Sport Biomechanics
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The Biomechanics of the Volleyball Spike / Attack

The following biomechanics project was designed to be a review of literature related to the most important skill in volleyball, the overhead spike, or attack. The literature has been reviewed and select articles dealing with the various components of the overhead spike are presented as exemplary and representative of the kids of biomechanical analyses that are available. Though not exhaustive in scope, the literature reviewed gives a significant scope for the purposes of this assignment. The first two articles deal with an overview, or what I am calling SECTION 1: Overall Attack Perspective. The first by Li-Fang and Gin-Chang is the broadest representation compiled in this project. They deal with the approach jump and the back swing action of the arms, the turn swing which involves hip and trunk rotation, and the forward swing which involves shoulder and elbow rotation. The first article also provides excellent visual illustrations of the points they are making with regard to range of motion. The second article I have used to represent an overview of the offensive volleyball attack or spike is the research article by Bittencourt, which address the overall relationship between trunk rotation and shoulder rotation in the volleyball attack. The final article in the overview section is a comparison of arm swing mechanics by Huang.

The second section of the project deals with research articles that deal with injury prevention through knowledge of proper mechanics. In our text for the course, we learned that biomechanics helps with injury prevention. In this project are two examples of biomechanics research as it relates to the volleyball spike that could definitely help coaches prevent volleyball injuries. The first article focuses on knee and ankle injury prevention in the volleyball spike. The second article discusses the shoulder.

The third section of the project becomes more technical. After providing an overview of the spike attack in section 1 and injury prevention related research in section 2, section three begins the more detailed analysis of the various components of the spike attack. It seemed logical to present the remaining articles in the order in which the spike attack is performed. Thus, I begin section 3 with a pair of articles on the approach, where the attacker runs up to hit the ball. The approach is the phase of the attack prior to leaving the ground or "take off." The final three technical research analyses move sequentially along the spiking continuum. There is an article on shoulder movement, ball contact height, and spin on the ball. Each of these three articles represents well research done on the concluding phases of the volleyball spike/attack.

SECTION 1- OVERALL ATTACK PERSPECTIVE

The purpose of the study by Li-Fang, Liu and Gin-Chang, Liu (2008) was to investigate the suitable timing and coordination of body segments during volleyball spike, and find the critical concepts applied to the midair spike of the volleyball. The duration of the spiking motion is 0.6 to 0.8 seconds, and can be divided into the following phases: back-swing, turn-swing, and forward swing. Elite level spikers hit the ball half way into the jump at 0.3 to 0.4 seconds. This makes the spiking technique one the most complicated skills in sports. In order to hit the ball powerfully, the researchers examined the range of motion of the arm swing required for the hitting hand to generate the most power. That is, the researchers found the range of motion of the hitting hand to be relative to the power of the spike. The authors of this study described the range of motion as a kinetic chain generating an impact like (or collision) motion in which a sequential acceleration from the proximal to the distal segments in the chain occurred. (i.e. shoulders, to elbow, to hand.) The authors further noted that the loss of the ground reaction force from jumping required that the main action motion of the swinging arm must be generated and balanced by the other reaction segments of the body (i.e. the legs and the opposite arm) that can be explained in biomechanics by the principle of the conservation of angular momentum.

Methods
Cinematography (250 frame/sec, sagittal plane) was used in this study, and Kwon 3D software was used to analyze the timing and coordination of arm swing motion in the air among top and second level female volleyball athletes. The data was collected to plot on several graphs the coordination of the various body segments.

Results
The results of this study as following: 1. Range of motion was 58 degrees greater for the elite athletes (120 degrees) vs. (62 degrees) for the intermediate athletes. Enough range of motion (ROM) before ball hitting is the main factor effecting power in the spiking technique. A Beginning Hitter's greatest mistake is hitting the ball when their jump is on the way down. Elite level players were shown to perform the three phases of hitting (back-swing, turn-swing, and forward-swing) as soon as possible in the jumping phase. 2. Body segment data analysis showed the actions of right elbow joint and right knee joint were the coordination of reactions. The characteristics were not similar in the second level athletes that were observed. Thus, the proper time-distribution of back-swing, turn-swing and forward-swing causes the proper timing of ball hitting.

I feel this study provides excellent teaching tools for demonstrating the proper technique for the volleyball spike.

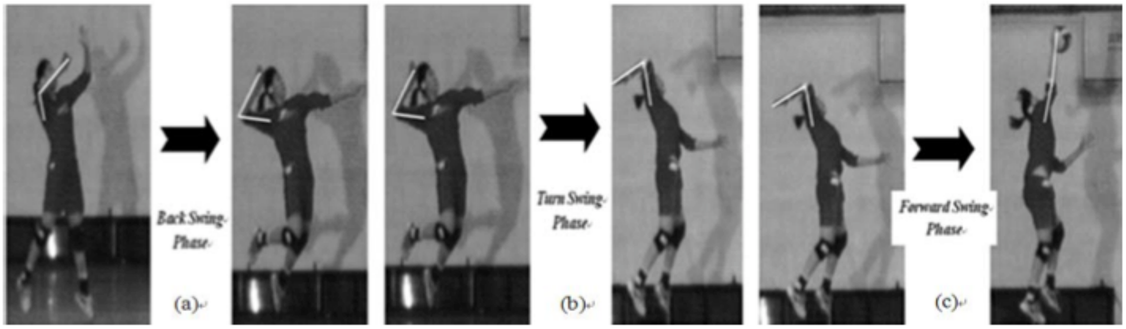


Figure 1: Segment motion of arm swing: (a) back swing phase, (b) turn swing phase, (c) forward swing phase

.The technical breakdown: During the backswing phase: a "lead" happens. This is a leading back swing at the beginning of takeoff and a "pulling" back, which is initiated by the pull of the elbow and wrist, simultaneously. During the turn-swing phase, a trunk "turn" occurs which allows for a greater range of motion as the arm naturally goes to the upside down V position just prior to the swing phase. Then, during the swing phase, the elbow joint straightens "up" going upward until the ball is hit by the upward extended hand which is slightly in front of the shoulder for the optimal range of motion and forward momentum as the ball is struck. Newton's 3rd law of motion "action and reaction force", and the conservation of angular momentum are used by the athlete to transfer power to the ball.

The research also shows graphically the greater range of motion that is achieved by the elite athlete vs. the 2nd level athlete. Where I could tell my athletes about this fact, it is much more effective to demonstrate the difference in pictures, as these researchers have done. (see figures 4 and 5 below for comparison)

One thing I wished was better in these articles was the poor English that was translated by the Chinese researchers. Nevertheless, I was very impressed by the detailed design of the study and the fresh insights that were gained. It was well worth mining through the broken English to make a coherent analysis of what they had discovered.

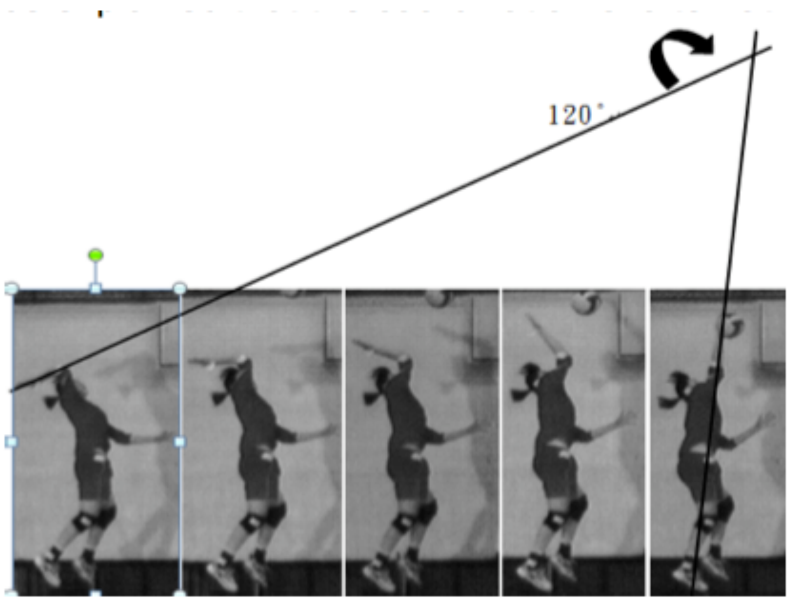


Figure 4: Rang of motion of top level female athletes

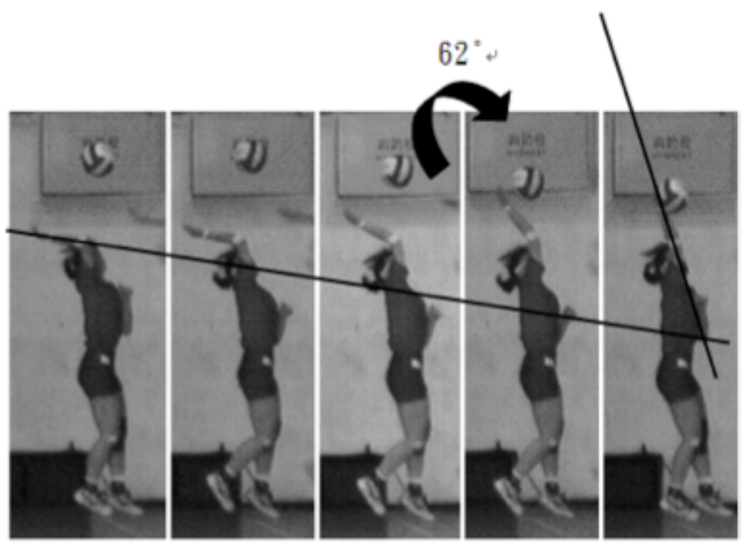


Figure 5: Rang of motion of second level athletes

APPROACH OVERVIEW- TRUNK TWIST and SHOULDER

Unlike the more technical biomechanical analysis of the spike motion, the following analysis of the spike motion was broken down to analysis of the trunk and shoulder. This study by Bittencourt, Neto and Franco, Natalia. (2007) entitled, “Isokinetic Analysis of Medial and Lateral Rotators Ratio of Glenohumeral Joint in Male Brazilian Volleyball Team” attempted to understand the mechanism of this motion and then from a practical standpoint, use the evidence collected to shape coaching pedagogy.

METHOD: Spike motions of the world-class volleyball players were videotaped with two high- speed VTR cameras. The cameras were placed in seats behind and lateral to the hitter’s position during the Men’s World Championship 2006. Two elite level players were video taped. The height and velocity of the right hand, the angles and angular velocities of the upper limb joints and trunk, as well as the whole body CG velocities were calculated from the coordinate data.

RESULTS: One Japanese and One Brazilian player’s spike motions were analyzed. The player GI (age: 29 yrs; body height: 1.92 m; body mass: 85 kg) from Brazil spiked the ball at higher velocity of the right hand, but at a slightly lower height than player IS (22 yrs; 1.97 m; 100 kg) from Japan. Upon further analysis of their form using the biomechanical data gathered throughout the spike jumps collectively, certain distinguishing characteristics emerged. Both players had their own unique components to their spikes. GI continuously rotated the trunk forward until the impact while IS changed from forward to backward trunk rotation a little before it. IS acutely horizontally adducted the shoulder before the impact. For both players, measurements of the trunk twist and shoulder horizontal adduction/abduction angles occurred from the moment the toe left the ground (toe-off) to the point at which the ball was hit by the hand of the spiker (ball impact).

DISCUSSION: Both players demonstrated the marked segments of the attack (remember the entire attack takes only 0.8 seconds). The Brazilian player’s (GI) continuous trunk forward rotation until the impact was smooth and produced powerful ball velocity. The Japanese player’s (IS) interruption of the trunk forward rotation just before the impact caused a decrease in the swing velocity of his arm. At the same time, IS’s slowing of shoulder horizontal adduction relative to the trunk forward rotation, the so-called “lagging back”, created a “whip” like arm swing in response to the interruption of his trunk forward rotation. Looking at both spikers through biomechanical analysis assists in identifying the key components of the distinctive spiking styles studied, and allows a coach to choose a spiking style that he is comfortable teaching and watching his players use.

I feel this study would have been difficult to follow if it weren’t for the helpful figures and diagrams that accompanied it. Therefore, I have included figure 1 of the study below. Firstly, figure 1 helps one to understand the dynamics of the trunk twist and shoulder abduction/adduction, and the differences between the two athletes spiking styles both at the beginning of the jump phase of the attack, and leading up to ball contact at the peak of the jump. Personally, I prefer to teach the Brazilian’s method of spiking, and will discuss the characteristics of it along the continuum. In figure 1, the red squares give evidence to a common technique that the Brazilian players are known for during take-off. During their approach to jump, when their feet land using the step-close approach method, their hips tend to rotate forward slightly. At 0.29 seconds prior to ball impact the trunk has rotated slightly forward to a -20 degree position. This allows for a greater range of motion for the Brazilian player who at 0.14 seconds prior to ball impact has now rotated his trunk to +25 degree position. Secondly, from the point of maximum backswing, the Brazilian player then demonstrates a consistently forward rotation of the trunk until the point of ball contact. This momentum adds to ball velocity. A second area to examine is the shoulder movement of the spiker. The Brazilian Player's shoulder (in adduction) moves consistently forward towards ball impact at a point along the continuum which begins 0.05 seconds after maximum backswing (0.14 to 0.09). The significance of this data from a practical perspective is that as a coach, one looks for cues to give to their athletes. One of my cues has been "Hips-Shoulder-Elbow-Hand." This is a common cue for a hitting progression. That is, you tell the athlete- first throw your hips at the ball, then your shoulder, then your elbow, then your hand. It is a skill one can feel, but, with this data in hand, it is also something the young athlete can see, too. In Figure 1, one can clearly see the shoulder following the hips (trunk). There is a clearly marked 0.05 second lag time for the Brazilian between his hips and his shoulder coming forward. For the Japanese player there is a 0.10 second lag time. (0.14 to 0.04 before ball impact). I honestly believe that this data can be a teaching tool for explaining my cues for spiking.

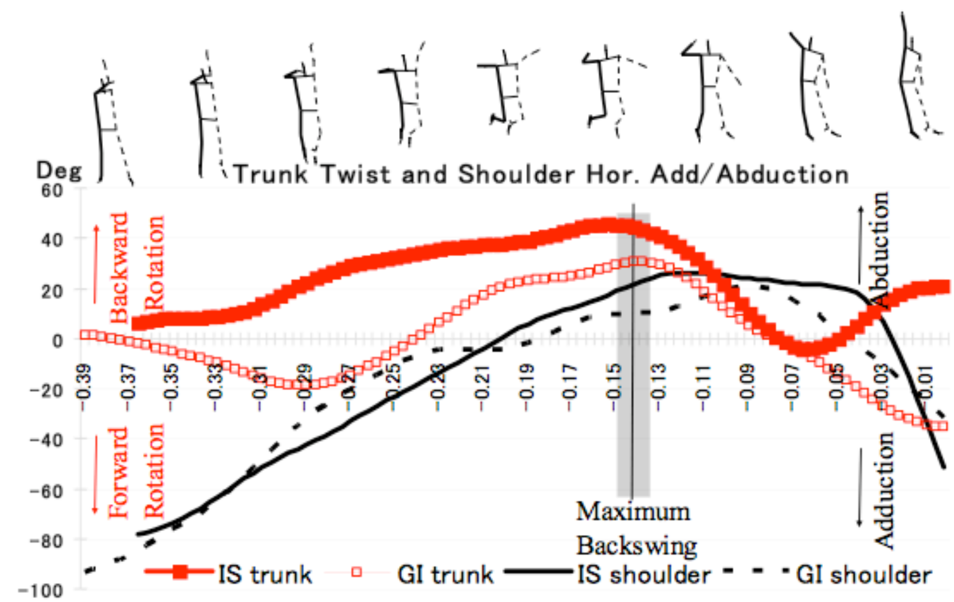


Figure 1 Trunk twist and shoulder horizontal add/abduction

DIFFERENCES IN ARMSWING MECHANICS

The purpose of the study by Huang (1998) was to analyze in a quantitative manner the spiking technique of the nine main attackers of the Chinese Women's Volleyball Team players in the Eleventh World Women's Volleyball Tournament in

Beijing. Where previous studies have relied on qualitative data, this quantitative approach is helpful in enabling the researcher to distinguish the two basic types of arm swings used by elite level performers.

Data Collection methods: A 200 pictures/second super-speed still image camera, a Japanese NAC movie camera, and a film analyzing instrument were used to analyze the acquired data. Data points for each of the subjects were acquired and diagramed in a tedious and meticulous manner along the joint axes of the athletes hips, knees, and ankles, as well as the shoulder, elbow, and wrist.

Results of the Study: The results of the study shows film analysis of spiking actions by the Chinese women volleyball players. The spiking actions were divided into the catergories of: Arm swinging type, Arm-raising type, and players attack speed. Li 14.26 m/s Sun 13.77 m/s Wang14.04 m/s Li 13.65 m/s Yang 13.53 m/s Wu 13.27 m/s Lai 12.65 m/s Wang 13.23 m/s Jiang 13.93 m/s V 13.62 m/s V 13.37 m/s. The hitting style employed tended to be classifiable by hitting position on the court. That is, middle attackers, who require a more sudden type of burst in their attacks, tended to use the arm-swinging action. While, the outside hitters along the antennas used the arm raising technique as described in the study. It was reported that, the fastest speed is the action by arm-swinging: 14.26 m/s and its equivalent, when compared to the action by arm-raising at 13.37 m/s. The data provided in the study (figure 4) shows that Chinese women's team shows the details of each type of arm swing. The swinging spike is smooth and coherent. The spiker can spike while leaping, which brings about a satisfactory spiking speed. Armswing spiking has great concealment and suddenness, and the swinging motion is suitable for a speedy attack. With this type of spiking style the Chinese players create the actions of front-fly, back-fly, and back-slide. The raising spike swing (used by outside attackers) is steady and accurate. This technique brings out in full the spiker's leaping and physical strength. This method of spiking is good for outside attacks and back row attacks. The researchers do point out, that more muscle injuries result from this type of spiking, however. the injury rate of their shoulder muscles is 45%, clearly higher than the action by arm-swinging (35%). Their data on this point comes from the Chinese National Volleyball Federation studies of subjects who use either technique in the training phase of competition.

My professional development was enhanced by the reading of this article. Too often hitters are trained the same way regardless of the position that they play on the floor. The Chinese research team has made it clear that training should not occur this way for a couple of important reasons. First, I now feel that I should train my middle hitters to hit with more of an arm swinging approach, as opposed to the arm raising approach. I had always taught hitters from all positions to hit with an arm raising approach. I see now the fallacy of such teaching. First, since I had taught my middles to use the arm raising approach, according to this research I was unnecessarily exposing them to a 10% greater risk of injury. Secondly, I was also limiting my middle attackers from having a more explosive attack of the ball. (14.2 m/s vs. 13.6 m/s). The research also gave me a step by step progression of the body position in the arm-swinging approach that I can study and teach my middle attackers. "*Arm-swinging type:* After leaping, the spiker's arm first bends naturally to chest height and no higher. Then her elbow turns around the axis of the shoulder joint from the back down position to the front up and accelerates to spike." In contrast, the arm raising type of approach, has the elbow going up and behind the head, "*Arm-raising type:* After leaping, the spiker's elbow first bends naturally towards the backside of the head, then swings around the axis of the shoulder joint and accelerates to spike in the front up direction" Of course, I will need to break down the subtle differences in these two techniques further. One deficiency of this research project is that it was not intended to be a teaching tool. I have seen other quantitative research done on hitting that has done a better job of keeping a pedagogical perspective within the results section that, thus, made it more practical and useful. In this particular study, this deficiency could have been linguistic in nature, as the researchers did not have English as their native language.

SECTION 2: INJURY PREVENTION IN THE VOLLEYBALL SPIKE / ATTACK

INJURY PREVENTION- KNEES AND ANKLES

The purpose of the study by Ciapponi, Teri and Hudson, Jackie (2000) was to look at a particular safety issue that is the bi-product of the aggressive attack in volleyball. Casual observations made by the researchers led them to believe that aggressive approaches to the net by attackers caused them to land on one foot after the completion of the attack jump. Previous research done (Coleman) indicated that landing on one foot increased chances for trauma related injury to the landing leg (due to dissipation of greater impact stresses). Thus, two footed landings are the recommended type of landings after an attack of the ball by a hitter in volleyball. Upon review of more than 100 hours of Video-taped footage from elite level volleyball competitions, approximately 67% of all front row attacking attempts resulted in one-legged landings. The researchers intent was to discover what factors in the aggressive attack led to mid air imbalance and the increased percentage chance of landing on one leg.

Methods

A three-dimensional video analysis was used to identify factors related to the development of ball speed and to the incidence of one-legged landings in high-outside, front-row volleyball attacks. Nine members of the 1999 USA Volleyball A2 Women's National Team (mean age 20.1 ± 0.9 years, mean height 1.91 ± 0.07 m, mean mass 76.6 ± 6.3 kg) were filmed at the United States Olympic Training Center in Colorado Springs, Colorado.

Results

Video analysis demonstrated that attackers possessed forward somersaulting, counterclockwise twisting, and counterclockwise "cart wheeling" angular momentum that resulted in faster hand speeds at contact but also a tendency for one-legged landings. Unfortunately, in this study, factors contributing to one-legged landings could not be clearly identified. There was, nevertheless, interesting data produced with regard to where speed was most generated by the body in the attack of the ball. At ball contact, hand speed was 11.9±O.9 m°s-1 (mean±SD). Post-impact ball speed was 19.4±2.3 m°s-1. Shoulder and elbow rotations accounted for about 75% of hand speed at the instant of ball contact while the speed of the CM itself accounted for about 16% of hand speed. Trunk rotation and wrist rotation contributed 11 % and 2% to hand speed, respectively.

Prior to reading this study, I had forgotten about the greater risk for injury that comes with a one legged landing during the high-outside volleyball attack. Landing on two feet is the best way to land after hitting the volleyball. Unfortunately, this study was not conclusive in determining an exact cause of one legged landings. However, the fact that "forward somersaulting, counterclockwise twisting, and counterclockwise "cart wheeling" occurred when the subjects tried to hit the ball faster/harder, is good reason to attempt to eliminate some of these types of movements in the training process. Further research needs to be done which would document the reasons for each of the biomechanical occurrences described, and then attempt to eliminate them from the hitters approach strategies. For example, if forward somersaulting occurred primarily when the hitter was late getting to the ball, specific timing issues could be addressed that would prevent the increased risk for injury. The research done here was good, but, it has begged further questions to be addressed. Nevertheless, the data collected which stated that Shoulder and elbow rotations accounted for about 75% of hand speed at the instant of ball contact while the speed of the CM itself accounted for about 16% of hand speed should indicate to the coach the importance of skill development in the area of the shoulder and the elbow rotation in the generation of speed and power in the attack.

INJURY PREVENTION- THE SHOULDER

The purpose of this study by Bittencourt, Neto and Franco, Natalia. (2007). was to analyze the ratio of medial and lateral rotators of glenohumeral joint in the male Brazilian Volleyball Team under 19 and 21 years-old. Twenty athletes under-19 and fifteen athletes under- 21, participated in this study. The rationale for the study was to take into account the high repetition of a specific skill, the volleyball hitting attack, and the effect it can have upon high level athletes. Movement efficiency is critical in such a high rep activity. The researchers point out that a highly skilled attacker with 16 to 20 hours of weekly practice time spikes, will hit the ball 40,000 times a year (Forthomme & Croisier, 2005). Other researchers have examined (Coleman et al., 1993; Forthomme & Croisier, 2005) repetitive movements in high speed in order to evaluate extremes range of movement (ROM), imposing great mechanical stress in the shoulder complex (Witrouw et al., 2005). The researchers also point out that the muscles of the shoulder complex play an important role in endurance, force and power production, allowing the accomplishment of sports movement in a balanced and coordinated way. These muscles keep the dynamic stability of glenohumeral joint. (Wilk et al., 1993; Alderink and Kuck, 1986; Ellenbecker and Mattalino, 1997). The glenohumeral joint is at risk among high rep elite athletes. (Gabriel and Patrick, 2002). A proposed solution involves the evaluation of the ratio between medial rotators/lateral rotators (RM/RL) and a dynamic and balanced stabilization between the lateral and medial rotators of the glenohumeral joint. (Cools et al., 2005; Forthomme & Croisier, 2005).

In this study, the Dynamometer Isokinetic Biodex 3 System Pro® was used to assess antagonist/agonist (RL/RM) ratio at 60º/s and 360º/s. The antagonist/agonist ratio was calculated through the division of peak torque of shoulder lateral rotators muscles by the peak torque of the medial rotators muscles multiplied by 100. (18). Multiple analysis of variance (MANOVA) with one factorial level (categories) and another of repeated measures (dominant and non-dominant limb) was used to evaluate the dependent variable antagonist/agonist ratio at the two speeds. Analyses of contrasts were used to locate the specific pairs between which the difference was significant.

A significant difference was found in ratio (RL/RM) between the categories, on the dominant limb (F= 11,840; p=0,0016 at 60º/s and F= 7,00; p= 0,0124 at 360º/s) and on the non-dominant (F= 20,269; p= 0.0001 at 60º/s and F= 11,223; p= 0,0020 at 360º/s). The under-21 athletes of Brazilian Volleyball Team presented RL/RM ratios below the expected values described in the literature.

The greatest values I gained from this study were with regard to performance enhancement and injury prevention. The factors discussed with regard to Medial Rotators (MR) and their correlation to volleyball spike velocity were informative. Characteristically, volleyball attackers possess strong MR's. However, the research article demonstrated that the necessary balance between the development of MR and lateral rotator strength (LR) is not always present in even elite level athletes. Since a decreased MR and LR ratio has been associated with shoulder injuries, it is a concern to the Brazilians, and to myself, when my own athletes do not have a strong LR/MR ratio. My concern is that in the gymnasium (non clinical) environment in which I find myself as a coach, that I will be able to conduct a similar test to determine the risk factors of my athletes. For example, how am I going to "calculate through the division of peak torque of shoulder lateral rotators muscles by the peak torque of the medial rotators muscles multiplied by 100." A more detailed description of the methodology employed would have been helpful. A further difficulty I had with this study was the discussion of improper hitting technique which is predominant in more inexperienced players. Improper technique puts extreme stress on the rotator cuff in volleyball attackers. Such form is present in college level players and was not addressed in the study. A comparison of the incidence of injury between athletes with poor technique which stresses the rotator cuff, vs. the more advanced concept of MR/LR ratio in athletes with excellent form would be excellent. Overall, however, this study helps in my professional quest to best prepare my athletes for success without injury.

SECTION 3: TECHNICAL MECHANICS OF THE ATTACK / SPIKE

APPROACH- SPEED and CONTROL

The purpose of the study by Ciapponi, Teri and Hudson, Jackie (2000) was to explore balance and skill in the volleyball approach and to gain insight into the following questions. The approach, is the means by which an attacker gains speed on the ground prior to jumping. That speed is translated into approach jump height. That is a horizontal force is transferred into a vertical force. Thus, the approach is a critical component of a successful offense in volleyball. Ideally, the biomechanics literature has shown that the hitter will use the approach to achieve a high jump with minimal horizontal motion (Prsala, 1982). According to Dusault (1986), greater height in the jump is predicated on greater horizontal velocity in the approach. Previous evidence has further shown that the hitter should maximize horizontal velocity at touch-down and minimize it at take-off. With this in mind, the following research questions emerged in this study: 1) How does the hitter arrest mobility? 2) If mobility and stability are inversely related, can mobility be decreased through increases in stability? 3) Do performers of distinct skill levels regulate the mobility and stability components of balance differently?

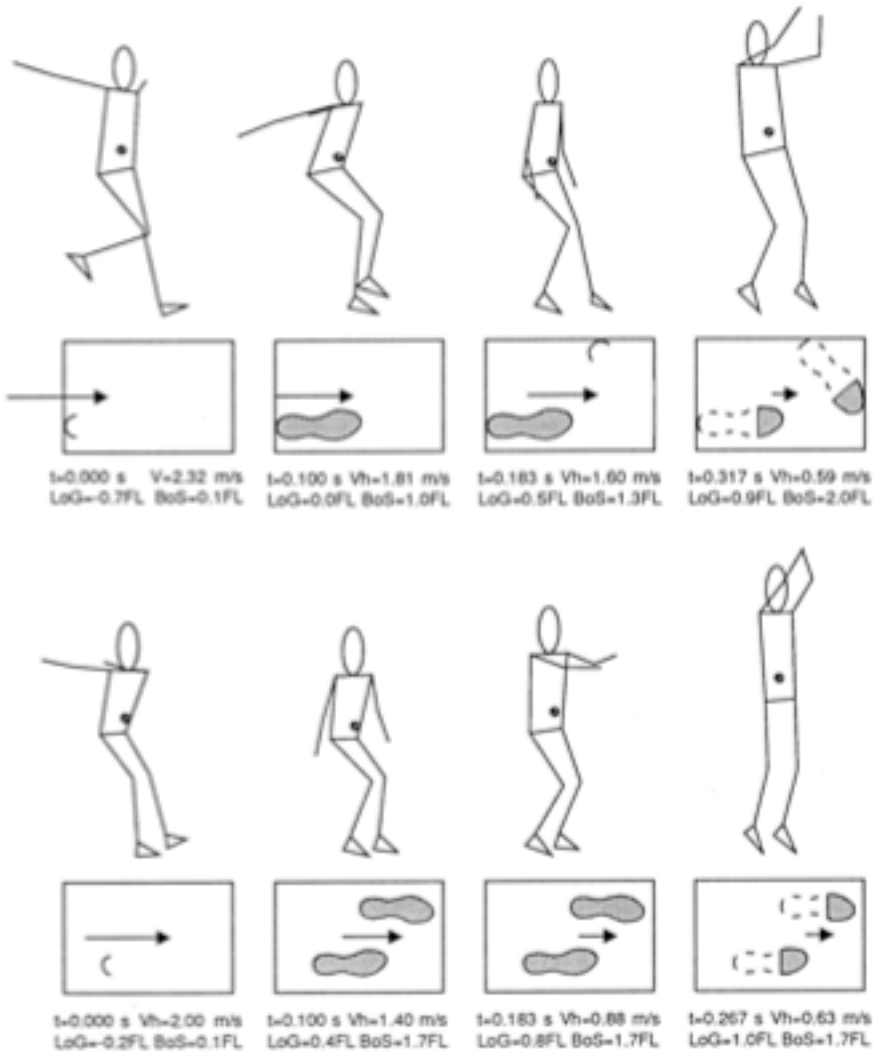
Methods

Two young adult females served as subjects in this study. An advanced performer (AdP) and an intermediate performer (ImP). Each subject executed several approach jumps from a hard, rubber runway onto a Kistler force plate (40x60 cm). Force data were collected at 250 Hz and reduced with Bioware software. The braking force (BF) was calculated as the resultant horizontal force. For comparison, forces were converted to units of body weight (BW). Each approach was videotaped at 60 Hz, and a representative trial with good force data was analyzed for each subject. Segmental end points were digitized and optimally smoothed with the Butterworth filter option in the Peak5 software. Body segment parameters were used to locate the position and velocity of the body's line of gravity (LoG).

Results

Because the advanced player (AdP) had greater stability and was better able to decrease mobility, there appears to be an inverse relationship between stability and mobility in the approach. Given that both players had less horizontal and vertical velocity than comparable subjects in the literature, both should try to increase horizontal velocity at touch-down. This should require greater BF (Neal & Sydney-Smith, 1992) and probable adjustments in stability. Both players, but especially the ImP, could move the LoG farther back relative to the BoS at touch- down. If the AdP could arrest mobility with a smaller BoS, she might be in a better position to apply vertical force for a higher jump.

I feel this study accomplished in large measure what it intended to do. One element of the research study with which the authors struggled was the fact that the athletes used a different technique for their approaches. With the AdP using the step close approach, and the ImP using the hop step approach, new calculations had to be made to make the data comparable. However, after that problem was solved, certain factors emerged which confirmed the researchers hypothesis that horizontal velocity can be efficiently converted to vertical velocity provided that the core stability of the athlete allows for horizontal velocity to dissipate and get converted to vertical velocity upon take-off. The step-close approach tended to help this conversion of energy from horizontal to vertical, and so, when teaching the approach, the teaching point should be made showing why the step-close approach is the preferred method of landing prior to take-off.   Braking Force, Base of Support, and Line of Gravity are all factors which improve the approach and lead to a more powerful jump and attack of the volleyball.



APPROACHES- A SECOND TECHNICAL ANALYSIS

The purpose of the study by Hu, Lin Huan and Sheu, Tai Yen. (2002) was to investigate the net muscle moments and work on the lower limbs in two different volleyball-spiking jump take-offs. The volleyball-spiking jump influences the height of the spike and the balance of the body in the in flight phase of the overall attack. Thus, the spiking jump is an important technique of volleyball spiking. It was assumed that spike-jumping techniques will vary considerably according to factors such as whether a) a hop jump (the feet step upon the ground simultaneously) or b) a step-close jump (one foot steps upon ground, then the other foot) was employed by the spiker. This study sought to reveal whether this was true or not. Furthermore, the study strove to compare if there were differences in the muscle groups power output (effecting ankle, knee, and hip muscles) depending upon which technique was used. Other factors to be considered, and which remained controlled in this study, were the approach speeds and lengths of the last stride employed. If the study were to show that both take offs (hop step or step close) produce the same power in the in flight phase of volleyball spiking, then both methods can be taught, although certain muscle groups may need more training depending upon which method is chosen over the other.

Sixteen volleyball players (8 males [height: 184.2±5.12 cm, body weight: 79.3±7.3 kg], 8 females [height: 171.5±5.66 cm, body weight: 63.8±4.56 kg]) volunteered as participants. After a warming up and stretching period, each subject performed hop jump take-off and then step-close jump take-off on a Kistler force platform(600 Hz). A Peak high speed camera was positioned perpendicularly 10 m from the subject and synchronized with a force platform to record the spike jump take-off action. A motion analysis video system (Peak Motus) was used to digitize the locations of five anatomical body landmarks (toe, ankle joint, knee joint, hip joint and shoulder joint). The raw data was smoothed with a four-order zero-log Butterworth low-pass filter. Net joint forces and moments were calculated following a standard inverse-dynamics approach.

Results: The results revealed that jump heights were virtually the same for both types of jumps. Thus, both types of jumping techniques could be taught with equal results. The step close approach, does put greater stress on the knee (36% of work) than the hop step (30% of work). The hop step puts a greater stress on the ankle (32%) vs. (26%) for the step close. The hips share of the work was equal for both types of jumps (38%) and also accounted for a greater work contribution on both types of jumps.

This study was beautifully designed and is tremendous help to myself as a volleyball coach. For over 18 years I have taught the step-close approach thinking it was by all accounts better than the hop step approach. However, now having read this research study, I am forced to reconsider my coaching methods with regard to the approach jump. Will I stop teaching the step-close approach method? No, I will not completely. However, there are reasons to do so. First, the work load on the knee is greater using the step-close method (36% vs 30%) of the work load. Since the knee is a primary area for injury among female athletes, this alone is a good reason for teaching the hop step approach. If I were to decide to do so, I must recognize further that teaching the hop step approach will put a greater work load on the ankle (32% vs. 26%) and my athletes will have to be trained to have stronger ankles by training the muscles supporting the ankle joint. By having this knowledge, I can also be flexible in my training techniques. For example, an athlete with a history of bad ankle problems, but strong knees, might be better off learning the step-close method of the approach take-off. Another very valuable fact from this study that I should employ in my training program is that fact that the hips account for the greatest percentage of the work load in the approach jump (38%) with both techniques. This fact further strengthens my belief in core stabilization training for my athletes. Either way they approach their attack of the volleyball core hip strength will be valuable in have a powerful in flight phase to their overall attack of the volleyball. An interesting improvement to the study would have been to see the differences that would have been made to the work load if an increase in the horizontal velocity of the approaching hitter changed the percentage of the work load (hips/knees/ankles) for the hitter (attacker) as they went from the preflight phase to the in flight phase of the attack.

SHOULDER MOVEMENT

The goal of this study by Romer, Karen and Kuhlmann, Claas. (2008) was to define parameters for the investigation of shoulder movement in volleyball spikes performed by sixteen elite athletes. The focus was set on the correlation between the trajectories of the elbow joint with respect to the shoulder joint coordinate system and the orientation of the resulting axis of rotation. For the description of the shoulder movement, quaternions, (a mathematical construct, and an interesting attempt to add the time dimension to the three space dimension coordinates in a calculation that involves the rotation of the shoulder.) were used. Using quaternions, the orientation of the resulting axis of rotation in the shoulder joint and the rotational angle were calculated. Additionally, the 3D coordinates of the elbow movement around the shoulder and the internal and external rotation were investigated. The results show that specific movement strategies for the humerus could be detected using these methods.

METHODS:
Motion analysis was done using four high speed Basler cameras (100Hz) and the software Simi Motion. The 3D coordinates were digitized manually and the movements were reproduced with high accuracy using the man model "Dynamicus." The data was time normalized with respect to take-off and ball-impact. The position and orientation of the coordinate systems fixed to the thorax, and the humerus, respectively.
The following assumptions were tested:
• Arm movements within the frontal plane correlate with the x-coordinate of the Axis of Rotation (RA)
• Arm movements within the sagittal plane correlate with the z-coordinate of the RA
• Arm movements within the transversal plane correlate with the y-coordinate of RA
The correlation between the upper arm movement in the frontal plane with the internal and external rotation was tested. All correlations were calculated for each spike.

CONCLUSION:
The comparison of elbow trajectories with those of the RA revealed high correlation of upper arm movement in the sagittal and transversal plane with the orientation of RA. the movements in the sagittal plane (elb x-coord. and elb y-coord.) and in the transversal plane influence the orientation of the axis of rotation. For movements in the frontal plane an additional dependency of internal and external rotation was found. That leads to the conclusion that concerning shoulder kinematics in volleyball spikes the abduction and adduction angles and the internal and external rotation are indeed interdependent and are indicative of different spike techniques.

This study assisted me the most in terms of understanding biomechanical concepts dealing with the rotation of the shoulder. Although there are complex mathematical analyses done on the shoulder in this study, there was also valuable information that broke down the study of the shoulder into basic concepts that could be better understood. For example, figure #1 from the study diagramed the frontal (x), sagittal (z), and transversal (y) planes along which the shoulder axes of rotation occurred.

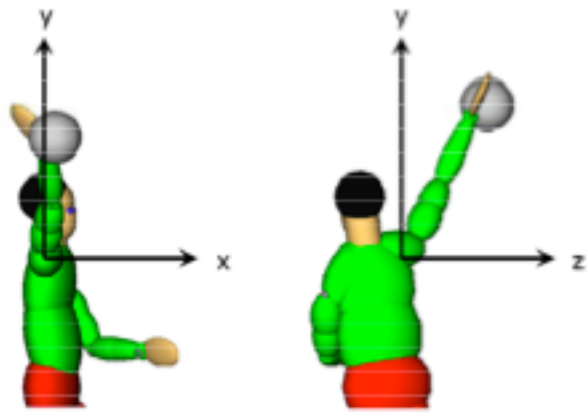


Figure 1: Definition of shoulder coordinate system (ISB standard)

If I didn't understand anything else, understanding that there are standards (ISB standard) and working groups that are continuing to develop the means by which to measure the interplay and interdependence between the joints, muscles, tendons, and ligaments of the hand, elbow, and shoulder. As a professional coach and teacher, anchors such as this are critical to my hope of ever being able to teach these concepts on the court or in the classroom. One hope would be that researchers will speak more in layman's terms about certain concepts such as "Gimbal Lock." I had to research for myself the phenomenon of Gimbal Lock as it related to everything from 3D animation to shoulder quaternions, and the efforts of an Irish mathemetician to explain movement of the shoulder along the rotations of axis along the frontal, sagittal, and transversal planes.

BALL CONTACT HEIGHT

The purpose of the study by Vint, Peter F. and Hinrichs, Richard N. (2004) was to quantify the deterministic factors of overall ball contact height among elite level volleyball attackers. In volleyball, a key factor is how high above the ground the attacker can get to hit the ball. When blockers move to block a hitter, they can put up an imposing block. Usually about 9 ft. 6 inches. Or, over three meters in height. Success to hit over a block requires full extension by the hitter so that they can hit the ball at the maximum height in the air. The researchers were able to divide the jump (which lasts less than 1.5 seconds) into meaningful segments of the jump. Thus, the researchers were able to analyze the important phases of the jump. Methodology: Thirty-two trials collected from nine members of the 1999 USA Volleyball National A2 Team were subjected to 3D analysis. Results demonstrated that takeoff height (Center of Mass (CM) height at takeoff) and reach height (vertical distance between the hand and CM at contact) accounted for 86.7% of the overall ball contact height. Flight height (in-flight CM elevation) accounted for only 14% of overall height. Reach height was the only meaningful sub-height that was significantly correlated with overall ball contact height (r=O.70) and appeared to be most sensitive to technique-related differences in performance. Horizontal approach speeds used by the athletes in this study were relatively slow (3.4±O.3 m°§s-1) but were positively correlated with flight height (r=O.60). Findings: All things being equal, the flight height, although the data shows that it accounts for 14% of overall jump height, is a critical component that can be improved through teaching techniques brought out in the article. The lowering of the non hitting arm at the height of the jump. Piking, and not extending the hips and hitting arm at the top of the jump also accounts for a loss in maximum reach height. There are graphs and pictures in the article that demonstrate this deficiency. On the other hand, the researchers point out that recruiting athletes that are tall and have a high CM and a high reach height is the major factor to be considered when recruiting a volleyball athlete. It is pointed out that flight height (which accounts for 14% of overall height) is the most vigorous part of the jump and involves three measurable factors. The first factor in determining flight height is horizontal speed obtained into the approach. In the study the horizontal speed of the attackers was approximately 3.4 meters per second as already mentioned. Forward Arm Propulsion (the forward swinging motion) was also an important component of flight height. Another factor in flight height is the take off angle of the attacker. Attackers CM averages 50% from the point of take-off into the air and towards the net. That is, there is also an ideal trajectory in which an attacker propels her body towards the ball in order to obtain an optimal flight height in the quest to achieve the highest possible ball contact height.

This article was extremely helpful for my coaching the sport of volleyball. The way the researchers broke the skills of hitting the volleyball down into various parts was valuable in and of itself. The study was good because I can now teach the attackers new and helpful things regarding their skill development. First, I will be able to teach them that although most girls at their age level, (I am coaching 14's this spring) have similar height and reach, the area where we can exceed them is in the flight phase of the jump. I can show them how we can increase our flight height by increasing our vertical velocity in our three and four step approaches to jump and hit. Having the data from this study in my mind, and having been given a target of 3.4 meters per second for approach speed, I can time my attackers bursts of speed in a three meter approach and get them closer to the idea time at takeoff. I can also work with them on arm swinging propulsion in assisting them in elevating off of the ground. Another teaching point I can make from this study has to do with a factor called ball contact LOSS height. I will emphasize that the mistiming of a jump makes one lose height on ball contact, and thus gives the blockers a better chance of blocking the ball. Thus, this article has helped me in my coaching ability. One thing I would have liked to have seen in the study is a control group. That is a group different than the homogeneous group that was evaluated. The researchers themselves admitted that the study looked at athletes who were all relatively speaking of the same body type and skill ability. Having a variance would have made the results more interesting and could have highlighted the differences in techniques, and how critical proper form really is. I am grateful that I have found many articles such as this one in my project research. And thankfully, there are others which do compare a wider spectrum of athletes in looking at skills in hitting, etc…

SPIN ON THE BALL

The study by Baudin, Peter F. and Wu, Tom (2004) entitled, "An Examination of the Biomechanical Factors that Produce Spin on a Volleyball in the Skill of Spiking," was a groundbreaking research effort on the subject of ball spin. Spiking is the most important attacking skill in the sport of volleyball and its effectiveness is in large part determined by the amount of topspin it has after leaving the attacker's hand. A spinning volleyball, because of the lift forces produced by the Magnus effect, has the advantage of being able to be hit with greater velocity, higher above the net, and at flatter angles over the net than balls with little or no spin while still landing in the court on the opposite side. The technique that creates topspin in a volleyball spike is agreed upon in the instructional literature (Howard, 1996; Scates, 1993). It is described as being produced by the heel or palm of the hand contacting first and then the fingers wrapping over top. However, very little research done on spiking has examined the hand contact with the ball (Alexander and Seaborn, 1980; Maxwell, 1982) and none has examined the actual torque production mechanism. Therefore, it was the purpose of this study to determine the biomechanical factors that produce the spin on a volleyball during the spiking action.

METHOD: Participants for the study were 7 men and 11 women's members of a university volleyball team. The subjects first warmed up and then performed 5 standing spikes each of a volleyball that they themselves tossed into the air. High-speed video of the subjects was collected using standard two-dimensional videography methods using a high-speed digital video camera operating at 500 Hz. The camera was positioned to allow a zoomed in view of the forearm and hand of each subject and the ball as it was struck. The video record of each of the 90 spikes was analyzed with the APASTM motion analysis system using a 3-segment spatial model to represent the arm and hand. Spatial data smoothed with a second-order Butterworth digital filter was then used in the kinematic analysis of hand segments and the ball. Descriptive statistics were used to present the kinematic data.

RESULTS: The study showed that two different hand contacts produce spin on the volleyball by a spiker's hand. The first technique, agrees with the literature, showing that the spin is produced by the palm of the hand first contacting the middle of the ball followed by a wrapping action of the fingers over top creating the torque. A second technique, not previously reported, was also seen in which the fingers of the hand contact first at a point high on the ball to create torque. In this group, the finger contact was followed by the palm of the hand striking the middle of the ball. Of the 90 trials, 47 were classified as palm first contact and 43 were finger first contact. The palm first contact technique produced a mean ball angular velocity of 39.02 rad/s that was not significantly different from the finger first technique that produced a mean ball angular velocity of 41.42rad/s.

I feel this study gives me greater flexibility in teaching the contact point (when striking a volleyball in the attack phase at the height of the jump) to my athletes. The results of the study above indicate that experienced volleyball players use two different but equally effective techniques of hand contact to produce spin in a spiked volleyball.

Like most volleyball coaches, it was drilled into my head during my training in the USA volleyball coaching accreditation program (CAP) to teach palm first, and then, fingers wrapped around the top of the ball to produce topspin. Teaching this critical skill (after all, a ball hit with a high velocity without topspin will sail out of bounds) with this added option is extremely valuable. In retrospect, it seems simpler to teach young athletes to hit the top of the ball with their fingers first, and with their palm following and making contact in the middle of the ball. I am honestly going to try out this teaching point. As the study has indicated, each of the two styles of hitting produced quite similar angular velocities, 39.02 rad/s vs. 41.42 rad/s. There is, however, a weakness to this data presented in the study. All of the data was taken, i.e. the videos were conducted, with the athletes hitting from a standing position. Hitting from a jumping position could change the results of the data significantly. A jumping hitter will need to have greater ball control. Hitting a ball palm first (in center of ball) and then wrapping the top half of the ball with fingers could prove to give the hitter better ball control and accuracy while hitting the ball in mid air, vs. in a standing position. The study would have benefited readers such as myself, with the next step of the study being to determine what sorts of losses in accuracy occur in a jumping position by hitting a ball fingers first, vs. palm first. However, this reader understands the video data capturing process would have been more difficult to complete if filming hitters from a jumping position. Therefore, I understand and appreciate the limitations that may have been present and considered in the design of the study. Thus, I will take the good from the study and experiment with teaching the topspin hit from a standing position using the finger first technique, the palm first technique, and perhaps a simultaneous contact (palm and finger) of the ball.

To conclude, the purpose of this study was to provide a review of the literature in volleyball biomechanics. As demonstrated there is literature which is both exhaustive and comprehensive. The researchers who have striven to create an overview of the volleyball spike/attack have been represented here, as have the researchers who have made their focus injury prevention. By the same token, the research that has been conducted that is of a more technical nature is also valuable. Just as our text mentioned the value of biomechanics in increasing sport performance, I believe to have demonstrated through my application of the findings sections that, indeed, sport skill performance increases can be achieved with the application of this biomechanical knowledge. Therefore, this has been a valuable project as it has added value to this researchers understanding of the mechanics of the volleyball spike from a teaching perspective, and in terms of injury prevention.

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