

# A kinesiological analysis of the tennis service

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The tennis serve has the capability of being the single most powerful weapon in the arsenal of tennis strokes. Its proper execution may result in the termination of a point without a single retort from the opponent. An imperfectly placed but powerful service can still force the opponent to react late, lose balance or force an error. A perfect service alone can save a player from defeat.

Groppe (10) described tennis "as a game of continual emergencies with each stroke accommodating to the ball." The service is an exception. It is the only stroke under complete control by the players alone. Alterations must be made for environmental conditions such as wind and sun. However the player's opponent cannot control the time allotted, spin of the ball, placement of the ball or contact point of the service. The service should be a self-controlled offensive weapon forcing the opponent to cope with the myriad of emergencies the server presents.

Service form has a number of variations dependent upon the proficiency of the player and the desired effect on the ball. Classical, popular styles, flat, slice and topspin services alter some aspects of the motion. However the basic principles underlying the service motion persist. The coordination of movements resulting from these principles will result in a successful service motion.

The service motion can be divided into five aspects:

1) preparation

- 2) toss
- 3) backscratch
- 4) contact
- 5) follow through

All actions described in this article will be from the perspective of a right handed player. Although the toss and backscratch are listed

separately, both maneuvers must be coordinated together. Each action flows smoothly into the next, contributing to the successful culmination of the service.

The preparatory phase begins with the player standing behind the baseline with his feet approximately

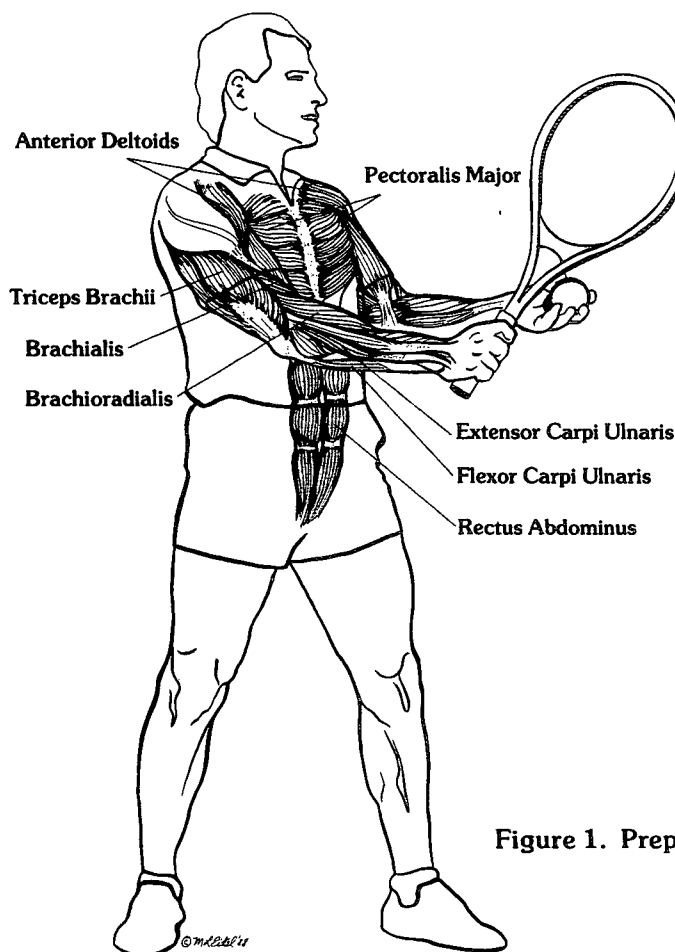


Figure 1. Preparation Phase

shoulder width apart. Stability is ensured by positioning the center of gravity comfortably within the limits of the base. The frontal plane of the body is aligned with the opposition's service box. This perpendicular position of the sagittal plane to the intended direction of the ball will result in an important 90 degree rotation of the hips, trunk and shoulders prior to contact. The front foot is placed at an approximate 45 degree angle to the baseline. Placement of the foot more parallel to the baseline inhibits rotation due to the restriction of the talofibular and calcaneofibular ligaments of the ankle. Some servers such as John McEnroe adopt this position forcing them to rise up on their toes or leave the ground in order to rotate the hips. This may lead to a loss of the balance and stability that was initially established.

An erect but relaxed posture is set. Arms are extended toward the target area, parallel to the frontal plane. Elbows are slightly flexed (Figure 1). This relaxed, balanced posture is maintained momentarily before initiating the service motion. It allows the competitor time to clear extraneous thoughts and narrow the focus of attention to the upcoming task.

A number of different grips may be utilized, dependent upon the desired effect on the ball. There are a multitude of texts which delve into detailed descriptions of the various grips. For the sake of brevity, a full explanation will not be attempted here. It is important to develop a firm but not vise-like grip. A firm wrist is necessary to prevent the racquet head from straying from its intended path under the influence of high angular speeds and torques. In addition, a malleable wrist will not provide the strong opposition to counteract the reaction of the ball on the racquet. All the motions prior to contact are inconsequential if a proper grip does not lead to a solid contact with the ball.

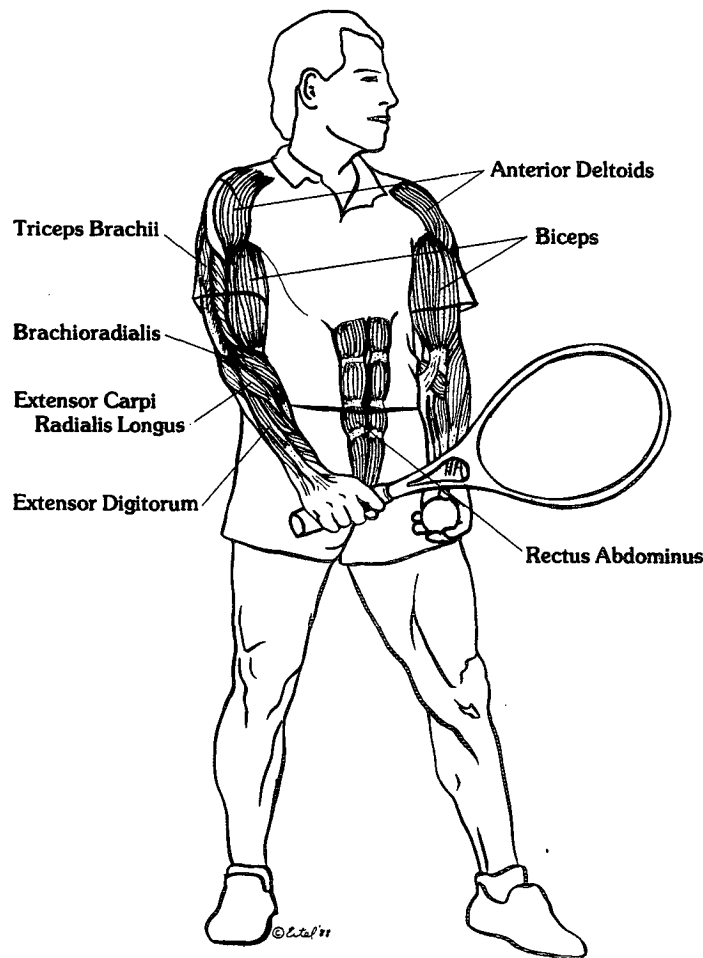


**Figure 2. Initiating Toss and Backscratch**

The ball and racquet arm in the toss phase move from their initial position in an arc to the anterior portion of the pelvic girdle. The racquet arm continues in its clockwise rotation to the opposite side of the body. Conversely, the ball hand stops its movement and proceeds in a counterclockwise rotation, past its original position (Figure 2). This seemingly unnecessary movement of the ball hand is important to ensure both arms travel the same angular distance. This should secure proper timing and coordination of ball release and subsequent contact. Shoulder flexion in the toss is

accomplished through concentric contractions of the supraspinatus and deltoid (Figure 3). The final segment of ball arm motion involves shoulder elevation and upward rotation of the glenoid cavity. Muscles involved with elevation include the trapezius and levator scapula, while glenoid cavity rotation is conducted by the lateral fibers of the trapezius. The shoulder continues to flex and elbow is fully extended until it is nearly perpendicular to the ground (Figure 4). Many players allow the ball arm to drop rapidly after the release of the ball. It should remain erect to inhibit premature

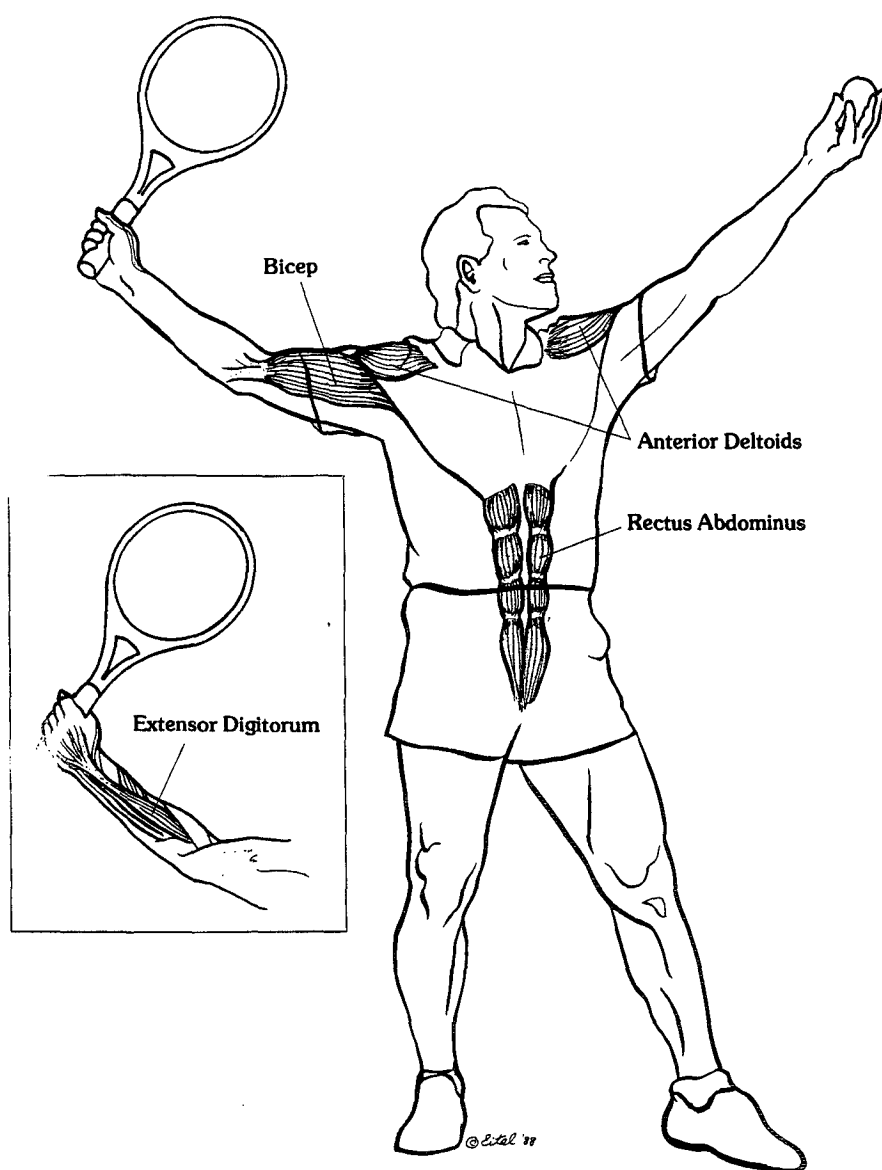


**Figure 3. Toss and Backscratch**

trunk and shoulder rotation until the racquet arm has descended to the backscratch position. It is also a physical reminder to keep the head up and eyes concentrating on the ball. The ball is released by the fingers sometime before the final position, reaching a height just greater than the fully extended racquet and 12 to 14 inches to the right of the leading shoulder.

Grasping the ball by the fingers and not the palm of the hand is a very important consideration. Fine control exerted by the fingers allows more precision than the gross control of the shoulder and arm.

This is due to the extensive network of fine muscles controlling the fingers (i.e. extensor digitorum, extensor digiti minimi, abductor and extensor pollicis longus, extensor indicis, dorsal interossei). Fine motor control may also be enhanced by a smaller motoneuron to fiber ratio allowing for finer gradations of activation and contraction (2). Since the force for tossing the ball is mostly attained from the momentum of the arm and shoulder, fine placement of the ball is delegated to the fingers.

Classical service style has the server remaining in an erect position with extended legs throughout the

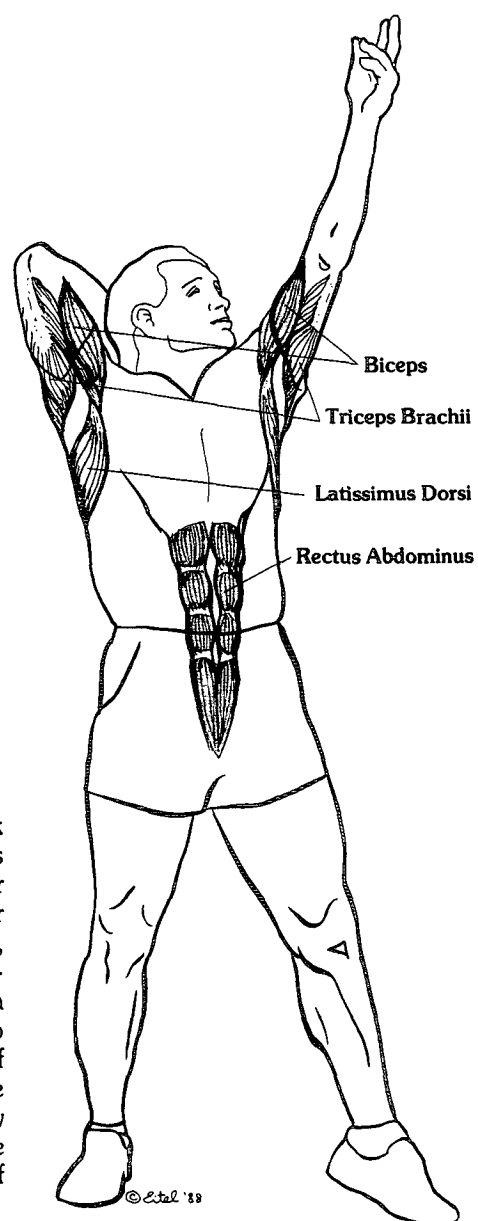


**Figure 4. Completion of Toss and Backscratch**

motion. Contemporary techniques increasingly utilize knee flexion during the toss and backscratch phase (**Figure 5**). This allows a powerful knee extension prior to contact which, through the ground reaction forces, contributes to the vertical forces on the ball. This is especially important for topspin services. This controlled knee flexion is accomplished by eccentric contractions of the quadriceps group. The server's center of gravity is displaced at the same time to a position nearer to the rear leg. This is in preparation for a forward linear movement prior to contact.

The backscratch movement is a neglected portion of many beginner's

services. The success and consistency of an effective serve is directly related to the proper execution of the backscratch. Backscratch action has the racquet arm circumducting from its preparatory position in a clockwise direction. This continues until the upper arm is level with the shoulder, marking the start of elbow flexion and external rotation of the shoulder. Shoulder circumduction and elbow flexion continue until the racquet head is placed on the inferior aspect of the back. At the same time, the elbow is brought to a vertical position perpendicular to the ground (parallel to the sagittal plane).

The backscratch is a complicated maneuver to master in concert with

a correct toss. The reason for this wide expanse of movement is lost to many beginners. Since the ball is contacted at a high position, many players mistakenly believe the ball should be stroked down over the net. However, a height of approximately 3 meters is the minimum contact height needed to hit down on the back making contact with the service area, with an adequate margin of error (**Chart 5**). A typical tennis player (6 feet) however, may make contact with the ball at a height of 2.8 meters (**Chart 6**). Therefore it is imperative that the ball is stroked with an upward motion. The positive angle at which the ball is released is dependent upon a number of factors including type of spin, height of contact, velocity of release and placement. The *raison d'être* of the backscratch is to allow the athlete to hit up and through the ball. The evolution of the backscratch marks the emergence of the service as an offensive weapon.

The effectiveness of this weapon is further enhanced by the speed of rotation of the hips, trunk and shoulders. The transfer of angular momentum is a major contribution to force exerted on the ball. A proper backscratch is a determinant in the efficiency of angular rotation. The resistance to the angular rotation is dependent upon the magnitude of the moment of inertia. Moment of inertia or resistance to angular movement is a function of the segment's mass and its radius squared. When in the proper backscratch position with the elbow high and parallel to the body, the radius of the rotating body is small. However when the arm is partially extended away from the body (lack of backscratch) the radius of the body is increased. Just as a figure skater can increase or decrease rotation by pulling her arms in or extending them, the tennis player can improve angular rotation by tucking the racquet arm in its proper

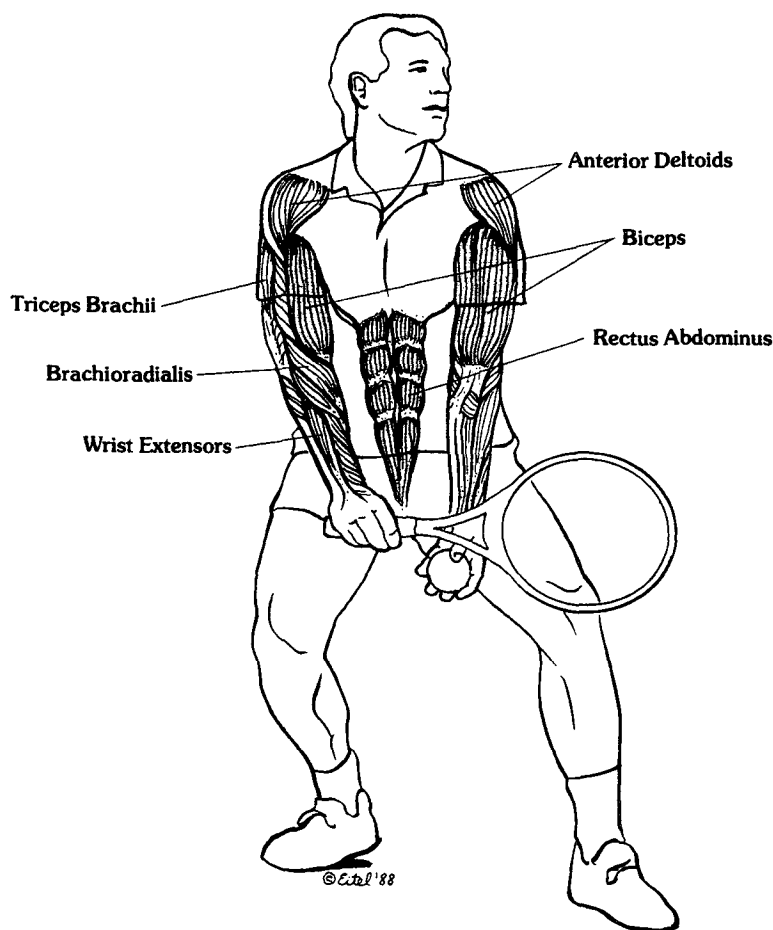
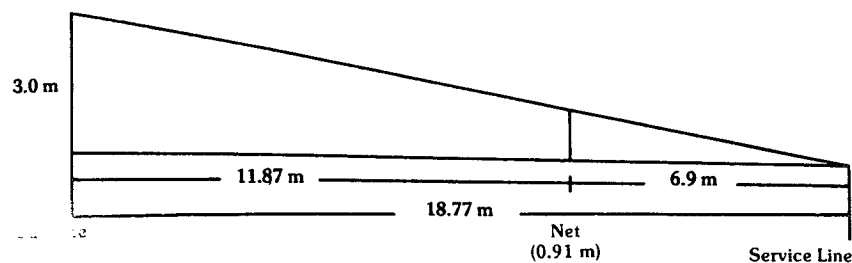


**Figure 5. Knee Flexion in Toss Backscratch Phase**

**Chart 1. Height calculation for a descending angle of projection on a service.**



**Contact height = 3.0 m (approximately 10.4 feet)**

**Chart 2. Trajectory of services allowing for margin of error.**



**Contact height = 2.8 metres (approximately 9 feet).**

backscratch position. This decrease in the moment of inertia translates into increased speed of angular rotation creating greater momentum to be transferred to the ball.

Many players, both novice and experienced, extend their elbow and upper arm to a position perpendicular to the sagittal plane. This positioning of the elbow decreases potential force by nullifying the contribution of the triceps prior to contact. In addition, the high elbow position places the triceps in a stretched position. This helps to generate more force through the help of the series elastic component. Series elastic component is composed of the muscles' connective tissue, which acts like an elastic when stretched to snap back to its

original position when shortened or relaxed. Thus, the potential of contractile and series elastic component forces are lost when the elbow remains low.

Movement and stances in the preparatory, toss and backscratch phases are relaxed, fluid and smooth. The generation of large forces created by muscular contractions is unnecessary and antagonistic to the desired fluidity. Circumduction of the arm can be subscribed mostly to gravity, which builds momentum due to the mass of the arm and racquet. Abduction of the shoulder in the up phase of circumduction may be aided by the supraspinatus and posterior fibers of the deltoid, while the trapezius

and levator scapula contribute to shoulder elevation and glenoid cavity rotation. Full circumduction is accomplished with external rotation of the shoulder. This action is executed through contractions of the infraspinatus, teres minor and posterior fibers of the deltoid. Gravity and the submaximal contractions of the aforementioned muscles contribute to the momentum to be exerted upon ball contact. However, many players develop hitches or pauses in their service motion. The hitch may be due to an excessively high toss which ruins the timing of the movement and arrests movement in the backscratch. This action obstructs momentum and results in a decreased capability of creating greater forces upon contact. The fluidity of the movement must now be replaced with an emphasis on "muscling" through the ball.

Some players have a tendency to hyperextend their backs during the toss and backscratch phase. This is especially prevalent for topspin services. Hyperextension followed by trunk flexion helps contribute to the vertical and horizontal forces exerted on the ball. Hyperextension is initiated by concentric contractions of the erector spinae group and controlled from excessive movement by the abdominal group. Although forceful trunk flexion would contribute to the forces exerted on the ball, the hyperextension places the center of gravity nearer or outside the confines of the base eliminating much of the player's stability. In most cases, only advanced players can control the dynamic balance needed to execute this maneuver properly.

Classical and popular styles differ in the movement of the body during the contact phase (Figure 6). Classical style shifts body weight from the back to the front foot without moving the back foot. A more popular method is a forward step of the rear foot to induce a more dramatic transfer of weight. Linear momentum must work in concert with angular

momentum to produce the greatest possible forces and torques. The stepping action facilitates angular rotation of the hips. The classical style has the rear foot rotating onto the toes to allow hip movement. Although the stepping action may provide greater propulsion to the ball, it also presents a less stable base. The use of either style must be dependent on the experience and skill of the player.

It is also popular to forcibly extend the flexed knees from the backscratch/toss phase. This contributes to the vertical forces needed for the parabolic flight to clear the net. This is accomplished through

concentric contractions at the hip of the gluteus maximus and superior fibres of the hamstring and the quadriceps at the knees.

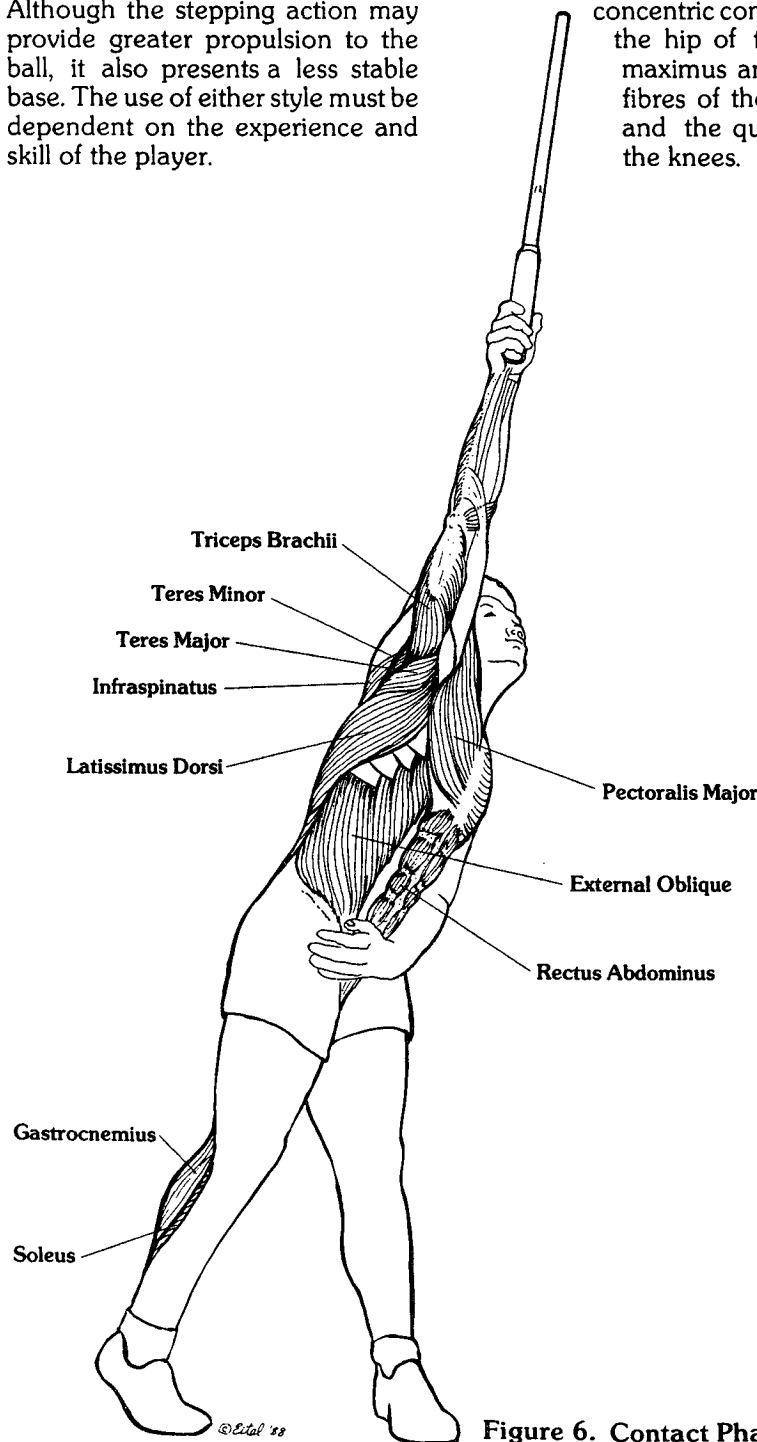


**Figure 6. Contact Phase**

In conjunction with the weight transfer and knee extensions is a powerful rotation of the hips, trunk and shoulders. External and internal obliques control the force and speed of this action. Rotation discontinues when the sagittal plane is aligned with the service area. The cessation of rotation is aided by the contralateral movement of the ball arm down and across the front of the body. Rotation of the relatively massive body segments builds up angular momentum which is transferred after rotation stops to the less massive arm and racquet. This transfer dramatically increases angular speeds of the limb prior to contact. Angular speed at the shoulder is further enhanced by the contractions of the latissimus dorsi, teres major and minor, upper fibers of the pectoralis major, infraspinatus and triceps. Powerful elbow extension is magnified by concentric contractions of the triceps as well.

The combination of these anatomical and mechanical forces should result in a high speed ballistic action. Research by Ariel and Braden (1) concurred, reporting the service action to be entirely ballistic. Conversely, they found ground strokes to be a combination of ballistic and tracking movements. Ballistic movements are characterized by a preprogrammed control which triggers neural firings and irrevocably commits the body to a path of motion. On the other hand, tracking movements are more controlled actions under the direct control of agonist and antagonist muscles. The neuromuscular triggering relies on feedback from muscle, tendon and skin receptors. The disparity between the two types of actions relate to Groppe's (11) initial description of tennis. Since ground strokes must adapt to the continual emergencies of a high speed, bouncing, spinning ball, it may be necessary to make modifications in the swing after it has been initiated. However, the service toss should not present any emergencies. A consistent and well

executed toss should allow the server to initiate movements that create the greatest possible torques and speeds without alteration or modification.

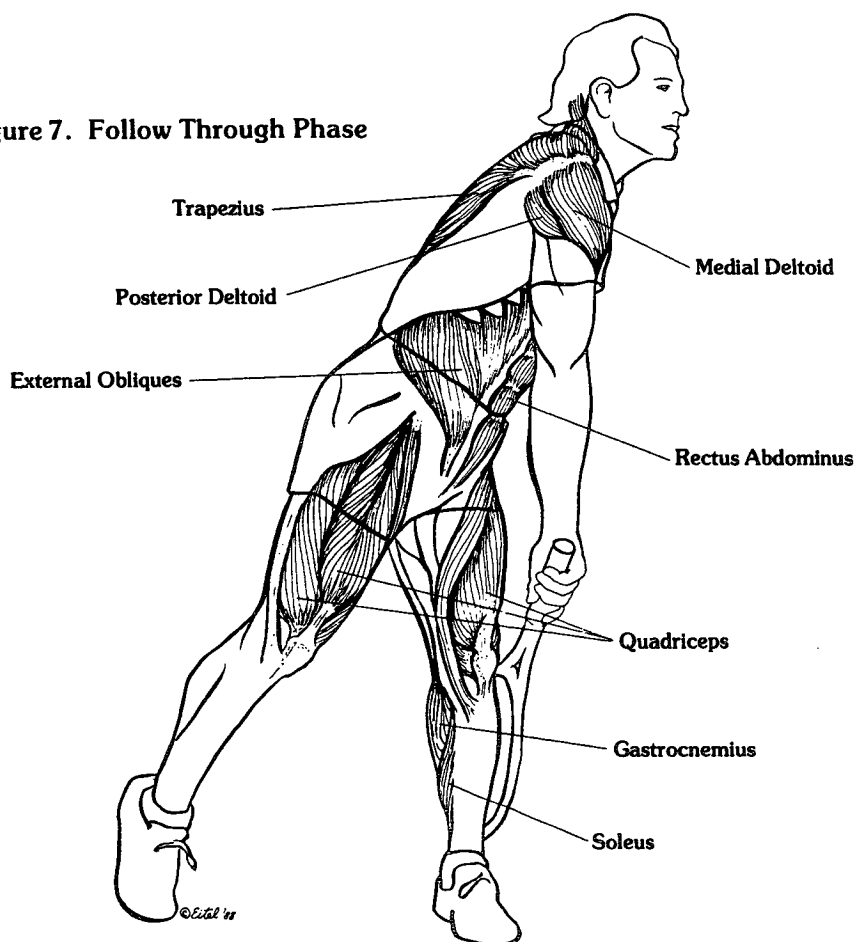
Finally, successful contact is dependent on the orientation of the wrist (**Figure 6**). Ball contact with a flat racquet face relies on medial rotation of the shoulder and wrist pronation. Pectoralis major, latissimus dorsi, teres major, subscapularis and anterior fibers of the deltoid work together for medial rotation, while the pronator teres and quadratus aid in wrist pronation. Slice and topspin services rely on partial pronation as well as wrist adduction (ulnar deviation). This action involves the combined forces of the flexor and extensor carpi ulnaris. Groppe (11), using cinematography, observed wrist hyperextension prior to contact, and wrist flexion upon contact with the ball. The lack of proper coordination of wrist flexion causes many players to stroke down on the ball into the net. Although wrist flexion provides added impetus to the force on the ball, it is imperative that the racquet face is not oriented down at the time of contact. Wrist flexion is achieved through the contractions of the flexor carpi radialis, flexor carpi ulnaris and palmaris longus.

The ultimate objective of all these movements is to contact the ball in the sweet spot of the racquet. Brody (4) highlights three possible theories defining the sweet spot:

- 1) center of percussion;
- 2) vibration node;
- 3) highest coefficient of restitution.

The center of percussion is a point on a body where if a force is applied outside the center of gravity, the linear and rotational motion of the eccentric force will cancel each other, allowing the object to pivot around that point. The player, as a result of the center of percussion, will not experience any forces tending to push or pull the grip from his hands.

**Figure 7. Follow Through Phase**



The vibration node theory accepts that every object has a tendency to vibrate. These vibrations are carried in the form of waves to create a natural frequency. Nodes are locations along the length of the body where waves have a tendency to cancel each other. A tennis ball contacted at this point will not have any vibrations transmitted to the player's arms.

The coefficient of restitution refers to the elasticity of contacting bodies. The less elastic the bodies are, the greater the height of the bounce and the higher the coefficient of restitution. The racquet is stiffest near the handle and, since less elastic energy will be absorbed, the coefficient of restitution is higher at this point. The highest coefficient of restitution of the strings is along the vertical center of gravity line.

In summarizing the locations of the three areas, Brody found the center of percussion to be two inches

below the center of the racquet head in conventional racquets, and nearer the center with oversized racquets. Conventional racquets had their vibration node five inches from the top of the racquet, or close to the center, while oversized racquets were a little above the center of the strings. The coefficient of restitution would be highest below the center of the strings, closer to the handle. Where exactly should the ball be contacted? It would seem Groppe (11) has the most appropriate term — "hitting area." There is probably not one precise area to hit the ball on the racquet, but rather a "hitting area," around and somewhat below the center of the strings, that provides an optimal compromise for the center of percussion, vibration node and coefficient of restitution.

The follow through is an integral segment of the service action (**Figure 7**). Since the service movement is ballistic, an abbreviated follow

through would be due to muscular contractions of antagonists interfering and slowing the motion. This would invariably commence prior to contact and nullify some of the summed forces that created the initial torques, velocities and momentum.

The follow through has the racquet continuing in its arc forward and across the median sagittal plane of the body (**Figure 7**). The racquet head should rest or be decelerating as it passes the lateral inferior aspect of the non-dominant shank. The action shifts the center of gravity forward over the front foot. This unweighting destabilizes the server, allowing ease of movement to the next position. He is now ready to react and contend with any emergencies the return of service may have to offer.

## Training Program

The ballistic movement of the tennis service is generated through muscular and mechanical means. Linear momentum, transfer of angular momentum and the summation of forces involved in the kinetic chain all contribute to the final result. These may be improved through better timing and coordination of the actions. The forces and speeds of these mechanics can also be improved through increased muscular efficiency. A strength and power training program for tennis would not only prove valuable for increasing the torque exerted upon the ball at contact, but the ability to continually repeat this action, time after time.

A training program for tennis must take into consideration the specific actions of the sport. Two concepts to consider when implementing a program are movement specificity and velocity specificity. The melding of these two factors can create the most advantageous program for the sport.

A neglected area in many training

programs is action specificity. Sport or movement specificity is an important concept in strength training. This concept is supported by both metabolic specificity and the contribution of different muscle fiber types (16). Psycho-motor learning theories also concur with the concept of movement specificity. Both Adam's perceptual trace mechanism and Schmidt's schema emphasize the continued repetition of a movement to encode the memory or set of rules for an action (15). Evidence suggests it is more beneficial to learn a task as a whole movement than to divide it into component parts (14, 3). Conversely, many weight training exercises attempt to isolate individual muscles. Other exercises are so general that they stress all the muscles in a region. The hypertrophy of inappropriate muscles may interfere with the efficiency of movement. Action specific training may reduce the number of exercises needed to stimulate the involved musculature. The shorter duration of the workout could result in improved intensity and more efficient time management. The continued repetition of the sport movement under normal and resisted conditions should result in an automatic and powerful reproduction of the action under a variety of conditions.

The concept of velocity specificity has also surfaced as an important consideration. Some early strength researchers demonstrated improvements in speed of limb movement with weight training (18, 8). However recent isokinetic research has illustrated a speed specificity of training. Researchers such as Caiozzo (5), Coyle (9), Sherman (19) and Carr (7) isokinetically trained their subjects and found improvements in peak torque only at the training speed. Knapik (12) explained that motor tasks become more dissimilar at different velocities, requiring different patterns of neural recruitment and coordination. Other

researchers have found training effects at the training velocity and below (17, 13, 6). Thus, the effects of power training seem to be restricted to a narrow spectrum of velocities.

However, it is necessary for the athletes starting a program to build a base of strength. The first macrocycle of the training program should involve progressively more intensive isotonic training. The movements should be slow and methodical, providing sufficient progressive resistance to stimulate the improved efficiency of the neuromuscular system and effect some muscular hypertrophy. The purpose of the strength base is in preparation for later speed work and the prevention of injuries.

The prevention of injuries through strength training is accomplished by the improved shock absorption capabilities of the muscles to the torques and vibrations presented by the racquet and ball. An increased tonus and/or hypertrophy of a muscle will increase the tension of the tendons encapsulating a joint. The improved tension of the tendons can aid the ligaments in their support of the joint integrity. Improved contractile forces of the muscles both concentrically and eccentrically can more efficiently decelerate the forces of momentum generated in the service and ground strokes. Finally, strength training can be utilized to help alleviate side dominance which is prevalent in many racquet athletes. The muscular imbalance of one side over another leads to alignment difficulties and strained muscles.

The strength training phase is progressively replaced by speed or power training. This can be attained through several means. One of the most advanced methods is isokinetic training with machines which control the speed of movement, providing variable accommodating resistance but lacking some of the movement specificity. On the other hand, surgical tubing is action and

speed specific, but due to the elastic resistance of the band does not provide overload resistance at the beginning of the motion (**Editor's Note:** See *NSCA Journal* 10(4):66, for specific use of surgical tubing in developing the tennis serve.). Free weights may be moved ballistically, but due to the law of inertia (any body in motion seeks to remain in motion) there is very little resistance to motion at the end of the range. In addition, the generation of momentum with the free weights could lead to injury. The solution is to develop a mixed training program which overloads the musculature through the full range of motion and a spectrum of velocities.

A September to June model will be used to illustrate a coach's annual training plan. In this instance, May/June will constitute the area of championship tournament play. The strength training base should be maintained for a minimum of two months. This will be followed by a gradual monthly introduction of more power sessions until power is the primary emphasis. The division of sessions would follow in this manner.

September-October:

3 isotonic/week

November:

2 isotonic: 1 power/week

December:

1 power: 1 isotonic/week

January-April:

3 power/week

May/June:

taper and peak for tournament play

Power sessions could be isokinetic, ballistic and/or plyometric. Unfortunately, the cost of many isokinetic machines is inhibitive, causing this to be an unlikely option in many cases. Ballistic surgical tubing is a simple, inexpensive option which can be incorporated around the practice sessions. However, problems with overload through the full range of motion have already been mentioned. Therefore the mixed

training routine might prove to be more beneficial.

Training Charts 3 through 6 offer some sport specific exercises to improve muscular efficiency for tennis. ●

## References

1. Ariel, G.B., Braden, V. 1979. Bio-mechanical analysis of ballistic versus tracking movements in tennis skills. *Proceedings: A National Symposium*

### Chart 3. Isotonic Training

| Exercises               | Sets | Repetitions*  | Function                            |
|-------------------------|------|---------------|-------------------------------------|
| Bench Press             | 3    | 12, 10, 8     | Warm-up<br>Upper Body               |
| Pullovers               | 3    | 12, 10, 8     | Overhead/Service                    |
| Shoulder Abduction      | 3    | 12, 10, 8     | Backhand                            |
| Shoulder Adduction      | 3    | 12, 10, 8     | Forehand                            |
| Seated Rowing           | 3    | 12, 10, 8     | Backhand                            |
| Tricep Extension        | 3    | 12, 10, 8     | Overhead/Service                    |
| Bicep Curl              | 2    | 10, 8         | Muscular Balance                    |
| Wrist Flexion-Extension | 2    | 15            | Racquet Control/Service             |
| Squats                  | 4    | 15, 12, 10, 8 | Acceleration From<br>Ready Position |
| Leg Extension           | 2    | 10, 8         | Court Movement                      |
| Leg Flexion             | 3    | 12, 10, 8     | Court Movement                      |
| Leg Abduction           | 2    | 12, 10        | Court Movement                      |
| Leg Adduction           | 2    | 12, 10        | Court Movement                      |
| Calf Raises             | 3    | 15, 12, 10    | Acceleration                        |

**Devices Include:** Free Weights, Machines, Etc.

**Disadvantage:** Lacks speed specificity

\*Stated repetitions are objectives only. Choose a resistance that will not allow completion of repetitions. When objectives are met, increase resistance.

### Chart 4. Isokinetic Training

#### Exercises

Shoulder Horizontal  
Abduction-Adduction

Shoulder Abduction  
Adduction

Shoulder Flexion-Extension

Shoulder Medial-Lateral Rotation

Bicep-Tricep

Leg Flexion-Extension

Leg Abduction Adduction

Plantar Flexion  
Dorsiflexion

#### All Exercises

: 4 Sets  
: 12-20 Repetitions  
: Set 1 @ 60°/Sec  
: Set 2 @ 180°/Sec  
: Sets 3, 4 @ 300°/Sec  
: Allows muscle to experience a spectrum of speeds and resistances

- on Racquet Sports. University of Illinois, Urbana.  
2. Berne, R., M. Levy, 1983. *Physiology*. C.V. Mosby Co.

3. Briggs, G.E., L.K. Waters. 1958. Training and transfer as a function of component interaction. *Journal of Experimental Psychology*. 56:492-500.

4. Brody, H. 1981. Physics of a tennis racquet II: The sweet spot. *American Journal of Physics*. 49:816.  
5. Caiozzo, J.T. 1980. Alterations in the in vivo force velocity relationships. *Medicine and Science in Sports and Exercise*. 12(2):134.  
6. Caiozzo, J.T., Werrin, T., Edgerton, J.R. 1981. Training induced alterations of the in vivo force velocity relationships in human muscle. *Journal of Applied Physiology*. 51(3):750-754.  
7. Carr, L. 1981. Effects of fast and slow isokinetic weight training on strength and endurance (abstract). *Medicine and Science in Sports and Exercise*. 13(2):108.  
8. Clarke, D.H., Henry, F.M. 1961. Motor specificity and increased speed from strength development. *Research Quarterly*. 32:315-325.  
9. Coyle, E.F., Feiring, D. 1980. Muscular improvements specificity of training velocity (abstract). *Medicine and Science in Sports and Exercise*. 12(2):134.  
10. Groppe, J., Conroy, B., Hubb, E. 1986. The mechanics of the tennis forehand drive: suggestions for training the tennis player. *NSCA Journal*. 8(4):5-10.  
11. Groppe, J. 1984. *Tennis for Advanced Players*. Illinois: Human Kinetics Publ.  
12. Knapik, J.J., M.U. Ramos. 1980. Isokinetic and isometric torque relationships in the human body. *Archives of Physical Medicine Rehabilitation*. 61:64-67.  
13. Lesmes, G.R. 1978. Muscle strength and power changes during maximal isokinetic training. *Medicine and Science in Sports and Exercise*. 10(4):266-269.  
14. MacGuigan, F.J., E.F. MacCaslin. 1955. Whole and part methods of learning a perceptual motor skill. *American Journal of Psychology*. 68:658-661.  
15. Magill, R.A. 1980. *Motor Learning: Concepts and Applications*. Iowa: Wm. C. Brown.  
16. McCafferty, W., S. Horvath. 1977. Specificity of exercise and specificity of training: a subcellular review. *Research Quarterly*. 48(2):35-41.  
17. Moffroid, M. 1970. Specificity of speed of exercise. *Physical Therapy*. 50(12):1693-1699.  
18. Mosley, T.W., A. Hairabedian, D.M. Donaldson. 1953. Weight training in relation to speed, strength and coordination. *Research Quarterly*. 24:308-315.  
19. Sherman, M. 1981. Isokinetic strength during rehabilitation following arthroscopy: specificity of speed. *Athletic Training*. 16:138-141.

### Chart 5. Ballistic Training Surgical Tubing

| Exercise         | Sets | Repetitions |
|------------------|------|-------------|
| Forehand         | 3    | 15-20       |
| Backhand         | 3    | 15-20       |
| Forehand Volley  | 3    | 15-20       |
| Backhand Volley  | 3    | 15-20       |
| Overhead/Service | 3    | 15-20       |
| Squat Jumps      | 4    | 15-20       |
| Leg Abduction    | 3    | 15-20       |
| Leg Adduction    | 3    | 15-20       |
| Leg Flexion      | 3    | 15-20       |

\*All exercises are attempted at near match speed.

\*\*Antagonistic muscle group exercises should be worked in pairs.

When the forehand is finished, rather than wasting time by resting, work the backhand.

\*\*\*The last few repetitions or the last set should not be completed successfully. If set is completed; increase the tension.

Disadvantage: Does not provide an overload resistance at the start of the range of motion.

### Chart 6. Mixed Training

- Provides a spectrum of speeds and resistances
- Provides resistance through the full range of motion

| Exercise                     | Sets | Reps       | Function            |
|------------------------------|------|------------|---------------------|
| Bench Press (Isotonic)       | 3    | 12, 10, 8  | Warm-Up             |
| Forehand (Ballistic)         | 3    | 15-20      | Action Specificity  |
| Backhand (Ballistic)         | 3    | 15-20      | Action Specificity  |
| Forehand Volley (Ballistic)  | 3    | 15-20      | Action Specificity  |
| Backhand Volley (Ballistic)  | 3    | 15-20      | Action Specificity  |
| Overhead/Service (Ballistic) | 3    | 15-20      | Action Specificity  |
| Shoulder Press               | 2    | 10, 8      | Overload Resistance |
| Seated Rowing                | 2    | 10, 8      | Overload Resistance |
| Lat Pulldowns                | 2    | 10, 8      | Overload Resistance |
| Cycling                      | 3-5  | Minutes    | Warm-Up             |
| Plyometrics                  |      |            |                     |
| i.e. Depth Jumping           | 3-5  | 12-20      | Court Quickness     |
| Lateral Jumps                | 3-5  | 12-20      | Court Quickness     |
| Forward Backward Jumps       | 3-5  | 12-20      | Court Quickness     |
| Others . . .                 |      |            |                     |
| Squats                       | 3    | 15, 12, 10 | Overload Resistance |
| Leg Flexion                  | 3    | 12, 10, 8  | Overload Resistance |

NOTE: Change plyometric exercises regularly  
Complete 2 plyometric exercises for each session