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3D variability in ball toss and impact location for tennis serves in collegiate female players

Javier Ignacio Hervas
University of Northern Iowa

3D VARIABILITY IN BALL TOSS AND IMPACT LOCATION FOR TENNIS SERVES IN COLLEGIATE FEMALE PLAYERS

An Abstract of a Thesis

Submitted

in Partial Fulfillment

of the Requirements for the Degree

Master of Arts

Javier Ignacio Hervas

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ABSTRACT

Recent research has been focusing in the tennis serve to get deeper knowledge about its phases and the factors involved for better performance. This study analyses one aspect of the tennis serve that it was not being considered before, and not too much information was available to the public: The tennis ball toss.

A player who can develop consistency and a high efficiency of serve percentage during a tennis match will increase their chances of success. The objective of the tennis serve is to place the ball in the opposite court within the opposite serve quadrant to where the opponent is located. The player who is able to produce a considerable amount of speed and spin using consistent ball contact has a greater chance to dominate the game from the start to win the point.

Previous research has been concentrated in the comparison of first and second serve but, there is no correlation of the tennis ball toss and its variability with impact location of the tennis serve so, understanding the implications of the toss and its relationship with the tennis serve was very motivating.

This study consists of a 3D analysis of the tennis ball toss and its implications with impact location and impact variability of the tennis serve. Several players were analyzed performing first serves in a tennis tournament and a 3D analysis of the tennis ball toss was made using different techniques to see how the toss will act in different dimensions.

The findings in this study are important for the development of athletes and also, to break down old beliefs about the right employment of tennis serves techniques and its relationship with a better execution of the technique itself.

This research finds facts about the behavior of the tennis ball during the tennis ball toss in a live tennis match. Although, no significant differences were found among dimensions in the tennis ball toss related with impact variability, there is a difference in the impact location in one of the dimensions analyzed in this study.

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has been approved as meeting the thesis requirement for the

Degree of Master of Arts

Date	Dr. Travis Ficklin, Chair, Thesis Committee
Date	Dr. Robin Lund, Thesis Committee Member
Date	Dr. Forrest Dolgener, Thesis Committee Member
Date	Dr. April Chatham-Carpenter, Interim Dean, Graduate College

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CHAPTER I

INTRODUCTION

The service in the sport of tennis is what initiates each point. It is a skill that is very difficult to learn but when it is mastered becomes a fundamental part of the resources that the player has to take advantage over their rivals (Ivančević, Jovanović, Đukić, Marković, & Đukić, 2008). A player who can develop consistency and a high efficiency of serve percentage during the match will increase their chances of success. The objective of the tennis serve is to place the ball in the opposite court within the opposite serve quadrant to where the opponent is located. The player who is able to produce a considerable amount of speed and spin using consistent ball contact has a greater chance to dominate the game from the start to win the point. Also, in real game play a high serve percentage increases the rate of success during the games wherein which the player is serving (Bahamonde, 2000).

If the player has total control of the serve, it is perhaps the most important stroke in the sport of tennis (Bahamonde, 2000). Even though it is a very difficult stroke to master (Chow et al., 2003), success and effectiveness are achieved with proper preparation and training throughout the years. The tennis serve is a very complex motion. It consists of a sequence of movements with multiple moving parts involved, where the muscles and joints are working with precise timing to produce an effective serve. In a serve, the hitting limb slowly raises the tennis racquet to make contact with the tennis ball while the other limb throws the ball in the air with the purpose of locating the tennis ball at a desired height and location for the player (See Figure 1; Brody, 1997). At the moment of impact, several phenomena will occur in the body of the athlete and all of these will be described later on in more specific detail in every phase of the tennis serve (Chow et al., 2003).

Figure1. Tennis Player executing a tennis ball toss.

A fundamental aspect of the tennis serve is the toss of the tennis ball. The location, angle, timing and rotation of the ball on the toss are very important elements of the serve. (Bahamonde, 2000; Cross, 2002; Goktepe, Ak, Sogut, Karabork, & Korkusuz, 2009) To-date few studies have examined the importance of the consistency of the tennis ball toss and its location at impact. One study examined the effect of wind on the toss, but it did not quantify consistency in collegiate female tennis players (Mendes et al., 2013). Consistency of the tennis ball toss would seem to be crucial to service success since it is integrated to proper timing of the complex service motion. While there are several studies making comparisons between different kinds of tennis serves (Chow et al., 2003; Elliott, Marshall, & Noffal, 1995) there is no research on the consistency of the tennis ball toss and its relationship to success in the tennis serve (Mendes et al., 2013). According to some studies that have examined volleyball and handball serve tosses (Ivančević et al., 2008) there is a strong relationship between the location of the tossing of the ball and the location at the point of impact with the tennis ball (Goktepe et al., 2009).

Although, research exists on the tennis serve and its phases, less is known about the toss or its relationship with the consistency and timing of ball impact in the tennis serve. The variability of the tennis ball toss may be an important aspect of the serve; the purpose of this study is to examine the 3-D variability of the impact point in serves by female collegiate players.

Statement of the Problem

The purpose of this study is to describe the variability of the tennis ball toss and its relationship to impact location and performance in collegiate female tennis players.

Research Questions

1. How much variability is there in the impact location for a typical serve toss?
2. Does impact variability have a bearing on the serve being In or Out?
3. Does impact location itself have bearing on the serve being In or Out?

Hypotheses

There will be a relationship between impact location and variability with accuracy of the serve as defined by it being in or out.

Significance of the Study

In competitive tennis, any advantage available to improve performance of the player is necessary. There is previous research and evidence (Chow, Park, & Tillman, 2009) that explains and describes the differences between the types of serves in tennis and their outcomes but there is no research related to the variability of the tennis ball toss and any possible outcomes and results for performance and success in the tennis serve. This study provides a description of typical ball impact variability, and a limited examination of its relationship to serve success.

Delimitations

This was a descriptive study. This study was exempt from review by the Institutional Review Board of The University of Northern Iowa. All data collection took place at a tennis tournament of the Missouri Valley Conference, which is a public event. There is no expectation of privacy at a public event. Researchers saw the participants at the public tennis event and their involvement was to make the video recording of the tennis players. The tennis players were executing tennis serves in a scheduled tennis match. Variability of the tennis ball impact location was measured. The direct linear transformation method (DLT) was used for the study of the tennis ball toss. The tennis serves were recorded using high-definition cameras to produce 3D data. The location of the ball was obtained during the period of time from release of the toss to the instant of impact. The mean location and standard deviation of the impact were used for the analysis of the tennis serves.

Limitations

- The study included a small number of participants.
- No information about point outcome was gathered beyond the serve being in or out.

Assumptions

In this study we expect that our participants:

- Are highly skilled players who execute the toss and serve expertly.
- Will do their best to serve with match intensity.
- Executed each serve similarly. To help secure this occurrence, only first serves were analyzed.

Definition of Terms

Tennis Serve: It is what initiates every point in the sport of tennis. It consists of the toss of the tennis ball up to impact with the tennis racquet. The player is located at the tennis base line in the right side of the court (view from the top down) and starts the point when it makes impact with the tennis racquet on the tennis ball.

Tennis serve In: Corresponds to the right placement of the tennis ball in the opposite serve quadrant.

Tennis serve Out: Correspond to the misplacement of the tennis ball in the opposite serve quadrant.

Top Spin (Spin): It is the effect imparted over the tennis ball when it is impacted. The tennis ball will develop a great speed and it will follow a curve path over its trajectory in the tennis court.

Service Percentage: It is the number of the first tennis serves that are in at the tennis court. The total of tennis serves in executed will be divided in the total number of tennis serves performed.

Variability: “The quality of being subject to variation or change.” (Mead & Sins, 2000)

Impact Variability: Is the variation or change in the impact of the tennis ball by the tennis racquet in the air after the tennis ball toss.

Impact Location: Is the location in the air where the tennis ball was impacted by the tennis racquet.

Momentum: The product of the player’s mass and velocity.

Acceleration: It is the rate of change of velocity of an object.

Airborne: Something that is ejected over the ground for a period of time.

Magnus Effect: “Physical phenomenon that can be explained by the presence of air passing through the tennis ball creating pressure changes throughout the ball.” (Mead & Sins, 2000)

Motor Learning: “Is a change, resulting from practice or a novel experience, in the capability for responding. It often involves improving the smoothness and accuracy of movements and is obviously necessary for complicated movements such as speaking, playing the piano, and climbing trees; but it is also important for calibrating simple movements like reflexes, as parameters of the body and environment change over time.” (Adams, 1976)

CHAPTER II

REVIEW OF RELATED LITERATURE

This literature review addresses the definition of the phases involved in the tennis serve in a biomechanical aspect. Theories regarding the origin of the learning of a motor task related with the action of tossing a tennis ball are also included. Emphasis is made on the variability of the tennis ball toss and its corresponding analysis in different dimensions with implications to the impact location in the tennis serve. The phases are described based on research in which an 8-stage model of the tennis serve was described (Kovacs & Ellenbecker, 2011) and a biomechanical analysis of the tennis serves and the forces involved are explained as well (Bahamonde, 2000).

Phases of the Tennis Serve

Preparation Phase

The preparation phase begins when the bounce of the tennis ball happens and ends when the ball is released from the player's hand. Tennis players begin the serve with characteristic pre-service ritual to start each point. Individual and unique gestures are what make up this part of the tennis service.

Though it may appear unimportant, this phase is closely related to the possibility of success in the tennis serve (Goktepe et al., 2009). Every gesture made by the athlete is unique, from how to grip the racket to the number of bounces that the athlete will give to the ball are part of a pattern of a very personal single motion and if repeated before each tennis serve, could help substantially to the success of the player at the moment of the tennis service (Hopper, 2001).

According to Kovacs and Ellenbecker, (2011) this phase also has three key points to be considered when it comes to research and study of the tennis serve. The start of the tennis serve (Bahamonde, 2000; Kovacs & Ellenbecker, 2011), the release of the tennis ball during the toss (Bahamonde, 2000; Kovacs & Ellenbecker, 2011) and the loading or charging phase prior to impact (Bahamonde, 2000; Gordon & Dapena, 2006; Kovacs & Ellenbecker, 2011).

Ideally, the player should be without any pressure and without symptoms of anxiety or any other kind of feeling that can cloud judgment (Choppin, 2013; Hopper, 2001). If all these conditions are present during this stage is very likely that the tennis serve will be very effective for the performing player. The player will face different situations during this phase, whether climatic, psychological or physical so it is extremely important that the athlete knows how to master, dominate and control each of these factors (Menayo Antúnez, Moreno Hernández, Fuentes García, Vaíllo, & Damas Arroyo, 2012). A big influence of these factors over the athlete may decrease the chances of success in the tennis serve (Reid, Whiteside, & Elliott, 2011).

It is also important to mention, during this phase, the muscular system is in a state of wakefulness, certain muscle groups will be activated on the next events that will demand significant coordination, timing and synchrony to ensure effectiveness in the tennis serve. This phase ends when the player releases the ball for the toss.

Acceleration Phase

This part of the service is initiated when the player is getting ready to start the point in the game. The phase is initiated when the player releases the tennis ball to make the toss (Reid et al., 2011) and it ends at the moment of impact of the tennis ball.

The location and height of the tennis ball toss becomes fundamental in the tennis serve, since these variables can help to identify tennis serve effectiveness and impact location on the tennis racket (Mendes et al., 2013). If the tennis ball toss is solid and consistent over time during the tennis match, and has proper height and location throughout the tennis serve performed by the athlete. The serve will have consistency and chances of success in the game of tennis will be extremely high (Menayo Antúnez et al., 2012).

After the start of the tennis ball toss, a chain of events that will be described starts. The muscles of the lower limbs begin to function in order to facilitate the stretch-shortening cycle that will contribute to storage of elastic potential energy in the muscles that are acting within the upper limb and lower limb muscle chain (Ellenbecker, Roetert, Bailie, Davies, & Brown, 2002).

The combined movements of both upper limbs are a result of newton's third law, (Bahamonde, 2000) which states that any type of movement or action has an equal and opposite action.

The muscle chain process begins after the start of individual muscle activation in the upper limb muscle chain and therefore the use and transformation of elastic potential energy is initiated. The muscles will start to move the arm towards to the impact of the tennis ball.

The muscular chain in the upper limb will follow a proximal to distal order of activation. The following order from proximal to distal in the upper limb muscle chain, in the extension muscles, is activated. The posterior deltoid, triceps brachii, Brachioradialis, Extensor carpi radialis longus, Extensor carpi, radialis brevis, Extensor digitorum, Extensor digiti minimi, Extensor carpi ulnaris, Supinator, Abductor pollicis longus, Extensor pollicis brevis, Extensor pollicis longus, Extensor indicis and lumbrical muscles of the hand. All of these muscles are activated pre-impact while the arm holding the tennis racket is facing up to the subsequent impact of the tennis ball (Elliott, Fleisig, Nicholls, & Escamilia, 2003).

Meanwhile, in the lower limbs, the muscle chains are also sequentially activated as the movement progresses from the tennis ball toss to the point of impact (Goktepe et al., 2009). Prior to the impact of the tennis ball, the lower limb muscle chain, especially the one that will help to generate energy from the core and, if it is synchronized effectively, a great production of force that will transfer momentum to the upper limbs to enhance the tennis serve (Knudson & Bahamonde, 2001; Kovacs & Ellenbecker, 2011). The lower limb muscular chain is composed by major muscular groups such as quadriceps, hamstrings, internal and external hip rotators (Kovacs & Ellenbecker, 2011).

All these muscles will be activated progressively from proximal to distal to facilitate the transfer of momentum in the forward direction from rear foot to front foot during the serve (Hopper, 2001). While all of this occurs it is vital that the player performs each movement with synchrony and coordination prior to impact with the tennis ball (Gordon & Dapena, 2006; Julienne, Gauthier, Moussay, & Davenne, 2007).

If the synchrony of the movement and motor abilities in the athlete are well developed, the possibility of transferring a larger amount of energy and momentum prior to the impact of the tennis ball will be higher (Latash, Scholz, & Schöner, 2002; Mead & Sins, 2000).

It is within this phase that an important part of the tennis serve happens. The angle and position of the tennis racquet behind the player's head changes prior to impact (Reid et al., 2011). This cocking of the tennis racquet prior to impact will influence the spin and speed of the ball in the serve and this will be produced by the rotations and combined anatomical movements of the joints involved in the upper limb during the action of the serve (Bahamonde, 2000; Goktepe et al., 2009; Kovacs & Ellenbecker, 2011). The processes involved in the generation of movement for this phase underscore how complex the tennis serve is (Hopper, 2001). This phase ends at impact of the tennis ball with the racquet.

Impact

This phase begins with the impact of the tennis ball. The previous phases are complete and momentum has been transferred to the racquet at this stage of the serve (Mendes et al., 2013).

After the impact of the ball, the deceleration of the upper limbs begins (Gordon & Dapena, 2006; Hopper, 2001). During this phase, the muscle chain of the lower and upper limb provides an essential aid to the athlete. Because of the use of the legs to propel the athlete upward and forward into the air, and the segmental rotations caused by the muscles in the upper limb, the athlete achieves the desired impact point for the tennis serve (Bahamonde, 2000; Gordon & Dapena, 2006; Kovacs & Ellenbecker, 2011).

The total weight of the athlete is smaller than the vertical force (GRF) and the athlete accelerates upward (Bahamonde, 2000). All of the player's motions leading up to impact with the ball transfer momentum from the legs, through the trunk, to the tennis racket for impact with the ball (Bahamonde, 2000; Brody, 1997). This transfer is initiated by rotation of the hips, after which angular momentum transfers to the hitting arm of the athlete (de Subijana & Navarro, 2010; Gordon & Dapena, 2006; Hopper, 2001). After impact, the flight of the tennis ball is dependent on the velocity and spin of the ball, which are influenced by the velocity and impact angle of the racquet which have been determined by the motions that have lead up to impact.

If the ball was hit squarely in the center of the racket, with the racquet face being normal to its velocity, the ball will have a flat serve trajectory, in which the tennis ball will not have much rotation or non-parabolic movement in the air favoring great speed over spin on the service (Reid et al., 2011). If it was hit with an oblique, glancing blow and wrist cocking, the tennis ball will obtain spin, depending on the velocity and angle of the racquet face relative to the ball at impact.

This affects the path after impact, increasing the chance of hitting the serve “in” and potentially making it more difficulty to the person who is returning the serve and exponentially increasing the chances of success (Menayo Antúnez et al., 2012).

This curving effect on the ball’s flight caused by spin is called “The Magnus effect” and is a physical phenomenon that can be explained by the presence of air passing around the tennis ball so as to create pressure changes (Mead & Sins, 2000, p. 87-107). This physical phenomenon will not be discussed further in this research. This phase is terminated once the athlete has made contact with the tennis ball and one of the feet makes contact with the ground again.

Follow-Through Phase

This phase is initiated when one feet of the player has touched the ground after impact. At this stage the involved joints play a key role in the post-impact deceleration movement on the athlete (Goktepe et al., 2009). All elements must interact gradually to enable the joint segments of the body to reduce their total momentum after the impact (Elliott et al., 1995). This stage will not be discussed further in this research.

Interpretations of the Tennis Serve Mechanics

The tennis serve is made by a complex combination of segmental movements. All of these movements combined will produce a racquet position and velocity at impact. The point of impact will be determined by the location and height of the ball in space and it will have a direct relationship with the success of the tennis serve (in or out). In the first phases of the learning process in tennis, it is common to hear tennis coaches preach about the height factor in the toss (Reid et al., 2011). The variability of the tennis ball toss in different dimensions in space may also be important to success in the tennis serve.

For a given serve, the variability of the toss has bearing on the repeatability and consistency of the serve. There could be a difference between the ball toss between the first and second serve, and the location of the toss is related to the type of serve chosen by the tennis player. For example, if the player wants to execute a flat serve - a powerful serve with minimal or no rotation in the ball - the toss should be in front of him/her to create a maximum acceleration with the tennis racquet, looking for an impact in front and ahead the tennis court base line. If the player wants to execute a topspin serve, he/she should toss the tennis ball behind his/her head and create a prolonged contact of the tennis racquet strings with the ball. A top-spin or “kick” tennis serve with a high rotation or “magnus effect” of the ball should be expected.

A key element is the variability of a motor task. The motor task in general is repeatable but will feature variability as in performing the tennis serve. Specifically, the upper limb that is tossing the tennis ball must have a highly developed learning of this specific action that will contribute effectively to the success of the tennis serve (Knudson & Bahamonde, 2001). This toss is just one part of a complex, multi-segmental task and should be executed will little or no variability (Girard, Micallef, & Millet, 2005).

In the development of the tennis athlete during his/her career the design of the program or practice, in this case, seems to be extremely important in the learning of this specific motor task such as the toss of the ball (Schack & Mechsner, 2006). Throughout the tennis player's career the flexibility and design of the practice system becomes extremely important. The schedules of practice will facilitate the learning of this motor task and will develop on the athlete the right motor control pattern for the tossing of the tennis ball (Ranganathan & Newell, 2010).

During the tennis practices, variability becomes extremely important because it relates the sense of generalization to the athlete (Latash et al., 2002). Or in this case, how the tennis player will adapt to the pattern of movement that will be learned for the tossing of the tennis ball during the serve (Latash et al., 2002). This learning process is designed in a particular way, in the context of the development of a variety of situations and scenarios that the athlete has never experienced before (Fitts, 1992).

One of the first steps for the introduction of the variability on a motor control task is to know which systems and theories are known for their effectiveness. There are two general systems and very contrasting ideas about the learning of variability on a motor task: (a) the specificity of practice hypothesis (Latash et al., 2002) and (b) the variability of practice hypothesis (Ranganathan & Newell, 2010).

The hypothesis of specificity on practice (Latash et al., 2002) states that the conditions in practice should be as close as possible with the conditions where the performance is required (Latash et al., 2002; Ranganathan & Newell, 2010) A good view about specificity declares that the optimal learning is when the conditions of practice and the test conditions are perfectly matched (Latash et al., 2002).

According to this view, the effects of the introduction of variability on the motor control task learning are extremely related to the variability of the tennis ball toss itself (Latash et al., 2002). In this case, the ability or skill of playing tennis requires producing a wide variety of outcomes (Latash et al., 2002). Therefore, the specificity of practice hypothesis prognosticates that the use of a practice schedule that includes multiple specific variations will be more helpful for the learning of a motor control task (Fitts, 1992).

On the other hand, the variability of practice hypothesis is based on principle called "the schema theory of motor learning" (Ranganathan & Newell, 2010). This theory declares that the learning and development of a motor skill like the tossing of a tennis ball and the inclusion of variability within the task is not only very important for the acquiring of motor tasks that require variability, but may expedite the learning process and it will not require motor variability (Ranganathan & Newell, 2010; Schack & Mechsner, 2006).

The idea behind the variability of practice hypothesis is the following: the introduction of task goal variations will create a stronger rule on the case, or “schema” (Ranganathan & Newell, 2010). The parameters of the outcome of the motor control task and task goal variations will lead to a enhancement of learning conditions and facilitate the generalization of the skill not dependent upon the experience of the athlete (Davids, Kingsbury, Bennett, & Handford, 2001). The ability to learn a general task under variations during practice has been denoted as structural learning (Davids et al., 2001).

The idea of introduction of task-variability in the learning process started around 1972 (Ranganathan & Newell, 2010). The principle of variability during practice emphasizes the practice of a very wide range of parameters for facilitating the learning and practice of the motor task. “The interference,” or in this case, the variability of the toss has been introduced by participants who have learned different variations in the motor task itself (Ranganathan & Newell, 2010).

The introduction of variability during tennis practice can happen at different levels of the motor task learning (Latash et al., 2002; Ranganathan & Newell, 2010). Generally, all the outcomes for the tennis practice can be introduced at any level of the task respecting the original goal (Fitts, 1992; Latash et al., 2002).

In this way, the variability of the motor task can be introduced at any level of execution in the athlete (Schack & Mechsner, 2006) where the goal is to have no changes in the desired outcome or motor task, but the variation is introduced as how the task goal will be achieved between trials (Schack & Mechsner, 2006).

Previous studies of variability of a motor control task have primarily been concentrated just in the motor task outcome or other measures of interest (Mead & Sins, 2000; Ranganathan & Newell, 2010). The problem is, there has been very little examination of how the variability over practice will influence the variability of the execution of the motor control task (Latash et al., 2002).

When we talk about the tennis serve, its stability and consistency over time are very important to the performance of the player (Brody, 1997). Many authors throughout the years have said that the serve is the most important stroke in the sport of tennis, marking a big difference with other movements executed in the same sport (Chow et al., 2003; Chow, Park, & Tillman, 2009). One aspect of the serve in which stability and consistency is key is in the toss, and research has been done on it in the last couple of years (Mendes et al., 2013; Reid et al., 2011). These previous studies have measured parameters such as: timing, comparison between first and second serves, magnitude of peak of knee flexion during the serve, ratio stability during serve, etc. (Elliott et al., 2003; Girard et al., 2005; Knudson & Bahamonde, 2001; Mendes et al., 2013; Reid et al., 2011).

Previous research on accuracy and effectiveness in first and second serve has not considered the variability of the serve toss and their relationship with the impact location on the tennis racquet.

In previous research noting the similarity between volleyball and tennis ball toss, analysis of the serves for both sports is justified and the ball toss for volleyball serves was analyzed by Cross (2002), however, no tennis serve tosses were analyzed for that study.

In one study that did analyze the ball toss in tennis serves, there was stabilization on the Z axis (vertical) during the ball toss, but this study did not examine other dimensions such as forward/backward (Y axis) and side-to-side (X axis; Mendes et al., 2013). This process of stabilization comes from the combination of a compensated variability of the toss on the X axis and the Y axis (Reid et al., 2011).

All the research investigations in the tennis serve have been helpful for the increase on performance of the athletes and a better understanding of all the elements involved in a tennis serve, but there is missing keys in the information provided. Much has been investigated about the outcomes of the tennis serve but there is unclear information about the variability – impact location relationship. Further, there is a lack of studies about the ball toss and its variability on impact location in female athletes.

Therefore, the purpose of this study is to describe the variability of the tennis serve ball toss, and relate this variability with impact location.

CHAPTER III

METHODOLOGY

The purpose of this study is to describe the variability of the tennis ball toss and its relationship to impact location and performance in collegiate female tennis players. In order to minimize the variability that stems from differences between first and second serves, only first serves were analyzed.

Research Design

This was a descriptive study. This study was exempt from review by the Institutional Review Board of The University of Northern Iowa. All data collection was taken at a tennis tournament of the Missouri Valley Conference, which is a public event. There is no expectation of privacy at a public event. Researchers videoed the participants at the public tennis event and their involvement was to make the video recording of the tennis players. The tennis players were executing tennis serves like they do in a regular tennis match. We measured the variability of the tennis ball toss using different outcomes. The direct linear transformation method (DLT) was used for the study of the tennis ball toss.

Research Participants

The research participants were NCAA Division I tennis players participating at a regular season tennis match of the Missouri Valley Conference (MVC). Athletes were video recorded for this study based on their affiliation with the University Of Northern Iowa Women’s tennis team but 3 were from different universities. Two of the subjects were University of Northern Iowa tennis players and three were from the South Dakota State University and Chicago State University tennis teams.

Instrumentation

- Video data were collected for tennis serves at a public tennis event during a tennis meet in which three NCAA Division I teams played.
- For each tennis serve of the tournament, video cameras shooting at 60 Hz were used to capture any first serve made, resulting in a total of 50 first serves captured.
- All the video files recorded by the two video cameras were downloaded into a PC computer. The location of the tennis ball during the tennis ball toss was manually digitized in the images captured by the recording devices during the trials, from toss up to impact, using MaxTrac software.
- Due to the lack of synchronization between the cameras, the exposure of frames in the video didn't correspond to the instants of exposure in frames of the other video. The time coordination between the frames of the two cameras in each recording was determined through visible events from both camera views. The events used were the last 3 bounces of the ball, ball leaving hand and the impact of the tennis ball. The frames where these events occur in the video of one of the cameras will be plotted against the matching frames of the same events on the other video camera

- The direct linear transformation (DLT) method of videography was used to calculate the location of the 3D coordinates of the tennis ball for each of the output frames in relation with the global reference frame R0.

Data were analyzed using SPSS 11 (SPSS Inc., Chicago, Illinois). The average standard deviation for each player was compared between “in” serves and “out” serves using a sample t-test. Alpha was set at 0.05 for all tests.

Procedures for Collecting Data

The data collection took place at the UNI Women’s Tennis team facilities during a regular season MVC tennis match. The participants were dressed for the tennis event.

Subjects performed serves during a tennis match. Each serve was recorded simultaneously with two high-definition digital JVC video cameras, recording at 60 Hz. The location of the cameras was the same for right-handed players and left-handed-players. Ten representative first serves from each subject were analyzed and the serves analyzed were the first five serves “In” and the first five serves “out.” (See Figure 2.)

All the video files recorded by the two video cameras were downloaded into a PC computer. The location of the tennis ball during the tennis ball toss was manually digitized in the images captured by the recording devices during the trials, from toss up to impact, using MaxTrac software.

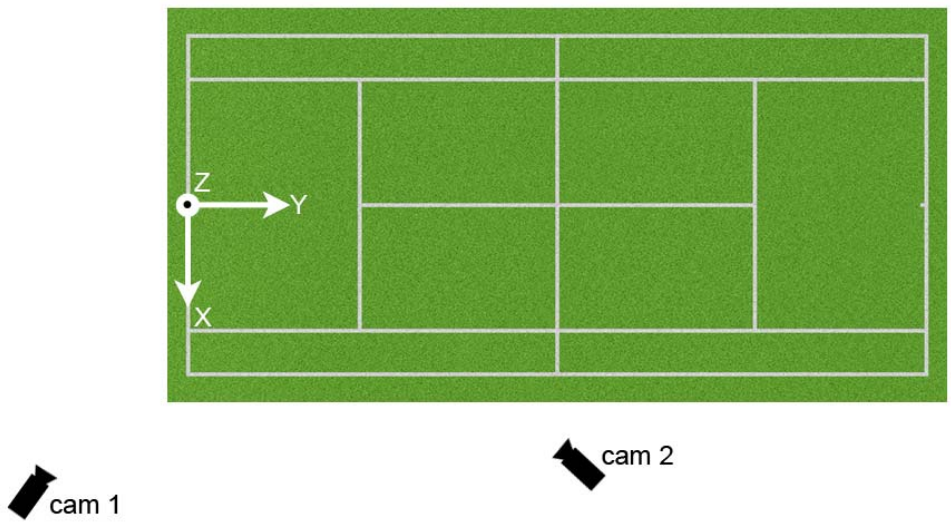

Figure 2. Diagram of camera location in the tennis court.

Analysis of the Recorded Data

The digitized video recordings were transferred to a personal computer. All calculations were made on this personal computer using personal custom software.

Due to the lack of synchronization between the cameras, the exposure of frames in one video didn't correspond to the instants of exposure in frames of the other video. The similarity between the frames of the two cameras in each recording was determined through visible events from both camera views. The events used were the last 3 bounces of the ball, ball leaving hand and the impact of the tennis ball. The frames where these events occur in the video of one of the cameras were plotted against the matching frames of the same events on the other video camera. A direct line with a slope of value 1 was fitted through the points by linear regression to the calculation of the correspondence between the frames of camera number one and two. The serves picked were the five first serves “In” and the five first serves “Out.”

Because of the corrections made to correct the camera rolling shutter system, each landmark had a small difference in the time scale, even though al the landmarks were digitized in the correspondent video frames. Quintic spline fitting functions (Dapena, 1978) were placed with no smoothing to the digitized coordinate-time data from each camera. The values were interpolated and computed. From the quintic spline fitting functions of the two video cameras for moments intermediate between the frames and which did correspond in time. To make the comparison between the trials more friendly, the time value t = 10.000s was randomly selected and assigned to the instant impact of the tennis ball by racquet, and the interpolation of the values were computed for separated instants by intervals of 0.002s from the instant before the throwing arm started its motion and after the tennis ball was released.

The direct linear transformation (DLT) method of videography (Dapena, 1978) was used to calculate the location of the 3D coordinates of the tennis ball for each of the output frames in relation to the global reference frame R0. R0 was a right-hand orthogonal reference point with a known origin at the midpoint of the front edge of the tennis court base line. Its axes were defined by the vectors X0, Y0 and Z0. X0 was the horizontal, and directed along the tennis court base line toward the right. Z0 was vertical and pointed upwards; Y0 was perpendicular to X0 and Z0 pointing the tennis court net.

The quintic spline functions were placed to the time series coordinates of each landmark using a smoothing factor that corresponded to a digital filter of approximately a cutoff value of 15Hz. These functions were used to calculate time-dependent 3D locations for the landmarks and tennis ball.

Each player was modeled as a sixteen-segment system, with the ball acting as seventeenth segment. The location of the center of mass of the body was calculated by the procedures described by Dapena (1978). All the inertial parameters for the segments were provided by DeLeva (1996), with the adjustment for the moment of inertia for each of the segments based on the subject's standing height and mass, following the procedure also described by Dapena (1978). The mass of the tennis ball was 0.057 kg, and was considered to have a moment of inertia about its own center of mass equals to 0.

Data Analysis

Data were analyzed using SPSS 11 (SPSS Inc. Chicago, Illinois). The direct linear transformation method (DLT) was used for the analysis of the tennis ball toss. A p-value lower than 0.05 was accepted. X, Y, Z location of the ball with respect of the body center of mass for each serve was calculated.

Standard deviations for in and out serves were measured and compared using paired t-tests in each dimension.

Results

There were no differences between “in” and “out” serves in terms of impact location variability as measured by standard deviation ($p = 0.27$, $p = 0.12$, and $p = 0.25$ for the X, Y, and Z directions respectively). The standard deviations of the average impact location for the “In” serves were: in the X dimension 0.37 ± 0.22m, in the Y dimension 0.31 ± 0.24 and in the Z dimension 0.13 ± 0.12. For “Out” serves, the standard deviations in each dimensions were: In the X dimension 0.30 ± .0.17m, In the Y dimension 0.20 ± 0.16m and in the Z dimension 0.08 ± 0.05m.

There was one difference between In and Out serves for location of impact with respect to the body center of mass. This was in the Y-direction, which is directed forward toward the opponent’s court. “In” serves were hit 13 cm further in front of the body center of mass ($p < 0.03$). Fifty serves total were analyzed, 25 of them were “In” and 25 were “Out”.

Table 1. Average location of impacts by players and location standard deviations indicates a difference between in and out serves

Average location of impact

IN		
X	Y	Z
-0.16 ± 0.22 m	0.87 ± 0.21 m *	1.53 ± 0.15 m

OUT		
X	Y	Z
-0.25 ± 0.18 m	0.74 ± 0.13 m	1.58 ± 0.12 m

Average impact location standard deviation of players

IN		
X	Y	Z
0.37 ± 0.22 m	0.31 ± 0.24 m	0.13 ± 0.12 m

OUT		
X	Y	Z
0.30 ± 0.17 m	0.20 ± 0.16 m	0.08 ± 0.05 m

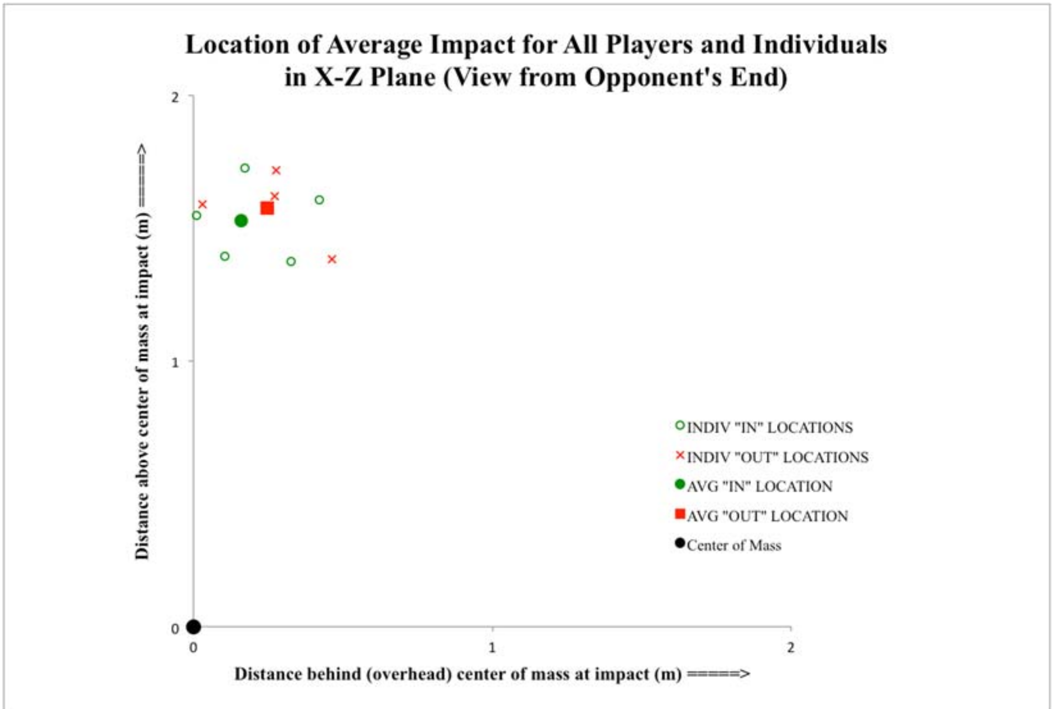

Figure 3. Location of average impact for all players and individuals in X-Z Plane (View from opponent's End)

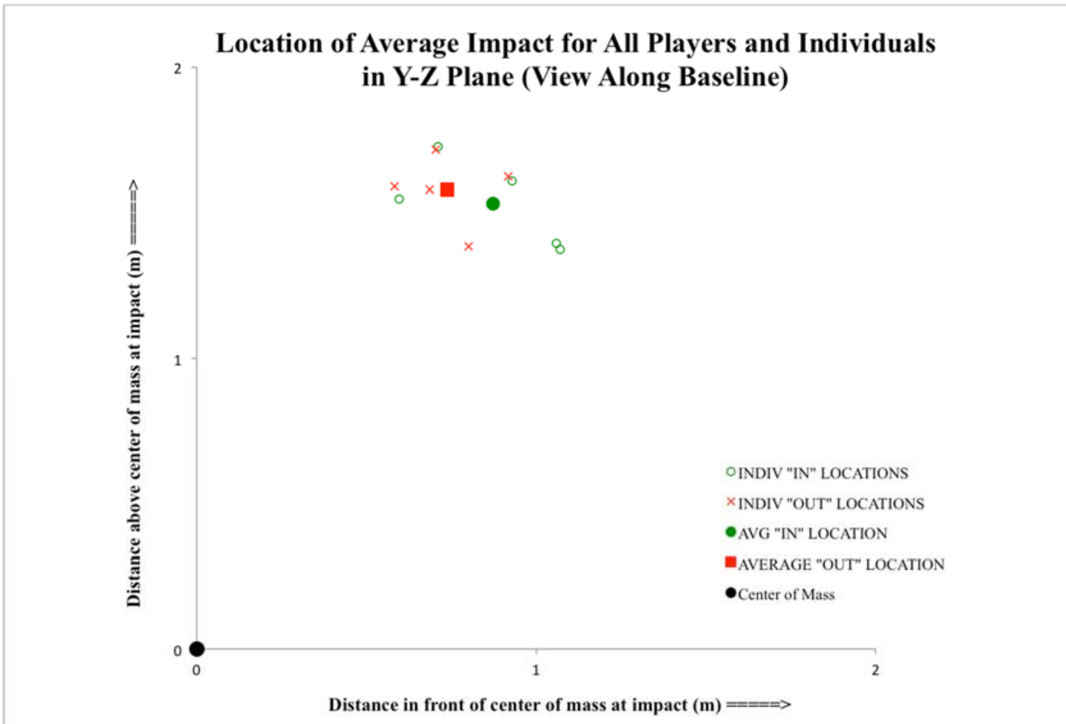

Figure 4. Location of average impact for all players and individuals in X-Z plane (View along baseline)

Discussion

This research is a descriptive study of the variability of a tennis ball toss and impact location for serves in collegiate female players. Although the phases of a serve are described in this paper, only impact location was quantified and analyzed. To simplify analysis, only first serves were analyzed, with the intent of limiting analysis to a hard, flat, typical first serve, thereby reducing variability that would arise from changing serve type for strategic purposes. Also, the only outcome associated with the impact location of the first serve was whether it was in our out. A very important aspect to be developed in future research is the need to relate the outcomes of the tennis serve (service in our out) with first serve percentage, percentage of won points with the first serve and efficiency for match success in the players. Also, a larger number of subjects and a larger number of serves will help to better understand the variability and impact location of the tennis ball toss among the tennis players. This could all still be done in match settings as in the present study. Another good way to accomplish this would be to instruct players to hit only flat serves and give them targets in the service court to hit under more tightly controlled practice conditions.

The variability of the tennis ball toss and impact location in space was caused by several factors that are unique and personal for every player. That is, even though there were equal numbers of In and Out serves in this sample, no differences in variability of impact location were found. This could be related with the statistical analysis performed in the impact variability variable. This is potentially related to having a small sample size, the no use of targets while performing the serves or the absence of the target itself makes the In area way to big, or in this case, a very big target but it could also be because players are consistent in the location of the toss for a given In or Out condition.

Impact location was one variable that was linked to serve success in terms of being In or Out. Although many practitioners may believe that the ball height at impact is the key to the serve being In or Out, data from the present study suggest that the forward and backward position of the ball at impact (along a line pointing forward to the opponent's court) is another dimension that is linked to the serve being In or Out. (See Figures 2 and 3.) Statistically there is a difference in the average location of impact: a 13cm difference in the average location of impact directed forward towards the opponents court. This may lead to a better tennis serve.

With this forward impact location, the angle of the tennis racquet will have time to strike the ball more squarely, helping to achieve an impact point with a tennis racquet angle directed better at its target. With no or minimum angle of the tennis racquet, an execution of a more powerful and flat first serve will be achieved increasing the chances of success in the serve.

Additionally, the trajectory of the tennis ball will be in the downward direction due to the toss in front of the center of mass of the tennis player. With this impact location in the Y dimension, the ball will follow a trajectory downward to the opposite quadrant at the opponent's court. This ball trajectory will help to a better speed in the tennis serve and better chances to put the serve "In." Relatedly, a bigger serving impulse will be possible. With a toss in front of the player, combined with adequate height, the time of serving impulse is increased, leading to bigger racquet head speed and therefore bigger service velocity.

All of these factors, together, combined with the toss in the right direction will help to achieve the desired goal: bigger and better directed velocity of the tennis ball after the impact. With this, the chances for the opponent to return the serve are reduced and if the server combines this with a strategic location of the serve, the chances of success are increased.

Recommendations

As mentioned, more subjects and more serves will be needed in future studies to determine if other dimensions are also related. The effectiveness of the tennis serve is related to more than just whether it lands In or Out, although this is of elemental importance. Therefore, other factors not detected in this study may have influence over serve success. To know this, in addition to more serves by more players, more criteria are needed for judging the effectiveness of a serve. For instance, accuracy could be measured in tightly controlled practice settings using targets in the service court, and a rating could be assigned to further subdivide serves beyond just being In or Out. Additionally, for match data, first serve percentage, second serve percentage, points won percentage, aces, and so forth could add deeper definition to "serve effectiveness." The tennis serve it is perhaps the most difficult stroke to master in tennis (Bahamonde, 2000) and once that is learned and mastered might lead to success in the sport (Bahamonde, 2000; Brody, 1997). Understanding what constitutes an effective serve, then, is a complex question that needs more analysis. The present study examines serve impact location and variability. Future studies should look at the kinematics of the ball's flight during the toss as well as varibility of segmental movements from the player.

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