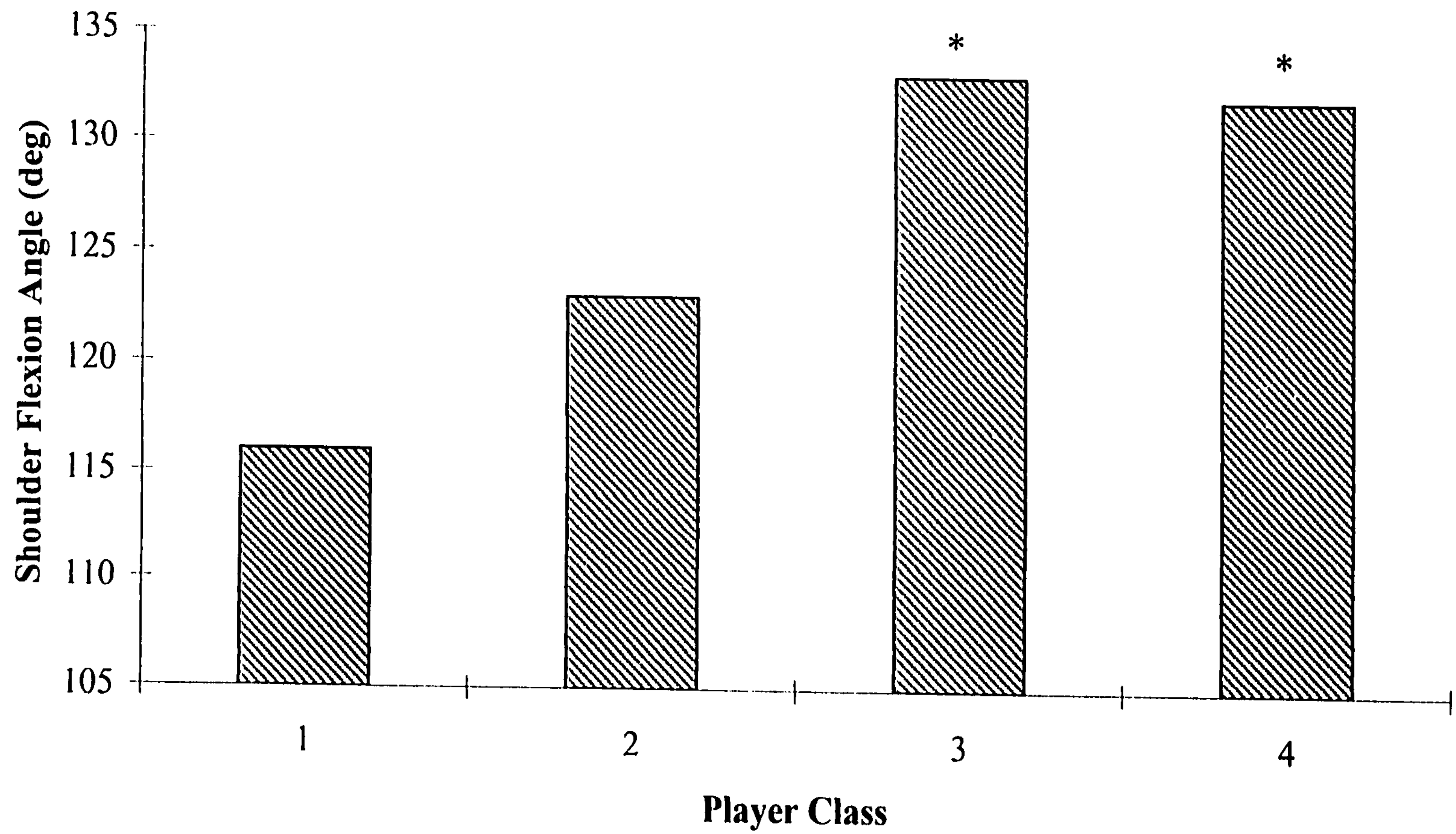

Figure 4-4 Average shoulder position at release for each of the player classes.
* Significant difference ($p < .01$) between the upper classes (3 & 4) and lower classes (1 & 2).

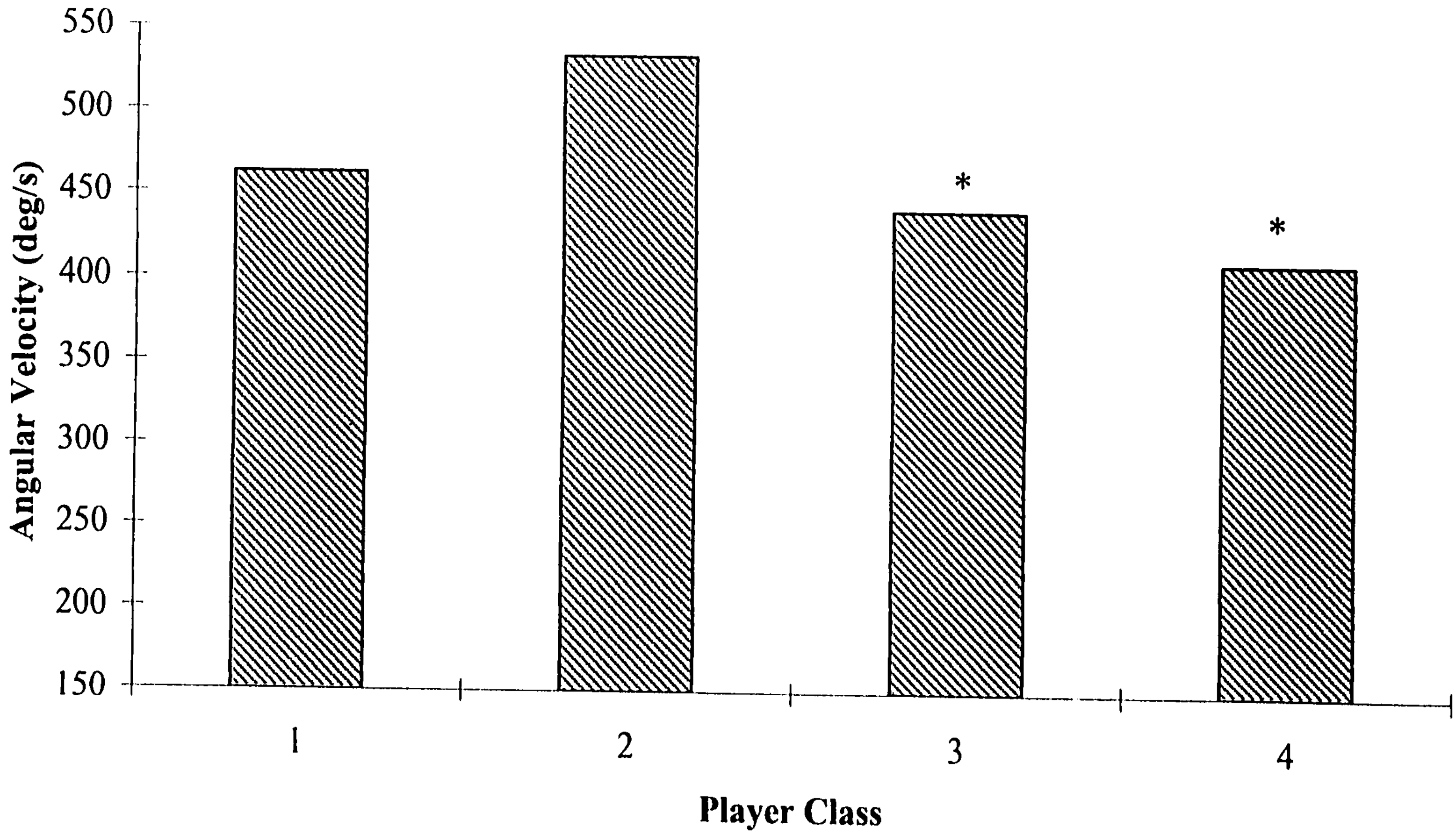

Figure 4-5 Maximum angular velocity of the shoulder for each of the player classes.
* Significant difference ($p < .01$) between Class 2 and the upper classes (3 & 4).

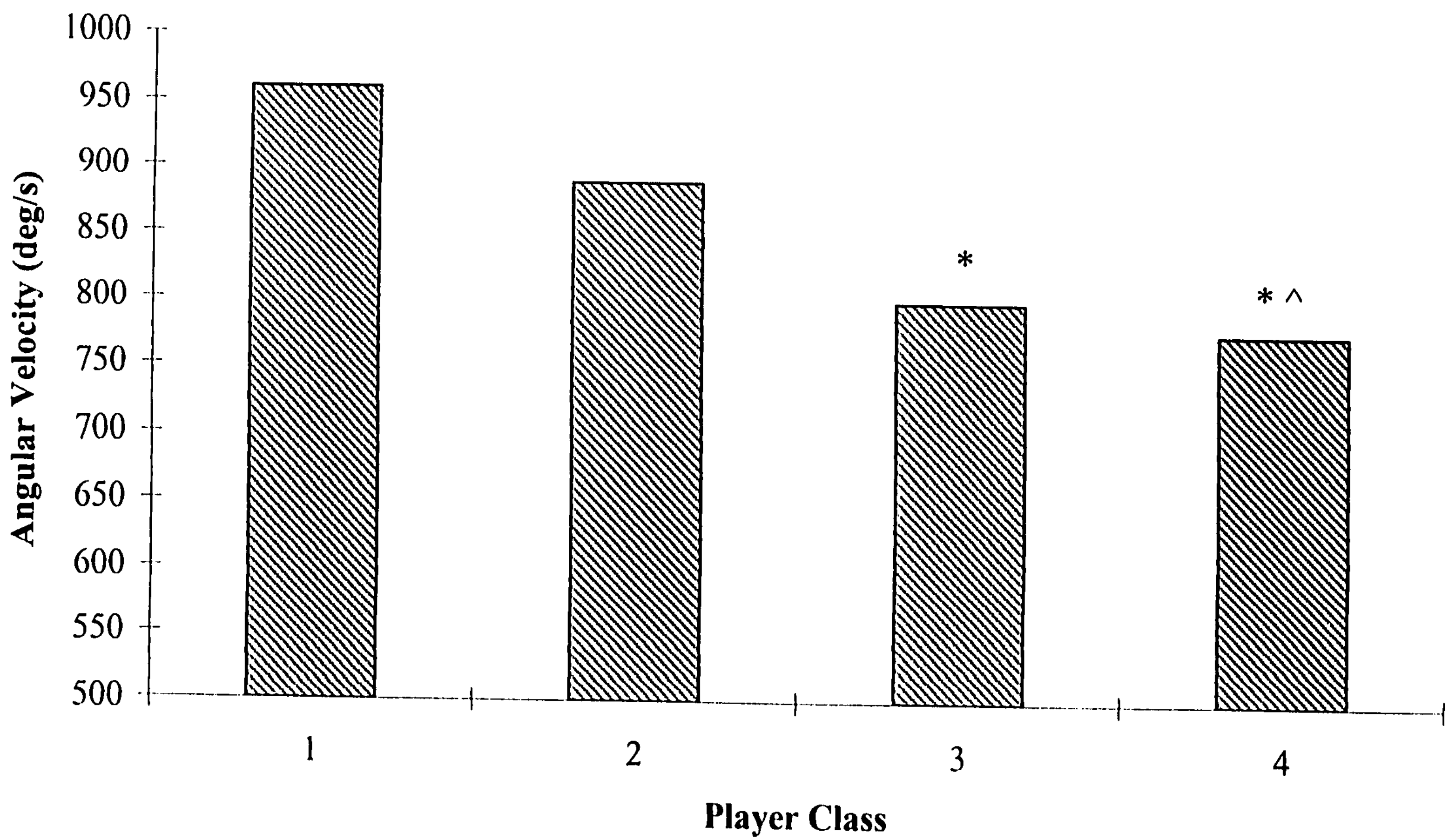

Figure 4-6 Maximum angular velocity of the elbow for each of the player classes.
* Significant difference ($p < .01$) between Class 1 and the upper classes (3 & 4).
^ Significant difference ($p < .01$) between Class 2 and Class 4.

In addition to the demands for increased accuracy with a high angle of release, is a requirement for a higher projection velocity and increased force production. This may pose a problem for some players in the lower classes who have functional limitations affecting their strength (Owen, 1982). If the necessary projection velocities are not attained, and the margin for error is exceeded, the shots will tend to fall short. In order to reduce the force requirements of a shot, and reduce the number of short misses that tend to occur (see Chapter 2), it may be advantageous for players to shoot with an angle closer to the minimum-speed angle as recommended by Brancazio (1981). Caution must be taken however, as such a strategy would reduce the margin for error, by lowering the angle of entry.

To shoot successful free throws with a steeper trajectory, the lower classes were required to generate more force and velocity in the shooting arm. As the results indicated, the lower classes accomplished this by using greater maximum angular velocities at the shoulder and elbow. These results coincide with those of Miller and Bartlett (1993), who found that elbow extension angular velocity increased as shooting distance increased. In addition, the lower classes tended to use a smaller start angle of the elbow (more flexed) which may have been an effort to increase elbow range of motion and generate the necessary impulse during arm elevation required for the ball to reach the basket.

The present analysis of clean swishes indicated that, on average, players in the upper classes used a higher point of release than did players in the lower classes. As indicated by Brancazio (1981), the higher the point of release, the more likely it is that a shot will be successful. The upper classes, therefore, had an advantage over the lower classes in shooting free throws by virtue of having a higher release point. Not only might players in the upper classes tend to be taller, but they also have the ability to lean the trunk forward and reach the arms upward while shooting without loss of stability. Based on the free throw percentages reported for each of the classes in Chapter 2, it appears that the upper classes did not fully utilise this advantage of a higher release point. As the height of release is increased, margins for error in both speed and angle become larger, and the necessary force and velocity of projection becomes smaller (Brancazio, 1981). With such advantages, it would be expected that the free throw shooting percentages of the upper classes would be greater. In addition to making sure that players in the upper classes utilise any height advantage they have, the combination of speed and angle used for clean swishes can perhaps serve as a guideline in efforts to improve overall free throw shooting performance.

There are numerous possible combinations of release parameters that can result in a successful free throw. Although it appears that certain guidelines can be recommended for the upper and lower classes in wheelchair basketball, every player should determine the best combination of speed and angle which produces the greatest consistency and accuracy in their own shot. In agreement with Higger (1984), it appears that Owen's (1982) suggestion of a minimum projection angle of 45° may be too small for wheelchair basketball players. Based on the minimum trajectory angles calculated in this study, it appears that a more reasonable suggestion would be a minimum of 50°. As indicated by Brancazio (1981), a shooter has very little leeway in projection velocity for a successful shot. For a given projection angle the difference in speed between a shot that passes through the centre of the basket and one that just clears the rim is generally less than 1% (Brancazio, 1981). Therefore, instead of using high angles of release, Brancazio (1981) indicates that successful shooters learn to shoot at or near the minimum-speed angle. In addition to providing the greatest margin for error in angle, a shot projected with the minimum-speed angle requires the smallest projection force (Brancazio, 1981). This is important to consider in wheelchair basketball where force requirements are increased due to increased distance from the basket, whereas force-producing capabilities are reduced due to lack of available power from the legs. Furthermore, as release height increases, the minimum-speed angle decreases. Although a person's height is fixed, efforts can be made to increase release height using strategies such as increasing shoulder flexion and elbow extension. In an attempt to develop the best possible trajectory for success, the numerous options available for making adjustments in technique should be carefully considered by each player and their coach.

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CHAPTER 5

General Discussion and Conclusions

Wheelchair basketball is an exciting, highly competitive sport. To gain the "competitive edge" required for success in basketball, there is a need to fully understand and develop the fundamental skills involved (i.e., shooting, passing, dribbling). Of the basic skills, shooting can be considered as the most important in putting points on the board and determining the outcome of a game. The free throw, in particular, is especially important as it provides an opportunity for a team to score free or uncontested points and is often the deciding factor in a close game or even of a championship title.

Unfortunately, success rate in free throw shooting by wheelchair basketball players has been reported to be quite low (Owen, 1982). Speculating that shooting percentages can be improved, a scientific analysis of the free throw as performed by wheelchair basketball players was deemed necessary in order to gather the information required for improving performance.

In an attempt to gain a broad understanding of the free throw and to obtain information that could be used by coaches in working with their athletes to improve performance, several aspects of the shooting skill were examined in this three-part investigation. Part I of the analysis centred on the notion that to improve shooting technique, effective instruction and appropriate feedback must be provided to the player. To accomplish this task, evaluation of technique must be based on actual performance. With regard to the free throw, this required a further breakdown of outcome from the traditional dichotomy of hit and miss. Actual performance occurs along a continuum ranging from clean swish to clean miss (air ball) and although the shooter can observe the outcome of each shot, additional information as to the characteristics of how the basket is actually hit or missed should also be provided. Using schematic diagrams, the objective of this study, therefore, was to observe and record the systematic nature of ball action at the basket, which in turn provided information beyond the traditional dichotomy as to the outcome characteristics (or errors) that were typical of an individual player or class of players. In addition, game statistics were reviewed in order to identify the contribution of successful free throw shooting to overall team success and to identify any differences in free throw shooting percentages between the classes.

Results of Part I confirmed the relatively low free throw shooting percentages in wheelchair basketball and the importance of successful free throw shooting to overall success. It was determined that almost one quarter of the games were lost by five or less points and on average, 17% of a team's total score during a game came from free throws. In addition, it was found that the majority of unsuccessful shots were thrown short, whereas clean swishes accounted for the majority of successful shots. Overall, it did not appear that classification was related to free throw shooting percentages or to patterns of ball action at the basket. Results supported the need for specific coaching and training techniques and provided direction for such interventions. With short shots comprising the most prominent free throw error, the need for proper technique training and improved physical conditioning to maximise the strength of the upper limbs was recommended. The instrument developed for this study provided a means to build individual practice profiles, which systematically address particular problem trends, a player might have in shooting.

Next, in Part II of this investigation, the issue of coordination as defined by the timing and sequencing of segment motion was addressed. The segments involved in the basketball free throw can be modelled as an open-link system in which the distal segment is able to move freely through space. For effective movement to occur in such a system, the combination of individual segment movements is required in a coordinated or well-timed motion (Kreighbaum & Barthels, 1996). Based on the timing and spatial characteristics of adjacent segment interactions and resulting movement patterns, skills can be grouped according to similar coordination patterns. At opposite ends of the continuum would fall those activities using a "throwlike" or sequential pattern of segment coordination and those using a "pushlike" or simultaneous pattern of movement (Kreighbaum & Barthels, 1996). Clearly, not all open-linked activities fall at one end of the continuum or the other. The expected pattern of motion is more simultaneous when accuracy is important and would tend to be more sequential when velocity is important (Hudson, 1986). In the middle of the continuum fall those movements that require an optimal combination of these factors, resulting in a blend of simultaneous and sequential segmental motion.

In basketball shooting, the overall performance objective is maximum accuracy of projection (Kreighbaum & Barthels, 1996; Miller, 1998). However in wheelchair basketball there is also a need to develop higher velocities at release due to the lower point of ball release. So the question was asked as to what pattern of segment coordination is utilised by wheelchair basketball players in shooting a free throw and does that pattern differ between the classes?

Utilising three-dimensional videography, the segmental coordination of the shooting arm during the force phase of free throw shooting was examined. Variables related to the timing and sequencing of joint motion at the shoulder, elbow and wrist were obtained from the digitised data. Coordination was assessed using the concept of shared positive contribution (SPC) developed by Hudson (1986). Based on the degree of SPC between adjacent joints, free throws were classified as using one of four shooting styles: SIM, SimSeq, SeqSim and SEQ.

In assessing the coordination characteristics of segmental motion in the shooting arm, it was determined that player class and shooting pattern were not related. It was found that wheelchair basketball players as a group used a combination of segmental movement patterns which tend to fall closer to the sequential end of the continuum (SEQ pattern). Initiation of movement most often occurred in a proximal to distal fashion, however, there was always some overlap between one of the pairs of segments (shoulder & elbow or elbow & wrist) in the timing and/or sequencing variables. The second most common pattern of segment coordination was SimSeq, a pattern in which a push by the shoulder and elbow was followed by a flick of the wrist. This corresponded to the finding of Elliott (1991, 1992) in his analysis of the basketball jump shot, which demonstrated a pattern of coordination of the arm segments in which flexion of the shoulder and extension of the elbow occurred simultaneously followed by final movement of the hand. Together, the SEQ and SimSeq patterns were observed in over 80% of the shots. The patterns of coordination observed, therefore, indicated that the free throw was performed with a combination of sequential and simultaneous rotations, falling somewhere in between the two extremes of the continuum, somewhat closer to the sequential end.

Although differences were not statistically significant, certain trends in shooting style between the groups were detected and supported by the calculated effect sizes. It appears that a greater number of players in the upper classes (3 & 4), those who have excellent stability and are able to move the trunk forward while shooting, may generate sequencing of movements in a more sequential fashion. On the other hand, players in the lower classes (1 & 2), who have loss of stability in the trunk affecting elevation of the arm and follow-through during shooting, may use a technique which reduces the chance of losing stability by constraining the limb to act more as a single unit. Such a technique would thereby enhance consistency and accuracy in their shot.

Although there are obvious disadvantages to shooting a basketball from a seated position as compared to standing up, it does not seem likely that the difference in success rates can be attributed solely to differences in the required shooting mechanics (Owen, 1982). Individual players in wheelchair basketball have demonstrated consistent shooting averages beyond 70% (Owen, 1982), so what is it that they do to achieve such success? Based on the premise that an understanding of movement mechanics and a scientific approach to the development of proper technique is necessary if an athlete's potential is to be fully developed (Brancazio, 1984; Elliott, 1991), in Part III of this investigation, the relationship between shooting mechanics and player classification for success in the free throw was examined. In an attempt to determine what factors are associated with successful free throw shooting in wheelchair basketball, a three-dimensional cinematography analysis of clean swishes was undertaken. The analysis focused on the parameters of ball release and joint kinematics associated with performance of the clean swish by each of the classes.

Results indicated significant differences between the wheelchair basketball classes in the free throw shooting mechanics employed for a clean swish. The lower classes (1 & 2) tended to release the ball from a lower height, with a greater velocity and angle of projection. In addition, they demonstrated a smaller angle of shoulder flexion at release, and greater maximum velocity at the shoulder and elbow. Although the trajectory used by the lower classes demanded greater accuracy, it appears that they managed to develop this relative to the upper classes (3 & 4) as was demonstrated in the similar shooting percentages between the two groups. One concern for players in the lower classes is the need to develop large velocities at release using the selected trajectories. An alternate strategy might be recommended in which an angle closer to the minimum-speed angle is used, thereby decreasing the force and velocity requirements of the shot.

On the other hand, the upper classes, did not seem to fully utilise their advantage of a higher release point of the ball. Not only are shots released from a higher point more likely to be successful, but they also require less force and velocity at projection (Brancazio, 1981). With such advantages, it would seem likely that the upper classes would have greater free throw shooting percentages compared to the lower classes. The combination of angle and speed chosen by players shooting clean swishes in this study, can perhaps serve as a guideline in efforts to improve overall success rate by the upper class players.

Overall, a better understanding of both outcome and performance has been provided, which in turn can be utilised by coaches and athletes in an attempt to improve success rates in free throw shooting. Although shooting is one of the most important fundamental skills in basketball, Smith (1994) notes that it is one of the least taught and is rarely practised enough (Owen, 1982). Likewise, based on the fallacy that players are "born" shooters, coaches rarely tamper with a player's shooting technique (Brancazio, 1984). With such low percentages in wheelchair basketball, extreme efforts must be taken to emphasise the importance of devoting practice time to this fundamental, yet critical skill. According to Brancazio (1984, p. 307), "it is possible to develop and improve one's ability to shoot a basketball accurately by taking a scientific approach to basketball shooting." This should be especially true for a standardised, unopposed performance setting such as that of the free throw.

In conclusion, as little scientific data was previously available regarding wheelchair basketball, the present research has provided empirical data on the outcome characteristics and shooting mechanics of elite level players and has contributed to the body of knowledge within the fields of adapted physical activity and biomechanics. The tendency of players to shoot short indicates a specific problem area that coaches should be aware of and on which practice time should be spent. As there was a trend toward the use of different coordination patterns between the upper and lower classes, different coaching strategies are warranted between the groups. It is further suggested that an examination of the technique strategies used by those athletes in the upper and lower classes who are most successful will provide additional insight as to where on the coordination continuum, performance of each of these groups would be most enhanced. Furthermore, this investigation has provided new information as to the relationship between actual performance on the court and the functional classification system. Although it appears that there is little difference in success rates between the four player classes, findings related to differences in shooting mechanics suggest a grouping of two player classes. Based on the results of this investigation regarding shooting performance in basketball, complementary study of the other fundamental skills involved (i.e., passing, dribbling) must be conducted prior to recommendations regarding changes in the classification system.

RECOMMENDATIONS

The need for prudence in using aggregate data and interpreting statistical significance in adapted physical activity research has been cited in the literature by various authors (Bouffard, 1993; Lavay & Lasko-McCarthey, 1992; Sutlive & Ulrich, 1998). As noted by Sutlive and Ulrich (1998, p. 110), certain problems, such as "too few subjects, high inter- and intrasubject variability, difficulty controlling intervening variables, and problems with measurement sensitivity", may result in lack of power to detect statistically significant differences at traditional alpha levels of .05 and smaller. To supplement the results of statistical significance testing, it has been recommended that effect sizes be reported (Keppel, 1982; Ottenbacher, 1992; Sutlive & Ulrich, 1998; Thomas, Salazar & Landers, 1991) and that selection of a larger alpha level be considered (Sutlive & Ulrich, 1998). Including such information will help ensure that the importance of certain finding are not overlooked (Rosenthal, 1979; Thomas, Salazar & Landers, 1991). A failure to detect a statistically significant difference between groups when one actually exists (Type II error) can easily occur in adapted physical activity research where small sample sizes and large variances in performance are often the case. Calculating and reporting effect sizes will assist in the interpretation of results by providing information as to the magnitude of difference between groups or the strength of the relationships between the independent and dependent variables, information that is not provided with the typically reported probabilities (*p* values) associated with significance testing.

As observed in the present investigation, sole reliance on the obtained *F* test results, would have resulted in certain performance differences between the groups being missed. In both Chapters 3 and 4, certain variables exhibited large standard deviations and were found to have medium to large effect sizes, lending support to different conclusions than those that the *F* test had indicated. Therefore, the findings of this investigation support the need for careful interpretation of statistical significance in adapted physical activity research and the need to consider additional measures for determining the meaningfulness of results (Sutlive & Ulrich, 1998; Thomas, Salazar & Landers, 1991) and/or alternative research designs (Bouffard, 1993; Lavay & Lasko-McCarthey, 1992).

Additional recommendations based on the present investigation include the following:

1. Expand the schematic diagram method to record information on lateral ball movements at the basket in order to fully assess the characteristic shooting errors of players.
2. Replicate this study with an equal number of players from each class, performing multiple trials in both a competitive and a non-competitive environment, in order to identify if, and if so how, shooting technique differs in these two settings.

3. Examine kinetic parameters of free throw execution in order to determine the torques required to obtain the selected shooting styles and trajectories used by wheelchair basketball players.
4. Investigate free throw shooting performance of high percentage shooters from all classes, collecting multiple trials for each player, in order to better understand the required mechanics for successful shooting.
5. Replicate this study with elite female wheelchair basketball players.
6. Complete similar investigations on different types of shots from a variety of shooting distances.
7. Study the effect of intervention on a selected group of individuals, based upon the data gathered in the present investigation, to determine how these techniques and findings can be used.

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APPENDIX A

Wheelchair Basketball Player Classification

The current system consists of four classes (Class 1, 2, 3 and 4) defined by the elements of trunk movement and sitting balance, with half point classes (Class 1.5, 2.5, 3.5, and 4.5) designated for borderline cases. *The 1996 Atlanta Paralympic Games General and Functional Classification Guide* (1995) provides a clear description of the functional breakdown between the player classes for the skill of basketball shooting. Classes 1 - 4 and the typical disabilities involved are outlined below.

Class 1 - Significant loss of stability in the trunk as the shooting arm is extended over the head during follow through, often requiring arm support following the shot. During a two-handed shot, the trunk makes contact with the back of the wheelchair. Loss of trunk stability occurs during minimal contact. Typical disabilities include T1-T7 paraplegia without abdominal muscle control; post-polio paralysis with arm involvement and without control of trunk musculature.

Class 2 - Mild to moderate loss of stability in the lower trunk during arm elevation and follow through, resulting in movement of the lower trunk away from the back of the wheelchair. Able to rotate the trunk toward the basket while shooting with both hands. Typical disabilities include T8-L1 paraplegia; post-polio without control of lower extremity movement.

Class 3 - Excellent stability of the trunk while sitting upright, particularly in follow-through of the shot. The trunk moves toward the basket with the shooting movement, without loss of stability. Typical disabilities include L2-L4 paraplegia with control of hip flexion and adduction movements, but without control of hip extension or abduction; post-polio paralysis with minimal control of lower extremity movements; hip disarticulations or above knee amputees with very short residual limbs.

Class 4 - Ability to move the trunk forcefully in the direction of the follow-through after shooting. Can lean laterally or rotate with a lateral lean to at least one side (away from the defender), while keeping both hands elevated and in contact with the ball. Typical disabilities include L5-S1 paraplegia with control of hip abduction and extension movements on at least one side; post-polio paralysis with one leg involvement; hemipelvectomy, single above knee amputees with short residual limbs, and most double above knee amputees; some double below knee amputees.

APPENDIX B

Error Analysis

The APAS system used for data reduction in this investigation was found to meet clinical standards for reliability and validity (Klein & DeHaven, 1995; Wilson, Smith, & Gibson, 1997). However, there are numerous potential sources for error associated with the use of cinematography procedures. Every attempt was made to minimise controllable inaccuracies and to evaluate the accuracy and consistency of the obtained results. First off, gross errors were minimised by the use of sound research methods, including repeated checks and careful observation.

With the use of non-metric cameras, the external and internal parameters of the camera must be defined. This was accomplished by the filming of a calibration frame and subsequent transformation using the DLT (Abdel-Aziz & Karara, 1971). In setting up the calibration frame, the following steps were taken to reduce the potential for error at this stage of the process: 1) use of a steel measuring tape with gradations of 1mm, 2) placement of control points on the frame as accurately and precisely as possible, and 3) distribution of sixteen control points evenly surrounding the activity space as recommended in the literature (Challis & Kerwin, 1992; Chen, Armstrong & Raftopoulos, 1994; Shapiro, 1978).

The level of accuracy required for the analysis of human motion depends on the desired outcomes and purposes for which the information will be used. In assessing the accuracy of cinematography procedures similar to the ones used in this investigation (non-metric cameras, absolute control distribution, DLT), the literature indicates error values in the range of 0.2 - 1.5 cm to be acceptable for practical purposes (Chen, Armstrong & Raftopoulos, 1994; Shapiro, 1978). To test the accuracy of the reconstruction in this investigation, the known values of sixteen extra points in the field of view were compared to the values calculated with the digitised coordinates of the sixteen control points. The average absolute errors associated with the X, Y, and Z coordinates for the sixteen additional points were 0.5cm, 0.4cm, and 0.2cm respectively. The three axes were orientated as follows: X axis– horizontal; perpendicular to the free throw line, in the direction of the basket, Y axis – perpendicular to the X axis in the upward direction, and Z axis – orthogonal to the XY plane. The accuracy levels of the present investigation, therefore, fall within acceptable limits. Furthermore, it has been suggested that the error in calibration procedures should be no more than about 0.5% of the calibrated field of view (as measured by the diagonal). In the case of the present investigation this equates to 1.35cm (0.5% x 270.4cm), thereby indicating that the calibration was within the accuracy of 0.5%.

During the digitising process, random error can be introduced due to the inability of the operator to consistently locate the point of interest. As a measure of consistency, the *Re-Digitize%* option on the APAS digitising module was selected during data reduction. For each trial, approximately ten frames were randomly selected and redigitised. The difference in location between the first and second attempts at digitising each point was used to determine a random error value for that point. The error values were then averaged, by point, for all frames redigitised in that particular view. The information for each trial was later used by the smoothing module to help determine the amount of smoothing required to remove random variations due to digitising of that point.

Finally, as an indication of the accuracy of the results, the calculated vertical acceleration of the ball after release was compared to the known value of acceleration due to gravity ($9.81 m/s^2$). The calculated acceleration value of the ball was considered to be the greatest potential source of error for two reasons: a) error due to inaccurate determination of the ball's centre of mass and b) magnification of error in the process of double differentiation for determining acceleration values from position data. Results indicated that the calculated vertical accelerations of the ball during free flight were on average within 5% (SD±4%) of the known value. It was presumed that the calculated displacements and velocities were more accurate as they underwent fewer differentiations.

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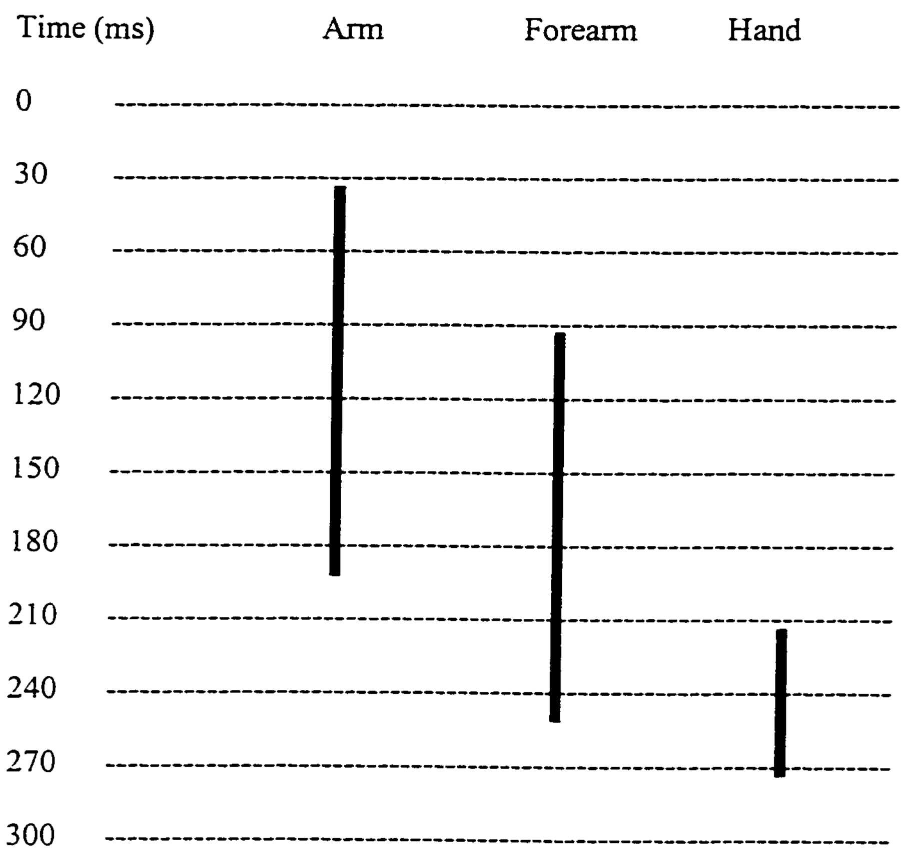
APPENDIX C

Example of Shared Positive Contribution (SPC) Calculation

Positive Contribution



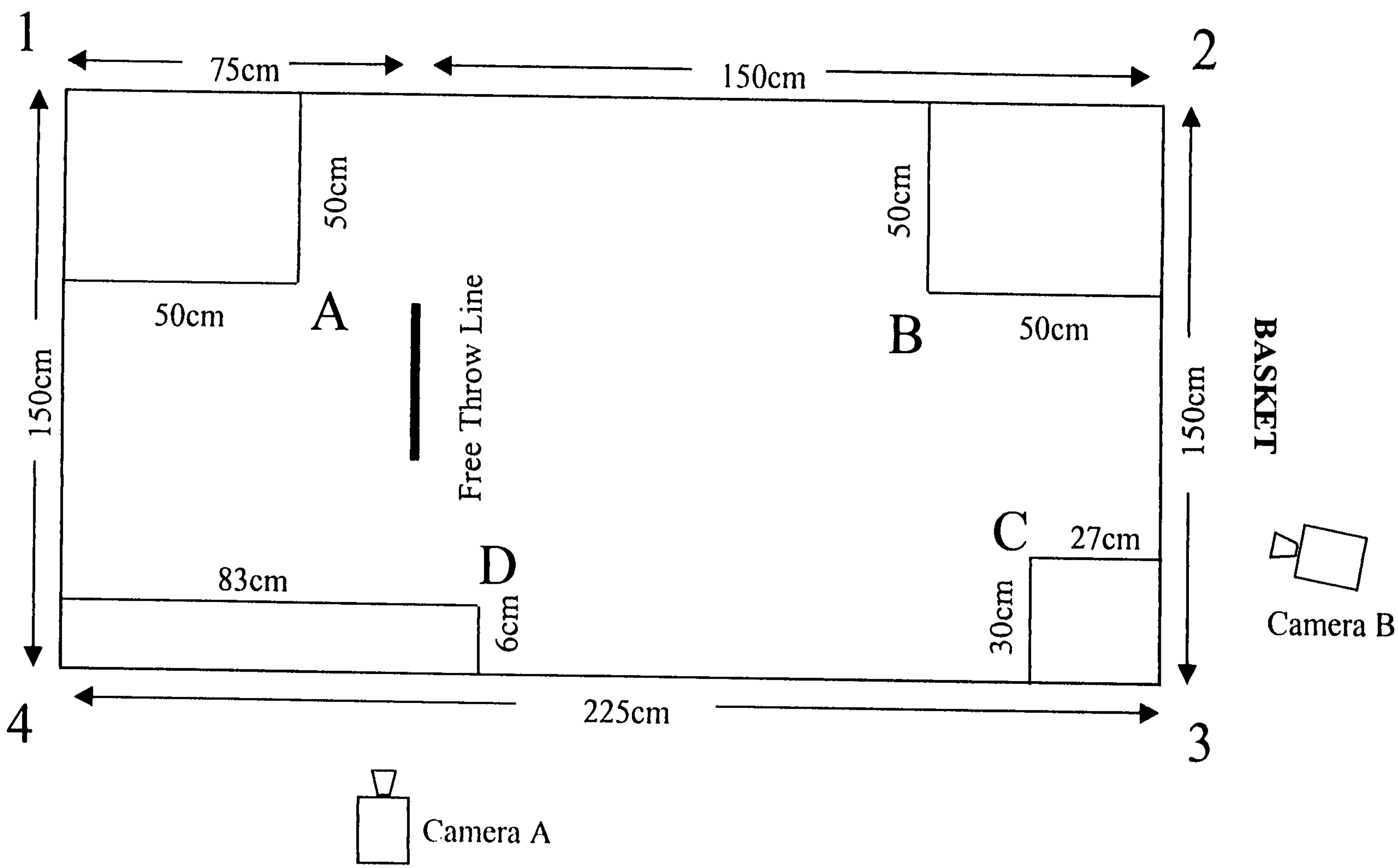
Segment	Initiation of Extension	Max Angular Velocity
Arm	30	180
Forearm	90	240
Hand	210	270

SPC of the Arm and Forearm: $SPC_{AF} = (180\text{-}90)/(240\text{-}30) = 0.43 = 43\%$

SPC of the Forearm and Hand: $SPC_{FH} = (240\text{-}210)/(270\text{-}90) = 0.17 = 17\%$

In comparing the SPC between the two pairs of adjacent segments it can be seen that the movement between the arm and forearm was more simultaneous (SPC = 43%) than the movement between the forearm and hand (SPC = 17%).

APPENDIX D Dimensions of Calibration Field



APPENDIX E

Position Coordinates of Plumbs and Poles (cm)

Plumb	Point	X	Y	Z	Pole	Point	X	Y	Z
1	1	0	14	0	A	1	50	30	50
1	2	0	100	0	A	2	50	50	50
1	3	0	200	0	A	3	50	100	50
1	4	0	300	0	A	4	50	123	50
2	5	225	14	0	B	5	175	30	50
2	6	225	100	0	B	6	175	50	50
2	7	225	200	0	B	7	175	100	50
2	8	225	300	0	B	8	175	123	50
3	9	225	14	150	C	9	198	30	120
3	10	225	100	150	C	10	198	50	120
3	11	225	200	150	C	11	198	100	120
3	12	225	300	150	C	12	198	123	120
4	13	0	14	150	D	13	83	30	144
4	14	0	100	150	D	14	83	50	144
4	15	0	200	150	D	15	83	100	144
4	16	0	300	150	D	16	83	123	144