7-2001

Effect of Two Volleyball Arm Swings on Post-Impact Ball Velocity

Jonathan A. Bowman
The College at Brockport

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by

Jonathon A. Bowman

July 2001

A thesis submitted to the Department of Physical Education and Sport of the State University of New York College at Brockport in partial fulfillment of the requirements for the degree of Master of Science

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by Jonathon A. Bowman

APPROVED BY:

Advisor — Date 6/26/01

Reader — Date 7/19/01

Reader — Date 6/26/01

Chair, Department of Physical Education and Sport — Date 7/24/01

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Abstract

The purpose of this study was to determine if differences exist between post-impact ball velocities generated by the bow-and-arrow arm swing (BAS) and circular arm swing (CS) in volleyball spiking. Ten female collegiate volleyball players were videotaped using two-dimensional cinematography. Markers were placed at the hip, shoulder, elbow wrist, end of the fingers, and the ball. Three videotaped trials of the BAS and the CS techniques for each subject were analyzed with Peak 5 Performance Analysis System. The mean post-impact ball velocity for the BAS was 12.72 m/s (SD = 1.30, SE = 0.41). The mean post-impact ball velocity for the CS was 13.26 m/s (SD = 1.49, SE = 0.47). A dependent t-test ($t_{(9)} = -3.131$) revealed significant differences ($p = 0.012$) between the CS and BAS post-impact ball velocity. No significant difference between CS and BAS pre-impact hand speed was found, which suggests that other factors (the time of contact between the hand and the ball and the transfer of angular momentum) affect ball velocity.

Chapter 1

INTRODUCTION

Volleyball is a continuous struggle between defense and attack. The offense tries to overcome the defense by power and deception. The most effective individual attack is the spike. "Spiking is the explosive and dynamic action of the hitting the ball into the opponent's court at a sharp angle" (Selinger & Ackermann-Blount, 1986, p. 86). As such, a successful volleyball spike that ends a rally has become the dominant offensive attack.

The basic spiking skill is divided into six phases: (1) approach, (2) take off, (3) flight, (4) contact with the ball (arm swing), (5) follow-through, and (6) landing. Although all phases are important, the arm swing prior to contact with the ball is directly related to spiking performance. An arm swing should generate the highest possible ball velocity, while minimizing injury and allowing good ball control.

Coaches advocate several arm swings. "The five most common arm swings in spiking are the straight arm, the bow-and-arrow, the snap, the circular, and the roundhouse" (Selinger & Ackermann-Blount, 1986, p. 92-94). Currently, the bow-and-arrow and the circular arm swings are popular. For the bow-and-arrow arm swing (BAS), the spiking arm moves into a position of extreme elbow flexion. This is called "cocking the hammer." Then, the spiking arm stops and holds this position until the ball is in the proper position to be hit (Cisar & Corbelli, 1989, p. 7). On the other hand, the circular arm swing (CS) resembles the natural throwing motion of a baseball. In this swing the elbow of the hitting arm moves around the shoulder, while never coming to a complete stop (Selinger & Ackermann-Blount, 1986).

Maximum effectiveness of a spike depends on which arm swing is going to generate the highest ball velocity after impact. Unfortunately, little research exists regarding the biomechanics of the arm swing during spiking in volleyball. It has been reported that shoulder extension at high speeds was the dominant variable related to post-impact ball speed for collegiate volleyball players (Ferris, Signorlie, & Caruso, 1995). This supported previous results suggesting a significant correlation between pre-impact humerus angular velocity and post-impact ball speed (Coleman, Benham, & Northcott, 1993). An additional investigation reported a correlation between pre-impact hand speed and post-impact ball speed, suggesting that the speed of the hand was a good predictor of ball speed (Chung, 1988). No researchers have focused on the comparisons of different spiking techniques.

Biomechanical analyses have reported contributing factors to ball velocity in various overhead swinging patterns of the arm (Pawlowski & Perrin, 1989). The major contribution to baseball throwing speed is the action of the shoulder, which is similar to the CS (Selinger & Ackermann-Blount, 1986, Wang, Ford, Ford, & Shin, 1995). Elbow angular velocity is an important contributor to ball speed for the water polo throws which is expected to be similar to the BAS (Feltner & Nelson, 1996). The comparison of additional factors for different techniques in specific skills has been reviewed in the literature.(Elliot, Marsh, & Overheu, 1989; Feltner & Nelson, 1996; Newshan, Keith, Sanders, & Goffinett, 1998.)

The literature reports comparisons between the overhead baseball throw, the football throw (Fleisig, et al., 1996), tennis ground strokes and serves (Behm, 1988; Ryu, McCormick, Jobe, Moynes, & Antonelli, 1988), and the water polo throw (Whiting, Puffer, Finerman, Gregor, & Maletis, 1985), which can then be compared to the volleyball spike.

The volleyball spike, baseball throw, tennis serve, and water polo throw each recruit the pectoralis major (clavicular fibers), posterior deltoid, and biceps brachii in the preparation phase; and the pectoralis major (sternal fibers), triceps brachii, and latissimus dorsi in the contact (release) phase (Jobe, Moynes, Tibone, & Perry, 1984; Behm, 1988; McMaster, Long, & Caiozzo, 1991). In the preparation phase, the hitting or throwing shoulder for the baseball throw, tennis serve, and water polo throw is hyper extended and abducted (horizontally extended), the elbow is slightly flexed which is similar to the CS. In the contact phase, the shoulder is extended and medially rotated. The follow-through phase involves antagonistic muscle action, which decelerates the arm. In contrast, the football throw puts an emphasis on elbow flexion and extension (Fleisig, et al., 1996), and comparisons can be made to the BAS in volleyball spiking.

Maximal velocity of the hand (distal segment of the kinetic chain) should be developed at the end of the contact (release) phase if maximal ball velocity is required in a given sport (i.e., volleyball spiking, baseball overhead throw). To do so, the pectoralis major, triceps, and latissimus dorsi are active on the arm (Behm, 1988; Cisar & Corbelli, 1989; Jobe, et al., 1984; McMaster, et al., 1991). The pectoralis contributes to shoulder extension, horizontal adduction, and internal rotation. The triceps brachii contributes to elbow extension, and perhaps shoulder extension (longhead only). The latissimus dorsi contributes to shoulder extension and internal rotation. The volleyball literature shows that shoulder angular velocity during extension and hand speed are good predictors of ball speed (Chung, 1988; Coleman, et al., 1993; Ferris, et al., 1995). These factors can be observed in similar movement patterns in other sports (Ellenbecker, Davies, & Rowinski, 1988; Wang, et al., 1995).

During the contact phase the circular arm swing, which has an emphasis on the shoulder musculature, is similar to the overhead throw, (Selinger & Ackermann-Blount, 1986); whereas, the BAS has an emphasis on the elbow musculature (Cisar & Corbelli, 1989). To maximize post-impact ball speed with the CS, shoulder musculature is recruited to maximize the angular velocity of the shoulder (in extension). In doing so, maximal shoulder angular velocity acts on the entire arm (i.e., upper arm, forearm, and hand) as a lever immediately prior to impact. Similarly, to maximize post-impact ball speed with the BAS technique, elbow musculature is recruited to maximize angular velocity at the elbow in extension. In this case, elbow velocity acts on only the forearm-hand segment as a lever immediately pre-impact.

In general, the product of the angular velocity of a lever arm and the length of that lever arm results in a predictable linear velocity at the distal end of the lever (or at any length) ($v = \omega r$). The anatomical analogy of the arm as a lever system in a volleyball swing places the hand at the distal end of the rotating lever (r). When comparing the length of the whole arm to the length of the forearm and hand only, the length of the lever arm increases. As the length of lever arm increases (r), the linear velocity of the hand (v) increases with the same angular velocity.

In addition to lever arm length, angular velocity (ω) of the rotating lever arm affects the resultant linear velocity of the hand. Maximal angular velocity at a joint (i.e., the shoulder and the elbow) is dependent on the angular acceleration produced by muscle torques. To maximize muscle torque, maximal muscle force is developed by recruiting as many muscle fibers as possible, and is a function of muscle mass and cross-sectional area. When comparing the mass of the muscles recruited in shoulder extension (i.e., pectoralis major, latissimus dorsi, posterior deltoid, longhead of the triceps brachii) and elbow extension (i.e., triceps brachii, anconeus), it is expected that the shoulder musculature can produce a greater force (torque) in extension by recruiting the pectoralis major and latissimus dorsi (posterior deltoid, triceps brachii longhead) than the elbow musculature in elbow extension (triceps brachii and anconeus). This is assumed to be true regardless of any differences in the moment of inertia of the rotating lever arms.

An additional factor affecting angular velocity results as a consequence of the Law of Conservation of Angular Momentum. In volleyball spiking and any movement in which a distal (terminal) segment moves at high velocity, each successive distal segment along the kinetic chain is accelerated as each successive proximal segment is decelerated in sequence. In this pattern, commonly referred to as proximal-to-distal sequencing, as each successive proximal segment is decelerated, the total moment of inertia of the rotating lever decreases. For example, the acceleration (swing) phase of a volleyball spike includes horizontal flexion and internal rotation at the shoulder and extension at the elbow. However, these actions occur sequentially such that as elbow extension begins, shoulder angular velocity slows. For a multi-segmented system in rotational motion, the Law of Conservation of Angular Momentum predicts that as the angular velocity of the proximal segment decreases (approaches zero), momentum is transferred to the distal segment, resulting in an increased velocity. Therefore, as the angular velocity at the shoulder of the upper arm–forearm–hand system decreases, the angular velocity at the elbow of the forearm–hand system increases. In this way, each successive distal segment is accelerated through the kinetic chain. When applied to volleyball spiking, it can be shown that the CS and the BAS both develop angular momentum that is transferred to the hand (the segment at the end of the kinetic chain). It is uncertain whether a significant increase in angular velocity results from the transfer of momentum between the spiking techniques. For the purpose of this study, no significance is assumed.

As the angular velocity and the length of a lever arm changes, the resultant linear velocity of the hand changes ($v = \omega r$). Based on the law of impacts, to maximize post-impact ball speed (v) in a volleyball spike, pre-impact hand speed (linear velocity) must be maximal. To maximize pre-impact hand speed, maximal lever arm length of the rotating lever and maximal angular velocity at the joint is desired. In a volleyball swing, it appears that when compared to the BAS, the CS has the potential to produce the greatest angular velocity (at the shoulder due to total muscle mass) and lever arm length (i.e., the arm), which would be expected to result in maximal hand speed. Consequently, as pre-impact hand speed increases, post-impact ball speed is expected to increase.

Need for the Study.

There have been few current scientific studies concerning the volleyball arm swing and no researchers have focused on the comparisons of different spiking techniques. Since several arm swings are taught in volleyball, and is important in transferring momentum to the ball during the spike, this study will provide information regarding how ball velocity is affected by different arm swings.

Purpose of the Study.

In regards to spiking in volleyball, several arm swings are currently practiced, two of which are the CS and the BAS. To maximize effectiveness of a volleyball spike, the determination of an arm swing that results in higher post-impact ball velocities is desirable. The purpose of the study is to determine if differences exist for post-impact ball velocities between the CS and BAS arm swing techniques in volleyball spiking.

Hypothesis.

With the emphasis of the CS on shoulder musculature (i.e., the shoulder extensors) to generate angular velocity of the entire arm as a lever, a higher pre-impact linear velocity of the hand will result in a higher post-impact ball velocity when compared to the BAS. Conversely, with the emphasis of the BAS on a smaller muscle mass (i.e., the elbow extensors) to generate angular velocity of a shorter lever (the forearm and hand only), a relatively lower pre-impact linear velocity of the hand results in a lower post-impact ball velocity.

Operational Definitions.

Bow-and-Arrow Arm Swing. In preparation for hitting, the arm is drawn backward into an extended and abducted position (horizontally abducted). The shoulder is medially rotated with the elbow flexed. The actual hitting motion begins with horizontal adduction and lateral rotation of the arm. Before contact, there is an elbow extension and pronation of the wrist.

Circular Arm Swing. In the preparation phase, the hitting arm is horizontally abducted and laterally rotated, while the elbow is slightly flexed. As the arm moves forward to contact the ball, the shoulder is horizontally adducted and medially rotated, while the elbow quickly extends.

Assumptions.

1. The subjects will complete all required testing with maximal effort.
2. The subjects will complete the testing using both arm swings.
3. There will be no significant differences in the general kinematic patterns for each swing type for a given subject.
4. There will be no significant differences in the general kinematic patterns for each swing type between subjects.

5. There will be no significant difference in the transfer of angular momentum between spiking techniques.
6. There will be no significant differences in recruitment patterns or muscle mass across subjects.
7. There is no significant effect on the relative torques of the shoulder and elbow due to changes in moment of inertia from changing lever arm length.
8. The coefficient of restitution between hand and ball is constant.

Limitations.

1. Three-dimensional cinematography is unavailable for use in this study.
2. The maximum filming rate of the video camera is 60 HZ.

Chapter 2

REVIEW OF LITERATURE

The purpose of this study is to compare post-impact ball velocity produced by two-arm swing techniques in volleyball spiking to better understand the factors related to successful spiking. Due to the limited literature in volleyball, the review of literature also includes other similar patterns from other sports.

Volleyball Muscle Involvement.

One of the factors affecting volleyball spiking and velocity of movement is muscle involvement. Cisar and Corbelli (1989) completed a kinesiological and physiological analysis of the volleyball spike. The arm swing they described was the BAS. The hitting arm moves into a position called "cocking the hammer." In preparation for hitting, their arm is drawn backward into an extended and abducted position (horizontal extension). The elbow is cocked posteriorly, well above the shoulder. The trapezius facilitates the extension of the head (humerus) by retracting the scapula. The posterior deltoid extends and abducts the arm. The pectoralis major, biceps brachii, and brachialis flex the upper arm and forearm. The supraspinatus helps to abduct the arm. The infraspinatus and teres minor laterally rotate the upper arm.

The hitting motion begins with extension, medial rotation, and adduction of the arm. There is an explosive extension and pronation of the forearm, which they refer to as "cracking the whip." "This movement lengthens the movement arm maximizing the potential velocity of the hand as it moves forward to contact the volleyball" (Cisar & Corbelli, 1989, pp. 8). The serratus anterior protracts and stabilizes the scapula. The anterior deltoid, pectoralis major, and triceps extend (horizontally flex) the arm. The latissimus dorsi and teres major help extend (horizontally flex), and medially rotate the arm. The subscapularis also medially rotates the arm. The pronator teres and quadratus pronate the forearm. The order of recruitment is such that the velocity of the arm becomes greater as the momentum is transferred to each sequential body part. After contact with the ball, Antagonistic muscles slow the hitting arm.

Volleyball Velocity and Different Techniques.

Ferris, Signorile, and Caruso (1995) investigated the relationship between maximum spiking speed and shoulder extension and internal rotation, elbow extension, and hand flexion. The researchers measured body fat percent, peak upper body power, arm segment lengths, vertical jump, and peak isokinetic torque of the four arm motions at three velocities. Using a radar gun to assess maximum spiking speed, the results of this study suggested that shoulder extension at high speed is the dominant physiological variable related to ball speed in spiking for collegiate female volleyball players. This supports the results of previous correlational studies (Chung, 1988, Coleman, Benham, &Northcott, 1993). Differences in swing type were not noted in the study.

Similarly, Coleman, Benham, and Northcott (1993) completed a three-dimensional cinematographical analysis of the volleyball spike. In the contact phase, a significant correlation was found between the magnitude of the pre-impact humerus angular velocity (in extension) and post-impact ball speed. In addition, the authors identified two styles of hitting, which includes the arm swings as a component. They intended to make comparisons across subjects. The majority of the subjects did not fall clearly into either identified style of hitting. Thus, it was not possible for them to compare the two styles.

Chung (1988) completed a three-dimensional analysis of the shoulder and elbow during the volleyball spike. The author collected anthropometrical, kinematic, and kinetic data. The data indicated that the speed of the ball after impact was greater as the speed of the hand increased immediately before impact. A significant correlation indicated that the speed of the hand was a good predictor of the ball speed. It is theorized that the goal is to maximize the speed of the hand at the instant of ball contact such that the maximal momentum is transferred to the volleyball at impact, thereby maximizing ball velocity. The author observed three distinct arm swing techniques in his subjects. The author reported that for subjects 1-5, the speed of the hand at impact was determined mainly by the extension at the shoulder and elbow; in subjects 6 and 7, the speed of the hand at impact was determined mainly by the combination of shoulder extension or elbow extension with internal rotation at the shoulder in subject 8, the speed of the hand at impact was determined mainly by internal rotation at the shoulder. No literature was found for volleyball in which subjects were asked to do multiple arm swing techniques or hitting styles. It has been reported that similarities exist between the volleyball arm swing and an overhead throwing motion used in baseball (Selinger and Ackermann-Blount, 1986).

Comparison Between Sports.

Further research has made comparisons of observed similarities between overhead throwing and arm swing patterns in other sports. Ryu, McCormick, Jobe, Moynes, and Antonelli (1988) used electromyography and synchronized high-speed photography to analyze shoulder function of subjects when performing the tennis forehand. The authors reported similar muscle activation patterns to the overhead throw in baseball. Furthermore, it was suggested that a program used by baseball pitchers might be beneficial for tennis players.

Whiting, Puffer, Finerman, Gregor, and Maletis (1985) compared the water polo throw and baseball pitch. The researchers noted that water polo throwers achieve approximately half of the peak angular velocity of baseball pitchers, however, this was attributed to a lack of ground support and a larger ball diameter. Therefore, to develop sufficient ball velocity of the water polo ball, the elbow is more involved (Feltner & Nelson, 1996).

Fleisig, Escamilla, Andrews, Matsuo, Satterwhite, and Barrentine (1996) compared baseball pitching and football throwing. The researchers found that the two throws had some similarities, but were not identical. Quarterbacks had greater shoulder external rotation at the instant of foot contact. Pitchers demonstrated greater maximum shoulder external rotation during arm cocking phase. "In addition, quarterbacks tended to 'lead with the elbow' more than pitchers, displaying greater shoulder horizontal adduction and elbow flexion during arm cocking and at the instant of ball release" (Fleisig, et.al., 1996, pp. 215).

The tennis forehand, water polo throw, football throw, and baseball throw have been compared; and baseball throw has been reported to be similar to the volleyball spike. Muscle activation patterns are similar in all. However, the CS is more closely associated to the baseball overhead throw and tennis serve for which shoulder velocity affects hand speed and post-impact ball velocity. The BAS is similar to the football throw (and water polo throw), in which quarterbacks were found to "lead with the elbow," puts an emphasis on elbow extension. On the other hand the volleyball spike, like the water polo throw, has a lack of ground support and uses a larger ball. It would be expected that the volleyball spike would result in lower angular velocity of the shoulder than the baseball overhead throw. However, technique differences in volleyball spiking can alter the influence of the shoulder and elbow.

Muscle Involvement in Other Sports.

The volleyball spike uses specific muscles to generate movement patterns (Cisar & Corbelli, 1989). In the preparation phase, the shoulder is extended, abducted and laterally rotated. The muscles involved are the deltoids, pectoralis major (clavicular fibers), biceps brachii, and brachialis. In the acceleration phase, the shoulder is extended, medially rotated, and adducted. The muscles used are the deltoids, pectoralis major (sternal fibers), triceps, latissimus dorsi, and teres major.

The follow-through involves slowing the motion of the arm. By examining movement patterns in related sports, similarities may be identified.

Jobe, Moynes, Tibone, and Perry (1984) completed an EMG analysis of the shoulder in pitching. The pitching motion was divided into four phases: (1) the wind-up, (2) cocking, (3) acceleration, and (4) the follow-through. "The wind-up stage is dominated by upper extremity flexion with both hands holding the ball" (Jobe, Moynes, Tibone and Perry, 1984, pp. 219). The cocking phase is a period of shoulder abduction and external rotation. The contact (acceleration) phase starts with a posture of maximum abduction and external rotation of the shoulder, adduct and internally rotate until ball release. The follow-through phase is after release and involves slowing down of the arm. Moderate biceps brachii activity was reported in the cocking phase, but peak biceps brachii action occurred during the follow-through to decelerate the arm. The triceps was active in the acceleration stage and into follow-through. The pectoralis major and latissimus dorsi were active in all stages, especially as forceful internal rotators in the acceleration. The serratus anterior was active in the late cocking, acceleration, and follow-through, providing a stable glenoid fossa against which the humerus could rotate.

A kinesiological analysis of the tennis serve was investigated by Behm (1988). The author reported that different styles of serving such as the flat, topspin, and slice alter the motion, but there are basic principles underlying the service motion. The researcher divided the service motion into five phases: (1) preparation, (2) toss, (3) back scratch, (4) contact, and (5) follow-through. In the preparation phase, arms are extended toward the target area and elbows are slightly flexed. In the toss phase, the racquet arm moves in an arc in clockwise rotation to the opposite side of the body in an effort to reach the back scratch position. In this position, the upper arm becomes level with the shoulder, marking the start of elbow flexion and shoulder rotation. "Shoulder circumduction and elbow flexion continue until the racquet head is placed on the inferior aspect of the back (back scratch). At the same time, the elbow is brought to a position perpendicular to the ground (Behm, 1988, p. 10).

Behm (1988) reported that during circumduction the shoulder is abducted by the supraspinatus and posterior deltoid. The trapezius and levator scapula contribute to shoulder elevation and glenoid cavity rotation. Full circumduction is accomplished with external rotation of the shoulder. The muscles involved are the infraspinatus, teres minor, and posterior deltoid. The angular speed of the shoulder is enhanced by contractions of the latissimus dorsi, teres major and minor, pectoralis major, infraspinatus, and triceps brachii. Elbow extension is improved by the concentric contraction of the triceps brachii. In the contact (acceleration) phase, medial rotation of the shoulder by the pectoralis major, latissimus dorsi, teres major, subscapularis, and anterior deltoid, and forearm pronation by the pronator teres and quadratus are necessary. The follow-through involves antagonistic muscles slowing the motion as the racquet head continues forward after contact.

McMaster, Long and Caiozzo (1991) investigated the water polo throw. Since the throwing position emphasizes adduction and internal rotation motions, the authors studied isokinetic torque imbalances in the rotator cuff of elite water polo players. It was reported that water polo players had stronger adductors causing an unbalanced adduction/abduction ratio. In addition, the internal rotators were stronger causing further imbalances. "The researchers felt the basis of these deviations from normal is [from a] sport-specific repetitive activity; and, similar to the baseball pitcher, is related to the emphasis on adduction and internal rotation inherent in the mechanics of swimming" (McMaster, Long & Caiozzo, 1991, pp. 74).

As described in the previous studies, the volleyball spike has similar muscle and movement patterns to the baseball overhead throw, tennis serve, and water polo throw (Behm, 1988, Jobe, Moynes, Tibone, & Perry, 1984, McMaster, Long & Caiozzo, 1991). In the preparation phase, the arm is extended and laterally rotated. In the contact (acceleration) phase, the arm is extended, adducted (horizontally flexed), and medially rotated by the pectoralis major, triceps brachii, and latissimus dorsi. Movements of the glenoid fossa of the scapula facilitate these actions. The follow-through phase involves antagonistic muscles slowing the motions.

Ball Velocity and Different Techniques in Other Sports.

Pawlowski and Perrin (1989) studied the relationship between isokinetic peak torque, torque acceleration energy, average power, total work, and throwing velocity at the shoulder and elbow in intercollegiate pitchers. The authors reported a significant correlation between average power and throwing velocity. The authors concluded that power and total work were more meaningful predictors of throwing velocity than other measures of peak torque.

Wang, Ford, Ford, and Shin (1995) completed a three-dimensional kinematic analysis of baseball pitching in the acceleration phase. The three phases of pitching are cocking (preparatory), acceleration, and follow-through. The authors reported that faster ball velocity at release was related to greater internal and external rotation of the shoulder at the beginning of the acceleration phase. In addition, slowing the wrist action just before ball-release transferred momentum to the fingers and increased the pitching velocity of the ball. Pawloski and Perrin (1989) suggested these results.

Newsham, Keith, Saunders, and Goffinett (1988) studied the isokinetic profile of baseball pitchers' internal and external rotation at 180, 300, and 450 degrees per second. The researchers reported that internal rotation values were significantly greater than external rotation values for all speeds of comparison. Internal rotation peak torque values were significantly greater than external rotation values at each speed. The intercollegiate baseball pitchers produced less torque for internal rotation compared to the professional pitchers. However, the two groups had similar torque values for external rotation.

Ellenbecker, Davies, and Rowinski (1988) tested the effect of two; six-week different training programs on maximal tennis serve velocity. One training group used eccentric isokinetic internal and external shoulder rotation. The other training group used concentric isokinetic internal and external shoulder rotation. Ball speed was measured using high-speed cinematography. Both training groups increased rotator cuff torque acceleration. However, only the concentric group was able to significantly transfer that improvement to the actual skill.

Feltner and Nelson (1996) completed a three-dimensional kinematic analysis of the throwing arm of national team players during the penalty throw in water polo. The ball speed at release was lower than other sports. "There was an extreme amount of variability in the contribution of internal rotation of the upper arm" (Feltner & Nelson, 1996, p. 368). The researchers found that angular velocity of the forearm in elbow extension was the main contributor to ball speed at release. The counterclockwise twisting rotation of the trunk was the second largest contributor to ball release. Many of these differences may be attributed to a lack of ground support.

The baseball throw results in the highest ball velocity of all the overhead patterns. The major contributor to the baseball throw is rotation at the shoulder, which is similar to the volleyball CS. Work and power (at the shoulder) were good predictors of throwing velocity, and would be expected to be important to the volleyball spike. Similarly, concentric shoulder rotation increases tennis serve velocity. External rotation and horizontal extension occur during the preparatory phase, and medial rotation and horizontal flexion occurs during the acceleration phase. This maximizes the range of motion (work, power) during internal rotation (Pawlowski & Perrin, 1989; Wang, et al., 1995), and indicates the importance of the preparation phase before contact (Ellenbecker, Davies, & Rowinski, 1988). These patterns appear to be similar to the CS technique.

By comparison, the CS has more of an emphasis on shoulder rotation than the BAS. In this way, the CS emphasizes the action of the shoulder. On the other hand, it is theorized that the BAS puts an emphasis on the action at the elbow. Thus, the BAS may be similar to the football throw and water polo throw, each of which has an emphasis on elbow action as the arm is "cocked" into position (Feltner & Nelson, 1996, Fleisig, et al., 1996). In this pattern, the angular velocity of the forearm was the major contributor to ball speed for the water polo throw, and may be expected to be similar to the BAS.

Although the importance on specific joints and segment motions are documented, it may be equally important to note the BAS and CS patterns in volleyball are multi-segmented. Elliot, Marsh, and Overheu (1989) compared different tennis forehand techniques, one of which included a subject group who contacted the ball with their hitting arm acting as a multi-segment unit. The second group hit the ball with their arm acting as a single unit. Ball velocity was determined by the use of three-dimensional photography. It was reported that the multi-segment group recorded higher velocities at impact and post-impact. It was suggested that sequential use of the multi-segment arm generated higher ball velocities, which is consistent with the theory of the Conservation of Angular Momentum.

Chapter 3

METHODS AND PROCEDURES

The purpose of this study was to determine if differences exist between post-impact ball velocities created by the volleyball BAS and CS. A group of 10 female volleyball players at the collegiate level (NCAA Division III) volunteered to participate in this study. The subjects' regular arm swings were somewhere along the spectrum between the BAS and CS, and more closely related to the BAS. Descriptive measures of age, height, weight, and upper arm, forearm, and hand lengths were recorded. Each individual indicated voluntary participation by signing an informed consent consistent with the policies and procedures of the State University of New York, College at Brockport. Subjects were then given five minutes of warm-up. The warm-up was consistent. It included static stretching and throwing then hitting balls against the wall.

Each participant performed a volleyball spike with a CS technique and a BAS technique from a standing position. They were instructed to perform a maximal spike, and to aim for a target on the ground. The target was included for directional purposes only. Digitizing markers were placed on each player at the superior, anterior iliac spine; the greater tubercle of the shoulder; the axis of rotation of the wrist; and distal end of the all digits. From these markers, a four-segment kinematic chain that included the trunk, the upper arm, the forearm, and the hand was identified for analysis. In addition, a sixth point was digitized that corresponded to the approximate center of mass of the volleyball. Each trial was recorded (60 Hz) with a Panasonic video camera positioned along a medio-lateral axis such that the field of view was perpendicular to the sagittal plane. At least three good trials for each spiking technique were recorded, and subjects were given rest between trials if needed. The subjects performed the BAS trials first, and then completed the CS trials.

A Peak 5 Performance Analysis System was used to analyze a 2-dimensional spiking movement for each trial. Recorded trials were digitized, and then each trial was smoothed using a cubic spline function. Average kinematic values for each technique were determined from the three-recorded trials. Kinematic variables included the linear velocity of the hand prior to impact with the ball (pre-impact), the angular velocity of the shoulder and elbow pre-impact, and the linear velocity of the ball immediately after impact with the ball (post-impact). Values for each of the kinematic variables were determined by averaging three consecutive data values immediately pre-impact for the linear velocity of the hand, angular velocity of the shoulder and elbow, and post-impact for the linear velocity of the ball, respectively.

The post-impact ball velocity was compared for the volleyball CS and BAS in a dependent t-test. Post-hoc comparisons of pre-impact hand velocity were included. In addition, the following post-hoc correlations were included: pre-impact hand velocity and ball velocity, pre-impact shoulder angular velocity and ball velocity, and pre-impact elbow angular velocity.

Chapter 4

RESULTS

The purpose of the study was to determine if differences exist between post-impact ball velocity created by the BAS and CS arm swings in volleyball spiking. It was observed that the number of required trials to successfully complete each swing type was higher for the CS. This suggests that subjects were more familiar with the BAS. The population descriptors for the female collegiate volleyball subjects included age, height, weight, upper arm length (UAL), forearm length (FL), and hand length (HL) (See Table 1). The descriptive data includes pre-impact hand velocity, pre-impact shoulder angular velocity, and pre-impact elbow angular velocity. Means (M) and standard deviations (SD) are presented in Table 2.

Table 1
Population Descriptors

	Age	Height (m)	Weight (kg)	UAL (m)	FL (m)	HL (m)
M	20.30	1.73	73.72	0.28	0.26	0.196
SD	2.31	0.03	10.60	0.02	0.01	0.01

Table 2
Descriptive Data

		BAS	CS
Pre-impact hand velocity (m/s)	M	11.66	11.406
	SD	1.37	1.09
Pre-impact shoulder angular velocity (d/s)	M	-386.29	-416.50
	SD	197.00	190.97
Pre-impact elbow angular velocity (d/s)	M	-974.11	-953.44
	SD	402.40	294.98

The comparison data was post-impact ball velocity. Table 3 includes number of observations, mean values, standard deviations, and standard errors (SE) for comparisons of post-impact ball velocity between the BAS and CS arm swings. The dependent t-test yielded a t-score of -3.131, which indicated significant differences ($t_{(9)} = -3.131$, $p = 0.012$). The results are presented in Figure 1.

Table 3
Post-Impact Ball Velocity M, SD, and SE

	n	M	SD	SE
BAS	10	12.72	1.30	0.41
CS	10	13.26	1.49	0.47

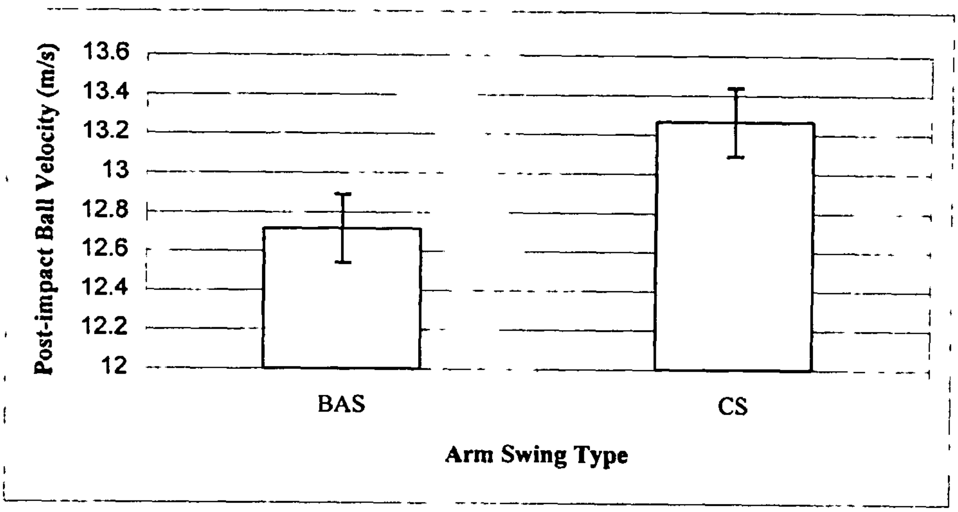

Figure 1. Comparison of BAS and CS Arm Swings Post-Impact Ball Velocity.

Post-hoc tests were included primarily for discussion. A dependent t-test was used to compare pre-impact hand velocity between the BAS and CS technique; the result of which did not indicate statistical differences ($t_{(9)} = 0.845$, $p = 0.420$). Post-hoc correlations, indicated by Pearson's correlation value (r), described the relationships between post-impact ball speed (1) and pre-impact hand speed (2), shoulder angular velocity, and elbow angular velocity. The results of the post-hoc correlations for the BAS and CS volleyball spike technique are shown in Table 4 and 5.

Table 4
Post-hoc Correlations for the BAS Technique (** indicates statistical significance $p < .05$)

Kinematic Variables		(1) Ball	(2) Hand
(1) Post-impact ball speed	r	—	—
	p	—	—
(2) Pre-impact hand speed	r	0.612	—
	p	0.060	—
(3) Pre-impact angular velocity at the shoulder	r	0.079	0.606
	p	0.828	0.063
(4) Pre-impact angular velocity at the elbow	r	-0.235	-0.694
	p	0.514	0.026 **

Table 5
Post-hoc Correlations for the CS Technique (** indicates statistical significance $p < .05$)

Kinematic Variables		(1) Ball	(2) Hand
(1) Post-impact ball speed	r	—	—
	p	—	—
(2) Pre-impact hand speed	r	0.823	—
	p	0.003 **	—
(3) Pre-impact angular velocity at the shoulder	r	-0.022	0.088
	p	0.951	0.810
(4) Pre-impact angular velocity at the elbow	r	-0.027	-0.103
	p	0.942	0.777

Chapter 5

DISCUSSION

The purpose of the study was to determine if differences exist for post-impact ball velocity between the BAS and the CS arm swings techniques in volleyball spiking. The results suggest comparisons to relevant literature, applications of the theoretical base, and directions for future research.

<u>Comparison to Literature.</u>

Previous studies have reported kinetic quantities that describe the volleyball spike. Chung (1988) using females, reported that (during the acceleration phase) mean hand speed was 17.8 m/s ($\underline{SD}$ = 1.4) and mean post-impact volleyball velocity was 18.75 m/s ($\underline{SD}$ = 2.1). Coleman, Benham, and Northcott (1993) using males, reported that mean hand speed was 19.2 m/s ($\underline{SE}$ = 0.6) and the mean post-impact volleyball speed was 27.0 m/s ($\underline{SE}$ = .9). The current investigation resulted in lower hand and ball velocities than the Chung (1988) or Coleman, et al. (1993) studies. The differences in hand and ball speed may be due to the use of different methodologies, higher skilled players, and the inclusion of the jump before the arm swing by Chung (1988) and Coleman et al. (1993).

Correlational results have also been reported. Chung (1988) reported a significant correlation of 0.81 ($\underline{p}$ < 0.05) between mean hand speed and mean post-impact ball velocity. Coleman, Benham, and Northcott (1993) reported a significant correlation of 0.75 ($p < 0.01$) between the angular velocity at the shoulder and ball speed. This has been reported to indicate that the speed of the hand and the angular velocity at the shoulder were good predictors of post-impact ball speed.

In the current investigation, no significant correlation was found between pre-impact hand speed and post-impact ball speed for the BAS technique (See Table 4). In addition, there was no significant correlation between pre-impact shoulder angular velocity and post-impact ball speed. Since it is theorized that the BAS technique is primarily dependent on action at the elbow (relative to the shoulder), this latter finding is expected. Although no significant correlation was found between pre-impact hand speed and post-impact ball speed, a significant correlation was found between pre-impact elbow angular velocity and post-impact ball speed for the BAS.

Regarding the CS technique, no significant correlation was identified between angular velocity at the shoulder or the elbow and post-impact ball speed (See Table 5). These results may be attributed to a greater number of required trials to successfully complete the CS, which may have resulted in greater variability of the kinetic parameters of the multi-segmented system of the arm.

If, in fact, subjects were more familiar with the BAS in which angular momentum is transferred along the multi-segmented system, a tendency to generate this transfer may explain the lack of correlation between shoulder angular velocity and hand speed. On the other hand, a significant correlation was found between pre-impact hand speed and post-impact ball speed for the CS. These correlational findings may be attributed to technique differences in the kinetic patterns associated with the BAS and CS volleyball spikes. In addition, it is possible that the techniques utilized in previous work (Chung, 1988; Coleman, et al., 1993) were similar to the CS technique in this study.

Alternatively, Fleisig, et al., (1996) compared football and baseball throwing in which data was originally collected at 200 HZ. When the authors re-evaluated three of the football trials at 67 HZ, shoulder internal rotation velocities were reduced approximately 25%. Hence, experimental errors (e.g., sampling rate) may partially explain differences in the results. Chung (1988) supported this possibility. He noted that post-impact ball velocity had higher variability. In addition, another possible factor resulting in differences between the patterns exhibited in this study and previous research include skill level, in regards to the general level of the subjects and the skill level for each technique.

Focus on Theoretical Base.

The CS was expected to generate a higher post-impact ball velocity and a higher pre-impact hand velocity due to its emphasis on the greater muscle mass (shoulder musculature) and longer lever arm. As expected, a significant difference in post-impact ball velocity ($p = 0.012$) was reported (See Table 3). From these results, it would appear that the CS technique is a more effective volleyball spiking technique, and this is in fact a conclusion of this study. However, pre-impact hand velocity between the two techniques was not significantly different ($p = 0.420$).

How the CS created a higher post-impact ball velocity while having a similar pre-impact hand velocity to the BAS is unclear. Based on the law of impacts, pre-impact hand speed must be maximal in order to maximize post-impact ball velocity. By maximizing hand velocity, greater momentum from the hand is developed and can be transferred to the volleyball. Maximal hand velocity is related to the acceleration of the hand (at the distal end of the rotating lever arm). As the mass of the hand is accelerated from rest (initial velocity of zero), it applied a force upon contact with the ball. As this impulsive force is applied to the ball, the motion (velocity, momentum) of the ball is changed.

The impulse-momentum relationship states that the impulse acting on an object is equal to the change in momentum of the object [$Ft = m(v_2 - v_1)$; where F = force, t = duration of force application, m = mass of object receiving force, v_1 = initial velocity of object receiving force, and v_2 = final velocity of object receiving force]. In this way, the impulse from the hand results in a change in momentum of the ball. Since the mass of the ball is constant, the change is observed as a change in velocity. Therefore, the momentum (velocity) of a system (volleyball) can be altered by changing the force and the time over which the force acts. Since significant differences were found between the BAS and CS technique for post-impact ball speed but no differences were found between pre-impact hand speeds, it is suggested that time of contact between the hand and the ball differs between the BAS and CS technique. In this case, time of contact was greater in the CS when compared to the BAS since ball velocity was greater but hand velocity was not different. Although every attempt was made to eliminate mis-hits and maintain consistent kinetic patterns, variability in theses factors may have contributed to differences in contact time and would also suggest a reason why no correlations were found between post-impact ball speed and elbow angular velocity or hand speed in the BAS. Unfortunately, time of contact could not be measured in the current study.

When applying the impulse-momentum relationship to sports performance, it should be noted that an equal change of momentum could be accomplished by either applying a large force over a short time or a smaller force over a longer time. Therefore, in sports skills in which quickness and deception increase the effectiveness of performance, it is advantageous to decrease the time interval such that the opposition is at a greater disadvantage to react. This is consistent with volleyball spiking in which it is preferable to limit the opponent's opportunity to react to the spike and return the ball. Since the CS generated greater post-impact ball velocity with an equivalent pre-impact hand velocity when compared to the BAS, it is suggested that time of contact was greater. Since it was observed that subjects appeared to be more familiar with the BAS, it is possible that time of contact was shorter due a greater ability to effectively spike the ball under game-like situations. If so, this is a possible explanation for an increased time of contact for the CS, and suggests that in game situations, the advantages from an increased post-impact ball velocity from the CS may be negated as time of contact increases.

A lack of significant differences between pre-impact hand velocity of the CS and BAS also contradicts expected results due to an emphasis by the CS technique on the greater muscle mass (shoulder musculature) and longer lever arm ($v = \omega r$). Although the factors of muscle mass and lever arm length are not disputed in this study, no effect from the contribution of the transfer of angular momentum in a multi-segmented system such as the arm was assumed. Based on the results of this study, it is suggested that the transfer of angular momentum from the shoulder to the elbow does in fact have an effect on hand velocity. A greater hand velocity (resulting in greater post-impact ball velocity) from the CS was expected. However, a greater transfer of angular momentum along the multi-segmented system from shoulder to elbow in the BAS would appear to negate advantages in velocity due to muscle mass or lever arm length. Unfortunately, the transfer of angular momentum was not measured in the present study. And while this contradicts an original assumption, it may provide a methodology to quantify the transfer of angular momentum, which can be difficult.

Recommendations for Further Study.

The following recommendations are made for future studies:

1. A future study could use three-dimensional cinematography.
2. A future study could use high-speed cinematography to account for the time of contact.
3. A future study could look at the transfer of momentum to the ball, and striking mass of the hand.
4. The approach and take-off phases should be accounted for in future studies.
5. Two groups could be compared. One group who use the BAS, and another group that uses the CS.

6. There are other arm swing styles besides the BAS and CS. They could be compared also.
7. Looking at ball velocity coupled with EMG analysis of muscle involvement would make for a more comprehensive understanding of the volleyball spike.
8. The volleyball spike can be compared directly in a future study to other sports.

Conclusions.

The CS resulted in a significantly higher post-impact ball velocity than the BAS. This finding occurs in spite of a lack of statistical difference between hand speed, which suggests that additional factors affecting ball velocity include the time of contact between the hand and the ball and the transfer of angular momentum.

APPENDIX A:

INFORMED CONSENT

Statement of Informed Consent

The purpose of the study is to determine if differences exist between ball velocities created by the volleyball bow-and-arrow arm swing and circular arm swing. Markers will be placed at the hip, shoulder, elbow, wrist and hand. From a standing position, each subject will have three trials for each of the two arm swing styles. No jumping is involved. The subjects will be videotaped in the sagittal plane as they perform the trials. This study is also being conducted in order for me to complete my master's thesis for the Department of Physical Education and Sport at SUNY College at Brockport.

In order to participate in this study, your informed consent is required. You are being asked to make a decision whether or not to participate in the project. If you want to participate in the study, and agree with the statements below, please sign your name in the space provided at the end. You may change your mind at any time and leave the study without penalty, even after the study has begun.

I understand that:

1. My participation is voluntary.
2. My confidentiality is guaranteed. If any publication results from this research I will not be identified by name.
3. There is a small risk of injury involved in the study.
4. My participation involves hitting three balls maximally for each of the two arm swings.
5. 10 people will take part in this study. The results will be used for the completion of a master's thesis by the primary researcher.
6. The videotapes will be stored in the biomechanics lab. The only people that will have access are the researcher, Dr. Williams and Dr. Too.
7. When the thesis has been accepted and approved, all consent forms and videotapes will be destroyed.

I am 18 years of age or older. I have read and understand the above statements. All my questions about my participation in this study have been answered to my satisfaction. I agree to participate in the study realizing I may withdraw without penalty at any time during the process.

Primary Researcher
Jonathon Bowman
[redacted]

Faculty Advisor
Dr. Chris Williams
Dept. of Phys. Ed. and Sport
(716) 395-5252

Please print your name:________________________________

Signature:____

Date:____

APPENDIX B:

DATA COLLECTION FORM

Data Collection Form

Date____________

Name_____________________________

Age____________

File ID #___ ___ ___ ___

Subject # Technique # Trial #

Height__________

Weight__________

Segmental Lengths

Arm____________

Forearm_________

Hand___________

Len's height__________

Camera distance________

Notes/Comments

APPENDIX C:

DATA SETS

Table 6
Data Set from BAS Technique

Subject #	Post Ball (v)	Pre Hand (v)	Pre Shoulder (ω)	Pre Elbow (ω)
1	12.84	9.06	-652.38	-486.68
2	13.17	13.26	-149.63	-1538.16
3	14.40	13.12	-304.64	-863.94
4	14.82	13.37	-331.89	-1154.87
5	13.32	11.23	-737.54	-508.54
6	10.95	11.20	-550.74	-612.36
7	12.31	11.66	-434.18	-1247.74
8	12.00	11.06	-261.29	-1206.91
9	10.83	10.02	-339.09	-547.62
10	12.53	12.63	-101.52	-1574.23
M	12.72	11.66	-386.29	-974.11
SD	1.23	1.37	197.00	402.40

Table 7
Data Set from CS Technique

Subject #	Post Ball (v)	Pre Hand (v)	Pre Shoulder (ω)	Pre Elbow (ω)
1	13.92	10.78	-639.09	-908.61
2	14.10	13.00	-132.78	-1468.97
3	14.46	12.56	-492.89	-478.12
4	15.49	12.70	-244.79	-1124.91
5	13.50	12.10	-649.97	-519.27
6	11.20	10.16	-137.00	-1189.00
7	12.38	11.38	-667.46	-1145.59
8	13.35	10.93	-359.78	-1043.66
9	10.58	9.55	-405.28	-712.91
10	13.65	10.89	-435.99	-943.40
M	13.26	11.41	-416.50	-953.44
SD	1.41	1.09	190.97	294.98

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VITA

The author, Jonathon Alan Bowman was born on a U.S. Air Force Base in [redacted]. He attended the State University of New York at Brockport from 1995 to 1997 and received a Bachelor of Science in Physical Education in 1997. He began work toward a Master of Science in Physical Education at the State University of New York at Brockport in the fall of 1998.