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A Comparison of the Traditional, Swing, and Chicken Wing Arm Movements on Volleyball Blocking in NCAA Division 1 Female Athletes

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A Comparison of the Traditional, Swing, and Chicken Wing Arm Swings on Volleyball Blocking in NCAA Division I Female Athletes

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ABSTRACT

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Blocking is highly correlated with team success. The identification of specific techniques that produce a more successful block would be helpful knowledge for coaches and players. This study compared the traditional, swing, and chicken wing arm swings in combination with the running step footwork pattern in order to determine which arm swing enabled athletes to perform a more effective block. The time it took the athletes to get off the ground and get their hands above (vertically) the net was calculated. The distance the hand reached over the net or hand penetration (displacement between the net and finger in the anterior and vertical planes) was also measured. Lastly, jump height was calculated. High-speed videography was used to capture the blocking movements of thirteen female NCAA Division I athletes. Data were analyzed using a repeated measures ANOVA test, pairwise comparison, and co-variate analysis. The chicken wing block arm swing was quickest in getting the athlete off the ground and getting their hands above the net. The swing block was greatest for hand penetration and jump height. These results can help coaches and players decide which arm swing will benefit them most as a blocking team and as individual blockers.

Keywords: blocking speed, jump height, net penetration, running step footwork pattern

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A COMPARISON OF THE TRADITIONAL, SWING, AND CHICKEN WING ARM MOVEMENTS ON VOLLEYBALL BLOCKING IN NCAA DIVISION I FEMALE ATHLETES

by Taubi J Neves

April 2010

Abstract

Blocking is highly correlated with team success. The identification of specific techniques that produce a more successful block would be helpful knowledge for coaches and players. This study compared the traditional, swing, and chicken wing arm swings in combination with the running step footwork pattern in order to determine which arm swing enabled athletes to perform a more effective block. The time it took the athletes to get off the ground and get their hands above (vertically) the net was calculated. The distance the hand reached over the net or hand penetration (displacement between the net and finger in the anterior and vertical planes) was also measured. Lastly, jump height was calculated. High-speed videography was used to capture the blocking movements of thirteen female NCAA Division I athletes. Data were analyzed using a repeated measures ANOVA test, pairwise comparison, and co-variate analysis. The chicken wing block arm swing was quickest in getting the athlete off the ground and getting their hands above the net. The swing block was greatest for hand penetration and jump height. These results can help coaches and players decide which arm swing will benefit them most as a blocking team and as individual blockers.

Introduction

Blocking is one of the most significant contributors in winning and losing volleyball games (Eom & Schutz, 1992; Lenberg, 2004). It is also one of the most difficult volleyball skills to master because it incorporates athletic ability with decision making (Scates, 1976). Decision making is difficult because every possession of the volleyball leads to a different scenario for blockers. The demand on blockers has increased because hitting has become more explosive and offensive combinations are being played at faster speeds (Coleman & Neville, 1990). Blockers adjust to these changes by anticipating where the ball will be set, making a quick decision, and executing a quick lateral move and jump with coordinated arm movements in order to defend the net effectively (Buekers, 1991; Cox, Noble, & Johnson, 1982).

Several characteristics define an effective block including lateral movement speed, quickness in getting off the ground and getting the hands above the net, jump height and hand penetration (displacement between the net and finger in the anterior and vertical planes) across the net. Lateral movement speed and quickness in getting off the ground are critical (Cox et al., 1982). A study performed on ten female national club league players showed the running step footwork pattern (Figure 1) resulted in the athletes getting from the middle to the right side of the court in the shortest time (Buekers, 1991). The time it takes a blocker to get both hands above the net height is an important characteristic because blockers are required to block quick offensive combinations. The ability to jump high and penetrate the plane of the net with the hands is another crucial characteristic in performing an effective block (Farokhmanesh & McGown, 1988). The farther the hands penetrate over the net, the more court area is denied.

Three different arm swings are used when performing a volleyball block. The “traditional” arm swing requires the player to keep their hands about shoulder level throughout the whole blocking motion until the jump (Figure 2). The "swing" arm movement utilizes a full arm swing where the arms and elbows are fully extended throughout the whole blocking motion (Figure 3). The last arm swing is relatively new and is referred to in this study as the "chicken wing" arm movement. In this block move, the upper-arms are swung back to get an upper-arm arm swing with the elbows flexed to a 90 degree angle throughout the move (Figure 4).

The effect of these three different arm swings combined with the running step footwork pattern on blocking efficacy is unclear. Since blocking is highly correlated to team success, knowing which of these arm swings lead to a more effective block is valuable for coaches and players. The purpose of this study was to better understand the effect of arm swing technique on blocking efficacy in NCAA Division I female volleyball players when performing a counter-movement jump in combination with the running step footwork pattern. To accomplish this purpose, the following research questions were addressed: a) Which arm swing allowed the athlete to get off the ground fastest? b) Which arm swing allowed the athlete to get their hands above the net quickest? c) Which arm swing allowed the athlete to reach over the net farthest? d) Which arm swing allowed the athlete to jump highest? It was hypothesized that the traditional arm swing would allow the athletes to get off the ground fastest and get their hands above the net quickest followed in speed by the chicken wing with the swing being the slowest. It was hypothesized that the swing would allow athletes to reach over the net farthest and jump highest followed in distance and height by the chicken wing with the traditional being the lowest.

Methods

Research Design

This study was a 1x3x4 repeated measures design. The independent variables of the study were the three different arm movements: traditional, swing, and chicken wing. The dependent variables were the a) amount of time it took the athlete to get off the ground from the start of the blocking motion, b) amount of time it took the athlete from the start of the blocking motion to get their hands above the net, c) amount of hand penetration the athlete had over the plane of the net, and d) athlete's jump height. The values for each dependent variable were the averages across trials for each subject for each arm movement.

Participants

Thirteen female NCAA Division I volleyball athletes (age = 19.4 ± 1.19 years, height = 182.2 ± 7.7 cm, mass = 70.63 ± 7.96 kg, and years of participation at the collegiate level = 2.23 ± 1.17 years) participated in the study. None of the participants had suffered an injury within three months of data collection that prevented them from playing in competitive matches and practices. Each athlete was highly practiced in the running step footwork pattern.

Data Collection

Spherical reflective markers, 1.4 cm in diameter, were placed on the following anatomical landmarks: the most distal, dorsal aspect of the second metatarsal of the right foot, the sacrum, and bilaterally on the dorsum of the proximal phalanx of the third finger. Two markers were placed on top of the net; one marker was 90 cm from the right net pole and the other was 152 cm from the left net pole. All markers were attached using double-sided tape (Figure 5).

A seven-camera Vicon Motion Analysis System (VICON Motion Technologies, Centennial, CO, 250 Hz) was used to capture a static trial and nine blocking movements. The static trial was used to document the relationship between each of the reflective markers while participants maintained a standing position. This was necessary to develop the transformation between the local segmental coordinate systems and anatomical coordinate systems. Camera location and orientation was determined using calibration procedures recommended by Vicon. All testing was performed in the same motion analysis laboratory and was completed on three consecutive days.

A portable outdoor volleyball net was placed in the middle of the calibrated motion analysis volume. The height of the net, measured at the center and sides of the net was regulation height (224 cm). The cameras were set up in a circle around the volleyball net with two cameras facing the athlete, two cameras on the sides of the athlete, and three cameras behind the athlete (Figure 6). Starting location was near the center of the net and was marked with tape on the floor.

Procedures

The study was described and explained to the athletes. Each athlete read and signed an approved informed consent form and completed a demographic questionnaire. The athletes then drew a paper from a hat listing the order of the arm swings to be performed. The orders on the paper were prepared beforehand using the Latin-square design.

Next, the athletes were taught the three different arm swings. They performed each arm swing in combination with the running step footwork pattern until they were comfortable with each movement. They practiced for two weeks. Each athlete met an acceptable performance level as evaluated by the primary researcher.

The athletes were required to follow a normal pregame routine the day before data collection which meant they did not work out 24 hours before their scheduled time, they ate a healthy meal, and they were in bed before midnight. The athletes came to the motion analysis lab dressed in their team issued spandex shorts, sports bra, and court shoes. The primary researcher measured and recorded the athletes’ height and weight (both with shoes).

Reflective markers were placed on the athletes when they arrived at the motion analysis lab. Once the markers were placed on the athlete, the athlete stood facing the net while a static trial was recorded. Next, the athlete was allowed five minutes of warm-up. The warm-up included performing three blocking movements for each different arm swing. Once the warm-up was complete, the athlete was asked to line up in their starting position facing the net with their left foot near the tape. When the primary researcher said “Go,” the athlete performed a maximum effort block jump to their right using the running step footwork pattern in combination with the appropriate arm swing for each trial.

The athlete was allowed one minute to rest between trials. During this rest interval, the athlete was asked if they a) used their maximum effort, b) used the appropriate arm swing, c) used the running step, and d) were comfortable with the performance of the trial. Additional trials were required if the primary researcher believed the performance of the trial did not accurately reflect the appropriate arm swing or if the athlete answered no to any of the aforementioned questions.

This process was repeated using the three different arm swings in the randomly assigned order. After three acceptable block movements had been performed for each arm swing, the reflective markers were removed and the athlete was free to leave.

Data Processing

Three-dimensional coordinate data were derived from video data in VICON Nexus software (VICON Motion Technologies, Centennial, CO) using a modification of the non-linear transformation method developed by Dapena et al. (Dapena, Harman, & Miller, 1982). These coordinate data were imported into Visual 3D software in order to calculate three-dimensional joint kinematics. Coordinate data were smoothed using a fourth order Butterworth zero phase-lag low pass digital filter (Winter, 2005), with a cutoff frequency of 10 Hz (Blackburn & Padua, 2009; Decker, Torry, Wyland, Sterett, & Richard Steadman, 2003; Kernozek, Torry, & Iwasaki, 2008). Three dimensional joint angles were then calculated using the joint coordinate system method suggested by Cole et al. (Cole, Nigg, Ronsky, & Yeadon, 1993). Next, the three-dimensional coordinate and joint angle data were imported into Matlab (The MathWorks, Inc., Natick, MA) for additional calculations.

Movement was recorded on x, y and z axes; x was the anterior-posterior axis, y was the medial-lateral axis, and z was the vertical axis (Figure 7). In order to calculate the time it took for the athlete to get off the ground, start time and takeoff time were identified. The start time of each trial was considered to be the instant when the right toe marker resultant velocity (derived from the coordinate data using standard central difference equations) exceeded 1 m/s. Takeoff time was considered to be the instant when the height of the right toe marker exceeded the static standing height of the right toe marker by six times (after visual inspection of a number of different trials, this appeared to be a valid algorithm for takeoff identification). The time that elapsed between start and takeoff was considered to be the first dependent variable.

In order to calculate the time it took for the athlete to get their hands above the net, start time and the instant the athlete raised their fingers above the height of the net were identified. Each hand was considered separately. Start time was the instant the right toe marker resultant velocity exceeded 1 m/s. The finger was considered to be above the height of the net when the finger marker was greater than the net height on the z-axis. This process was repeated for both finger markers. The time that elapsed between start and the instant the finger was above the net was considered to be the second dependent variable.

When determining how far the athlete reached over or penetrated the net, each hand was assessed separately. The data included in this measurement were those recorded after the finger marker was greater than the net height on the z-axis and when the finger marker was greater than the anterior-posterior line of the net on the x-axis. The hand penetration was defined as displacement between the net and finger in the x-z planer (Figure 8). This process was repeated for both finger markers. The displacement was considered to be the third dependent variable.

Jump height was determined by finding the maximal height on the z-axis of the whole-body center of mass, which was represented by the sacral marker (Gard, Miff, & Kuo, 2004; Gullstrand, Halvorsen, Tinmark, Eriksson, & Nilsson, 2009; Saini, Kerrigan, Thirunarayan, & Duff-Raffaele, 1998). The maximum height was considered the fourth dependent variable.

Statistical Analysis

A repeated measures ANOVA was performed to determine the effect of the different arm swings on the dependent variables within each subject. If a significant difference was noted, Sidaks post-hoc comparisons were used to determine specific within subject differences among the different arm swings. Height, weight, age, and years of participation of the athletes at the collegiate level were used as co-variates in the analysis. The alpha level was set at $\alpha \leq 0.05$. Statistical analysis was performed using the Statistical Package for Social Sciences V18 (SPSS Corporation, USA).

Results

Table 1 lists the results, standard deviations, and statistical significances for the independent variables. The chicken wing was fastest in takeoff speed ($F = 4.39$, $p = 0.024$), quickest in getting both hands above the net (left hand $F = 9.52$, $p = 0.001$; right hand $F = 5.83$, $p = 0.009$), and second in amount of hand penetration and jump height compared to the other three techniques. The swing block was second fastest in take off speed, second quickest in getting both hands above the net, and farthest in the amount of hand penetration (left hand F = 10.73, $p < 0.001$; right hand F = 14.592, $p < 0.001$) and jump height (F = 61.56, $p < 0.001$) compared to the other three techniques. The traditional block was the slowest in take off speed and getting both hands above the net, and shortest in the amount of hand penetration and jump height compared to the other three techniques.

Discussion and Implications

Since blocking is highly correlated with team success, the purpose of this study was to determine which arm swing enabled athletes to perform a more effective block. The time it took the athletes to get off the ground and get their hands above the net, the amount of hand penetration over the net, and the jump height were calculated.

The data collected in this study showed the chicken wing technique allowed the athletes to get off the ground fastest compared to the other two arm swings. The results did not support the hypothesis that the traditional block would get the athletes off the ground faster. In fact, the traditional block was the slowest of the three arm swings. Even with a full arm swing, the swing technique got the athletes off the ground quicker than the traditional block which utilized no arm swing. One explanation might be that when the athletes performed the full arm swing, it lowered their center of mass which prepared them to perform the counter-movement to jump. Meanwhile, the traditional block did not have an arm swing to lower the center of mass; in order to jump, the athlete had to go from an almost standing position down to perform a counter-movement before they jumped which might have taken more time. On the same token, the chicken wing might be the quickest because the arm swing did prepare them for the counter-movement; however, the arm swing was not as big of a movement as utilized in the swing block, thus it did not take as much time to perform.

The time difference between the chicken wing block and the swing block is 0.03 seconds; the time difference between the swing block and the traditional block is 0.03 seconds. During a volleyball attack, approximately 0.34 seconds elapse from the instant of takeoff until the instant of ball contact. It takes an athlete 0.29 seconds to jump and cock their arm which means only 0.05 seconds are needed to swing the arm forward and strike the ball (Chung, 1988). If a blocker is not over the net by the time the attacker has started their arm swing, they will not have time to penetrate the net before the ball has passed them. The ability to get off ground faster by performing the chicken wing block as opposed to the traditional block and even the swing block is practically significant. Therefore, the differences in takeoff speed could influence a decision to change from one arm swing to another arm swing.

The data collected in this study showed the chicken wing technique allowed the athletes to get their hands above the net quickest compared to the other two arm swings. The hypothetical advantage of the traditional block was that the hands are closer to the top of the net from the start to the end of the blocking motion (the hands never drop); therefore, it was hypothesized that the traditional block would enable athletes to get their hands above the net more quickly than the other two arm swings (both drop their hands). However, the findings in this study do not support this hypothesis. The traditional arm swing was the slowest of the three arm swings. This study determined that both the chicken wing block and the swing block enabled athletes to get both their hands above the net quicker than the traditional block. Speculating, this may be explained by a lower center of mass that is created with an arm swing. The traditional block does not incorporate an arm swing to lower the center of mass; hence it might take longer for athletes performing a traditional block to get their hands above the net because it takes them longer to perform the jump compared to the chicken wing and the swing block.

A strong block is formed by having both hands above and reaching over the net at the same time. It is interesting to note that the left hand was above the net quicker than the right hand in the chicken wing block; the hands were above the net at the same time with the swing block; and the right hand was above the net quicker than the left hand in the traditional block. When the blocker turns to the right to perform the running step, the left side of their body is closer to the net. This may explain why the left hand gets above the net quicker than the right hand in the chicken wing block. If the blocker performed a block move to the left, theoretically, the right hand would be above the net quicker than the left hand. However, the swing block resulted in getting the hands above the net at the same time. This may be explained by the fact that the athletes who participated in this study were familiar with the swing block and their respective coaches had made them aware of the need to reach farther and faster with the right hand in order to get it above the net at the same time as the left hand. The traditional block is defined by having no arm movement. Keeping the hands at shoulder level is an unusual way to move in any sport. It may have been more familiar for the athletes to move with some arm movement like is used in the chicken wing block and swing block, than no arm movement that is typical of the traditional block. The lack of familiarity may have caused the different results of having the right hand above the net before the left hand found in the traditional block.

Offensive combinations are being played at quicker speeds. It is common for the sets to the outside hitters to be low and fast (Coleman & Neville, 1990). In order to block these sets, blockers must beat the ball to the outside of the court and have their hands above and penetrating over the net before the ball is hit by the opposing hitter. Experienced hitters take advantage of blockers when they only get one hand above the net by hitting it off the one hand that is over. The time difference between the right (slower) hands of the chicken wing block and the swing block was 0.01 seconds and between the left (slower) hands of the swing block and the traditional block was 0.06 seconds. To better understand these results, six random trials from each arm swing were selected and the velocity of the right finger was calculated after takeoff. The average of these velocities was 7.36 m/s. Assuming 7.36 m/s was the average velocity for the fingers of all the trials, the average amount of displacement was calculated. The average displacement in 0.01 seconds between the right hands of the chicken wing and the swing block was 7.36 cm. This means that at the same point in time, the right hand of the chicken wing block would be 7.36 cm higher than the right hand of the swing block. The average displacement in 0.06 seconds between the left hands of the swing block and the traditional block was 44.16 cm. This shows that at the same point in time, the left hand of the swing block would be 44.16 cm higher than the left hand of the traditional block. This is valuable information for coaches to understand. Coaches should be aware that blockers performing a running step in combination with the chicken wing or traditional arm swings result in getting the hands above the net at differing times; they should take this information into consideration when choosing an arm swing to use.

The data collected in this study showed the swing block was greatest for hand penetration compared to the other two arm swings. These results supported the hypothesis that the swing block would allow the athletes to reach over the net farther than the other two arm swings. The swing block incorporates a counter-movement and a full arm swing which have been shown to increase jump height (Walsh, Bohm, Butterfield, & Santhosam, 2007). The higher an athlete jumps, the farther they will be able to reach over the net. The chicken wing block was second farthest in hand penetration followed by the traditional block. Using the same reasoning, even a small arm swing is better than no arm swing (like the traditional block) in the amount of hand penetration over the net that is possible.

This study showed that in both the chicken wing and swing block arm swings, the right hand had more hand penetration compared to the left hand. This is interesting because in the chicken wing block, the right hand was the last hand to get above the height of the net. Even though the right hand took longer than the left hand to get above the net, it still reached farther than the left hand. The swing block, on the other hand, had both hands reach above the height of the net at the same time; however, the right hand still reached farther than the left hand. In theory, the momentum gained by swinging the arms back with the shoulders perpendicular to the net and then over the net, brings the shoulders parallel to the net and might also carry the body past being square to the net which could lead to more hand penetration of the later hand. If the blocker performed a block move to the left, theoretically, the left hand would achieve greater hand penetration compared to the right hand. The amount of hand penetration was the same for both hands in the traditional block. According to the aforementioned theory, this might be because there was no arm swing involved in this movement.

When looking at the right hand, the differences in hand penetration between the three different arm swings are practically significant. The difference between the right hands (which resulted in a farther reach compared to left hands) of the swing block and the chicken wing block is 2.90 cm. The difference between the right hands of the swing block and the traditional block is 5.10 cm. A penetration of 2.54 cm by the middle blocker takes away about 19.05 cm of court at the cross court sidelines (Lenberg, 2004). Thus, an additional 5.10 cm and 2.90 cm in net penetration is a very important variable to consider when choosing which arm swing to perform.

The data collected in this study showed the swing technique allowed the athletes to jump higher compared to the other two arm swings. It was hypothesized that the swing block would produce a higher jump height followed in height by the chicken wing block and the traditional block would be the lowest. The results of this study support this hypothesis. These findings also support the large amount of research that indicates that an arm swing together with counter-movement increases jump height (Harman, Rosenstein, Frykman, & Rosenstein, 1990; Lees, Vanrenterghem, & Clercq, 2004; Lees, Vanrenterghem, & De Clercq, 2006; Shetty & Etnyre, 1989; Viitasalo, 1982; Viitasalo & Bosco, 1982; Walsh, et al., 2007).

The differences in jump height between the three arm swings were statistically and practically significant. There was a 2.10 cm difference between the swing block and the chicken wing block, and a 3.00 cm difference between the chicken wing block and the traditional block. Research has shown that jump height is crucial because it allows the player to get their hands and arms over the net farther (Farokhmanesh & McGown, 1988; Gladden & Colacino, 1978; Richards, Ajemian, Wiley, & Zernicke, 1996; Viitasalo, 1982). Players or coaches of players who are shorter would benefit by using the swing block arm swing because it allows them to jump higher.

There were some limitations related to this study. The athletes in this study were familiar with the running step footwork pattern and were all competent in the swing block arm swing because this method was preferred by their respective coaches. This may have influenced the results. Additionally, these results probably do not completely represent results that might have been found during competition as this study was performed in a laboratory without a real visual start cue or hitter to block against.

Another limitation of this study was the limited number of participants and the inclusion of defensive specialists, who never block in a real competition. Future studies should select a greater number of participants from multiple NCAA Division I volleyball programs. This study focused on the running step footwork pattern going to the right. It would be important to look at the footwork pattern going in both directions because usually only the middle blocker is familiar with going both directions. The setter is usually more comfortable going to the right and the outside hitters are usually more comfortable going to the left. The last limitation of this study was the chicken wing block arm swing was still a relatively new arm swing for most of the athletes.

In order to more fully understand the results of this study, future research should record the amount of time it takes from the start of the blocking motion to the point of maximum hand penetration. Studies should calculate the angle of the arms over the net at the point of maximum hand penetration. Along with these variables, future studies should examine the distance in the anterior direction of the hands over the net. The calculation of joint angles and foot angles relative to the net would also provide coaches and players with valuable information.

Conclusion

In conclusion, the chicken wing technique was the quickest in getting the athlete off the ground and getting their hands above the net. The swing block proved superior in reaching farther over the net and jump height. This knowledge can help coaches and players decide which arm swing will benefit them most as a blocking team and as individual blockers. If coaches or players are looking for a quick block move that will get the blockers' hands above the net fast, the chicken wing block arm swing is preferred. If coaches or players are looking for the maximum jump height and hand penetration over the net, the swing block arm swing is suggested. The traditional technique does not seem to have any advantages. It may benefit athletes, especially middle blockers to learn both the swing and chicken wing techniques. Then the blockers would have the option to use either arm swing in a competitive setting. If they have ample time, the swing block would be recommended. However, if the blocker had to make a quick move, they could utilize the chicken wing block.

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Table 1

A comparison (mean ± SD) of the time to takeoff, time to hands above the net, hand penetration, and jump height between the traditional (T), swing (S), and chicken wing (CW) arm movements and post hoc comparisons.

	T	S	CW	T vs S (p value)	T vs CW (p value)	S vs CW (p value)
Time to takeoff (s)	1.37 ± 0.12	1.34 ± 0.13	1.31 ± 0.13	0.167	0.054	0.497
Time to hands above net (s)						
Left Hand	1.39 ± 0.11	1.33 ± 0.11	1.31 ± 0.10	0.005*	0.007*	0.843
Right Hand	1.38 ± 0.11	1.33 ± 0.11	1.32 ± 0.10	0.020*	0.030*	0.894
Hand penetration (cm)						
Left Hand	29.0 ± 6.02	32.8 ± 7.33	30.5 ± 7.20	0.001*	0.265	0.069
Right Hand	29.4 ± 5.89	34.5 ± 6.83	31.6 ± 6.83	0.001*	0.025*	0.045*
Jump height (cm)	152.2 ± 5.55	157.3 ± 6.23	155.2 ± 5.87	<0.001*	<0.001*	<0.001*

*Significant difference ($p \leq 0.05$)

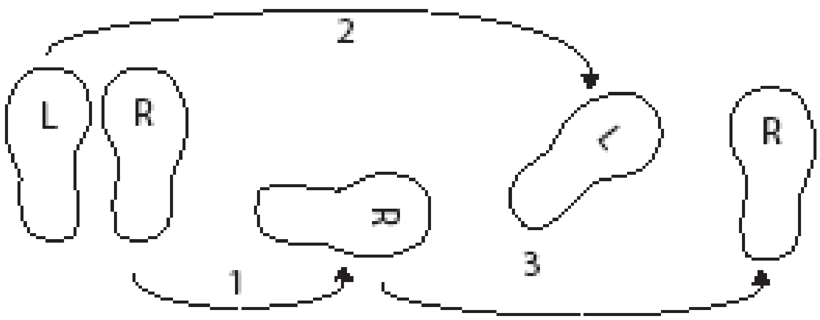

Figure 1. The running step footwork pattern. The athlete pivoted on the ball of the left foot and took a step with the right foot with the toes pointed parallel with the net. The shoulders turn from being square to the net to being perpendicular to the net. This step is followed by a long cross-over step with the left foot in front of the body. The third step brings the right foot around to plant so the toes are perpendicular to the net and the shoulders are squared to the net.

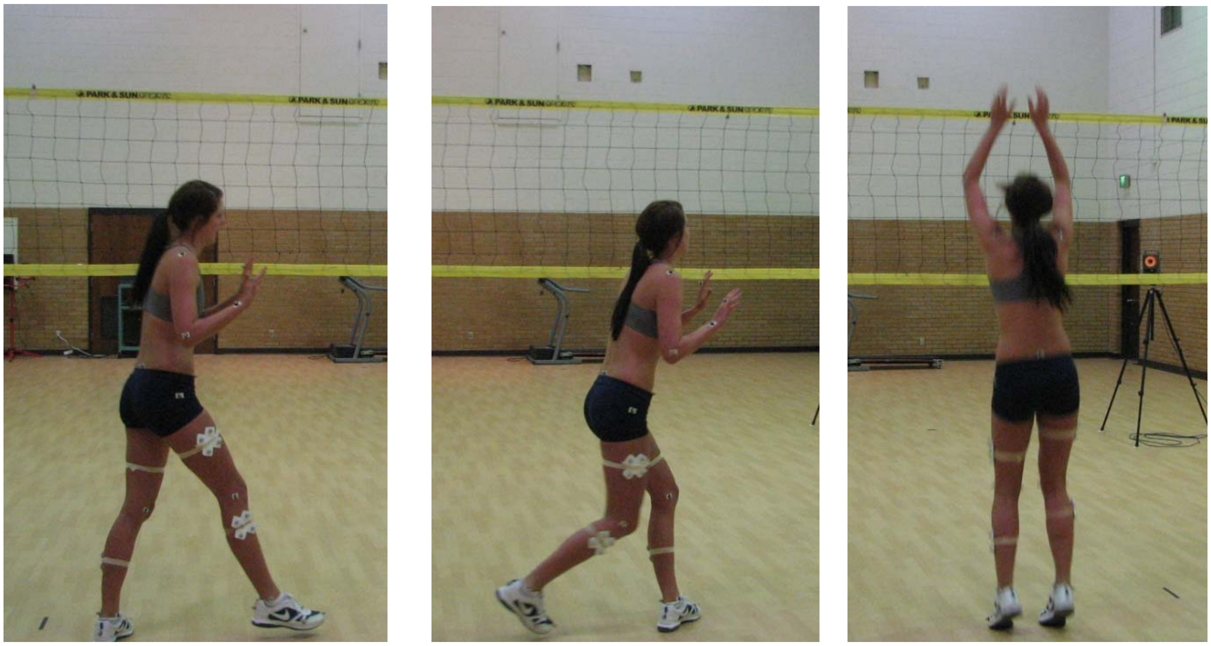

Figure 2. The traditional arm swing. Throughout the whole blocking movement, the hands stay close to shoulder level. At the final step, the athlete performed a counter-movement jump but did not drop their hands. The athlete then reached over the plane of the net as far as possible.

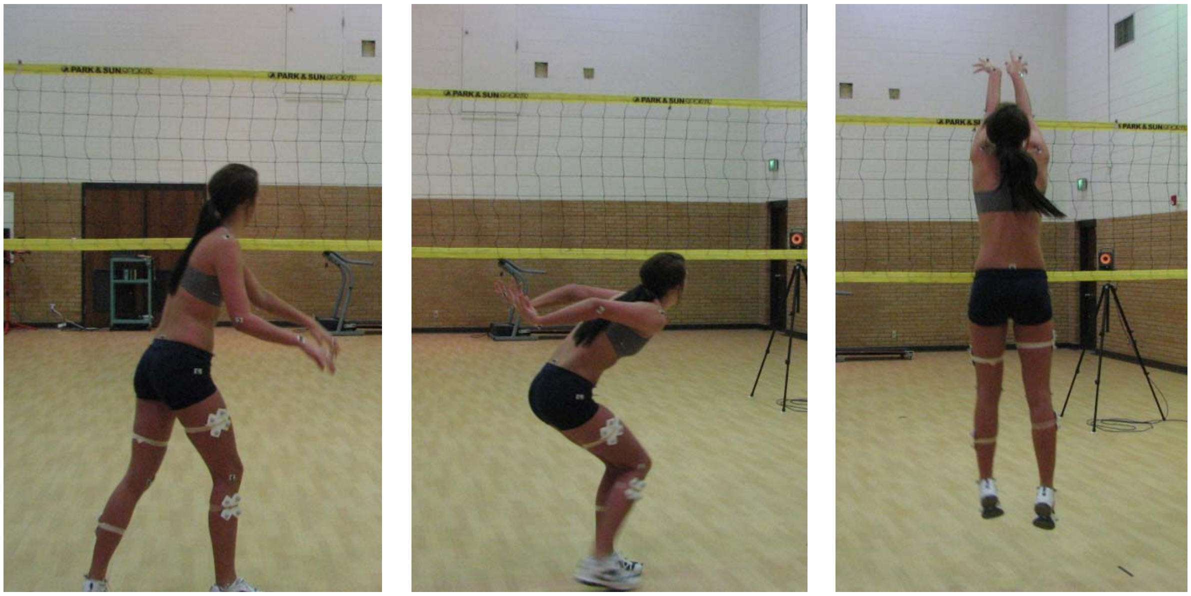

Figure 3. The swing arm swing. On the first step, the athlete dropped both hands in front of their body so the elbows were extended and fingers were pointed at the toe of the foot that took the first step (right foot). On the cross-over step, the arms were swung backwards as far as possible, allowing the athlete to be in position to perform a counter-movement. On the third step, the arms were swung up like a pendulum and over the net. The hands started penetrating over the net as soon as the hands cleared the plane of the net.

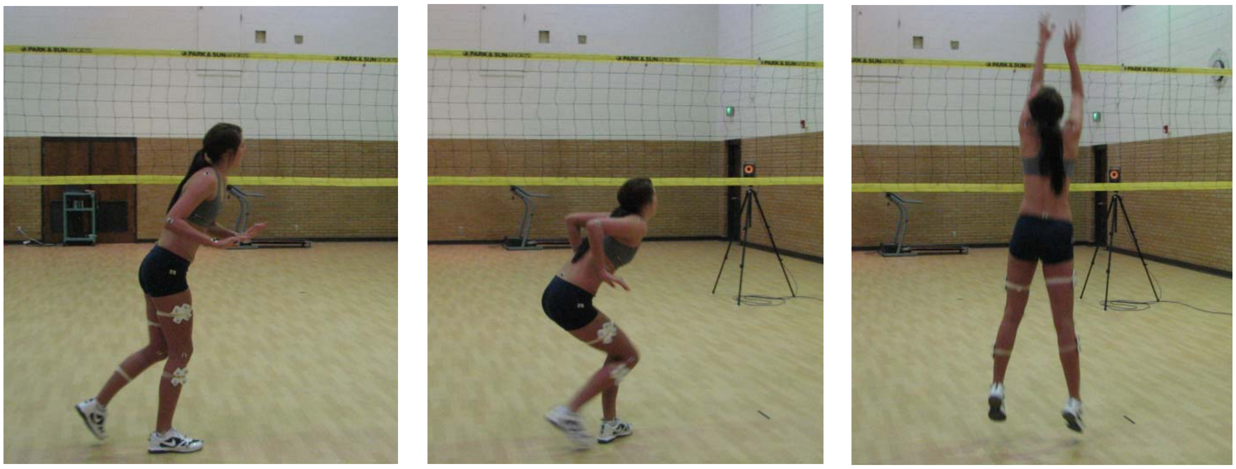

Figure 4. The chicken wing arm swing. On the first and second steps, the athlete performed an arm swing that felt natural to them with the elbows flexed to a 90 degree angle throughout the whole movement. The athlete performed a counter-movement jump and raised their arms over the net. The hands started angling over the plane of the net as soon as they are above the net.

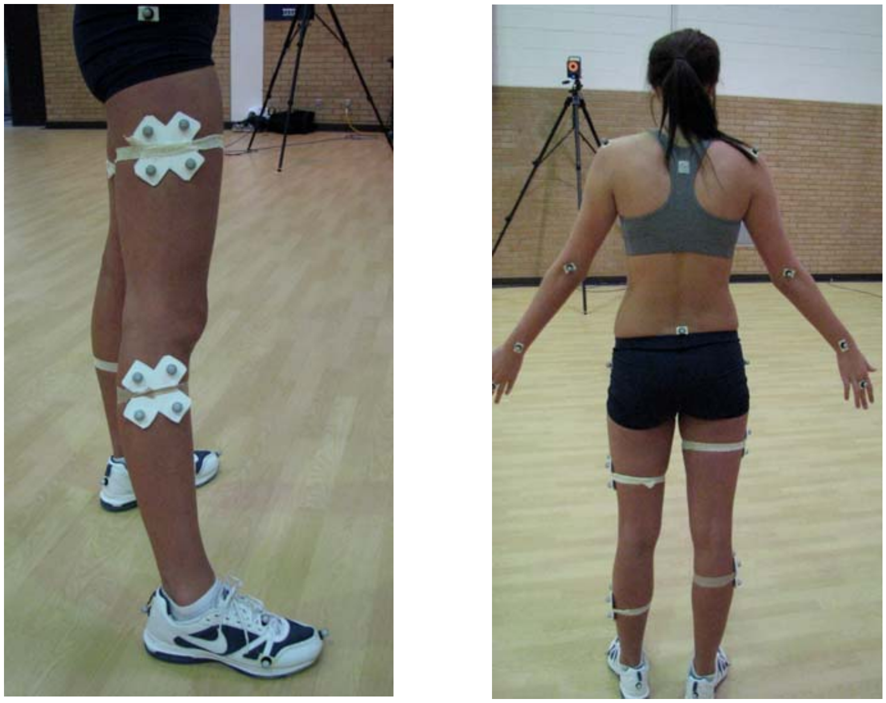

Figure 5. The placement of the reflective markers. All markers were attached using double-sided tape. The clusters were held in place with co-flex bandage wrap.

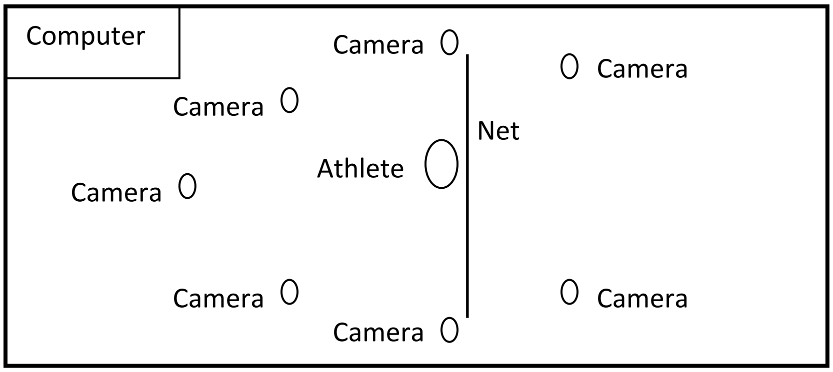

Figure 6. The set-up of the motion analysis laboratory. The cameras were set up in a circle around the volleyball net with two cameras facing the athlete, two cameras on the sides of the athlete, and three cameras behind the athlete.

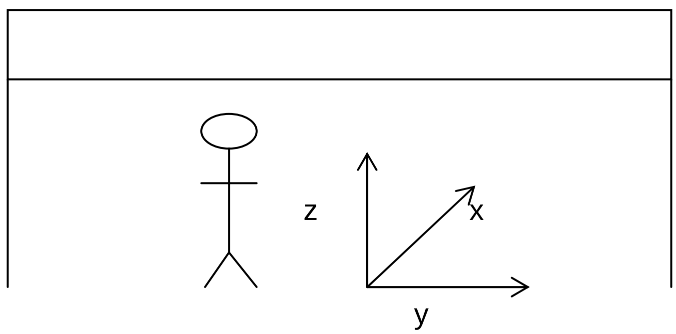

Figure 7. The axes used to measure the variables. Movement was recorded on x, y and z axes; x was the anterior-posterior axis, y was the medial-lateral axis, and z was the vertical axis.

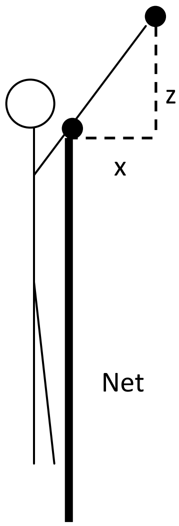

Figure 8. The hand penetration over the net. Hand penetration is defined as the displacement between the net and finger in the x-z planer. The penetration is demonstrated as the vector between the two black dots.

Appendix A

Prospectus

Chapter 1

Introduction

Blocking is one of the most significant contributors in winning or losing volleyball games (Eom & Schutz, 1992; Lenberg, 2004). However, it is one of the most difficult volleyball skills to master due to factors such as decision making, anticipation, jumping ability, and movement speed (Scates, 1976). In a volleyball game, not only are there many decisions to make, but also the circumstances in which these decisions are made change for every situation (Cox, Noble, & Johnson, 1982).

The level of volleyball play has progressed over recent years. Hitting has become more explosive in advanced levels of competition. Volleyball has evolved into a fast paced game because offensive combinations are being played at very high speeds. It is common to see a low and fast set to the outside hitter (Coleman & Neville, 1990). Thus, blocking techniques need to be more efficient to counter the hit. Often, in high competitive levels of play, two blockers are needed. The need for a double block (two blockers) forces blockers, especially the middle blocker, to execute an appropriate movement to the outside of the court in a shorter period of time (M. J. A. Buekers, 1991). The quicker offense increases the demand on the blockers, requiring them to adjust to increased requirements on movement speed, jumping height, anticipation, and decision making in order to defend the net effectively.

Movement speed, therefore, becomes a very important aspect in blocking. Several studies have investigated various footwork patterns to find the one that guarantees the fastest movement time. According to the literature, there are mixed results concerning the effectiveness of the different blocking footwork patterns. The most common footwork patterns are the slide step, cross-over step, jab step, and the running step. Recent research, performed on ten first and second national league female players, showed that the running step, which has gained popularity in recent years, was the fastest footwork pattern compared to the slide step and cross-over step. Still, the time difference between the fastest pattern (running step with 1,899 ms) and the slowest pattern (sliding step with 2,013 ms) was very minimal (M. J. A. Buekers, 1991). Another study performed on men and women in a beginning volleyball class found that the jab cross-over step, which is similar to the running step, produced the greatest vertical jump. The jab cross-over step produced an advantage of 0.6 inches; but again, the advantage was minimal (Farokhmanesh & McGowen, 1988).

The ability of a blocker to jump high and penetrate the net is crucial (Farokhmanesh & McGowen, 1988). The farther the arms penetrate over the net, the more court area is denied to the offense. Thus, jumping ability becomes a fundamental and vital skill component of volleyball (Richards, Ajemian, Wiley, & Zernicke, 1996). Ideally, a blocker must get to the blocking point and jump quickly without sacrificing vertical jump height. Most research conducted on the vertical jump does not incorporate the horizontal movement prior to jumping that is used in blocking (Fukashiro & Komi, 1987; Harman, Rosenstein, Frykman, & Rosenstein, 1990; Hudson, 1986; Robertson & Fleming, 1987; Shetty & Etnyre, 1989). Of the research that has been conducted on volleyball, most of the attention has been devoted to spiking while less than five studies have been dedicated to the total movement of volleyball blocking (M. J. A. Buekers, 1991; Cox, 1978, 1980; Cox et al., 1982; Farokhmanesh & McGowen, 1988; Kwak, Jin, Hwang, & Yoon, 1989).

Most athletes, when performing a maximum vertical jump, precede the jump with a counter movement and rapid arm swing to increase the jump height. An arm swing together with counter movement increases jump height (Walsh, Bohm, Butterfield, & Santhosam, 2007).

Counter movement is defined as a quick flexion of the knees during which the body's center of mass drops somewhat before being propelled upward (Harman et al., 1990). There is ample evidence that jump height, and therefore block jump height, is improved by a counter movement (Bobbert, Gerritsen, Litjens, & Van Soest, 1996).

Vertical jumps are often characterized by the swinging of arms. One study showed when arm movement was not used, the maximum ground reaction force was 2.5 times body weight, but when arm movement was unrestricted, the maximum ground reaction force was 3.7 times body weight. The study concluded that arm movement contributed approximately 30 – 40% of the height of a jump (Ramey, 1982). Another more recent study showed that arm movement contributed to vertical jump force, power, work done, and velocity but the contribution was 6, 14, 15, and 6%, respectively, which is less than the previous study (Shetty & Etnyre, 1989).

As jump height increases, the arms are hyper-extended to a greater extent and go through a greater range of motion (Lees, Vanrenterghem, & De Clercq, 2006). The greater hyper-extension provides more energy which can be used to "pull" on the rest of the body (Lees et al., 2006). It seems that the bigger the arm swing, the greater the jump height. There are, however, situations in volleyball where it would not be advantageous to use an arm swing. For example, if an athlete must reach up on very short notice to block a quick volleyball spike, the hands can reach the ball most quickly if they start in the up position and go directly to the ball without going down for the swing.

Until recent studies on women athletes and knee injuries, most of the research looking at jumping has been performed on men (Walsh et al., 2007). There are a number of physical and physiological differences between men and women that could possibly affect jump performance.

There are differences in anthropometric proportions, muscle architecture, capability of storing elastic energy, and strength between men and women (Chow et al., 2000; Komi & Bosco, 1978). Vertical ground reaction force is proportional to the accelerations of all body segments; therefore, changes in the distribution of body mass would change the acceleration of the body segments which in turn would change the ground reaction force. Because there are differences in upper and lower body anthropometric proportions between men and women, ground reaction force will be affected which will in turn affect jump height. There are also gender differences in muscle architecture and elastic energy storage capabilities. Women have greater fiber bundle length, lesser pennation angles, and are able to utilize a larger percentage of the energy stored during the eccentric phase of jumps (Chow et al., 2000; Komi & Bosco, 1978). Also, women in general have greater lower body strength in proportion to upper body strength (NASA, 1978). Thus, although the use of arms has been shown to contribute more to jump performance than the counter movement for men and women, women may benefit more in performing a counter movement than an arm swing (NASA, 1978; Walsh et al., 2007). These differences alone may influence the mechanics of jumping which shows that models used to represent men jumping will not accurately represent women jumping.

Volleyball players have been taught different types of arm swings to use when performing a block. The “traditional block” move requires the player to keep the hands at ear level (like Mickey Mouse ears) throughout the whole blocking motion. This kind of block can be compared to a jump with counter movement but no arm swing. The “swing block”, which has gained popularity over recent years, utilizes a full arm swing in which the arms and elbows are fully extended throughout the whole blocking motion. The arms swing back and up in a movement similar to that of a pendulum. This type of block is a typical counter movement jump with a full arm swing. The last and relatively new arm movement in a volleyball block will be referred to as the "chicken wing block." When performing this block move, the arms are swung back to get an upper arm swing, but the elbows are flexed to a 90 degree angle.

Research Problem and Purpose

Research literature has not explored the different types of arm movements combined with the footwork patterns used in volleyball blocking. Knowing which arm movement is associated with a quicker jump takeoff, getting the arms over the net faster, a farther net penetration, and a higher jump is valuable information for coaches as well as athletes. Because of the lack of available research on the arm movement in a volleyball block, there is a need for information regarding this subject. The purpose of this study is to determine which of the three arm movements (traditional, swing, and chicken wing) allows a player to 1) get off the ground faster, 2) get their hands over the net faster, 3) reach over the net farther, and 4) jump higher when performing a counter movement block jump with a running three-step footwork pattern.

Hypothesis

Reason shows that the advantage of a traditional block is that the arms are closer to the top of the net. Athletes that use this type of arm movement should be able to get their hands over the net relatively quickly. The swing block arm movement uses a counter movement and a big arm swing and should therefore allow athletes to reach over the net farther and jump higher. No research has been performed on the chicken wing block; therefore, the results are difficult to hypothesize. However, the chicken wing incorporates parts of the traditional and swing block, and thus may have the advantages of both. The chicken wing block may be faster than the swing block, but slower than the traditional block in getting the athlete's hands over the net. The chicken wing block may result in reaching over the net farther and a higher jump than the traditional block, but less than the swing block.

Null Hypothesis

1. No significant difference will exist between the three blocking techniques in the time it takes the athlete to get off the ground.
2. No significant difference will exist between the three blocking techniques in the time it takes the athlete to get their hands over the net.
3. No significant difference will exist between the three blocking techniques in the distance they can penetrate over the net.
4. No significant difference will exist between the three blocking techniques in jump height.

Alternative Hypothesis

1. The traditional block arm movement will require significantly more time compared to the other two arm movements for the athlete to get their hands over the net.
2. The traditional block arm movement will require significantly more time compared to the other two arm movements for the athlete to get off the ground.
3. The swing block arm movement will show a significant difference compared to the other two arm movements for the distance an athlete can reach over the net farther and the athlete's jump height.
4. The chicken wing block will require significantly more time compared to the traditional block arm movement for the athlete to get their hands over the net;

however, the chicken wing block will require significantly less time compared to the swing block arm movement for the athlete to get their hands over the net.

5. A significant difference will exist between the time it takes for the athlete using the chicken wing block arm movement in reaching over the net farther and a higher jump than the traditional block, but less than the swing block.

Definition of Terms

Chicken Wing Block – the footwork pattern utilized in the chicken wing block is the running three-step pattern. On the first and second steps, the blocker will perform an arm swing that feels natural to them with the elbows flexed at a 90 degree angle. The athlete will perform a counter movement jump and raise the arms over the net. The hands start angling over the plane of the net as soon as they are above the net.

Elite athlete – an athlete that has demonstrated enough competency in the sport of volleyball to be recruited by an NCAA Division I volleyball program.

Middle Blocker – the blocker that is positioned in the middle of the court and is responsible to block all the quick sets in the middle of the court and also the slower set to the outside of the court.

Running three-step footwork pattern – a pivot on the ball of one foot and taking a step with the other with the toes pointed parallel with the net. The shoulders turn from being square to the net to being perpendicular to the net. This step is followed by a long cross-over step with the opposite foot in front of the body. The third step brings the other foot around to plant so that the toes are perpendicular to the net and the shoulders are squared to the net.

Starting position – all athletes will have the same starting body position. The athlete will start standing the distance from their elbow to their fingers away from the net. They start with feet shoulder width apart, knees slightly flexed (around 20 degrees), and their weight centered on the balls of their feet. The hands will be held up by their ears in the Mickey Mouse ear position. All blockers will start in the starting position in the middle of the court.

Swing Block – the footwork pattern to be used for the swing block is the running three-step pattern. On the first step in the footwork pattern, the blocker will drop both hands in front of the body so the elbows are extended and fingers are pointed at the toe of the foot that took the first step. On the cross-over step, the arms are swung backwards as far as possible, allowing the athlete to be in position to perform a counter movement. On the third step, the arms are swung up like a pendulum and over the net. The hands start penetrating over the net as soon as the hands clear the plane of the net.

Traditional Block – the footwork pattern utilized in the traditional block is the running three-step pattern. Throughout the whole footwork pattern, the hands are positioned by the ears, like Mickey Mouse ears. At the final step, the athlete performs a counter movement jump but does not drop their arms. The hands reach over the plane of the net as far as possible.

Delimitations

The participants of this study will be female NCAA Division I volleyball players from Utah State University between the ages of 18 – 21 yrs. The study will be performed in a laboratory setting. The participants are familiar with the running three-step footwork pattern. They are all competent in the swing block arm movement because this method is preferred by their respective coaches.

Assumptions

1. Subjects will perform each test with the intent of performing their best.

2. The results will not completely reflect the results that may be found in a competitive setting.
3. Each subject probably has a preferred arm movement that may influence the results.
4. The calibrations of the equipment used will be accurate.

Limitations

1. The lack of a competitive, game-like situation.
2. The subject's effort during the testing.
3. The direction of the footwork patterns only being to the right.
4. Subjects are not randomly selected.
5. The accuracy of putting the reflector dots on the same spot for each subject.
6. The subjects will consist of varying degrees of healthy and fit conditions.
7. The chicken wing arm swing will be relatively new for most of the participants.

Significance

Blocking has been shown to be a very important aspect in the game of volleyball (Eom & Schutz, 1992; Lenberg, 2004). Blocking is highly correlated to team success; thus, this study will be useful to coaches of teams of all ages and players of all ages. This study will provide coaches and players with greater insight as to which arm movement will benefit them most as a blocking team and individual blockers. This study will also be beneficial because it will add to the small amount of research that has been performed on women's volleyball blocking.

Chapter 2

Review of Literature

Volleyball is a sport composed of six main skills: serve, serve receive, set, spike, block, and dig (Eom & Schutz, 1992; Grgantov, Dizdar, & Jankovic, 1998). A volleyball game consists of an integrated playing action of these six main skills (Eom & Schutz, 1992). Several studies have been performed to collect quantitative data on each of these skills in order to help coaches predict game outcomes and to investigate the relationship between skill performance and team success (Cox, 1974).

In the 1974 World Games, the blocking average of a team correlated higher with tournament rank, win-loss ratio and percentage of games won than any other factor. Blocking was second only to spiking in determining team success in the 1984 Olympic Games (Lenberg, 2004).

Eom and Schutz (Eom & Schutz, 1992) defined the measure of team success as game outcome, either a win or a loss. They found that of the six main volleyball skills, three formed the most significant contributors that differentiate between winning and losing volleyball games. Listed in order of greater to lesser relative importance, these contributors were the block, the spike after a dig, and the spike after the serve (Eom & Schutz, 1992). A better performance of these skills led to more points, which resulted in the team winning more volleyball games. A successful team, therefore, has the ability to recover from the opponent's initial attack, organize a team play, and perform a successful counterattack.

The block, the spike after a serve, and the spike after a dig, are skills that have direct team interactions at the net. The block is the team's first line of defense. The purpose of the block is to angle one's arms over the net as far as possible into the opponent's half of the court and stop the opponent's spike at the net by either stuff blocking or channeling the attack options to a selected court area (Grgantov et al., 1998). The farther the arms penetrate over the net, the more court area is denied. For example, one inch of penetration by the middle blocker takes away about seven-and-a-half inches of court at the cross court sidelines (Lenberg, 2004). So, twelve inches of penetration will cut off seven-and-a-half feet of court sideline. The purpose of the spike is to put the ball on the opponent's court. This is accomplished by avoiding the block (Eom & Schutz, 1992). A perfect execution of either of these skills results in the scoring of a point. Winning a game is determined by the number of points scored, so the better performance of these skills is directly related to team success (Eom & Schutz, 1992).

Because spiking has become very explosive at advanced levels of play, a spiker usually beats a single blocker in most cases. For this reason, it has become important to attempt to put two and sometimes three blockers on one spiker. There are several different blocking systems utilized by coaches. The spread blocking system positions the two outside hitters close to each antenna. The middle blocker has more responsibility than the other blockers in this system because they must stay with the setter and middle hitter in order to block all the quick middle sets, as well as block against the high outside attack (Lenberg, 2004). The bunch blocking system positions the two outside hitters close to the middle of the court. They help with the quick sets in the middle of the court and move with the middle blocker to block the sets to the outside of the court. To block outside, the middle blocker must move quickly along the net and coordinate with the outside blocker to form an effective two-player block (Lenberg, 2004).

According to Scates, blocking is one of the most difficult volleyball skills to master because it depends on many different factors (Scates, 1976). These factors include decision making, anticipation, jumping ability, and speed of movement (M. Buekers, 1987). Not only are there a number of decisions to be made, but also the circumstances change for every situation (Cox et al., 1982). A predictable set on the opponent's side allows enough time for the team to form a solid block against the spiker (Eom & Schutz, 1992). However, offensive combinations are being played at greater speeds. In today's fast paced game, it is common for the set to be low and fast to the outside (Coleman & Neville, 1990). It is part of the offensive strategy not to reveal which hitter will get the ball. This forces blockers, especially middle blockers, to wait to see the direction of the set then execute an appropriate movement in a shorter period of time (M. J. A. Buekers, 1991). One of the major problems facing middle blockers is the time constraints that determine their actions (M. J. A. Buekers, 1991).

Speed of Movement

Movement speed, therefore, plays a very important role in the execution of a block. There are several things a blocker can do to increase their movement speed. One factor is anticipating where the ball will be set. The blocker can watch the attackers peripherally while concentrating on the setter. By watching the setter's body movements, the setter's position in relation to the attackers and analyzing the attackers on the other side of the net, blockers can predict, or anticipate to a certain extent, the future course of play instead of reacting to the situation. This helps blockers get to the appropriate blocking position. A study performed by Neumaier confirmed the importance of this anticipation in volleyball blocking (Neumaier, 1983).

However, even though anticipation behavior may help a blocker predict from which position the ball will be spiked, there are many game situations when the speed of lateral movement and quickness in getting off the ground are critical (Cox et al., 1982). The blocker in the middle of the court will still have to execute a very quick lateral displacement to get to the outside edges of the court to form a double block with the outside blocker. In many game situations, a fast lateral movement is required to reach the correct takeoff position (M. J. A. Buekers, 1991). Often times, the middle blocker must jump immediately upon arrival to the outside position. Therefore, another important factor is footwork patterns. It is important to use a footwork technique that will guarantee the fastest movement time.

Several studies have investigated various footwork patterns to determine which pattern guarantees the fastest movement time. According to the literature, there are mixed results concerning the effectiveness of different blocking footwork patterns. The most common footwork patterns that middle blockers use to move to the outside are the slide step, cross-over step, and jab cross-over step (Lenberg, 2004).

The slide step involves three separate steps. The first step moves the lead foot laterally in the direction of the target surface. Step two is a quick slide step which closes the trailing foot to within six inches of the lead foot. The last step is made laterally by the lead foot again into the center of the target surface (Figure 1).

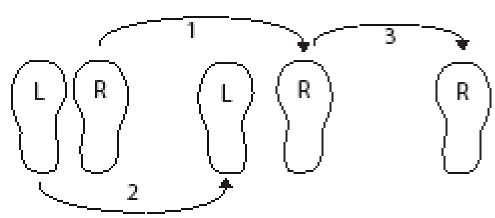

Figure 1. The slide step

The cross-over step involves two separate foot movements. The player crosses one foot in front of the other for the first step. If moving right, the player initiates the first step with the left foot. The second step is made by bringing the right foot around into the center of the target surface. The last step closes the left foot to the right foot and brings the feet perpendicular to the net (Figure 2).

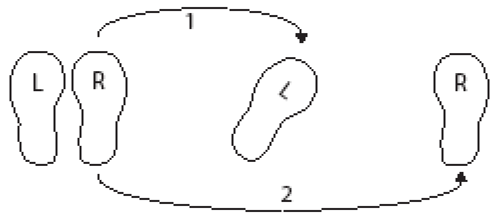

Figure 2. Cross-over step

The jab cross-over is another three step footwork pattern. The first step is executed by pivoting on the ball of one foot and taking a big step with the other. If moving right again, the blocker pivots on the ball of the left foot and takes a step with the right foot. This step is followed by a long cross-over step with the left foot, planting the foot so the toes point toward the opponent's court. The final step swings the right foot around and into the center of the target surface keeping the shoulders squared to the net (Figure 3) (Cox, 1978; Cox et al., 1982).

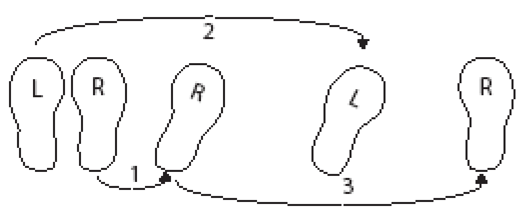

Figure 3. Jab cross-over step

In 1978, Cox compared the slide step, the cross-over step, and the jab cross-over step footwork patterns (Cox, 1978). He selected 45 male volunteers to participate in his study. Each volunteer was untrained in competitive volleyball, right-footed, and randomly assigned to one of the three footwork patterns. The volunteers straddled a line in a ready position (knees slightly bent, feet shoulder width apart, and hands held at shoulder height) marked between two contact mats. In front of them was a display board. Subjects performed the appropriate footwork in the direction of a light stimulus from the display board. Time was measured at the beginning of the light stimulus and ending upon contact with the contact mat. Cox found the slide step technique was the best technique for fast lateral displacement compared to a cross-over step and a jab cross-over step. Still, the difference between the slide and cross-over steps was only 45 milliseconds. However, inexperience of the participants may have skewed the results.

In 1980, Cox investigated the response times for skilled volleyball players versus the unskilled subjects in his earlier study (Cox, 1980). He selected 30 male and 12 female skilled volleyball players to participate in his study. The procedure was the same as his 1978 study, and his findings were in agreement with his earlier work. He found the slide step technique was faster than the cross-over step techniques in lateral movement. The results of these studies conclude that a volleyball player, regardless of gender, can move from one point to another point more quickly using a slide step instead of a cross-over or jab cross-over step. However, these findings show nothing about the effectiveness of getting the blocker into actual airborne blocking position which is an essential aspect of blocking (Cox et al., 1982).

Cox, Noble, and Johnson performed another study in 1982 looking specifically at the relationship between selected time variables involved in the jumping and blocking action, and the same step techniques (slide step, cross-over step, and jab cross-over step) (Cox et al., 1982). Three male and three female skilled volleyball players, who were well practiced in the three steps, volunteered to participate in the study. The trials were filmed using two 16mm Locam cameras at 100 fps. One of the time variables studied was gathering time, defined as the time that elapsed from the instant the subject's outside foot hit the target surface until the whole-body center of gravity started upward continuously. Another time variable recorded was called portioned impulse time, which is the portion of impulse time from the instant the whole-body center of gravity started an uninterrupted upward motion from the target surface until both feet left the base of support, or when the whole-body center of gravity was no longer stationary or displacing downwards but displacing upward in a continuous motion until both feet had left the surface of support. Cox(Cox et al., 1982) found the jab cross-over step was superior to the other two methods. The difference could be attributed to gathering time and portioned impulse time (Cox et al., 1982).

According to this study, the slide step seemed to require an excessive amount of time during the gathering and portioned impulse phases of the vertical jump (Cox et al., 1982). This was explained by the fact that when the third step placed the athlete’s foot on the target surface, the inside foot still had to close with the outside foot before the jump could be performed. So, although Cox’s first study showed the that slide step actually got the blocker to the target position faster, a larger amount of time was required to gather and jump (Cox et al., 1982).

The jab cross-over step allowed the blocker to begin gathering for the jump on the second step and be nearing the portioned impulse time phase of the jump by the time the outside foot contacted the target surface. This combination resulted in a lower gathering time in the jab cross-over step compared to the other two techniques which may explain the superiority of the jab cross-over step (Cox et al., 1982). Cox concluded that the step method that exhibited the smallest gathering and portioned impulse times would also produce the superior vertical jump. The literature also provides evidence that shorter take-off times are associated with higher jumps (Aura & Viitasalo, 1989).

The jab cross-over step allows the athlete to get into the air quicker. The dilemma that remains is that the coach cannot teach a blocker to use the slide step for one part of the block and the jab cross-over step for the other part of the block. The whole blocking action, which includes the lateral movement along with the vertical jump, has to be one continuous whole. Because the speed of lateral movement and quickness in getting off the ground are sometimes critical in a volleyball game, the results of this investigation support the conclusion that the jab cross-over step was superior. The advantage that the slide step had by getting to the outside of the court more quickly was outweighed by the advantages of a quicker take-off, smaller portioned impulse time, and possibly greater vertical jumping height that comes with the jab cross-over step (Cox et al., 1982).

The data collected by Cox in this experiment still failed to answer the question of which technique allowed the fastest total movement time (lateral displacement and block) (Cox et al., 1982). Total movement time is of the utmost importance in game situations. Farokhmanesh and McGowen conducted a study in 1988 with both men and women in a beginning volleyball class, using set distances and measuring both movement time and vertical jump (Farokhmanesh & McGowen, 1988). The subjects traveled nine or fifteen feet, because a middle blocker is not always in the center of the court. The subjects performed the slide step, cross-over step, and jab cross-over step. Farokhmanesh and McGowen found little difference in speed among the footwork patterns, whether the blocker was male or female. The difference between the fastest and slowest pattern was only 0.0014 seconds. The jab cross-over step did produce the best vertical jump, but the advantage was just 0.6 inches. Farokhmanesh and McGowen questioned the preference to any one technique based on such small differences. However, the small differences may be explained by lack of experience of the participants of this study.

Kwak, Jin, Hwang, and Yoon examined the slide and the cross-over steps in 1989 (Kwak et al., 1989). Ten male collegiate athletes and fourteen female professional athletes were filmed using a 16 mm high speed camera. The ground reaction forces were also recorded using an Advanced Medical Technology Incorporated (AMTI) force platform. When the horizontal velocities, which measure the speed of lateral movement, were compared, the horizontal velocity was greater in the cross-over step compared to the slide step in the case of males, while there was no difference in females. The authors stated that training biases may have been present because the males were trained using the cross-over step while the females were trained using the slide step. They also suggested the shorter reaction times of the cross-over step may be due to the body position upon arrival to the platform. The body position upon arrival to the platform for the cross-over step requires little counter movement, while the slide step requires greater counter movement.

In 1991, Buekers stated that the jab cross-over step used in Cox's experiments is different than the running step technique that is used in volleyball now (M. J. A. Buekers, 1991; Cox, 1978, 1980; Cox et al., 1982). The running technique, described by Beal and Crab, is a step out with the foot on the side of the intended direction with the toes pointed parallel to the net, cross step with the opposite in front of the body, and swing the other foot around to plant (Figure 4) (Beal & Crab, 1987).

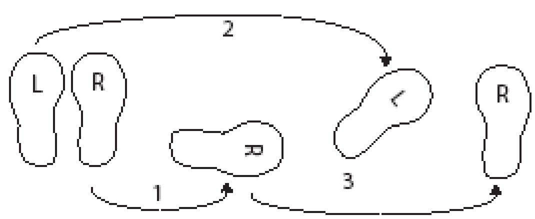

Figure 4. Running step

Buekers studied whether the running step technique was superior in terms of lateral movement speed and total movement time (M. J. A. Buekers, 1991). Ten experienced volleyball players volunteered for the study. On the floor along the net, two floor mats were placed over pressure sensors. Each time the subject touched or released one of the mats, the corresponding time was recorded. A photoelectric cell and a reflector were mounted above the net that transmitted a signal to a computer each time a subject reached over the net. Each subject performed a double block jump (jumped once in the middle, did the footwork to the outside and jumped again on the outside). The total movement time was recorded and divided into successive movement phases: the duration of the lateral displacement (when the subject completely left mat A until they arrived at mat B) and the time spent on mat A after the first block. Buekers found that total movement time for the running step technique was shorter than the total movement time for the slide step technique. The running step showed a shorter movement time, but the preparation for the lateral movement (the 90º turn) was more time consuming compared to the other step techniques. Even though this movement was more time consuming, the running block was still more effective in getting the blocker not only to the outside takeoff position fast, but also into the blocking position (M. J. A. Buekers, 1991).

The results from this study support the opinion that the running step technique should be used for a lateral movement of more than 1.8 meters (Beal & Crab, 1987). However, coaches agree that since the slide step favors the blocker's body and hand position in the air, the slide step should be used whenever time constraints are not present (M. J. A. Buekers, 1991).

A problem in every study was the use of only one starting position and distance because blocking must be performed from many different spots along the net. Furthermore, most studies used experienced male players with established habits that may have affected the results. Although the research is controversial, I have chosen the running three-step footwork pattern because it is the fastest footwork pattern, it produces the greatest vertical jump, and because the team I am choosing to study is familiar with this footwork pattern.

Jumping Ability

In volleyball, the height of an individual player and their ability to jump are important variables for front row players in both offense (spike) and defense (block) (Viitasalo, 1982). Gladden and Colacino performed a study that looked at the Women's Open Division of the United States Volleyball Association's national championship tournament and found that the final standings were significantly correlated with the team averages of player height, reach, and the maximal height of the vertical jump (Gladden & Colacino, 1978). If the middle blocker has ample time to move to the outside of the court, the ability to jump high and penetrate the plane of the net is crucial in performing an effective block (Farokhmanesh & McGowen, 1988). Considering the fact that a player's height can not be changed during the course of training, jumping ability becomes a fundamental part and vital skill component of volleyball (Richards et al., 1996).

There is a great amount of research available on the vertical jump. However, most articles do not incorporate a horizontal component prior to jumping that is used in blocking, and uses a protocol that requires a static squat or counter movement jump (Fukashiro & Komi, 1987; Harman et al., 1990; Hudson, 1986; Robertson & Fleming, 1987; Shetty & Etnyre, 1989). Researchers have investigated the vertical jump after an approach. However, most of the attention of this research has been devoted to spiking; only limited literature is available concerning volleyball blocking (M. J. A. Buekers, 1991; Cox, 1978, 1980; Cox et al., 1982; Farokhmanesh & McGowen, 1988; Kwak et al., 1989).

The height of the vertical jump depends on the ability of muscle groups to raise the body's center of gravity (Shetty & Etnyre, 1989). It also depends on the position and orientation of the body about the center of mass at the instant of takeoff and again when the maximum height is evaluated (Dowling & Vamos, 1993; Vint & Hinrichs, 1996). The study of muscular function in a vertical jump is complicated because of the interactions between the position of the body, angle of take-off, muscles involved, eccentric and concentric contractions of antagonist muscle patterns, and the use of arm movements. All of these factors affect ground reaction forces, which is the primary factor contributing to the effectiveness of a vertical jump (Shetty & Etnyre, 1989).

Jump height is defined as the difference between the height of the body's center of mass at the apex of the jump and the height of this center of mass when the subject is standing upright with heels on the ground (Bobbert et al., 1996). Jump height can be increased by plyometric training, or the specific training for the increase of explosive type strength (Stojanovic & Kostic, 2002). This explosive type strength refers to the individual ability of the neuromuscular system to show signs of strain in the shortest time possible (Stojanovic & Kostic, 2002). This strength consists of two phases: the eccentric phase (the stretch) and the concentric phase (the shortening). The fundamental principle of the plyometric method is a fast shift from a state of flexibility (stretch) to a state of shortening (returning to original position) (Stojanovic & Kostic, 2002).

During the early part of the push-off phase in a vertical jump, the biceps femoris contracts eccentrically and at the end of the push-off phase it contracts concentrically (Visser, Hoogkamer, Bobbert, & Huijing, 1990). Visser et al. stated that the biceps femoris, which is lengthened with the change of hip angle, can begin the concentric contraction at a higher rate following an eccentric contraction (Visser et al., 1990). Biarticular muscles, or muscles that cross two joints, are involved in the fine regulation of the distribution of net torques of the two joints crossed whereas monoarticular muscles seem to act mainly as force or work generators (Van

Ingen Schenau & Bobbert, 1993). It has been found that force, force-time, and force-velocity parameters of biarticular muscles are significantly related to kinematic variables in complex movements such as jumping (Jaric, Ristanovic, & Corcos, 1989). In these biarticular muscles, energy is transferred from one joint to the other.

Although muscles that surround the knee contribute significantly to the performance of a vertical jump, the muscles surrounding the hip and ankle generate the most energy (Robertson & Fleming, 1987). In a study performed in 1980, it was found that muscles that crossed the hip and ankle produced energy while muscles that crossed the knee absorbed energy (Robertson & Winter, 1980). The contributions of the hip, knee, and ankle were found to be 40.0%, 24.25%, and 35.8%, respectively (Robertson & Winter, 1980).

The height of the jump will partially dictate the success of a blocker. A blocker with a poor jump will typically not be successful. It is therefore critical for a blocker to maximize their jump when attempting to block. Ideally, the blocker must get to the blocking point and jump quickly without sacrificing vertical jump height.

Counter Movement

Human beings typically start motor tasks with a counter movement, or a movement in a direction opposite to the desired direction (Bobbert et al., 1996). In many sporting events where jumping is involved, the jump is preceded by a counter movement and arm swing to increase the jump height. Counter movement has been described as a quick flexion of the knees during which the body's center of mass drops somewhat before being propelled upward (Harman et al., 1990). It uses the stretch-shortening cycle. It is commonly understood that a muscle can perform with greater power if it is slightly stretched prior to execution.

It has been theorized that besides improving the force-producing capacities of the muscle itself, counter movement utilizes some of the elastic properties of muscles and tendons (Bobbert, Mackay, Schinkelshoek, Huijing, & Van Ingen Schenau, 1986). Counter movement increases the "pre-load" on the lower extremity musculature and enables these muscles to utilize the stretch-shortening dynamics of muscular contraction (Anderson & Pandy, 1993). Counter movement not only increases the distance over which force can be exerted, thereby prolonging the upward propulsion phase, but also takes up some of the muscular slack that is associated with the initial stages of the development of muscular tension (Anderson & Pandy, 1993; Harman et al., 1990; Van Ingen Schenau, 1984).

In the descent phase of the counter movement, the ankles, knees, and hips are flexed into positions which stretch the muscles. Later, the muscles act to extend those same joints. When a muscle stretches (eccentric phase), it stores elastic energy. This energy is in part released during an immediate shortening (concentric phase) muscle contraction (Enoka, 1988). Individuals with predominately fast twitch muscle fibers are better able to recover stored elastic energy in high speed counter movement jumps with less knee angular displacement, where individuals with predominantly slow twitch muscle fibers can recover more stored energy in slower jumps involving greater knee angular displacement (Bosco, Tihanyi, Komi, Fekete, & Apor, 1982). It has been argued that during a counter movement in a counter movement jump, active muscles are prestretched and absorb energy. Some of the energy is stored in elastic elements and later utilized again in the concentric phase. The elastic energy released in the concentric phase helps increase the work produced in a counter movement jump compared to a squat jump. However, Bobbert et al. found that it was the dynamics of force development that determined the differences in the amount of work produced, not the storage and reutilization of elastic energy (Bobbert et al., 1996).

There is ample evidence that task performance is improved by a counter movement. When compared to a squat jump (SJ) where subjects are instructed to start from a semisquatted position and make no counter movement, subjects achieve a greater jump height if they perform a counter movement jump (CMJ) where subjects start in an erect position and make a downward movement before starting to push-off (Bobbert et al., 1996). There are several explanations for this difference.

First, because humans usually naturally perform a counter movement before a jump, subjects may not be used to performing a SJ. As a consequence, the subjects may be unable to properly coordinate this type of jump. Second, the muscles utilized in a SJ are unable to achieve a high level of force before the start of concentric contraction. When a muscle is performing a maximal voluntary muscle contraction, time is needed for the muscle force to reach a maximum value. If the concentric active state starts as soon as the force begins to rise, part of the shortening distance of the muscle-tendon complexes is traveled at a submaximal force, and thus the work produced is submaximal. This effect can be avoided by performing an isometric contraction before the start of the concentric contraction or by performing a counter movement. This would allow the muscle to build up a maximum active state before the concentric contraction starts (Bobbert et al., 1996).

Another possible explanation is that the stretch that occurs in the counter movement triggers spinal reflexes as well as longer-latency responses. This increases muscle stimulation during the concentric phase to a level surpassing the level that was achieved in a SJ because no prestretch occurs. The muscles may produce a larger force because of this higher stimulation level, and thus producing more work during the concentric phase. It cannot be ruled out that reflexes help to increase muscle stimulation during the countermovement phase in a CMJ, and thus partly contribute to the development of a high level of active state and muscle force before the start of push-off (Bobbert et al., 1996).

The last explanation is that the prestretch of active muscles in a CMJ alters the properties of the contractile machinery. It has been shown that prestretch enhances the force produced by artificially stimulated isolated muscles. This enhancement is also called potentiation. It has been shown that potentiation increases with the speed of prestretch and decreases with the amount of time elapsed after the prestretch (Edman, Elzinga, & Noble, 1982). The enhancement of force in a CMJ could help to increase the work produced in a CMJ over that produced in a SJ (Bobbert et al., 1996).

In a study performed by Bobbert et al., six male volleyball players performed the following four types of jumps while holding their arms behind the back: counter movement jump according to the subjects own preferred style, squat jump starting from a posture that was identical to that at the start of push-off in a counter movement jump, squat jump starting from the posture preferred by the subject, and a squat jump starting from a posture that was as low as possible (Bobbert et al., 1996). They found that at toe-off, body position was the same in all jumps. However, jump height was more than 2.5 cm greater in a CMJ than in all other jumps as a result of a greater vertical velocity at toe-off. They also found the magnitude of the ground reaction force in a CMJ was much greater than in the other jumps. This greater force is due to greater hip extension moments, knee extension moments, and plantar-flexion moments at the start of push-off (Bobbert et al., 1996).

In this study, Bobbert et al. confirmed the conclusion that subjects are able to jump less high in a SJ than in a CMJ (Bobbert et al., 1996). The greater jump height seems to be due primarily to the fact that the counter movement allowed the subjects to attain greater joint moments at the start of push-off. As a consequence, joint moments were also greater over the first part of the range of joint extension in a CMJ, so that more work could be produced than in squat jumps (Bobbert et al., 1996).

Bobbert et al. also reported that the greater achievement in a CMJ compared with a SJ starting from a posture that was identical to that at the start of push-off in a counter movement jump was mainly due to the fact that the counter movement allowed the extensor muscles to build up active state and force prior to shortening (Bobbert et al., 1996). In a SJ starting from a posture that was identical to the posture during a CMJ at the start upward movement of the mass center of the body, shortening started as soon as the level of muscle stimulation was increased above that required for maintenance of the starting position, and consequently less force and thus less work was produced over the first part of the shortening distance (Bobbert et al., 1996).

It should be noted that optimal depth and rate of the counter movement will probably be different for each athlete because each athlete has a different physique and muscular strength. Also, even though it leads to higher jumping, counter movement can not always be performed before a vertical jump. Counter movement jumps take considerably longer to execute and may result in only modest performance gain (Harman et al., 1990). In some sporting situations, the athlete may already be in a squatting or semisquatting position before jumping. In other situations, the athlete may not have time to perform a counter movement and it might be worth sacrificing the 2 cm gain in jump height in order to make a reactive movement more quickly (Harman et al., 1990).

Arm Swing

Vertical jumps are often characterized by swinging the arms. Hay, Wilson, and Dapena showed that contrary to the common belief that the action of the legs were primarily responsible for the vertical jumping action, the head, trunk, and upper-limb segments played an important role in the vertical jump (Hay, Wilson, & Dapena, 1976). Arm position and movement throughout a vertical jump help maintain balance by reducing instability of the horizontal forces (Shetty & Etnyre, 1989). In 1987, Beal and Crab stated that the two most critical forces for obtaining a maximum jump height are the coordination of the heel-toe action, and a violent arm swing (Beal & Crab, 1987). They recommended the backswing of the arms should be at least parallel to the floor or higher which results in a body position of extreme shoulder flexion and elbow extension at takeoff (arms extended and raised above the head) (Beal & Crab, 1987; Feltner, Fraschetti, & Crisp, 1999). Ramey found that arm movement during a vertical jump contributed approximately 30 to 40% of the height of the jump (Ramey, 1982).

In 1989, Shetty and Etnyre investigated the kinetic and kinematic contributions of arm movement to the vertical jump (Shetty & Etnyre, 1989). Eighteen males participated in their study. Each subject performed vertical jumps with and without arm movement on a force platform. They found the average maximum force, work done, power, and the release velocity were greater with the use of arms, and the impact force was less with arm movement. The impact force was reduced by 12% when arm movement was used. The contribution to vertical jump force, power, work done, and velocity of their study was less than previous studies. Shetty and Etnyre concluded that skilled volleyball players may have a greater contribution to their vertical jump with arm movements because they have developed the skill of using their arms more effectively compared to unskilled individuals (Shetty & Etnyre, 1989). The reduction of impact force with arm movement when landing may reduce the incidence of hamstring injury. Shetty and Etnyre also concluded that arm movements during a vertical jump increased maximum take-off force and decreased landing impact (Shetty & Etnyre, 1989).

Luhtanen and Komi measured the impulse produced during no-counter movement jumps using only one body part at a time and found the arms contributed 10% to takeoff velocity (Luhtanen & Komi, 1978). Payne, Slater, and Telford claimed that the use of arms ensured that the center of gravity was as high as possible before flight began (Payne, Slater, & Telford, 1968). They also reported that the arms produced a second peak in force for the propulsion of the body which resulted in a 5% greater jump height (Payne et al., 1968). Miller found that the second peak is due to trunk acceleration and the arm swing serves to reduce the depression separating the two peaks of force production (Miller, 1976). The cause of the height increase has been hypothesized to be because the arm swing increases the downward load on the legs in the stretch phase of the stretch-shortening cycle, or in other words, that the arm swing transfers momentum to the rest of the body near takeoff (Dowling & Vamos, 1993).

When the muscles crossing the hip and knee are in the most advantageous position to exert vertical ground reaction force, the upward acceleration of the arms creates a downward force on the body at the shoulders. This slows the rate of shortening of the large quadriceps and gluteal muscles. Slower concentric (shortening) actions of the leg muscles result in enhanced muscle tension and presumably larger vertical ground reaction forces (Harman et al., 1990). When the arms decelerate near the end of their swing, they pull up on the rest of the body, making the quadriceps and gluteals contract at a more rapid speed which diminishes their force generation capability. However, this occurs when the knees and hips are almost fully extended, and the muscles around them are not in position to generate much positive vertical ground reaction force anyway (Harman et al., 1990). Still, the mechanisms that enable the arms to increase jump height are not well understood.

Because the height achieved by the body's center of gravity is a function of vertical velocity and takeoff position, one of the fundamental objectives of the vertical jump is to achieve the greatest vertical velocity at takeoff (Dowling & Vamos, 1993). Some individuals are more proficient at this than others due to the differences in strength, speed, and coordination between individuals (Dowling & Vamos, 1993). Arm swing increases the height and velocity of the center of mass at takeoff and is due directly to the elevation of the arms. It has been shown that this increase in velocity of the center of mass has the greatest influence on performance. The increase of velocity of the center of mass has been shown to contribute between 60% and 72% to the increase of performance (Lees et al., 2006). The muscles of the shoulders and elbow joints as well as the muscles around the hip joint as the hip extends to initiate the upward movement of the center of mass, build up energy in the arms (Lees, Vanrenterghem, & De Clercq, 2004). This energy, which accounts for 16% of the total work done during the jump, is built up early in the jump and is transferred to the rest of the body during the later stages of the jump (Lees et al., 2004). The energy increases the velocity of the center of mass, increases the kinetic and potential energy of the arms at takeoff, stores and releases energy from the muscles and tendons around the ankle, knee and hip joints, and increases the energy of the rest of the body through the transmission of a pull force at the shoulder joint (Lees et al., 2004).

As jump height increases, the arms are progressively used more forcefully. The arms are hyperextended to a greater extent on the backswing and go through a greater range of motion. The greater hyperextension means that more potential energy is available to increase the kinetic energy of the arms at the lowest point of their downswing (Lees et al., 2006). The energy benefit of using an arm swing increases as jump height increases. As jump height increases, energy in the arms is built up by a greater range of motion at the shoulder and greater effort of the shoulder and elbow muscles, which also serves to increase the kinetic energy of the arms. These sources are supplemented by energy supplied by the trunk due to its earlier extension in the jump movement. Therefore, as jump height increases, greater emphasis is placed on trunk extension, which increases the energy of the arms during the downswing (Lees et al., 2006). Emphasizing early trunk extension in a jump may be one method for improving jump height. The energy reduces as the arm swings upward. The energy is used to store and return energy from the lower limbs and to "pull" on the rest of the body (Lees et al., 2006).

There are, however, situations where it would not be advantageous to use an arm swing. For example, if an athlete must reach up on very short notice to block a quick volleyball spike, the hands can reach the ball most quickly if they start in the up position and go directly to the ball without going down for the swing. This is true only if the athlete can jump high enough to reach the ball without the arm swing. Thus, there are tradeoffs with the arm swing as there are for the counter movement.

Counter Movement and Arm Swing

Most athletes, when performing a maximum height vertical jump, use a preparatory counter movement. The counter movement results in a coordinated flexion of the hips, knees, and ankles and a subsequent rapid extension of these same articulations before takeoff. The athlete usually uses a rapid arm swing at the same time as these leg motions.

Researchers have indicated that an arm swing together with counter movement increases jump height (Walsh et al., 2007). Viitasalo performed a study that looked at jump height variables in game situations for members of the Finnish and Russian male national volleyball teams (Viitasalo, 1982). He looked at height of the rise of body center of gravity for three different types of jumps: a static squat jump with no preliminary counter movement, a counter movement with and without arms, and a drop jump from varying heights. The static jumps measure pure concentric force production, while the counter movement jumps and drop jumps tap the elastic and proprioceptive feedback mechanisms which are intensively activated during the eccentric phase of contact (Viitasalo & Bosco, 1982). He found that both types of counter movement jumps (with hands free and hands fixed) resulted in a higher rise in the center of gravity for both teams. He also found that counter movement jumps where the hands were free compared to fixed hands during the jump had the highest correlation to the height of rise of center of gravity in the block jumps (Viitasalo, 1982).

Harman et al. conducted a study looking at arm swing and counter movement (Harman et al., 1990). They had eighteen physically active male subjects jump on a force platform four different ways: with arms and counter movement, with arms and no counter movement, no arms and counter movement, and no arms and no-counter movement. They reported that the arms contributed a mean 10% to takeoff velocity for both a counter movement condition and a no-counter movement condition.

Gender Differences

Most of the research looking at jumping, with the exception of recent studies on women athletes and knee injuries, has been performed on men (Walsh et al., 2007). Because there are a number of physical and physiological differences between men and women that could affect jump parameters, there is a large gap in the research regarding information on women jumping performance.

Because the vertical ground reaction force is proportional to the accelerations of all body segments, changes in mass distribution in the body would change the ground reaction force for a given movement. Women have an average of 55.8% of the upper extremity strength of men and 71.9% of the lower extremity strength (NASA, 1978). These differences probably influence the effects of arm swing and counter movement on jumping performance. For instance, the greater upper body strength that men possess would seem to show that arm swing would play a greater role in determining jump height in men than in women. Also, because women have greater lower extremity strength in proportion to upper extremity strength, the contribution of the counter movement in women might be larger than that of men.

There are also differences in fiber bundle length and pennation angles between men and women (Chow et al., 2000). A study performed by Komi and Bosco showed that women were able to utilize a larger percentage of the energy stored during the eccentric phase of various jumps (Komi & Bosco, 1978). This should increase the benefit of performing a counter movement for women.

Walsh et al. examined gender differences in the contribution of the counter movement and arm swing (Walsh et al., 2007). He compared 25 physically active college-age men and 25 physically-active college-age women, none of which had ever competed at the collegiate level. Each subject performed four jump techniques: a squat jump with hands on the hips, a counter movement jump with the hands on the hips, a squat jump with use of the arms, and a counter movement jump with use of the arms. The counter movement jump was performed starting with the arms at the subject's sides.

They found that the use of the arms contributed more to the jump performance than the counter movement for everyone but with a greater improvement for the men. Men usually have greater strength and mass which would allow the subject to create a greater ground reaction force when swinging the arms upward. A greater ground reaction force produces greater center of mass acceleration without needing the lower extremity muscles to contract at faster rates. This allows the lower extremity muscles to contract at lower velocities, which is favorable for force production when considering the force velocity relationship of muscle contraction. However, simply swinging the arms up forcefully does not guarantee an increased jump height. The arm swing has to be coordinated with leg extension. Walsh et al. concluded that upper body strength is an important factor in vertical jumping and may play a larger role in jump performance than is currently realized (Walsh et al., 2007).

Equipment

Most studies that have been performed looking at blocking footwork have used a camera to film the blocking motions and collect data for the analysis of horizontal velocity and the reaction time. A force platform has been used to measure the ground reaction force. Cox filmed his footwork sequences with a 16 mm Locam camera that used a film transport speed of 100 fps (Cox et al., 1982). Kwak et al. used a 16 mm high speed camera and an AMTI force platform to collect their data (Kwak et al., 1989). Buekers used a photoelectric cell and a reflector to record each time a player reached over the net (M. J. A. Buekers, 1991). He also used pressure sensors to record each time the subject touched or released one of the pressure sensors.

Richards et al. collected their data by using a four-camera, high speed (200 frames/sec) video digitizing system which recorded the three-dimensional coordinates of the lower extremities during volleyball spike and block jumps (Richards et al., 1996). They placed the video cameras in a semicircle around the testing area so that at least two of the four cameras always captured the positions of the reflective markers. The reflective markers used were 1.5 cm in diameter. The markers were taped to the skin at anatomic landmarks (thigh, leg, foot) on the limb closest to the arc of cameras. Using the reflective markers, they were able to calculate joint coordinate systems for the hip, knee, and ankle of each player (Grood & Suntay, 1983). They also used a force platform to record the ground reaction force. Richards et al. used a portable volleyball net which was set to regulation height (Richards et al., 1996). They also used an integrated software package, Kintrak, to quantify the three-dimensional kinematics and dynamics and ground reaction forces.

Vint and Hinrichs used a Panasonic model D5100 video camera to collect two-dimensional video data (Vint & Hinrichs, 1996). The selected jumps were digitized with the Peak Performance motion measurement system. Dowling and Vamos recorded the vertical force component on a AMTI model OR6-5 force platform (Dowling & Vamos, 1993). When Domire and Challis were studying the depth of a squat on vertical jump height, they used a Pro-Reflex Motion Analysis System sampling at 240 Hz (Domire & Challis, 2007).

In a study looking at the benefit of an arm swing, reflective markers were recorded using a six-camera opto-electronic motion capture system (Pro-Reflex) (Lees et al., 2006). The data were collected at 240 Hz, and the force data were collected at 960 Hz. All the data were electronically synchronized in time.

In the Bobbert et al. study, they placed retroreflective spheres of 2 cm diameter on the joints of each subject (Bobbert et al., 1996). The locations of the spheres were monitored using four electronically shuttered cameras (NAC 60/200 MOSTV) connected to a Vicon high-speed video analysis system operating at 200 Hz. The three-dimensional coordinates were reconstructed using AMASS software.

Other volleyball studies have used the Vicon Nexus motion analysis system to record and reconstruct three-dimensional data, including total time of movement, maximum velocity, time to maximum velocity, and deceleration time (Gonzalez-Alvarez, Subramanian, & Pardhan, 2007; Kao, Sellens, & Stevenson, 1994). The advantage of the Vicon Nexus motion analysis system is that it can be used in almost any environment and it has flexibility in landmark locations. The operator can define segment properties such as joint centers and orientations with respect to marker positions. The software will scale the generic model to the specific anatomy being captured. The Vicon cameras can be mounted on tripods which allow full flexibility in camera placement and measurement of volume size. The infra-red light used by the camera's strobes is invisible to the eye and will not distract subjects. Reflective markers are attached either to the skin or on top of tight-fitting clothing. The cameras stream marker data straight to the real-time engine which calculates the three-dimensional positions of the markers and also the underlying biomechanics. The biomechanics information can be displayed in a three-dimensional model.

Summary

Due to the fact that blocking is one of the most influential factors in determining team success, it is important to study different blocking techniques. Different blocking studies have been performed on beginning volleyball players and have studied different segments of the block, but none have focused on the whole blocking motion in Division I female volleyball players.

There are several critical components of a block. One of these components is movement speed which incorporates footwork patterns. Although the literature shows mixed results for the fastest footwork pattern, the running step has gained popularity in recent years. Another factor that helps make a block successful is counter movement and arm swing. It has been well documented that a counter movement and arm swing increase jump height. An increase in jump height is important because the higher an athlete jumps, the farther over the net their hands and arms will penetrate. However, the literature does not explore the different types of arm movements combined with the footwork patterns that are used in volleyball blocking.

The traditional block move requires the player to keep their hands at ear level (like Mickey Mouse ears) throughout the whole blocking motion. This kind of block can be compared to a jump with counter movement but no arm swing. The swing block, which has gained popularity over recent years, utilizes a full arm swing in which the arms and elbows are fully extended throughout the whole blocking motion. The arms swing back and up in a pendulum type motion. This type of block is a typical counter movement jump with a full arm swing. The last and relatively new arm movement in a volleyball block is what I call the chicken wing block. When performing this block move, the arms are still swung back to get an arm swing, but the elbows are flexed to a 90 degree angle. This study will look at these three different types of arm movements while performing a counter movement block jump with a running three-step footwork pattern.

Chapter 3

Methods

Research Design

This study will be a 1 X 3 X 4 factorial design. The independent variables of the study will be three different arm movements: the traditional block arm movement, the swing block arm movement, and the chicken wing arm movement. The dependent variables will be 1) the amount of time it takes for the athlete to get off the ground from the start of the blocking motion, 2) the amount of time it takes the athlete from the start of the blocking motion to get their hands over the net, 3) the amount of hand and arm penetration the athlete has over the plane of the net, and 4) the athlete’s jump height.

Subjects

The participants of the study will be 14 non-injured female elite NCAA Division I volleyball athletes ranging in age from 18 to 21 years who compete on the Utah State University volleyball team. Each athlete on the team is highly practiced in the running three-step footwork pattern. A questionnaire will be given to each athlete to obtain their demographic information which includes their height, weight, age, volleyball position, year of participation in volleyball at the collegiate level, and injury history. The lead researcher will measure the participant’s height and weight. Each athlete will be required to read and sign an informed consent prior to data collection. The procedures used in the study will be approved by the Utah State University and Brigham Young University institutional review boards.

Instruments

High-speed videography (VICON Motion Technologies, Centennial, Colorado) will be used for data collection. Seven cameras (500 Hz) will record the motion of the athletes. The three-dimensional coordinates will be reconstructed using VICON Nexus software. The VICON Nexus system will be set up in the Utah State University Motion Analysis Laboratory.

A portable outdoor volleyball net will be placed in the middle of the motion analysis laboratory. The height of the net, measured at the center of the net, will be 7 feet 4 1/8 inches. The cameras will be set up in a circle around the volleyball net with three cameras facing the athlete and four cameras behind the athlete (Figure 5). Camera location and orientation will be determined using calibration procedures recommended by VICON.

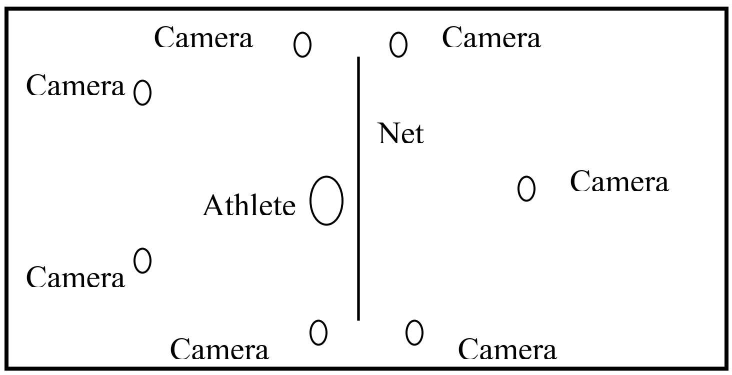

Figure 5. Laboratory set-up

Procedures

The lead researcher will describe and explain the study to all participants. The lead researcher will also explain the inclusion and exclusion requirements which include a normal pregame routine the night before data collection. Then, the participants will read and sign an informed consent and complete a preparticipation questionnaire. Lastly, the participants will draw from a hat a paper listing the order of the arm movement they will perform. The order will be prepared beforehand using the latin square design.

The lead researcher will then instruct the participants on the three different arm movements. The participants will practice, under the supervision of the lead researcher, the different arm movements in combination with the running three-step footwork pattern until they are comfortable with each movement. Each participant must also meet an acceptable performance level as evaluated by the lead researcher.

Each participant will be tested in the same room at a time that is convenient for them. Each participant will come to the motion analysis lab dressed in their team issued spandex shorts, sports bra, and court shoes.

Reflective markers will be placed on the participants when they arrive at the motion analysis lab. One trained researcher will perform all the marker placements on each of the participants. Markers will be placed bilaterally, using double sided adhesive tape, on the following anatomical landmarks: dorsum of the proximal phalanx of the third metacarpal, ulnar styloid process, lateral humeral epicondyle, acromion process, sacrum (mid-way between the skin dimples formed by the posterior superior iliac spines), anterior superior iliac spine, greater trochanter, a thigh cluster (a plastic mold with four reflective markers attached to it that is held in place on the thigh with prewrap) on the lateral thigh, medial and lateral knee (joint line), a shank cluster positioned on the distal lateral shank, medial and lateral maleolus, calcaneus, dorsum of the foot, head of the fifth metatarsal, and on the shoe above the second metatarsal. Two other markers will be placed on the top of the net; one marker will be placed by the antennae and the other will be placed close to the middle of the net.

Once the markers have been placed, the participants will stand by the middle of the net and the researcher will record one static trial. The researcher can then remove the markers from the medial and lateral knee and the medial and lateral maleolus. Participants will then be allowed five minutes of warm-up. The warm-up is familiar to the participants and includes performing nine blocking trips. Once the warm-up is complete, the participants will be asked to perform maximum effort block jumps using the three different arm movements in the assigned order.

Participants will be recorded performing each condition. The lead researcher will make sure that the participants perform three acceptable blocking motions meaning they perform the correct footwork in combination with the correct arm movement. Additional trials will be given if a participant or the lead researcher does not feel comfortable with the performance of a trial. The average of each dependent variable across the three trials will be calculated for statistical analysis purposes.

In order to make the block movement more realistic, a setter will stand on the opposite side of the net just to the left of the blocker. A researcher will toss a volleyball to the setter who will set the volleyball to another researcher who will catch the ball. This will be the visual cue to make the experiment as game like as possible. The subjects will start in the middle of the net in the starting position. We will mark the starting position on the court where each participant will line up. When the ball is set, participants will perform a running three-step footwork pattern to the outside of the court in combination with the appropriate arm movement like they would do in a regular volleyball game. They would time their block the same as they would against a normal hitter. In order to reduce any fatigue felt from previous jumps, participants will be allowed at least one minute rest between jumps.

Statistical Analysis

The averages of the three jumps, determined by computer software, will be used for statistical analysis. Using the VICON Nexus software, the following variables will be determined: 1) the amount of time it takes for the athlete to get off the ground from the start of the blocking motion, 2) the amount of time it takes the athlete from the start of the blocking motion to get their hands over the net, 3) the amount of hand/arm penetration over the plane of the net, and 4) the athlete's jump height (Table 1).

Dependent Variables	Definition
1. Amount of time it takes for the athlete to get off the ground from the start of the blocking motion.	Start time = ToeV(x) > set m/s Toe off = Toe(z) >static position for 5 frames Total Time = Toe off – Start time
2. Amount of time it takes the athlete from the start of the blocking motion to get their hands over the net	Start time = ToeV(x) > set m/s Hands over net = Hand(z) > Net Marker(z) Total Time = Hands over net – Start time
3. Amount of hand/arm penetration over the plane of the net	Hand Penetration = $\sqrt{}(\text{Hand}(z) - \text{Net}(z))^2 + (\text{Hand}(y) - \text{Net}(y))^2$
4. Athlete's jump height	Start height = static position Jump height = Max change of mass(z) Max Jump = Jump height – start height

Table 1. Dependent variables and their definitions.

The time variables will be measured using movement in the x, y, and z axes (Figure 6). The starting time, when looking at the amount of time it takes for the athlete to get off the ground from the start of the blocking motion, begins when the medial/lateral (x) velocity is greater than a set meter/second (start time = ToeV(x) > set m/s). The time when the athlete gets off the ground will be recorded when the toe marker is above the static marker position for at least five frames (Toe off = Toe(z) > static position for at least five frames).

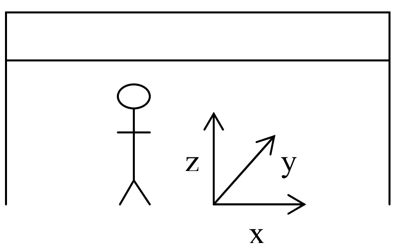

Figure 6. The axis used to measure the time variables.

x = medial/lateral
y = anterior/posterior
z = vertical

The second variable, or the amount of time it takes the athlete from the start of the blocking motion to get their hands over the net, will be measured in a similar manner. The start time begins when the medial/lateral (x) velocity is greater than a set meter/second (start time = ToeV(x) > set m/s). When looking for the time it takes the athlete to get their hands over the net, time will be recorded when the hand marker on the z axis is greater than the net marker on the z axis (Hand(z) > Net Marker(z)).

The maximum amount of hand/arm penetration over the plane of the net is the square root of the hand on z axis minus the net on the z axis squared plus the hand on the y axis minus the net on the y axis squared (Hand Penetration = $\sqrt{(\text{Hand}(z) - \text{Net}(z))^2 + (\text{Hand}(y) - \text{Net}(y))^2}$) (Figure 7).

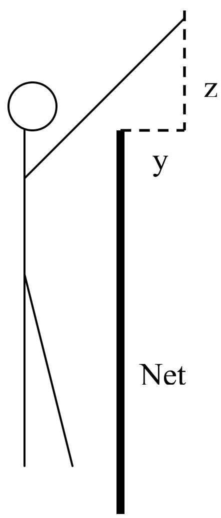

Figure 7. A drawing of an athlete penetrating the net with their hands/arms. The y and z axis are shown.

The last variable, or the athlete's maximum jump height, will be measured by the change of center of mass (COM) on the z axis (Jump height = max COM(z)) between the static measure of the athlete and the peak jump height.

An ANOVA test will be performed to see if there is a difference between groups. To determine where the difference is between groups, Tukey's HSD post-hoc test will be performed. The means and standard deviations will be reported. A table will be formulated listing the athlete's height, weight, volleyball position, age, and year of participation in volleyball at the collegiate level.

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Appendix A-1a

Consent To Be A Research Subject

A Comparison of the Traditional, Swing block, and Chicken Wing Arm Movements on Volleyball Blocking in NCAA Division I Female Athletes

Consent to be a Research Subject

Introduction

This research study is being conducted by Taubi Neves, Masters Student at Brigham Young University in order to determine which of the three arm movements (traditional, swing, and chicken wing) allows you to 1) get off the ground faster, 2) get your hands over the net faster, 3) reach over the net farther, and 4) jump higher when performing a counter movement jump with a running three-step footwork pattern. You have been selected to participate in the study because you are a female Division I volleyball athlete.

Procedures

You will be asked to complete a questionnaire consisting of questions about your height, weight, age, volleyball position, year of participation in volleyball at the collegiate level, and injury history. You will then draw an assigned order of arm movement that you will perform. You will be taught the three different arm movements and will then practice the arm movements in combination with the running three-step footwork pattern until you are comfortable with each movement. It is anticipated that this will take 30 – 60 minutes.

In order to participate in the study, you will be asked to fulfill the following requirements: follow a normal pre-game routine the day before the data collection session, eat a good meal, go to bed before midnight, and avoid working out 24 hours before data collection. The day of data collection, you will come to the motion analysis lab at Utah State University dressed in your team issued spandex shorts, sports bra, and court shoes. A trained researcher will place reflective markers on various body areas including hands, arms, shoulder, lower back, hips, thighs, legs, and shoes. You will then be allowed five minutes of warm-up. This warm-up will include nine blocking trips.

You will be asked to perform maximum effort block jumps using the three different arm movements in the assigned order in combination with the running three-step footwork pattern. You will be filmed using infrared cameras while performing each block movement. In order to make the block movement more realistic, a setter will stand on the opposite side of the net and set a volleyball to another researcher who will catch the ball. You will start in the middle of the net and perform a normal block movement when the ball is set. You will be allowed at least one minute rest between jumps to avoid fatigue. This process will take approximately 60 minutes.

Risks/Discomforts

It is possible, but not very likely, that you sprain an ankle or twist a knee while performing the block jumps. If you do sustain these or any injury, you will be sent to the athletic training room for evaluation. We may also take photographs of the three different arm movements to include in the article to help readers visualize the three different arm movements. We will not show your face in the photograph so you will not easily be identified.

Benefits

There are no direct benefits to the participants. However, we hope that through your participation in this research, coaches of teams of all ages and volleyball players of all ages will know which arm movement will benefit them most as a blocking team and individual blockers.

This study will also add to the small amount of research that has been performed on women's volleyball blocking.

Confidentiality

All information recorded will remain confidential and will only be reported as group data with no identifying information. All data, including questionnaires, will be stored in a locked office and only those directly involved with the research will have access to them. Once the research is complete, all questionnaires and photographs will be destroyed and erased.

Compensation

You will be compensated for participation by 1) Gas reimbursement ($0.15 per mile). You will also receive a $25.00 gift certificate to a local restaurant as payment for your time. You will receive this gift card and gas reimbursement at the completion of the study.

Participation

Participation in this research study is voluntary. You have the right to withdraw at anytime or refuse to participate entirely without jeopardy to your playing time or position on the Utah State University volleyball team.

Questions about the Research

If you have questions regarding this study, you may contact Taubi Neves at 435-881-5150 or taubi.neves@usu.edu.

Questions about your Rights as Research Participants

If you have questions regarding your rights as a research participant, you may contact Christopher Dromey, PhD, IRB Chair, 422-6461, 133 TLRB, Brigham Young University, Provo, UT 84602, Christopher_Dromey@byu.edu.

I have read, understood, and received a copy of the above consent and desire of my own free will to participate in this study.

Signature____ Date___________

Appendix A-1b

Demographic Questionnaire

Athlete Demographics

Name:

Subject Number:

Arm movement order:

Position:

Height:

Weight:

Age:

Years of experience playing collegiate volleyball:

Injury History:

Appendix B

Raw Data

Table 2

Demographics of the participating athletes

Subject Number	Arm Swing Order *	Volleyball Position +	Height (m)	Weight (kg)	Age (yrs)	Years of participation in collegiate volleyball	Injury History ^
02	CAB	MB	1.880	83.91	18	1	0
03	CBA	MB	1.854	66.68	20	3	1
04	ABC	S	1.778	69.40	20	3	0
05	CBA	S	1.715	57.70	18	1	0
06	CBA	OH	1.867	70.40	19	2	0
07	BAC	MB	1.899	87.82	21	4	1
08	ACB	DS	1.664	65.86	19	1	0
09	BCA	OH	1.842	64.05	19	2	0
10	BAC	MB	1.829	70.76	21	4	1
11	BCA	OH	1.867	66.95	21	3	0
12	ABC	DS	1.727	68.13	20	3	0
13	ABC	OH	1.905	71.67	18	1	0
14	BAC	OH	1.867	74.84	18	1	1