Biomechanical Analysis of the Tennis Serve

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Introduction:

The serve is one of the most important skills a tennis player must acquire in order to have an effective attack. The primary objective of the serve is to direct the ball into the service area on the opponents side of the court. The serve is an effective offensive weapon because the ball can be hit with a tremendous amount of velocity, thus reducing the oppositions reaction time and consequently their ability to return the ball. Variations of the service action can also cause the ball to spin. A slice serve is used in order to gain an advantage via the unpredictability of a spinning balls bounce. The serve can be broken down into the following four phases: preparation, wind-up, force-generation and the follow through/recovery. Biomechanical analysis of the skills involved in each phase, enables us to give effective instruction and appropriate technical cues to improve the performance of students and athletes.

Preparation:

The preparation phase primarily consists of the mental set in which the athlete prepares mentally for the skill he/she is about to perform. During this phase the athlete determines the location and type of serve they are going to hit based on the positioning of the opponent and their knowledge of the opponents limitations. In addition the athlete conducts preliminary movements in order to prepare the body for the motion required of the skill. Both Pete Sampras and I begin these preliminary movements in a fixed position, eyes are intently focused on the target. Sampras' holds the ball and racquet out in front of his body, and his weight resting primarily on his right leg (fig.1). Sampras' maintains a relaxed body position throughout and he initiates the action by straightening his back and lowering the racquet (fig.2). His eyes remain fixed on his opponents court.

Psychologically this is an imperative skill, if an athlete feels frustrated, pressured or anxious they are unlikely to perform well. These heightened states of arousal can cause the athlete to be tense, while the service action requires the body to be relaxed and loose.

Wind-up:

The purpose of the wind-up is to store elastic potential energy or strain energy. Strain energy occurs because the athletes muscles are stretched, the elastic recoil of the athletes muscles convert the strain energy into kinetic energy, thus generating a tremendous amount of force and momentum (Carr, 1997, p. 38). During the course of the windup the athletes weight is initially shifted from the front foot to the rear foot. Concurrently the left arm tosses the ball; consistency is imperative to the performance of the serve. It is important for a consistent toss, to have the left arm extended throughout the toss. Sampras' has somewhat poor mechanics in the toss because he throws the ball up with his elbow slightly flexed and extends the arm, rotating it from the shoulder, across his body from his outside hip (fig. 2 & 3). While this works for him now, the action will potentially breakdown as he ages.

Consistency in the ball toss is an area I have been struggling with; however, figures 10 and 11 display that the action of my tossing arm is correct. Therefore the inconsistency of my ball toss is not a matter of arm action, but rather timing the release of the ball.

The left arm carries up to a fully extended position and aids concentration on the ball. This action occurs in order to counter the action of the racquet arm, which is moving to the rear of the body. The action of the non-racquet and racquet arm is an example of Newton's third law, which states that every action has an equal and opposite reaction (Carr,1997, p.20). The action of the left arm balances that of the right arm so that the racquet arm does not initiate unwanted angular momentum. This action is more easily apparent in figures 11 and 12 of my service action, note that the plane of my shoulders are in line.

As the action of the arms and torso occur the weight is shifted from the rear leg back to the front leg and the knees are bent in order to store potential energy. Notice the degree to which Sampras bends his knees in figure 4, this enables him to generate more thrust against the ground therefore generating a more powerful jump into the air. This concept is known as ground reaction force and will be discussed in greater detail in the force generation phase. As I begin to develop consistency in my serve and begin increasing its power, I will have to start bending my knees more in order to store up more potential energy in an attempt to produce a more powerful jump. Figures 4 and 12 illustrate that the hips shift forward, also as a result of Newton's third law. The action of the arms and torso to the rear is equal and opposite to the hips shifting forward. The body therefore maintains balance and allows the body to flex further backward, storing more strain energy and increasing impulse.

According to John Yandell (2000, p.1), the motion of the racquet head is crucial in the development of power, consistency, and spin. Sampras' uses a compact racquet arm action, he flexes the arm almost to 90 degrees and brings the arm up as opposed to around as is apparent in my service action in figures 11 and 12. As a result, Sampras' non racquet arm is extended long before his racquet arm is up. However, this compact motion speeds up his racquet arm action and therefore catches up to his left arm. In contrast the motion of my arm tends to follow a more semi circular path, hence I am required to bring my racquet and tossing arm up simultaneously. While the compact motion that Sampras uses works for him, there is no particular biomechanical advantage to it, the difference between these serve variations is really a matter of personal preference. I find the semicircular motion more balanced, relaxed and comfortable, and players such as Mark Philippoussis apparently do as well. Regardless, the classic wind up position in which both arms point upwards, is depicted in figure 4 of the Sampras' and figure 12 in the Emery pictures. Students will benefit from the cue "LAAA" which can be related to an over zealous opera singer.

The sequence of body movements associated with the wind-up increases the time with which the stretched muscles can apply force to the racquet prior to striking the ball; this concept is known as impulse and increases the angular momentum of the racquet (Carr,1997, p.33). Lowering the centre of gravity and shifting ones hips and weight from the back foot to the front foot, enables the player to accelerate the racquet over a longer time frame, resulting in an increased impulse (fig. 4 & 12).

Force-generation:

The striking action of the force generation phase is initiated via the extension of the legs and the downward acceleration of the tossing arm. Sampras' pushes off both feet launching himself into the air (fig. 5 & 6). According to Newton's third law, as the athlete pushes against the ground, the earth pushes back up against the athlete with the same force, this is also known as a ground reaction force (Carr,1997, p.20). Therefore, to get into the air Sampras' must apply an explosive thrust with the legs against the ground to exert a force, which exceeds his own body weight. The upward motion of both the racquet and non-racquet arms are a form of momentum transfer that helps to propel the athlete into the air by increasing the amount of downward thrust exerted upon the ground. The ground pushes back up against

the athlete and the athlete becomes airborne. Dropping the tossing arm serves a duel function, it initiates force generation along with hip rotation, and increases the angular momentum of the racquet arm.

The next key element of the service action is the hyperextension of the spine and torso. Again due to Newton's third law, the athletes legs counteract the angular momentum induced by the backwards flexion of the spine and striking arm action by moving to the rear of the player. The hips move forwards also as a result of Newton's third law because the upper and lower body move backwards, thus balancing the action (fig. 5).

The power that Sampras' is able to achieve in his serve is largely a result of his remarkable flexibility and range of motion in both his shoulder and back. This flexibility enables Pete to attain a more complete racquet drop, which in turn increases the impulse of the racquet head. Although this is a desirable characteristic to achieve there is little I can do to improve my racquet drop. While figure 13 displays that my racquet is in the correct position for the racquet drop I am limited by flexibility. As a result, the power of my serve is reduced because I can not physically increase the acceleration time of the racquet. Another important characteristic that distinguishes Sampras' serve from mine is that Sampras' has already left the ground when he has reaches full racquet drop (fig.5). In contrast, I am just starting to leave the ground, which may be a limiting factor in my ability to achieve maximal range of motion and therefore a complete racquet drop (fig. 13).

"Scratching the Back" is a cue that is often used to teach this motion; however, it is a term that should be avoided because it insinuates that the racquet remains in the centre of the back, using this term could cause biomechanical errors in beginning players. The racquet is instead parallel to the right side of the body, thus "racquet drop" or "DIII" are a more effective cues.

The rotation of the trunk and arm shifts the angular momentum of the body forwards and the legs are forced to compensate by also rotating forward. The abdomen is flexed and the rear end and hips move backwards as a result of Newton's third law (fig. 6 & 14).

The sequential body movements of the hips, torso, shoulder, arm, elbow, forearm, wrist and racquet simulate the action of a whip. The body is comprised of a series of segments, which form third class lever systems. A third class lever is when the pivot point is at the end of the lever and the force is generated along the lever arm between the fulcrum and the resistance (Carr,1997, p.57). For example, the

elbow is a pivot point, the bicep attaches to the forearm in front of the pivot and the resistance is the tennis racquet. Each of the body's segments progressively become less massive and , thus while the slower moving, more massive segments (hip and trunk) rotate forward to initiate the force generation the lighter body segments (arm, forearm, wrist and racquet) complete their backward extension (Carr,1997, p.173-4). Furthermore each of these body segments are third class levers that become shorter in length. The combination of these two factors result in a whip like action in which each of these segments sequentially accelerate, thus producing tremendous racquet head velocity. This concept demonstrates the importance of the wrist rotation as it forms the final accelerating segment that produces racquet head velocity, hence service power. This segment of force generation can be taught using the cue "DAAAAR, which emphasizes explosive power.

The ball is contacted though the centre of the racquet and the athlete can do one of the following: 1) apply top spin by flexing the wrist over the ball, 2) cut the ball to the side by contacting the ball through the its centre of gravity and then flexing and rotating the wrist to the side of the ball inducing sideways rotation on the ball. To help students visualize this action instruct the student to "wrap the racquet around the pole." This action induces spin on the ball creating the Magnus effect, which causes the ball to follow a curved flight path. The Magnus effect essentially describes the action of a spinning ball through the air. As a ball spins, it creates a boundary layer of air that adheres to the ball and rotates with it. As a result, on the side of the ball that this boundary air collides with the air flowing past the ball, it decelerates the ball producing a high pressure zone. While on the opposite side, the spinning ball moves in the same direction as the air flowing past it, which accelerates the ball and creates a low pressure area (Carr, 1997, p. 125). As a result, the ball curves in the direction of the low pressure. Applying the Magnus effect to the serve, flexing the wrist over top of the ball produces a low pressure gradient below the ball and therefore a ball hit at a tremendous velocity will still drop down and into the service box. While the side spin will cause the ball to violently curve to the outside of the service box , thus after it bounces it shoots outside of the court. Once the ball leaves the racquet the force generation phase is complete. Sampras' arm, finishes the follow through rotation and he prepares for the next shot.

Follow-through / recovery:

This phase of the skill commences following contact with the ball. Sampras' racquet arm follows across the body to the centre line. In contrast, my arm and racquet carry beyond the centre line to the left leg (fig. 16). Consequently, I tend to excessively follow through, which potentially hinders my ability to return to the ready position quickly. In order to reduce the stress placed upon the muscles, joints and bones the server must increase the amount of time that the force of his body contacts the ground. Sampras' and I accomplish this by landing first on the ball of the left foot, flexing at the ankle, lowering the heel to the ground and flexing at the knees and hips (fig. 7 & 8). Sampras' converts the angular momentum produced via the body and arm rotation into forward linear momentum. This is accomplished by arresting the rotation of the hips and shoulders once they become perpendicular to the court, forcefully pushing off the left leg and driving the right leg into the court (fig. 8 & 16). Sampras appears to generate much more power via the hip and trunk rotation because his right leg is forcefully whipped around and through. The motion depicted in my pictures indicate that my hips do not rotate as forcefully and follow a much more narrow pathway. Finally, Sampras' is immediately crouched in a low and prepared stance upon the conclusion of the follow through, while I appear to stand up (fig. 8 & 16). In preparation for the opponents return, I need to immediately conduct the split step, in order to get into a proper ready position. My knees should be bent, I should be on the balls of my feet and my racquet should be up and in front of my body so that I can react quickly and anticipate the oppositions attack.

References:

Carr, Gerry. (1997). Mechanics of Sport: A Practitioner's Guide. Windsor: Human Kinetics.

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Prep Phase:

Figure 9

Figure 10

Wind-up Phase

Figure 11

Figure 12

Force-Generation

Figure 13

Figure 14

Follow-through / recovery

Figure 15

Figure 16