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A Biomechanically Based Observational Tennis Serve Analysis Method Can be Used to Assess Serve Mechanics

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A BIOMECHANICALLY BASED OBSERVATIONAL TENNIS SERVE ANALYSIS
METHOD CAN BE USED TO ASSESS SERVE MECHANICS

_____

DISSERTATION
_____

A dissertation submitted in partial fulfillment of the
requirements for the degree of Doctor of Philosophy in the
College of Health Sciences
at the University of Kentucky

By

Natalie L. Myers

Lexington, Kentucky

Co-Directors: Dr. Timothy L. Uhl, Professor of Athletic Training and

Dr. Robert A. English, Associate Professor of Physical Therapy

Lexington, Kentucky

ABSTRACT OF DISSERTATION

A BIOMECHANICALLY BASED OBSERVATIONAL TENNIS SERVE ANALYSIS
METHOD CAN BE USED TO ASSESS SERVE MECHANICS

Traditional sports science motion analysis techniques using three-dimensional
(3D) kinematics have demonstrated that proper mechanics enhance serve performance
and improper mechanics overload tissues resulting in injury. However 3D analysis is
costly, time-consuming, and requires extensive knowledge of biomechanical properties
and data analysis. Currently there are no simple, reliable, and valid observational
methods for health care providers (HCP) and tennis professionals to evaluate tennis serve
mechanics. Researchers investigating observational analyses have determined that
superior reliability may be a result of specific operational definitions and the
incorporation of educational training sessions on how to perform the analysis.

The first purpose of this dissertation was to investigate the reliability of an
observational tennis serve analysis (OTSA) tool between two HCPs that helped create the
analysis method. The OTSA assesses nine key body positions/motions during the service
motion. These specific body positions have been called "nodes." The second purpose
was to determine the OTSA reliability in a group of novice users unfamiliar with the
analysis method undergoing two different forms of instructional training. The third
purpose was to determine the discriminant and convergent validity of the OTSA in
grading tennis serve mechanics among tennis players using the national tennis ranking
program commonly used in the United States to evaluate level of tennis play.

The first study demonstrated that reliability of the OTSA ranged from 0.36-1.0
across the nodes, with five out of the nine nodes displaying substantial reliability (>0.61).
In the second study results demonstrated there were no statistical differences in the intra-
observer reliability values between the two instructional training groups. Additionally,
the majority of the inter-observer kappa values were not statistically different between the
two instructional training groups. In the third study, six of the nine nodes were able to
discriminate between high and low ranked tennis players. Additionally, there was a
strong correlation between the OTSA and ranking level, indicating that there is
convergent validity and supports the construct of the OTSA as deficits in the service
motion are associated with lower ranked tennis players. These results suggest that

nearly all of the nodes associated with the OTSA are reliable and valid and can be used to assess tennis serve mechanics.

Natalie L. Myers
Student's Signature

November 29, 2016
Date

A BIOMECHANICALLY BASED OBSERVATIONAL TENNIS SERVE ANALYSIS
METHOD CAN BE USED TO ASSESS SERVE MECHANICS

By

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November 29, 2016
Date

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Chapter 1: Introduction

Background

In 2008, there were an estimated 30 million tennis players in the United States alone.[1]   As the sport grows in popularity emphasis has been placed on the tennis serve. Many coaches and health care professionals (HCP) would agree that the primary outcomes when developing and/or teaching the serve are to improve serve performance and to prevent injury.[2] Velocity is indeed an essential element of successful play because it puts the opponent under pressure during the return.[2] Injury prevention is always a priority as any injury may pose a threat to future competition and longevity of competition. Since the serve is the shot the initiates the start of each point, and it accounts for 60% of all strokes it is categorized as the most important and predominant shot of the service game.[3] The complex sequence of movements involved in the stroke along with its repetitive nature makes it one of the most commonly researched shots in the game of tennis.   A player showing true mastery of the serve can utilize the kinetic chain through a sequence of motions that originate at the lower limbs. These lower limb actions are followed by trunk rotation that ultimately leads to upper limb rotation.[4] However, a break in the kinetic chain during the serve has potential implications on injury and serve performance.

The serve is biomechanically divided into 3 phases: 1) preparation phase, 2) acceleration phase, and 3) follow-through phase.[5] An effective tennis serve requires the generation of energy flow through these three phases.[6] Potential energy is stored during the preparation phase of the serve and released during the acceleration phase of the

stroke.[5] In a proper tennis serve the legs and trunk generate more than 50% of the force

and kinetic energy delivered to the hand.[7,8] The lower extremity is responsible for

producing ground reaction forces critical to the overall force development of the service

motion, and for creating a stable proximal base that is essential for distal mobility.[7,9,10]

The role of the lower extremity has been found to be critical in decreasing upper

extremity demands. Knee bend greater than 10° during the serve has been reported to

increase serve velocity by 15 mph and decrease upper limb kinetics by approximately

25%.[4,11] Investigators have also found players that do not rotate the trunk about the

anterioposterior and transverse axes during the early stages of the service motion have

decreased serve velocities and increased upper limb loads during the service motion.[12]

Additionally, excessive time in shoulder horizontal abduction during maximal shoulder

cocking was observed in injured players over non-injured tennis players resulting in

decreased serve velocity and increased upper extremity loads.[2] It is clear that both

performance and injury parameters are affected during the serve. Therefore, it is

imperative that players execute correct mechanics throughout the body in orderly

sequence commonly referred to the kinetic chain to avoid performance deficits and

injury.

　　　　Researchers investigating the biomechanical demands associated with the tennis

serve have successfully targeted the threats to serve performance and upper limb loads

that may contribute to upper extremity injury.[2,4,6,9,11-15] All of these studies have utilized

three-dimensional (3D) motion analysis to investigate the kinematics and kinetics that

accompany the serve. 3D analysis is widely accepted by researchers as the gold standard

in movement analysis.[16] However this assessment requires a specialized laboratory, with

expensive equipment that requires considerable time to both collect and data processing.[17-19] Consequently, this scenario has several researchers investigating more practical methods of assessment through visual observation.

Observational analysis is the most common approach to providing an estimation of kinematics[19,20] allowing clinicians to detect proper and improper movement patterns. Observational analysis of movement dysfunction dates back to the early 1970s as investigators began assessing gait patterns in patients with partial paralysis.[21] Visual assessment continued to flourish into the following decades where researchers were not only observationally quantifying gait patterns, [17,18,20,22-34] but visually examining scapular impairments,[35-38] lower extremity functional tasks,[39-49] and sport specific movement.[5,50] The observational approach is typically based on visual examination of the human body performing a specific task(s), and can be implemented via live assessment or with a standard video recording device that enables slow motion and freeze frame capabilities,[19] making movement analysis through observation a commonly investigated design due to its practicality and time effectiveness. To promote movement screening in the field or clinical setting, a tool must be quick and easy to use allowing a clinician or coach to provide almost immediate feedback. Additionally, analysis tools must obtain certain psychometric properties. The most common psychometric properties of an outcome measure include reliability and validity. Reliability refers to the degree of consistency of a measurement while validity refers to the degree of accuracy of a measurement.[51] A measurement tool should be established as both reliable and valid.

The implementation of a scientific observational analysis must be executed with precision. Without an appropriate study design, poor outcomes specific to reliability are

likely. A good observational study must include clear operational definitions and educational training. For example, studies that lacked an educational training component on the implementation of an observational analysis yielded poor reliability outcomes compared to those studies that incorporated an educational training session.[20,46,48] The few articles that did incorporate a standardized training session executed its instruction through self- instructional DVDs or PowerPoints before actual rating sessions of the desired movement pattern commenced and demonstrated moderate to substantial reliability.[38,46] Consequently, to execute a good observational analysis an expert on the desired movement pattern must teach individuals how to evaluate the human motion. Some authors have suggested incorporating more intensive training programs such as interactive classroom education as a teaching strategy, which may improve reliability of observational analyses.[48]

Previous authors have investigated the effectiveness of classroom versus web-based instruction when assessing knowledge and concluded that both modes of instruction were equally effective at teaching declarative and procedural knowledge. [52] In addition, both forms of training have been investigated in medical professionals, and have yielded similar outcomes when assessing satisfaction, factual knowledge, and examination skills.[53] However, to the author's knowledge, no study has compared if one mode of instructional training is superior to the other when teaching others how to visually evaluate a specific movement pattern.

With an understanding of the biomechanical influences required during the tennis serve, previous authors have described a potentially clinically applicable observational serve analysis system used to evaluate the mechanics of the serve.[5,50] Kovacs and

Ellenbecker introduced an 8-stage model for assessing the tennis serve that was based on 3D motion analysis data.[5] This model was a descriptive analysis that had three distinct phases (preparation, acceleration, and follow-through). Within each phase the function of the serve was described and the phases were further broken down into stages. Each stage outlined the kinematic and kinetic forces associated with the movement along with specific muscle activation patterns. Another observational analysis, initially described in 2008,[50] and later refined in 2013,[54] provided health care professionals (HCPs) with a detailed framework of specific body positions essential during the serve. These specific body positions essential for creating maximal force and energy with minimal energy expenditure were termed nodes. Kibler et al.,[54] suggested that each node be categorized as either present or absent allowing HCPs and tennis professionals to evaluate potential problem areas that may lead to performance deficits or injuries in the future. The majority of these body positions are identified during the preparation phase of the service motion and are suggested to represent normal mechanics. As suggested by Kibler et al., the absence of achieving these specific body positions would result in abnormal mechanics.[54] Similar to Kovacs et al,[5] Kibler and co-authors compiled specific body positions through 3D motion analysis studies investigating serve mechanics.[2,4,6,9,11-15,55-57]

Despite the framework presented by Kibler et al.,[54] this observational method used to assess tennis serve mechanics has yet to be put under scientific scrutiny to evaluate its psychometric properties. A reliable and valid observational tennis serve analysis system that can be carried out either in real-time or on the court by videotape could be valuable to coaches in order to identify potential deficits in serve mechanics. These observed mechanical deficits may be correctable with either instruction or

enhancement of physical training. These flaws may also be associated with musculoskeletal injuries or serve performance. However, before this can be investigated, the reliability and validity of the instrument to grade the mechanics of the serve must be investigated.

A second issue is evident that the most reliable manner to teach an observational analysis is unknown. An appropriate method for education will provide insight as to which instructional training method should be utilized when introducing and instructing coaches and HCPs on how to assess serve mechanics using the OTSA.

Problem

Traditional sports science motion analysis techniques using 3D kinematics have demonstrated that proper mechanics enhance tennis serve performance and improper mechanics overload tissues resulting in injury. [2,6,12,13] However, 3D analysis is costly, time-consuming, and requires extensive knowledge of biomechanical properties and data analysis. Currently, there are no simple, reliable, or valid observational methods health care providers and tennis professional have to evaluate tennis serve mechanics. Second, there are many components that are important in performing an observational analysis such as clear operational definitions and educational training on the desired movement patterns. It is currently unknown if traditional classroom or computer-based teaching of an observational analysis are comparable. This study is designed to investigate these gaps in the literature.

Specific Aims

The overarching aim of this research is to describe the reliability of an observational tennis serve analysis (OTSA) tool and to determine it discriminant validity.

This will provide both tennis coaches and health care providers (HCPs) with a field-based method to evaluate the mechanics of the tennis serve in order to potentially improve performance by identifying mechanical flaws that may contribute to musculoskeletal injury. Within this global aim, there are three specific aims.

Specific Aim 1: **Inter-observer reliability of the OTSA tool**

Determine the inter-observer reliability for of the OTSA between two HCPs that helped create the analysis method. An orthopedic surgeon and a licensed physiotherapist will serve as raters. Each rater will independently review 28 videos of healthy professional women's tennis players, and grade the mechanics of the serve using the OTSA. This aim will test one hypothesis, that the inter-observer reliability will be moderate (≥ 0.41) or higher for the majority of the nine components associated with the OSTA as determined by an unweighted Kappa coefficient. This study will provide insight into whether the creators of the tool can reliably use the OTSA. If the creators of the OTSA cannot agree on the specific body positions throughout the serve it is unlikely other healthcare providers and coaches can use the tool to identify improper mechanics of the service motion.

Specific Aim 2: **Enhanced external validity: Intra and Inter-observer reliability of the OTSA tool**

Compare the OTSA intra and inter-observer reliability in a group of novice users (tennis coaches and HCPs) unfamiliar with the analysis method undergoing two different forms of instructional training. One group will receive classroom instructional training and the second group will receive computer-based instruction training. Upon completion of instructional training, each rater will review 16 videos. The same 16 videos will be

reviewed a week later in a random order. This aim will test two hypotheses: 1) the reliability of all novice users (coaches and HCPs) will be moderate (≥ 0.41) or higher for the majority of the nine components associated with the OSTA as determined Kappa coefficients, and 2) reliability results will be equal among the novice participants receiving computer-based instruction and classroom instruction for all nine components as determined by a two-sample Wald test. This study will demonstrate if the OTSA can be performed reliably by novice users of the system to evaluate serve mechanics. Second, it will identify which instructional training method should be used, classroom or computer-based when teaching coaches and HCPs on how to use the OTSA tool. If our hypotheses are supported, then coaches and HCPs will gain the same amount of information via a computer-based tutorial when compared to a traditional classroom tutorial session, which will allow for easier access to more people interested in implementing the OTSA tool.

Specific Aim 3: **Discriminant and Convergent validity of the OTSA tool**

Determine the discriminant validity of the observational serve analysis in grading the serve mechanics. One health care professional with previously established reliability will grade 35 player's tennis serve via video analysis. Each player will possess a United States Tennis Association National Tennis Rating Program (USTA NTRP). This is the standard ranking system used by tennis players participating in all USTA competitive events. The aim will test two hypotheses 1) nine components will be able to discriminate between high (>5 NTRP) and low (< 4 NTRP) ranked tennis athletes as categorized by the USTA NTRP. A significant chi-square will indicate that the OTSA can discriminate high and low ranked players. 2) We hypothesize that the total composite score (9

8

components summed together) of the OTSA will be positively associated with USTA

NTRP. A Spearman Rank-Order correlation will be utilized to determine the strength of

association between the two variables. A strong correlation between the OTSA and

NTRP would indicate that there is convergent validity and support the construct of the

OTSA, as it is reasonable to suggest that deficits in the service motion may be associated

with ranking level of tennis players. Further, if deficits are observed and can be

improved this may lead to higher performance for tennis players.

Operational Definitions

Observational Tennis Serve Analysis (OTSA) Tool: Method for identifying efficient and

inefficient serve mechanics. The analysis method is broken down into nine components,

the first eight components are called nodes, and the last component is an assessment of

motion. The first eight nodes are evaluated at maximal knee flexion while the last

component is assessed during the entire serve motion, and represents the composite

motion of the entire serve to identify if the individual used their legs to push the body

upward from the cocking position into ball impact. Each of the 8 nodes and an additional

motion position are graded binomially as either good (efficient mechanics) or bad

(inefficient mechanics).

Node: A body position at a specific joint that has been designated as a key point in the

serve motion and is associated with efficient force production and minimal joint

loading.[54]

Node 1: Foot Position

Node 2: Knee Position

Node 3: Counter Hip Rotation Position

Node 4: Posterior Hip tilt Position

Node 5: No front hip lean

Node 6: X-angle Position

Node 7: Trunk Rotation Position

Node 8: Arm Position

Motion 9: Composite Motion of the kinetic chain

Kinetic Chain: a linkage system with overlapping segments connecting multiple body segments into one functional segment.[58] The linkage system works in sequence to absorb and transmit forces to perform a daily activity of living and sport.[59,60]

Tennis professional: an individual who teaches or coaches tennis

United States Tennis Association National Tennis Rating Program (USTA NTRP): Determines at what level of competition a player should compete during USTA sanctioned leagues.[61]

Observer or Rater: Any participant who used the OTSA tool to assess the mechanics of the tennis serve.

Assumptions

It will be assumed that:

1. During reliability testing, none of the observers discussed the results of the video assessments when grading serve mechanics using the OTSA.

2. All tennis players that were video recorded serving completed the subjective questionnaires honestly reflecting their current level of function.

3. All players performed what was considered his or her first serve during the testing session.

4. Players honestly self-ranked according to the USTA NTRP if participants were not previously ranked by a USTA professional.

5. Observers in the computer-based training session watched the training session in full before initiating the final assessment.

Limitations

1. No randomization of participants between the computer-based training and classroom instructional training groups

2. The health care professional grading all 35 service videos was unblinded to the USTA NTRP when observing the serve on video.

3. Serve mechanics were not assessed using the gold standard of measures of 3D kinematic imaging. However, the protocol reflects practical field tests that can be used in a field setting.

Delimitations

1. Participants were healthy male and female tennis players recruited from the ages of 14-65.

2. Tennis players had to participate in tennis at least once a week.

3. One clinician graded all of the serve mechanics using the OTSA for aim 3.

4. Tennis players without a USTA NTRP were instructed to self-rank based off the USTA NTRP guidelines.

Chapter 2: Review of the Literature

Introduction

Traditional sports science motion analysis techniques using 3D kinematics have demonstrated that proper mechanics enhances serve performance and improper mechanics overload tissues resulting in injury. However, these are laboratory-based analyses that are difficult to use in the field leaving clinicians and coaches without a practical method for examining serve mechanics. The purpose of this literature review was to 1) discuss the importance of the serve during the game of tennis, 2) discuss the biomechanics of the tennis serve and the implications the stroke has on serve performance and injury risk, 3) examine observational analyses as an alternative avenue of biomechanical kinematic assessments, 4) discuss the key components that must be included within a reliability study utilizing observational analysis, 5) explore the validity of pre-existing observational analysis studies, and 5) to provide an algorithm to researchers interested in developing a successful observational analysis.

The Serve in the Game of Tennis

The serve is the most predominant stroke during the service game and is thought to be the most important shot as it initiates the start of each point.[3] The serve is used as a weapon to dictate the point between two opponents. The execution of a perfect serve requires dynamic function of the entire kinetic chain. It is a movement that requires a sequence of coordinated movements that requires the transfer of energy from the lower

limbs to the upper limbs in a period lastly approximately 1 second.[62] As such, serve

speeds may reach up to 160 miles per hour with rotational velocities and torques at the

Glenohumeral Joint reaching up to 2420°/sec and approximately 55Nm respectively,

depending on the phase of motion during the serve in elite level players.[4,13,62,63] Torque

over 50Nm in the upper extremity may have the potential to cause injury.[4] Along with

the shoulder, the trunk undergoes significant torques that may also contribute to injury.[4,64]

Investigators have therefore categorized the motion as a violent maneuver to which

proper power and acceleration are essential to optimize performance and diminish risk of

injury.[62,65]

Biomechanics of the Tennis Serve

There are three major types of serves in tennis.[66] A player's first serve is

accompanied with the flat serve, which is considered the fastball of tennis. The slice or

sidespin serve may also be executed as a first serve but is more often used as a second

serve and causes the ball to bounce away from the opposing player. Lastly, the kick

serve is typically used as a second serve and incorporates topspin. [66] Ball velocity is

sacrificed for spin rate during the slice and kick serve.[67] As a result the major differences

between these three serves are seen within the upper limb of the kinetic chain during

impact and are specific to long axis rotation, which is defined as forearm pronation and

internal shoulder rotation during follow-through.[10,68] Therefore, the remaining

contributions from the lower limbs and trunk are similar for all three serves.

Consequently, the mechanics of the flat serve will be addressed in this review as it is

predominantly used as a weapon of attack and commonly assessed in the biomechanical

literature.

The serve is generally broken down into three different phases. While these phases have received varying terminology[5,55] within the literature, the categorization of the joint movements that occur during each phase are similar. Kovacs and Ellenbecker[5] illustrated serve mechanics through an 8-stage model that incorporated three phases (Figure 2.1). This review will introduce the mechanics of the serve from a slightly different perspective, discussing the mechanics from a proximal to distal sequence, and the potential implications that joint positioning and timing have on serve performance and injury risk.

Figure 2.1: Three phases of the tennis serve illustrated using an 8-stage model. Figure adopted from Kovacs et al.,[5]

| Start | Release | Loading | Cocking | Acceleration | Contact | Deceleration | Finish |

Preparation Phase   Acceleration Phase   Follow-Through Phase
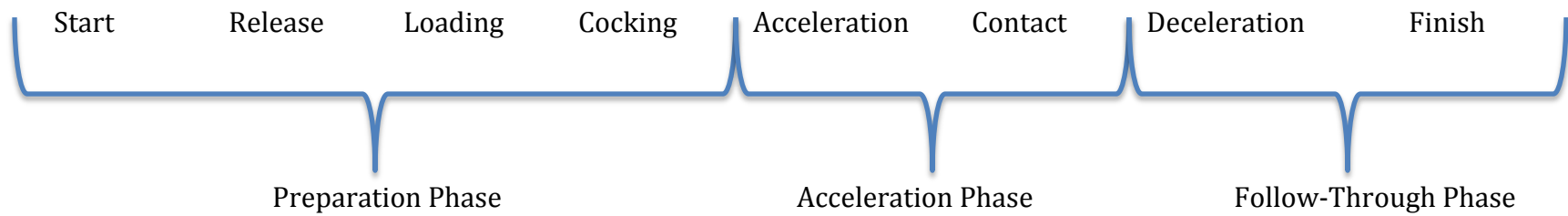
Lower Limb Mechanics

Foot Mechanics

The feet should provide a stable base of support while the legs become fully loaded. An efficient loading stage sets the player up for optimal cocking before the onset of acceleration.[5] Proper foot position is imperative as the feet initiate ground reaction forces that help to propel the player up and through the ball during the end stages of the motion. There are two types of foot positions during the serve: 1) foot-up (FU) and 2) foot-back (FB). Players with a FU position bring the rear foot (ipsilateral foot as the serving arm) up to the front foot during ball toss. In contrast, player's demonstrating a FB position leave the rear foot behind the front foot.[14] The majority of literature investigating these different foot positions has found that the FU position elicits greater velocities (Table 2.1).

Table 2.1: Studies investigating foot position and the implications this position has on serve performance

Study	Population	Outcome	Results
Elliott[14]	9 A-grade players 6 males 3 females	Ball Velocity	No differences between the two foot positions FB: 89 ± 10mph FU: 89 ± 11mph
Reid[56]	12 high performance male players	Forward Racket Velocity	Significance not recorded FB: 95 ± 7mph FU: 98 ± 7mph
Martin[69]	15 expert players 11 males 4 females	Ball Velocity	Significant difference between the two foot positions FB: 103 ± 13mph FU: 107 ± 15mph

Data is presented with mean ± standard deviations
Abbreviations: FB=Foot-Back position, FU=Foot-Up position, mph=miles per hour

The FB position is highly advantageous for those players executing a serve-and-volley strategy as players can generate larger propulsive forces to the net compared to those with a FU position.[14] Both foot stances produce similar shoulder joint loading during maximum knee flexion to maximum external rotation.[56]

Leg Drive Mechanics

Leg drive, has been previously defined as the period from maximum knee bend to racket low point.[70] Leg drive is the first component of engaging the kinetic chain, specifically generating momentum that may be transferred to the trunk.[71] Whiteside et al.,[55] discovered that triple extension velocities (combined peak extension velocities at the ankle, knee, and hip) were significantly larger in elite female adult players (1,742±.166°/s) compared to elite prepubescent players (1,325±152°/s). While there are distinct velocity differences between these two cohorts, these authors did not investigate if triple extension correlated with serve velocity. At this time, it may only be assumed that higher triple extension velocities are positively correlated with serve velocity. However, other researchers have investigated the impact knee flexion angles (initiation of leg drive) have on serve velocity. Some researchers believe peak knee flexion is a poor indicator of leg drive due to the similarities of knee flexion angles across different age level players.[55] However it is the primary visual aid coaches use when assessing leg drive.[72] Consequently, authors have investigated the implications poor knee bend has on serve performance[4,11] and injury risk.[4] The evidence suggested that players demonstrating minimal knee flexion produce increased upper limb joint loading and reduced serve velocities (Table 2.2).

Table 2.2: Studies investigating knee joint angle and the implication these angles have on serve performance and upper limb joint loading

Study	Population	Knee Angle during loading	Outcome	Results
Elliott[4]	20 professional players 8 males 12 females	G1: >10° n=14 G2: < 10° n=6	Serve Velocity	No differences between groups G1: 102 ± 13mph G2: 100 ± 17mph
Girard[11]	13 male elite players. *Note: same players in both groups	S_r: = 10° n=13 S_n: >10° n=13 *Note: players outstretched by splints in S_r group	Serve Velocity	Significance not recorded S_r: 90 ± 9mph S_n: 105 ± 7mph
Elliott[4]	20 professional players 8 males 12 females	G1: >10° n=14 G2: < 10° N=6	Upper Limb Torques	**Shoulder internal rotation torque** G1: 44 ± 8Nm G2: 58 ± 15 Nm **Elbow valgus torque** G1: 47 ± 17Nm G2: 60 ± 13 Nm **Elbow flexion torque** G1: 20 ± 20Nm G2: 36 ± 16 Nm **Shoulder proximal force** G1: 459 ± 162N G2: 468 ± 151 N

Data is presented with mean ± standard deviations
Abbreviations: G1=Group1, G2=Group2, S_r=serve restricted, S_n=normal serve, mph=miles per, Nm=newton meters, N=newtons

Pelvic and Trunk Mechanics

Pelvic Mechanics

Pelvis and shoulder lateral tilt away from the non-racket arm during the loading phase is another component of a powerful flat serve.[56] This tilted body position facilitates rotational momentum through lateral trunk flexion during the cocking stage into the acceleration phase; a critical factor in producing high velocity serves.[71] Furthermore, the tilted alignment may help to load the back leg (ipsilateral leg as the racket) before the transfer of energy is initiated through the trunk and into the upper limb.[73] As a result, trunk rotation about the anteroposterior axis drives the shoulder upward during the acceleration phase, which is an essential movement in differentiating between those with high and low serve speeds.[71,73] Moreover, in injured players, the maximum rotational velocity of the shoulder occurred before pelvis rotation, while it was the opposite in non-injured players.[2] As such, a proximodistal sequence of rotation was being observed in non-injured professional tennis players while this sequence was absent in players occupied with an upper extremity injury.

Trunk Mechanics

Sagittal, frontal, and transverse trunk rotation is essential in the development of inertial energy and the transfer of momentum to the serving arm. Bahamonde investigated trunk angular momentum about these three planes of motion in 5 college tennis players.[71] Despite the small sample size, Bahamonde concludes that the largest contributor to rotational momentum during the serve is about the anteroposterior and medial/lateral axes of rotation between maximum elbow flexion and shoulder external rotation. Moreover, Bahamonde "found that the difference between the players with the

highest ball speeds (114, 104, 113mph) and the players with the lowest ball speeds (89, 98mph) was the contribution of the trunk to the total anteroposterior axis angular momentum."[71] The rotational momentum about the longitudinal axis (rotation about a vertical axis) was small relative to the other two axes, yet it is important because it puts the trunk segment in an advantageous position for lateral flexion, a critical factor in producing high ball velocities.

Literature pertaining to pitching mechanics has suggested that safe and efficient energy transfer during pitching is dependent on the quality, timing, and sequence of motion.[74] Similar constructs have been investigated concerning the tennis serve as energy flows from the trunk to the hand during this overhead motion.[50] More specifically, research has focused on the effects of trunk rotation timing on upper limb joint loading and angular velocities in both injured (upper limb injury) and non-injured male players.[2] Non-injured players displayed significantly lower peak joint kinetics compared to injured players, specifically, shoulder inferior and anterior force, shoulder horizontal abduction torque, elbow medial force, elbow flexion torque, and wrist flexion and radial deviation torque.[2] Furthermore, non-injured players rotated the trunk at maximal velocities earlier in the service motion compared to injured players (Table 2.3), "allowing energy to pass from the trunk to the shoulder at precisely the right timing within the correct sequence of movements."[2]

Table 2.3: The comparison between injured and non-injured male tennis players in regards to the timing of maximal angular velocities

Temporal Parameters	Non-injured players (n=9)	Injured players (n=11)	P-Value	Effect Size
Left and right pelvic rotation	85.7 ± 3.9%	91.5 ± 4.1%	<0.001	0.61
Left and right upper torso rotation	87.4 ± 3.4%	91.1 ± 2.7%	<0.001	0.54
Trunk flexion & extension	85.6 ± 3.5%	89.2 ± 2.3%	<0.001	0.45
Trunk abduction and adduction	92.6 ± 2.7%	94.9 ± 1.9%	<0.001	0.45

Data is presented with mean ± standard deviations along with significance and effect sizes.   Table adopted from Martin et al.,[27]
The parameters are expressed in percentage of serve (where 0% corresponds to ball toss and 100% corresponds to ball impact).

The quality of trunk position and timing affects the integrity of the upper limb during the service motion which may increase the risk of upper limb injury. However, low back injuries and pain may also be of concern as one study showed that 38% of adolescent tennis players reported a lumbar region injury that resulted in missed training.[75] The lumbar region absorbs a significant amount of force during the tennis serve compared to the other strokes.[64]   In fact, male players that experienced low back pain used greater lateral lumbar force (4.1 ± 1.3Nm/kg^{-1}) during the drive phase of the flat serve compared to players with no low back pain (2.7 ± 1.4Nm/kg^{-1}).[64] Although not significant, the low back pain group also experienced higher compression force, extension moment, left lateral flexion moment, and right rotation moment than those players without low back pain.[64] In the same study, the pain group exhibited 4° less transverse rotation (towards the racket arm) than the no pain group. Additionally, players

with a history of low back pain had significantly reduced transverse rotation (2°) and pelvis/shoulder separation angle (14°), and greater right pelvic tilt (the pelvis was tilted such that the right side was higher than the left side) (6°) during the drive phase compared to those without a history of low back pain.[76] Such results indicate movement restrictions that have been shown to be imperative for generating momentum, leg drive, optimizing serve performance, and minimizing joint loads to the upper limb.[71,73] However, it must be noted that these studies only included elite male adolescent players within the study population.[64,76] Therefore, these results should be used with caution when generalizing to other ages and females.

Separation Angle Mechanics

Separation angle has been described as the angle between the hips and the shoulders and is commonly investigated in overhead athletes.[55] The separation angle has been shown to differentiate players with and without a history of low back pain in cricket fast bowlers.[77] Moderate positive correlations have been observed between ball velocity and separation angle at the top of the backswing in golfers.[78] To the author's knowledge, one tennis study has investigated the association between separation angle and ball speed.[79] Investigators found a moderate positive correlation between separation angle and ball speed.[79] This positive association (r=0.44) in separation angle and velocity suggests the importance of priming the interaction between the hips and shoulders in the transverse plane during the service motion. Theoretically, an appropriate separation between these segments may result in eccentric loading of the torso that could lead to a more efficient acceleration phase; ultimately inducing increased racket and ball velocity.

Furthermore, there have been several tennis studies that have documented this separation angle in different age and skill level tennis players (Table 2.4).

Table 2.4: Separation angle during the loading stage of the tennis serve across different age level tennis players

Study	Population	Prepubescent	Pubescent	Adult	Results
Reid[79]	28 elite female players Prepubescent: age=10.5 ± 0.5 n = 10 Pubescent: age=14.6 ± 0.6 n = 10 Adult: age=21.5 ± 3.7 n = 8	30 ± 6	26 ± 6	17 ± 11	Significance not recorded
Whiteside[55]	31 elite female players Prepubescent: age=10.5 ± 0.5 n = 12 Pubescent: age=14.6 ± 0.7 n = 11 Adult: age=21.3 ± 3.8 n = 8	30 ± 7	25 ± 6	17 ± 11	Significant difference (p=0.006) between prepubescent and adult groups
Reid[57]	12 high-performance male players	N/A	N/A	FS: 32 ± 7 KS: 32 ± 8	No difference (p=0.96) between FS and KS

Data is presented with mean ± standard deviations
Abbreviations: FS=flat serve, KS=kick serve

Adult men reach greater separation angles compared to adult females; however, prepubescent females have nearly identical separation angles to adult men. Consequently, the priming of the trunk is most pronounced in prepubescent females and adult males during the service motion. Musculoskeletal flexibility may explain the

inverse relationship between age and separation angle in elite female tennis players. This same phenomenon has been seen when measuring the total arc of glenohumeral rotation motion in elite junior (males and females) and professional female tennis players across three different time points.[80] The data show apparent discrepancies with junior players exhibiting more motion than adult players (Figure 2.2), similar to that of the separation angle.

Figure 2.2: Comparison of glenohumeral rotation range of motion on the dominant arm in two different age level tennis players across three different time points
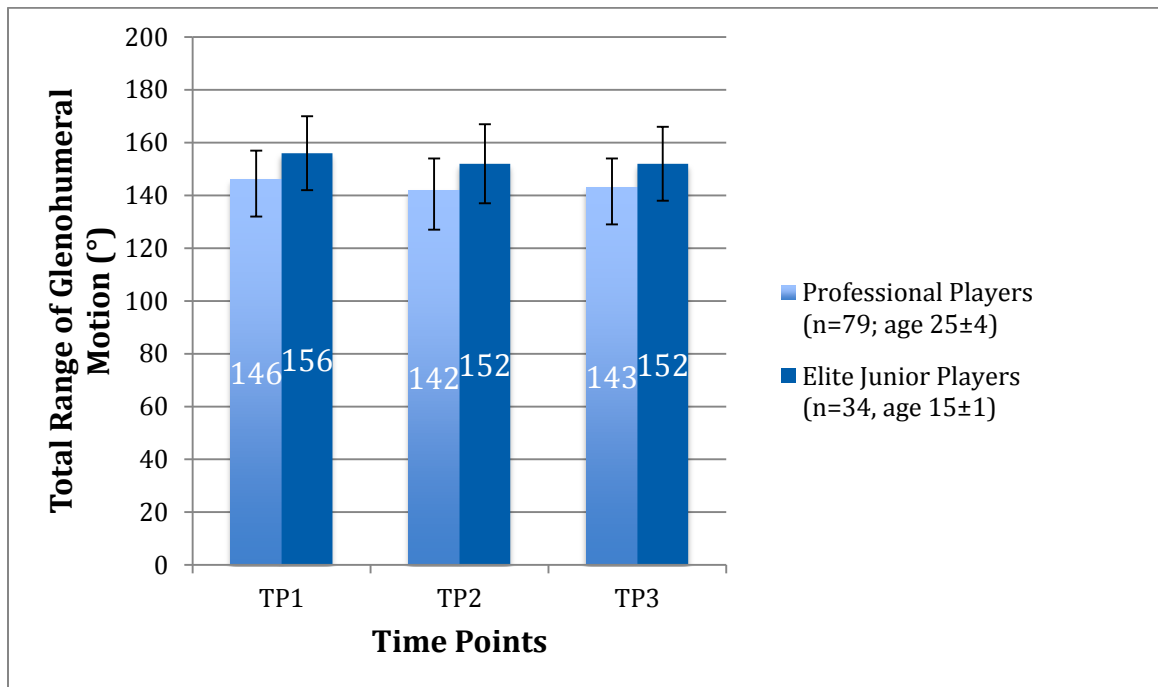
Data is presented with mean ± standard deviations
Professional player data generated from Moore-Reed et al.,[80] Elite junior player data generated from unpublished data (Myers)
Abbreviations: TP1=baseline before match play, TP2=immediately after match play, TP3=24-hours after baseline

Upper limb Mechanics

Upper limb joint positioning during the cocking stage or the instant of maximal external rotation is well documented in the literature. The shoulder should be abducted to approximately 101 ± 13°, horizontally adducted to 7 ± 13°, externally rotated to 172 ±

12°, while the elbow should be flexed and the wrist extended to approximately 104± 12°

and 66 ± 19°, respectively.[63] In conjunction with joint positioning, researchers have

examined appropriate timing sequences at the upper limb, specifically timing between

shoulder horizontal adduction and external rotation of the shoulder. These two

parameters have been shown to have implications on upper limb joint loading and

velocity in the professional population.[2] A correlation analysis showed there were

increased joint loads (shoulder anterior force (r=0.40, p <0.001) and shoulder horizontal

abduction torque (0.40, p<0.001)) and decreased ball velocities(r=-0.26, p <0.05) in

players that exhibited shoulder external rotation before the instant of 0° horizontal

adduction. Additionally, injured players left the arm in horizontal abduction for too long

during the shoulder external rotation phase resulting in lower ball velocities and higher

joint loading compared to non-injured players.[2]

      During the tennis serve, players undergo high loads on the shoulder, elbow, and

wrist joints. Despite these high loads, professional players have been shown to

demonstrate more efficient stroke production than advanced players. More specifically,

professional players maximize ball velocity (20mph faster than advanced players) with

similar and in most cases lower upper limb joint loads compared to advanced players

(Table 2.5).[13]

Table 2.5: Comparison between male professional and advanced tennis players in regards to upper limb peak joint kinetics

Joint Kinetic Parameters	Serving Phase	Professional players (n=11)	Advanced players (n=7)	P-Value
Shoulder forces (N/BW)				
Inferior	Deceleration	2.9 ± 0.6	4.0 ± 0.8	<0.001
Anterior	Cocking	2.8 ± 0.8	3.2 ± 0.6	0.003
Proximal	Acceleration	5.4 ± 0.9	5.2 ± 1.0	0.21
Shoulder torques (Nm/BW*H)				
Internal Rotation	Cocking	34.3 ± 7.4	33.1 ± 7.7	0.47
Horizontal adduction	Cocking	54.5 ± 11.8	54 ± 12.5	0.91
Horizontal abduction	Deceleration	19.7 ± 6.2	22.8 ± 5.6	0.01
Elbow forces (N/BW)				
Anterior	Acceleration	1.7 ± 0.3	1.7 ± 0.5	0.30
Medial	Cocking	2.4 ± 0.5	2.7 ± 0.5	0.01
Proximal	Deceleration	5.5 ± 1.2	5.3 ± 0.9	0.01
Elbow torques (Nm/BW*H)				
Flexion	Acceleration	19.8 ± 5.5	19.7 ± 5.2	0.39
Varus	Cocking	36.1 ± 8.0	34.8 ±7.7	0.29

Data is presented with mean ± standard deviations along with significance from Martin et al.,[13]

Abbreviations: N=newtons, BW=body weight, Nm=newton meters, H=height

As documented above, substantial amounts of the biomechanical literature discussing the contributions of the kinetic chain during the tennis serve are geared towards the preparation and acceleration phase of motion. Yet, the follow-through phase incorporates both upper and lower body eccentric loads to decelerate the body. "The deceleration force between the trunk and the arm during the deceleration stage can be as high as 300Nm."[5] As a result, this phase has been categorized as the most violent of the tennis serve.[5] The continuation of glenohumeral internal rotation and forearm pronation from the acceleration phase into the follow-through phase is a critical component of proper upper limb mechanics that are thought to improve racket velocity. Combined, these two motions are referred to as long-axis rotation.[4,10] Finally, the body lands on the

front foot creating large horizontal braking forces as the center of mass is transferred forward.[81]

Summary

In conclusion, players wanting to decrease upper limb loads and improve serve performance should consider the following: 1) foot position, 2) leg drive (knee flexion angles) 3) pelvic, trunk, and shoulder rotation, and 4) long-axis rotation. There are two primary foot positions that elite level players utilize during the loading stage of the tennis serve (FU and FB). Effective knee bend is essential in decreasing forces at the shoulder and elbow. The execution of lateral shoulder and pelvic tilt along with trunk rotation about the anteroposterior and transverse axis allows the body to store energy so that velocity can be generated during the acceleration phase of the movement. Lastly, the execution of long axis rotation must be incorporated into the end stages of follow-through. These components are essential for improving serve speed and diminishing the risk of injury during the tennis serve.

Observational Analysis as an Avenue for Kinematic Assessment

Practicing clinicians regularly make visual observations during clinical exams to locate impaired forces, muscle actions, or motion patterns that may be responsible for disordered movements. These observational assessments are critical and remain an essential component in both evaluating and developing therapeutic treatment plans for patients.[82] An observational analysis attempts to quantify human movement patterns subjectively without the presence of advanced technology that tends to be complex, expensive, and time-consuming.[17] Equipment requiring instrumentation such as 3D motion analysis is widely accepted by researchers as the gold standard in evaluating

kinematics due to its precision and repeatability.[16] Investigators in the early 1990s speculated that the cost of motion analysis would decrease enabling clinics to purchase such equipment.[83] Although, despite cost-lowering efforts for motion analysis equipment, clinicians still find it impractical for daily use.[18] Consequently, this scenario has clinicians implementing more practical and manageable methods of clinical assessment through visual observation.

Observational analysis dates back to the early 1970s,[21] as investigators found that experienced physical therapists were able to consistently agree 93% of the time on sagittal trunk and knee motion deviations during gait in adult hemiplegic patients. This foundational study carved the path for future observational research not only specific to gait,[17,18,20,22-34] but geared towards appraising scapular impairments,[35-38] lower extremity functional tasks,[39-49] and sport specific movement.[5,50]

Since the tennis serve requires function of the entire kinetic chain to transfer forces from a proximal to distal sequence, it has been considered the most complex stroke during the game. The complexity of the stroke led researchers to investigate specific body positions and motions essential for creating energy and force while minimizing energy expenditure. These body positions and motions were collected through 3D motion analysis studies.[2,4,6,9,11-15,55-57] The findings from these studies allowed tennis researchers to develop observational analyses focusing on the evaluation of serve mechanics that could be assessed with standard video recording equipment. Lintner et al.,[50] proposed a 5- tiered observational system that optimized the use of the kinetic chain during the service motion. Years later, the system transitioned to an 8-tiered observational model that provided descriptive characteristics defining both normal and

abnormal mechanics prior to acceleration.[54]   This is the only observational model

specific to the serve that provides operational definitions for both efficient and inefficient

mechanics. Kovacs et al[5] established an 8-stage descriptive model of normal serve

mechanics. This model also derived from the 3D literature and provided readers with a

detailed breakdown of proper mechanics. Authors not only described specific body

positions and motions but also reported the forces and rotational velocities that

accompanied the joints during all the different phases of motion. While the analysis is

comprehensive in nature, it is difficult to use as an observational tool via standard video

recording, due to the detailed kinematic and kinetic assessment.

Many authors have attempted to establish the reliability of multiple observers

using an observational assessment method. The majority of articles examining

observational assessment generate poor to moderate agreement between multiple raters.

Yet, there are visual assessment scales that have demonstrated moderate to almost perfect

agreement between multiple observers.

Critical Components of an Observational Analysis
Educational Training

Investigators have shown moderate to substantial reliability results when a

standardized educational training protocol is administered.[38,46] McClure et al.,[38]

investigated the inter-rater reliability of the scapular dyskinesis test. The investigators of

this study distributed a self-instructional slide presentation to 6 observers before initiating

the study. The presentation included operational definitions, photographs, and embedded

video examples. The examples provided within the presentation allowed the observers to

view normal and abnormal motion. The authors did not provide in-person training as

they felt this would have hindered the external validity of the results. On average, the results demonstrated 79% agreement between raters with a weighted kappa of 0.55 (moderate). Kreb et al.,[17] had 3 raters assess gait in children with lower limb disabilities. Authors stated each rater received training, but the type of training, and the details of the training were not discussed. The average ICC between raters overall motion and subphases of gait was 0.73.[17] Another study, assessing dynamic knee valgus recruited three physical therapists to visually assess female soccer players performing a double leg drop-landing task.[46] The observers were instructed to categorize the athletes as high or low anterior cruciate ligament (ACL) risk based on previously established definitions of knee valgus. Prior to the initiation of the rating protocol all observers received a 20-minute instructional CD including information about ACL injury risk, rating instructions, and practice rating trials. Observers also underwent an onsite review consisting of more practice sessions before the commencement of the rating protocol. Here each observer had the opportunity to clarify questions that may have arisen during the instructional CD. Substantial agreement was established between raters (kappa=0.79) and within raters (kappa = 0.80).[46] Other authors have suggested incorporating more intensive training programs such as interactive classroom education.[48]

To the author's knowledge, no observational assessment study has explored classroom education as a potential for delivering training sessions prior to the commencement of a rating protocol. Currently, the best evidence available for a similar comparison is on the technique assessment of meter-dose inhalers (MDI). Pharmacy students were evaluated pre and post intervention on their ability to assess MDI technique using a subjective protocol.[84] Students were randomized into one of three groups: 1)

lecture group, 2) web group, or 3) control group (no intervention). Following the educational training, a study investigator performed a pre-scripted scenario of a patient incorrectly using a MDI. All students, regardless of group, visually observed the MDI technique and documented any steps that were performed incorrectly. MDI technique was based on a12-step procedure; each step was accompanied with specific instructions. Ultimately, the MDI technique evaluation was no different between the lecture and web-based group; however both significantly differed from the control group. As a result, web-based learning was shown to be just as effective as classroom instruction in evaluating a mock patient exhibiting incorrect MDI technique.[84] This study confirms that an educational component is essential when teaching a group of individuals a task, as the control group did not improve MDI technique. Consequently, it should be determined if similar results would be seen in instructing coaches and HCPs on how to visually identify appropriate human movement patterns (gait, upper or lower functional tasks, or sport specific movement). In the proposed study, if multiple observers in the computer-based session demonstrate similar reliability results to those in the classroom session the method of observationally grading tennis serve mechanics could be taught to individuals worldwide generating access to more people.

Operational Definitions

The standardization of specific operations definitions has proven to be essential during studies utilizing observational assessment. Children with lower-limb disabilities were assessed via video by 3 different observers. Each observer was given a three-page instructional manual that included operational definitions for all joint motions that were being examined.[17] Results yielded substantial inter-rate reliability (ICC=0.73) for all

motions and phases of gait. Four raters were asked to evaluate gait in children with spastic cerebral palsy.[27] Scale construction followed a script that was adapted from previous gait models. Observers delivered a range of moderate to substantial agreement using a 24-item scale. Inter-rater reliability in observers that assessed knee and hip function in children with spastic hemiplegia proved to have substantial agreement. These findings may be related to the fact that both joints had subjective and objective defining criteria.[32] Another study only providing objective criteria for grading of the knee and hip revealed moderate agreement between observers,[28] further supporting the need for both subjective and objective descriptions when standardizing joint movement characteristics.

Incorporating specific reference points into definitions have also shown to yield substantial levels of agreement.[43,46] Raters assessing knee position during a step-down task were instructed to use the tibial tuberosity as a reference point when assessing knee adduction: "the knee deviated medially and the tibial tuberosity crossed an imaginary vertical line over the medial border of the foot."[43] A similar study, also yielding substantial reliability, categorized knee adduction during a drop-landing task as "the patella moves inwards and ends up medial to the first toe."[46] The absence of operation definitions and poorly defined criteria is one possible component that may yield less than desirable outcomes when investigating the reliability of an observational method of assessment. In fact, Mackey et al[26] attributed the fair agreement (Kappa = 0.38) between observers for "base of support" during gait to poorly defined criteria. Operation definitions should be clear, concise, and contain both subjective and objective (when appropriate) criterion to help guide observers during observation for each specific rating criterion.

Selected video pace

Several authors have suggested the importance of multiple viewings incorporating slow motion videos or freeze-frame capabilities for improving the repeatability of an observational tool.[17,20,27] Observers recruited to evaluate children's gait had the opportunity to review each gait sequence 3-4 times until each observer felt satisfied with their analysis.[17] Similarly, McClure et al.,[38] allowed observers to view video recordings twice (if requested) when evaluating scapular dyskinesis in a group of collegiate athletes. One study generated moderate agreement (ICC =0.41) between observers that were permitted to implement slow motion playback while rating ankle flexibility during stair descent.[45] The same observer's inter-rater reliability scores dropped when asked to view videos at normal speed (ICC = 0.29).[45] The use of slow motion video has been shown to improve the inter-observer reliability of observational gait assessment at the foot and ankle compared to live assessment.[28] Furthermore, video strategies incorporating multiple viewings, freeze frame, and slow motion features seem to contribute to better reliability of observational assessments.[26,27,38]

Establishment of face validity

Before an observational scale is used for data collection, a panel of experts should review and revise operational definitions specific to each criterion associated with the scale. This step can be executed through the establishment of face validity. Face validity is the extent to which a test is subjectively viewed as covering the concept it purports to measure. To rate the performance of a single leg squat a consensus panel of 5 experienced physical therapists developed specific criteria for the trunk, pelvis, hip, and knee joints.[48] The panel met as a group and discussed the criteria that would be used for

future rating. It was determined by the panelists that squat performance should be graded as good, fair, or poor (with each criteria representing specific definitions). The consensus panel demonstrated substantial to excellent agreement in the rating of the single leg squat performance. However, the members of the research team admit that while the consensus panel strengthened the internal validity of their study, more physical therapist outside the panel should have been approached to evaluate the rating criteria further.[48] Harrison et al.,[39] used a 3-point rating scale to judge single-leg balance in two groups: 1) healthy recreationally active male and females and 2) males and females 10-18 months postoperative ACL reconstruction. To establish a level of face validity, the rating scale was sent to 3 physical therapists before data collection. These therapists were asked to review and revise the operational definitions. Face validity is a quick and easy method to apply to any observational study before the initiation of data collection. It is an essential step within the methodological process to confirm that the operational definitions specific to the rating scale are being represented appropriately.

Validity of observational analysis studies

The assessment of validity is less common than reliability when investigating outcomes directed towards observational analysis. Concurrent validity assessing the relationship between observational analysis and other validated measures has been shown to generate more consistent outcomes than studies measuring criterion validity. A good correlation (r = 0.69) was found between observational gait score and the walking mobility scale in patients that suffered from a spinal cord injury.[85] A strong correlation (r=0.77) was found between observational gait score and walking time in patients that suffered from a stroke.[30]

Criterion validity is most often assessed with a gold standard of measure. The gold standard is the criterion that best represents the condition of interest. [86] For example, 3D motion analysis is the gold standard for measuring joint kinematics. Few articles are able to conclude that observational analysis is as accurate as the gold standard. Tate et al.,[37] compared McClure's[38] observational analysis on scapular dyskinesis to the gold standard and discovered that individuals visually observed as having dyskinesis did, in fact, present with impaired scapula motion as determine by 3D motion analysis. Other studies implementing similar methods were unable to draw as definite conclusions.[36,41,46] This may be because the data were analyzed using sensitivity and specificity rather than analysis of variance to assess group interactions. DiMattia et al.,[41] revealed that the observational methods used to assess the single leg squat had low sensitivity but high specificity when compared to a kinematic analysis. Yet the kinematic analysis was assessed 2-dimensionally instead of 3-dimensionally, and while the 2D analysis is often used for sagittal and frontal plane motion the 3D analysis has been widely accepted by researchers as the gold standard in evaluating movement due to its precision and repeatability.[16] Thus, diagnostic accuracy may have improved if a 3D analysis was utilized. Relatively high sensitivity and specificity were found when validating an observational screening tool evaluating dynamic knee valgus compared to kinematic analysis.[46] Similar to Tate et al.,[37] a yes/no system was used to categorize soccer players into high or low-risk ACL groups. Two-point grading scales reportedly have good accuracy when establishing criterion validity.

An observational analysis should be both reliable and valid. Researchers should consider all of the above components as study design can potentially limit the results of a

research project aimed towards visual assessment. The following algorithm was designed

to help researchers interested in developing a successful visual observational assessment

method (Figure 2.4).

Figure 2.3: Algorithm for implementation of an observational analysis
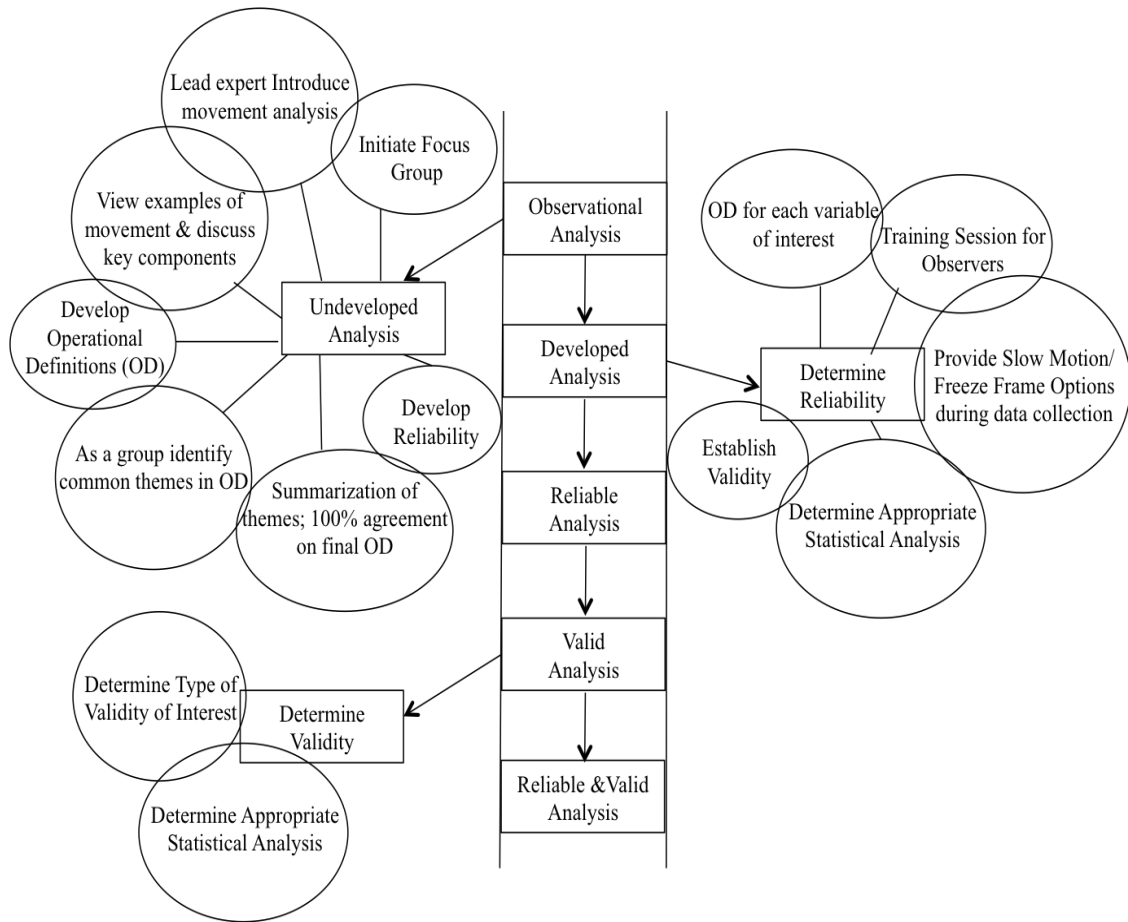
Conclusion

The tennis serve requires a sequence of kinetic chain movements that originate at the lower limb. These lower limb movements stimulate trunk rotation allowing for energy to be transferred to the upper limb. Several studies utilizing 3D motion tracking have discovered that inefficient biomechanics at the lower limbs and trunk result in upper limb injury and diminished serve performance. Therefore, it is imperative that tennis professionals and clinicians working with players can recognize abnormal mechanics to combat these negative implications. While many tennis professionals are unable to

assess players three-dimensionally, other options are available that may lend themselves useful when assessing serve mechanics. Observational analysis through standard video recording is inexpensive, practical, easy to use, and has been found to be valid and reliable between multiple viewers if executed appropriately. Observational methods used to grade the mechanics of the tennis serve are available in the literature; however, these methods of assessment do not hold any clinical utility. A field method available to coaches and HCP that is reliable between users and provides a simple valid way to discriminate the mechanics of the tennis serve would be invaluable to those without a 3D motion laboratory.

Chapter 3: Inter-Observer Reliability of a Biomechanically Based Analysis Method for the Tennis Serve

Introduction

An effective serve is a key component and can be a major weapon for success in tennis. However, a serve can place high demands on the athlete's musculoskeletal system.[4,7,63] High distraction, compression, and shear loads along with large ranges of motion are frequently developed in the back shoulder, elbow, and wrist.[4,13,63,64] Furthermore, excessive loads and ranges of motion, along with the improper timing of rotation can have an adverse effect on tennis performance and lead to increased injury risk.[2,4,13]

Many coaches and health care professionals (HCP) would agree that the primary outcomes when developing and teaching the serve is to improve performance, specifically serve velocity, and to prevent injury.[2] Injury prevention is always a priority as any injury may pose a threat to future competition and longevity of competition. Since the serve is the shot that initiates the start of each point, and it accounts for 60% of all strokes it is considered the most important and predominant shot of the service game.[3] The complex sequence of movements involved in the stroke along with its repetitive nature makes it one of the most commonly researched shots in the game of tennis. A player showing true mastery of the stroke is able to utilize the kinetic chain through a sequence of motions that originate at the lower limbs. These lower limb actions are followed by trunk rotation that ultimately leads to upper limb rotation.[4] However, a breakage in this kinetic chain during the serve may have implications on injury and performance.

Researchers investigating the biomechanical demands associated with the tennis serve have successfully targeted the threats to serve performance and upper limb loads that contribute to upper extremity injury.[2,4,6,11,13,14,64] All of these studies have utilized 3-dimensional (3D) motion analysis to investigate the kinematics and kinetics that accompany the serve. 3D analysis has been widely accepted by researchers as the gold standard in movement analysis.[16] However this technique is not widely applicable, cannot usually be utilized on court, and is costly and time-consuming for clinicians and sports professionals who implement screening programs into therapeutic treatment and performance protocols.[17-19] Consequently, the investigation into field based visual observational analysis may be more practical for coaches and clinicians to evaluate tennis serve mechanics.

To promote observational analysis in the field or clinical setting tools must be quick, easy to use, allow a clinician or coach to provide almost immediate feedback, and demonstrate reliability, and validity. Previous serve analysis descriptions include Kovacs and Ellenbecker's.[5] 8-stage kinematic based model broken into 3 phases to help players identify proper mechanics. With an understanding of the biomechanical demands required during the tennis serve other researchers created a clinically applicable observational serve analysis to evaluate the mechanics of the serve.[50,54] The observational tennis serve analysis, initially described in 2008,[50] and later refined in 2013[54] provided a detailed framework of specific positions representing normal mechanics, abnormal mechanics, and potential strategies to improve altered mechanics.

To help improve the effectiveness and applicability of the serve analysis presented in 2013[54] the authors and the Women's Tennis Association (WTA) refined the

analysis tool to be observational on the court and by video. The analysis method is

broken down into 9 components that are associated with efficient force production

responsible for creating maximal energy and optimal ball speed with minimal energy

expenditure and joint loading.[4,6,54] The first eight components are evaluated at maximal

knee flexion while the last component is assessed during the entire service motion. The

eight components are defined as nodes, and represent a body position at a specific joint

and have been compiled through 3D motion analysis studies.[2,4,11,13,14,55,57,64,71] The ninth

component is a an assessment of the entire service motion. The node framework can be

used visually to evaluate the effectiveness of the service motion.

The purpose of this study was to describe the observational tennis serve analysis

(OTSA) tool and to investigate its inter-observer reliability for each node between two

HCPs that helped to create the analysis tool. We hypothesized that the inter-observer

reliability will be moderate or higher for the majority of all nine components of the

OTSA.

Methods

Participants

The serves of 28 professional women tennis players were recorded during actual

Women's Tennis Association (WTA) matches using a standardized technique and

viewing angle. All of the players who were video recorded were participating in tennis

on a regular basis at a competitive level. Players were excluded if diagnosed with a

neurological disorder, or had a history of fractures and/or surgeries within a year of the

video collection. The Institutional Review Board of the Lexington Clinic approved this

study.

Procedures

Data Collection

All serves were recorded from the deuce court for each player. The camera was placed at the back corner of the court at approximately 45° angle to the player's back. All matches were outdoors on a hard court surface. The videos were uploaded to a USB drive, which was then supplied to 2 observers, an orthopedic surgeon (WBK) and a licensed physiotherapist (BS). The observers were not provided any information on if the service trial was a first or second attempt or whether the serve was successful.   Both observers were experienced in tennis sports medicine (combined experience of 40 years) and were instrumental in creating the OTSA tool. Each observer then independently evaluated each serve, using a standardized scoring sheet. The scoring sheet allowed the observers to categorize each component associated with the OTSA in a binomial format of either "good" or "bad." The observers reviewed the videos as much as needed.

The nodes have been previously described,[54] and were refined by the authors and the WTA so an observer could use specific criteria to determine whether the player's motion demonstrated or failed to demonstrate the node. Each of the nodes is accompanied by operational definitions describing the criteria of both "good" and "bad" mechanics for each position (Table 3.1). Preliminary versions of the tool were presented to 2 tennis coaches and one clinician to establish its face validity. Previous researchers establishing validity prior to data collection had improved reliability results.[39,48]

Table 3.1: The Observational Tennis Serve Analysis Tool

	Good Mechanics	Bad Mechanics
Node 1: Foot Position	Good: Back foot stays behind front foot in shoulder cocking	Bad: Back foot stays in front of front foot in shoulder cocking
Node 2: Knee Position	Good: Both knees to bend greater than 15°	Bad: Both knees bend less than or equal to 15°
Node 3: Counterhip Rotation	Good: The hip on back side is rotating away from the net	Bad: The hip on back side is not rotating away from the net
Node 4: Posterior Hip Tilt	Good: The hip on back side is dropping towards the ground	Bad: The hip on back side is not dropping towards the ground
Node 5: Forward Hip Lean	Good: The hip on front side is not leaning forward towards the net	Bad: The hip on front side is leaning forward towards the net
Node 6: X-angle	Good: x-angle describes the relationship between the shoulders and the hips and should be approximately equal to 30°	Shoulders rotate to far behind the hips or don't rotate behind the hips Bad: the x-angle is greater than 30° Bad: the x-angle is less than 30°
Node 7: Trunk Position	Good: Trunk rotation around a vertical axis	Bad: No trunk rotation, lateral trunk bending only, lumbar hyperextension, hyper-rotation, or hypo-rotation
Node 8: Arm Position	Good: Shoulder in line with the plane of scapula	Bad: Hypercocking – shoulder behind the plane of scapula; Hypococking – shoulder in front of the plane of scapula
Motion 9: Kinetic Chain	Good: Used knee flexion and back leg drive to maximize ground reaction forces that push the body upward from the cocking position into ball impact	Bad: Use trunk muscles to pull the trunk and arm from cocking into ball impact
*Note: Evaluate nodes 1-8 at maximum knee bend. Kinetic chain node to be evaluated throughout entire motion.		

Data Analysis

Each observer recorded categorical data for each of the 9 components on each player; achievement of the node (good position) was rated one while failure to achieve the node (bad position) received a zero. Percentage of observed agreement and kappa (K) coefficients were used to investigate inter-observer reliability for each of the 9 body positions using Statistical Package SPSS version 21 [IBM Corp. Armonk, NY. USA]. The kappa static is the preferred statistic for reporting the reliability of categorical data.[87] It represents the agreement between raters beyond that expected by chance. If agreement between raters occurs simply by chance, the Kappa will return a value near 0. The authors of this paper used the following scale to interpret the strength of agreement between two raters: ≤ 0 = poor agreement, .01-.20 = slight agreement, .21-.40 = fair agreement, .41-.60 = moderate agreement, .61-.80 = substantial agreement, and .81-1 = almost perfect agreement.[88]

In combination with the Kappa statistic, several researchers have suggested the proportion of positive agreement be calculated to provide readers with a clearer understanding of inter-observer reliability.[89-93] Furthermore, this proportion should be considered when a kappa paradox is present, in which a low kappa statistic accompanies a high level of observed agreement between raters.[89,90] When this paradox is present interpretation of the kappa on its own may not be meaningful, and calculation of the proportion of positive agreement should be generated to interpret the results.[89,90,93] The following equation was used to calculate the proportion of positive agreement using the same data within the 2 x 2 contingency tables exported from SPSS when generating Kappa statistics.

$P_{pos} = 2a / (N + a - d)$ where "N" represents the number of observations, and "a" and "d" represent cell one and four, respectively within the 2 x 2 contingency table.[93]

Results

The percentage of observed agreement between the 2 observers varied by node and is presented in table 3.2. The kappa score ranged from 0.36 to 1.0, and the level of agreement ranged from 76 to 100% agreement. Five out of the nine components scored substantial to almost perfect agreement with kappa values > 0.61. The kappa paradox (low kappa with high level of agreement) was present in four out of the nine nodes (Nodes 2, 5, 7, 8). The proportions of positive agreement for each of the 9 components range from .40 to 1.0 and are presented in table 3.2.

Table 3.2: Inter-observer reliability between two experienced sports medicine professionals evaluating 28 serve videos

Node	Percentage of Observed Agreement (%)	Kappa Coefficient	95% Confidence Intervals	Proportion of Positive Agreement
Node 1	89%	0.77[b]	0.53, 1.01	0.85
Node 2	78%	0.43[c]	0.02, 0.84	0.57
Node 3	96%	0.84[a]	0.53, 1.15	0.97
Node 4	100%	1.00[a]	1.00, 1.00	1.00
Node 5	89%	0.36[d]	-0.54, 1.26	0.94
Node 6	96%	0.78[b]	0.20, 1.36	0.98
Node 7	92%	0.47[c]	-0.24, 1.18	0.96
Node 8	85%	0.51[c]	0.07, 0.95	0.91
Motion 9	96%	0.86[a]	0.61, 1.11	0.97

[a]Indicates almost perfect level of agreement
[b]Indicates substantial level of agreement
[c]Indicates moderate level of agreement
[d]Indicates fair level of agreement

Discussion

The OTSA was developed using kinematic findings from 3D motion analysis studies to design an observational tool that evaluated the mechanics of the serve by video

assessment. The developers of this tool suggested the analysis might be practical for coaches and HCP to evaluate tennis serve mechanics in the absence of costly biomechanical equipment. However, the practicality of such a tool cannot be suggested without basic psychometric properties. Therefore, the current study investigated the inter-observer reliability of a field-based tool used to grade the mechanics of the tennis serve between two health care professionals that helped to create the analysis tool. It was hypothesized that inter-observer reliability would range from moderate to almost perfect agreement for the majority of the 9 body positions.   This study supports this hypothesis as 5 (56%) of the 9 nodes generated substantial to almost perfect agreement, 3 (33%) generated moderate agreement, and 1 (11%) generated fair agreement. However, caution must be taken when interpreting the kappa values of the nodes generating fair to moderate agreement, as the kappa paradox was present within these 4 nodes.

The kappa paradox is "affected by the prevalence of the finding under consideration much like prediction values are affected by the prevalence of the disease under consideration."[89,91] For example, the low kappa value (0.36) associated with forward hip lean (node 5) presents with a percentage of observed agreement of 89% (two raters in agreement 25 out of 28 observations). This was because 24 out of the 25 agreed responses were that players did exhibit forward hip lean, and only 1 time did the raters agree that the athlete did not exhibit forward hip lean during the serve. Therefore, there is much agreement between the observers, but there is an uneven distribution of observations within the 2 x 2 contingency table.   With the proportion of positive agreement value reaching near 1, (0.94 in this case) it can be interpreted that the decline in kappa is a result of the high prevalence of "yes" responses (24 responses) compared to

"no" responses (1 response) in the 2 x 2 contingency table between the raters.[93] Similarly, there was a substantial improvement in the proportion of positive agreement for trunk position (node 7), and arm position (node 8) compared to the kappa value alone. The remaining kappa value that generated moderate agreement was knee position (node 2), and while the proportion of positive agreement improved it did not substantially increase compared to the other nodes generating fair to moderate agreement. This was because only 4 times out of 22 responses did the observers agree that the athlete flexed the knee past 15° during the serve, leaving 18 times where the raters agreed that the player did not flex the knee past 15°. Therefore, the raters were in total disagreement 6 times when evaluating knee bend during the service motion. Moreover, the reliability of the OTSA is further enhanced when considering the proportion of positive agreement. The kappa value representing nodes 5, 7, and 8 seems to be underestimating the true agreement between these two raters as the proportion of positive agreement is high providing a more robust interpretation of the data. Experts in this field have not identified the exact values for interpretation of the proportion of positive agreement, but explain through examples, that values near 1 should provide evidence of relying solely on the kappa statistic as a measure of agreement.[93] Consequently, the proportion of positive agreement should be reported along with the kappa, as a low kappa statistic reported with a high level of percent observed agreement may give misleading results.[93]

Furthermore, it should be addressed why several of the nodes generated different kappa values with the same percentage of observed agreement. For example, counterhip rotation (node 3) and x-angle (node 6) possessed different kappa values with the same level of agreement between the raters. This is because the distribution of "yes" to 'no"

responses is proportioned differently within the 2 x 2 contingency tables for node 3 and node 6. This affects the mathematical calculation of the kappa, despite the raters agreeing 27 out of the 28 observations for both nodes, resulting in observed agreements of 96% (Table 3.1).

Tennis researchers have demonstrated that faulty mechanics during the serve are associated with decreased serve performance (velocity) and increased risk of injury, specifically in the shoulder and elbow.[2,4,12,13] In a properly functioning kinetic chain the legs and trunk generate more than 50% of the force and kinetic energy delivered to the hand.[7,8] The lower extremity is responsible for producing ground reaction forces critical to the overall force development of the serve motion, and for creating a stable proximal based initiated at the feet that are essential for distal mobility.[7,9,10] Knee bend has been reported to increase serve velocity and decrease upper limb kinetics during the serve.[4,11] Players developing less than 10° of knee flexion have demonstrated increased shoulder internal rotation and elbow valgus torque of 32% and 27%, respectively, during 3D analysis compared to those with more than 10° of knee flexion.[4] Investigators have also found that injured players displayed delayed trunk rotation timing compared to non-injured players resulting in increased upper limb joint loads.[2] Another contributing factor to performance and injury is arm-cocking position. Players must properly horizontally adduct and externally rotate the upper arm in the appropriate sequence. Decreased serve velocity and increased upper extremity loads were present in injured tennis players as these players remained in horizontal abduction during maximal shoulder cocking for an extended period compared to non-injured players.[2] Therefore, it is imperative that players execute correct mechanics throughout the body in an orderly sequence commonly

referred to as the kinetic chain. These positions were gathered from laboratory-based biomechanical studies, but can also be identified using the OTSA tool with the intention to combat performance deficits and diminish injury risk without the presence of expensive laboratory equipment.

Observational analysis dates back to the early 1970s as investigators found that experienced physical therapists were able to consistently agree 93% of the time on sagittal trunk and knee motion deviations during gait in adult hemiplegic patients.[21] Observational analysis is the most common approach to providing an estimation of kinematics.[19,20] The approach is based on visual examination of a joint(s), and can be implemented via live assessment or with a standard video recording device that enables slow motion and freeze frame capabilities.[19] Our results are comparable to other previously published observational studies. Mackey et al.,[26] found *K* values ranging from 0.43-0.86 from video observational gait analysis in children with spastic diplegia. Children with spastic cerebral palsy have also been assessed using observational analysis with inter-observer reliability ranging between 0.59-0.79.[27] Crossley et al.,[48] reported inter-observer agreement using a 3-point scale categorizing movement during a single leg squat test with kappa values ranging from 0.60-0.81.

There are several advantages to this type of analysis. First, it is portable to practice or tournament sites and can be implemented by using a standard video camera. Second, it has been established that improper serve mechanics throughout the kinetic chain can have negative implications on performance and injury. Thus, coaches and health care professionals must be able to easily identify mechanical flaws within the service motion to improve performance and diminish possible injury risk. Third, by

specifically demonstrating failures to achieve specific nodes, it can highlight areas for detailed musculoskeletal evaluation and conditioning. In turn, coaches and clinicians may evaluate specific body regions that aid in the improvement of the serve technique. Fourth, by identifying node deficiencies, it may be possible to develop programs for injury prevention, as one tennis study has linked the development of injuries to alterations in serve kinematics and kinetics.[6]

There are several limitations to this study. First, it only evaluated professional female tennis players. Other groups of professional or recreational players may have different characteristics even though the serve motion is qualitatively the same. Second, two experienced sports medicine professionals who were involved in the development of the method performed the analysis. Future research is underway to address this specific limitation by incorporating more HCP and tennis coaches that have not developed the OTSA tool. Third, there is no direct correlation between the findings of this analysis and either the incidence of injuries or the prevention of injuries or performance. Future studies need to investigate this tool as one of the primary outcomes in both serve performance and injury related studies.

Conclusion

This preliminary reliability of the observational tennis serve analysis tool using nodes to identify specific positions and motions associated with optimum force development, and minimal joint loading has a high degree of agreement among two experienced observers. This system has the potential to help coaches, players, and HCPs better analyze the rapid and dynamic service motion to combat performance deficits and diminish the possibility of future injury.

**Chapter 4: Two Different Instructional Methods used to Investigate the Reliability
of the Observational Tennis Serve Analysis Tool**

Introduction

The tennis serve is a predominant stroke during the service game accounting for more than 50% of all strokes.[3]   The serve is complex in nature, as it requires synergistic movement patterns from multiple segments throughout the kinetic chain. Several authors have collected kinetic and kinematic data using traditional three-dimensional (3D) motions analysis on healthy players to determine the loads, joint angles, and rotational velocities that accompany the service motion.[2,4,6,14,55,57,71] To investigate if serve mechanics play a role in injury risk, tennis injuries to the upper extremity were tracked prospectively following biomechanical data collection on elite male players.[2] Martin et al.,[2] found that injured players rotated the trunk later during the service motion, left the arm in horizontal abduction for an extended period of time during cocking, demonstrated larger upper extremity joint kinetics, and decreased ball velocities compared to non-injured players. While these findings have direct implications on injury risk and serve performance it is imperative that tennis coaches and health care professionals (HCPs) are able to properly assess tennis serve mechanics.

The observational tennis serve analysis (OTSA) tool is one method that can be used to visually evaluate serve mechanics without the presence of expensive laboratory equipment. Preliminary data from chapter 3 have shown that this method for assessing serve mechanics is reliable among the HCPs that helped create the tool. However, it is currently unknown whether novice users can reliably use the tool to assess tennis serve mechanics, and the best method of instruction when teaching novice users how to use the OTSA as an assessment tool.

Researchers investigating observational analyses have determined that an educational training session is imperative to yield superior reliability between multiple raters. Self-instruction slide presentations and instructional compact discs have yielded moderate to excellent reliability when used in studies of scapular dyskinesis and knee valgus motion, respectively.[38] [46] While self-instruction has been generally successful, other authors have suggested incorporating more intensive training programs such as interactive classroom[48] or computer assisted learning.

The web has become a powerful tool for teaching at a distance through the use of computer-assisted learning (CAL).[94] CAL allows students to direct their own learning and provides multiple opportunities for reviewing subject or course material.[95] This method of instruction is being applied in industry, government, and higher education. The percentage of industries using the computer to disseminate knowledge increased by 70% between 1999 and 2004.[96] Additionally, the U.S. Department of Education conducted a survey on students enrolled in web-based courses within degree granting postsecondary institutions between the fall of 2002 and 2011 and found a compound annual growth rate of 17%.[97]

Computer assisted learning is becoming increasingly popular within medical education. Averns et al.,[98] showed that an online module is just as effective as tutor-led classroom groups in teaching clinical hand assessment skills. CAL has also been seen to be just as effective in teaching medical students suture and knot-tying skills when compared to face-to-face feedback.[99] Web-based instruction was shown to be just as effective as classroom instruction in evaluating a mock patient exhibiting incorrect meter-dose inhaler (MDI) technique.[84] In general, internet based learning has been shown to be

an effective alternative to traditional classroom interventions when assessing satisfaction and knowledge among different medical professions.[53]

In most cases web-based and classroom instruction is equally effective for teaching declarative and procedural knowledge.[52] However, the effectiveness of different types of educational training when examining a specific movement pattern is relatively unknown. Therefore, the purpose of this study was to compare two different forms of instructional training, computer based versus classroom based to determine which method yields the best intra and inter-observer reliability of the OTSA in a group of novice users. First, it is hypothesized that the reliability for all novice users (tennis coaches and HCPs) will be moderate (Kappa≥0.41) or higher for the majority of the nine components associated with the OSTA. Second, it is hypothesized that reliability results will be equal among the novice participants (coaches and HCPs) receiving computer-based instruction and classroom instruction for all nine components.

Methods

Participants

Sixteen observers were recruited from a sample of convenience and placed into one of two instructional training groups (Figure 4.1). Tennis coaches were included if they were actively coaching at the recreational, high school, or college level. Retired coaches were able to participate if they had tennis coaching experience lasting longer than 10 years. HCPs were included if they were a certified athletic trainer or licensed physical therapist.

Figure 4.1: Non-randomized group allocation for instructional training
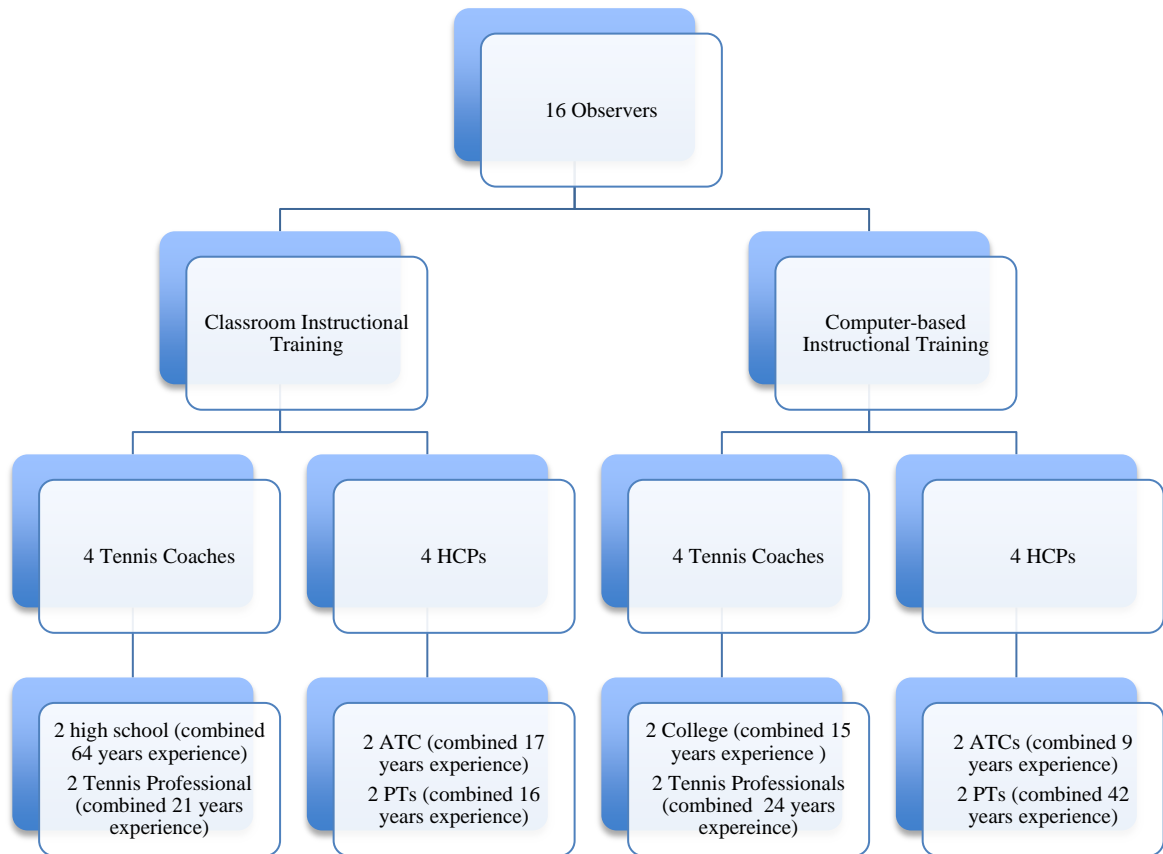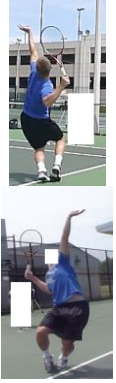
The sample size was based on a goodness-of-fit formula provided by Donner and Eliasziw[100] factoring for 80% power with a 1-tailed test null value of Kappa to be 0.00.

Observational Tennis Serve Analysis (OTSA) Tool

An observational method for evaluating tennis serve mechanics was first described in 2008,[50] and later updated in 2013.[54] To help improve the effectiveness and applicability of the serve analysis presented in 2013, the authors and the women's tennis association (WTA) refined the analysis method, calling it the Observational Tennis Serve Analysis (OTSA) tool (Myers et al., in review). The analysis method is broken down into

nine components that are associated with efficient force production responsible for

creating maximal energy and optimal ball speed with minimal energy expenditure and

joint loading.[4,6,54] The first eight components are evaluated at maximal knee flexion while

the last motion is assessed during the entire service motion. The first eight components

are defined as nodes, and represent a body position at a specific joint and have been

compiled through 3D motion analysis studies.[2,4,11,13,14,55,57,64,71] The OTSA is

accompanied by operational definitions describing both "good" and "bad" mechanics for

each of the nine nodes (Table 4.1). For this study the operational definitions for node two

and seven were altered from Chapter 3 in hopes of eliciting improved reliability.

Table 4. 1: The Observational Tennis Serve Analysis Tool

Nodes	Operational Definitions for Good Mechanics	Picture of Good Mechanics	Operational Definitions for Bad Mechanics	Picture of Bad Mechanics
1: Foot Position	Rear foot stays behind or equal to the front foot		Rear foot stays in front of front foot	
2: Knee Position	Substantial knee bend (Both knees bend > 15°)		None to minimal knee bend (both knees ≤ 15°)	
3: Counterhip Rotation	The hip on the back side is rotating away from the net		The hip on the back side is not rotating away from the net	

4: Posterior Hip Tilt & Loading	The hip on the back side is dropping towards the ground and back leg is loaded		The hip on back side is not dropping towards the ground and the back is not loaded	
5: Forward Hip Lean	The hip on the front side is not leaning forward towards the net		The hip on front side is leaning forward towards the net	
6: X-Angle	the shoulders rotate past the hips (x-angle = 30°)		The shoulders rotate too far behind the hips (x-angle > 30°)	
			The shoulders rotate a little past the hips (x-angle < 30°)	
7: Trunk Rotation	Trunk rotation around a vertical axis		No trunk rotation around a vertical axis	
8: Arm Position	Shoulder in line with the plane of scapula		**Hypercocking:** shoulder behind plane of scapula	
			Hypococking: shoulder in front of plane of scapula	
9: Composite Motion of Kinetic Chain	Uses knee flexion and back leg drive to maximize ground reaction forces that push the body upward from the cocking position into ball		Uses trunk muscles to pull the trunk and arm from cocking into ball impact	

	impact			

Procedures

The lead author led the classroom instructional rating session. Scheduling

conflicts prohibited three coaches from attending the session. Those three coaches were

given the identical training session on a different day. The training session took place in

a conference room and was comprised of an hour and fifteen minute interactive

PowerPoint presentation on the OTSA tool followed by the first rating session. The

training session included background information on the OTSA, information regarding

the significance of the analysis method, detailed rating instructions, practice rating

sessions for each individual node using picture and video examples from 17 player

videos, and a final video assessment using the OTSA to grade tennis serve mechanics.

Each coach and HCP had to receive a 75% or better on the final assessment to participate

in the rating session; all observers met the passing criteria. Observers were encouraged

to ask questions and permitted to share their decisions during the practice session. Any

disagreements between the observers were discussed until a consensus could be reached.

The first rating session lasted approximately one hour and commenced once all

observers felt confident with the instructions. The lead author individually projected 16

player videos (different from those in the instructional training session) onto a screen in

the same conference room as the training session. The videos being graded had 3 service

trials for each player; however, due to time constraints, observers were asked to grade the

first 2 service trials using a standardized scoring sheet. The scoring sheet allowed the

observers to categorize each node in a binomial format of either "good" or "bad." Each

player video was edited identically and had three different parts in order: 1) the observers

were presented with an anterior view of the service motion and prompted to evaluate

node 1 (5 second freeze frame at maximum knee bend), 2) next, from the posterior view

observers had one minute to evaluate nodes 2-8 (video was freeze framed at maximum

knee bend), and 3) from the posterior view observers had 10 seconds to evaluate the

composite motion of the kinetic chain (motion 9) while viewing a slow-motion video of

the entire serve. The rating session had the following set of rules: 1) if needed, raters

were permitted multiple viewings, and 2) they were to refrain from sharing their ratings

or making any comments. To evaluate intra-observer reliability, observers were provided

with a Universal Serial Bus (USB) drive to view the videos on their own computer.

Observers were asked to reassess the same video footage one week later (range 7-22

days) to reduce the likelihood of observers remembering their initial assessment. The

videos in the second viewing were presented in a different order from the first rating

session.

Observers in the computer-based instructional training session were provided a

USB drive. The drive included the training presentation and videos for rating sessions

one and two. The training presentation was pre-recorded using Camtasia Studio 8

(TechSmith Corporation Okemos, Michigan). Camtasia is a video-based screen

capturing software program to which the presenter can deliver and share content in mass.

The program allows for video capturing along with screen drawing, allowing for

interactive presentations. The training session included the same material as the

classroom presentation, with all observers scoring greater than 75% or higher on the final

assessment. Observers were instructed to begin the first rating session following the

training presentation. However, several of the observers did wait until the following day

to complete the first rating session. Each participant was advised to reassess the same video footage one week later (range 10-31 days).

Both groups had access to a printed document that identified the operational definitions and picture representations describing both 'good" and "bad" mechanics for all nine components associated with the OTSA during the training session, and rating sessions one and two (Table 4.1). All 33 tennis players who were video recorded and used in the training and rating protocol were verbally informed of the study and voluntarily signed an informed consent form if over the age of 18 or assent form if under the age of 18. The University of Kentucky Institutional Review Board approved this study.

Statistical Analysis
Unweighted kappa (K) coefficients were used to investigate intra-observer between day reliability for each of the nine components in both groups.[87] Intra-observer reliability was calculated between days using service trial 1 for all observers. The K from service trial 1 was reported in the final analysis as the within observer agreement between trial 1 and 2 was above 90% indicating that observers recorded nearly identical findings for Trial 1 and 2 for each node. Data was analyzed using Statistical Package SPSS version 21 [IBM Corp. Armonk, NY. USA].

Fleiss's multi-rater Kappa (K) coefficient was used to investigate inter-observer agreement for each of the nine components in both groups.   This statistic has been recommended for measuring agreement among two or more raters.[101,102] The multi-rater K from service trial 1 was used to represent the inter-observer reliability for day 1. The multi-rater K from day 2 was not reported as the kappas were similar between day 1 and

day 2 results for each node as determined by a two-sample Wald test (p>0.05). All

Fleiss multi-rater Kappas were generated using an online calculator.[103]

To determine if the intra and inter-observer kappa values were statistically

different between the two groups a two-sample Wald test was utilized. This test allows

for the comparison between the kappa values. A α level of $p < 0.05$ was considered

significant for statistical analysis.

Results
Intra-observer reliability

The average kappa values among the 16 observers were moderate and higher for 8

out of the 9 components. Node 5 generated fair agreement among the novice users

(Figure 4.2).

Figure 4.2: Intra-observer reliability for each of the nine nodes
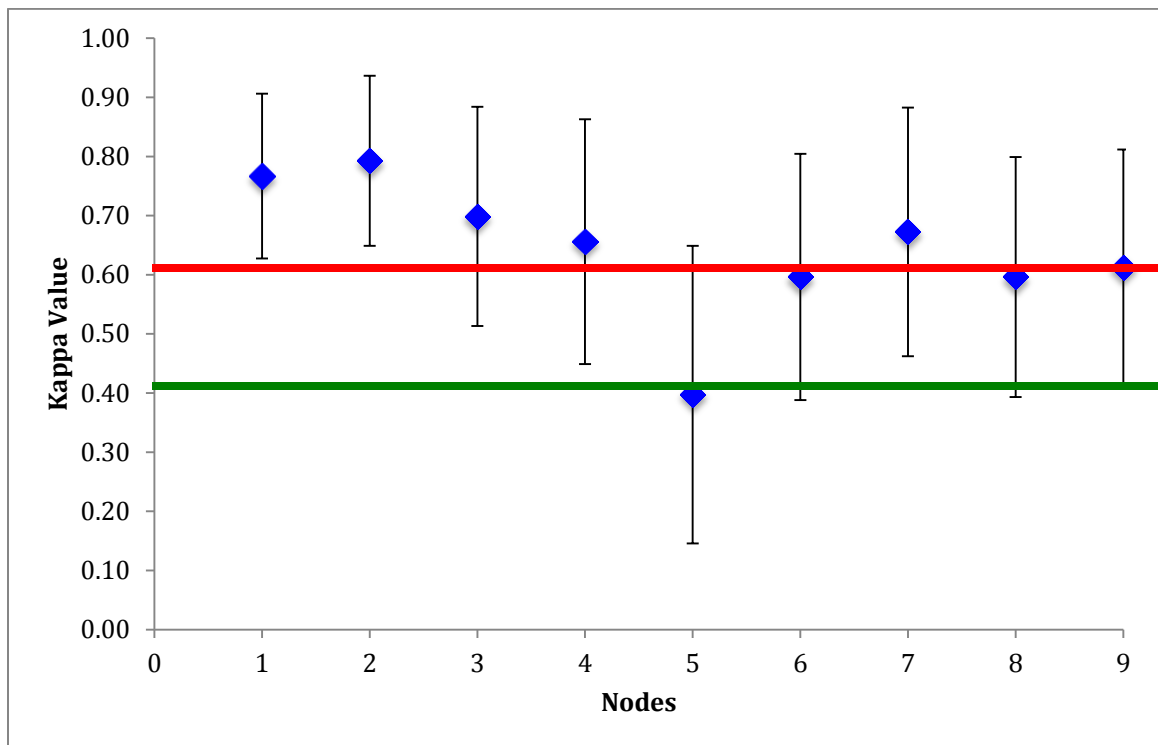
Data represents the averaged kappa ± standard error values for all 16 observers. Data
above the green line demonstrates nodes exemplifying moderate agreement. Data on or
above the red line demonstrates nodes exemplifying substantial agreement.

There were no significant differences in intra-observer kappa values between the two instructional training groups when considering all the observers, only HCPs, and only coaches (Table 4.2).

Table 4.2: HCPs and tennis coach comparisons of intra-observer reliability between two groups undergoing different forms of instructional training

Nodes	Classroom Instruction All 8 Observers	Computer Instruction All 8 Observers	P-Value	Classroom Instruction 4 HCPs	Computer Instruction 4 HCPs	P-Value	Classroom Instruction 4 Coaches	Computer Instruction 4 Coaches	P-Value
1	0.83	0.71	0.54	0.70	0.70	1.00	0.96	0.70	0.15
2	0.78	0.80	0.92	0.78	0.73	0.83	0.79	0.87	0.64
3	0.73	0.67	0.82	0.71	0.83	0.62	0.74	0.52	0.46
4	0.61	0.69	0.79	0.55	0.73	0.56	0.69	0.66	0.91
5	0.42	0.38	0.91	0.39	0.58	0.65	0.45	0.17	0.36
6	0.57	0.63	0.83	0.42	0.59	0.62	0.71	0.67	0.87
7	0.63	0.72	0.76	0.64	0.68	0.90	0.61	0.76	0.57
8	0.65	0.55	0.72	0.60	0.53	0.81	0.70	0.56	0.62
Motion 9	0.66	0.57	0.75	0.66	0.55	0.72	0.66	0.59	0.79

Data is represented using the averaged kappa coefficients between all observers, the 4 coaches, and 4 HCPS in each group for each node.

Inter-observer reliability

Multi-rater kappa values were above moderate agreement for 8 out of the 9 components between all 16 observers. Similar to the intra-observer agreement, node 5 displayed only slight agreement (Figure 4.3)

Figure 4.3: Inter-observer reliability for each of the nine nodes
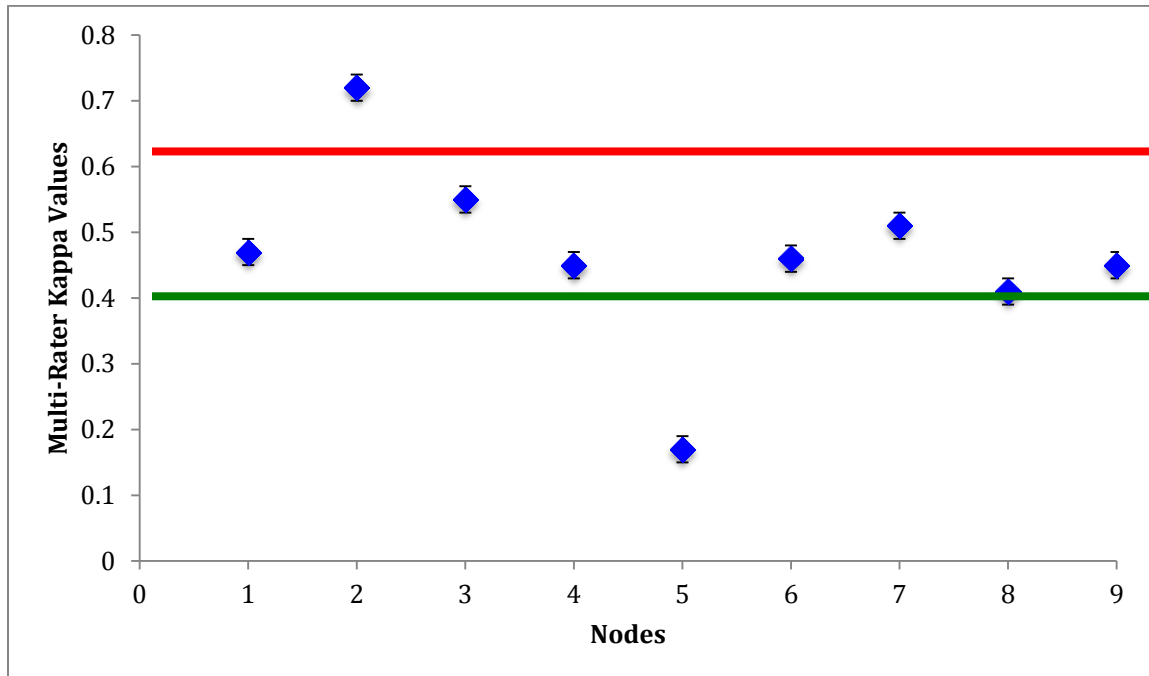
Data represents the multi-rater kappa ± standard error values among all 16 observers. Data on or above the green line demonstrates nodes exemplifying moderate agreement. Data on or above the red line demonstrates nodes exemplifying substantial agreement.

The majority of kappa values revealed no significant differences between the two groups when considering all observers, only HCPs, and only coaches. Kappa values were significantly higher in the classroom instructional group for node 7 and node 1 when considering all 8 observers and all 4 coaches, respectively when compared to the computer-based group. Kappa values were significantly higher in the computer-based group for node 5 and node 6 when considering all 8 observers and all 4 coaches, respectively when compared to the classroom instructional group (Table 4.3).

Table 4.3: HCP and tennis coach comparisons of inter-observer reliability between two groups undergoing different forms of instructional training

Nodes	Classroom Instruction All 8 Observers	Computer Instruction All 8 Observers	P-Value	Classroom Instruction 4 HCPs	Computer Instruction 4 HCPs	P-Value	Classroom Instruction 4 Coaches	Computer Instruction 4 Coaches	P-Value
1	0.65	0.46	0.11	0.52	0.45	0.62	0.93	0.39	<0.001*
2	0.72	0.74	0.72	0.79	0.66	0.36	0.67	0.77	0.48
3	0.57	0.52	0.38	0.59	0.61	0.89	0.55	0.41	0.32
4	0.47	0.42	0.38	0.51	0.27	0.08	0.37	0.56	0.18
5	0.09	0.21	0.03*	0.25	0.39	0.32	0.01	0.26	0.07
6	0.49	0.43	0.28	0.49	0.27	0.12	0.42	0.73	0.03*
7	0.62	0.41	<0.001*	0.60	0.33	0.05	0.56	0.54	0.89
8	0.43	0.40	0.60	0.37	0.37	1.00	0.48	0.37	0.44
Motion 9	0.46	0.48	0.72	0.43	0.37	0.67	0.45	0.71	0.07

Data is represented using the multi-rater kappa coefficients for each of the nodes

Discussion

  This study suggests that the majority of the nodes associated with the OTSA are reliable among a group of novice users, with intra-observer reliability yielding higher kappa coefficients than inter-observer reliability. Forward hip lean (node 5) was consistently the weakest node exemplifying poor outcomes for both intra and inter-observer reliability. Additionally, the type of instructional training does not seem to affect reliability scores.

  Intuitively, one would expect novice learners would benefit most when information is organized, and provided in a logical and relevant sequence no matter what the subject matter being taught. When information is organized into specific manageable portions, material is recalled more easily.[104] The traditional techniques used to disseminate knowledge are becoming challenged as the access to online and computer based learning is becoming universally acknowledged.[94] Several studies have demonstrated that web-based learning is equally effective to traditional lecture-based learning, and that participants are satisfied with this type of learning.[53,99,105] While there were a few significant findings between the two instructional training groups, our study is similar to previous literature as the majority of nodes yielded similar outcomes between a classroom and computer based learning environment.

  To the author's knowledge, this is the first study to investigate reliability outcomes following two different forms of instructional training specific to an observational movement pattern. Currently, the best evidence available for a similar comparison is on the technique assessment of meter-dose inhalers (MDI). Pharmacy students were evaluated pre and post intervention on their ability to assess MDI technique

using a subjective protocol.[84] Students were randomized into one of three groups: 1)

lecture group, 2) web group, or 3) control group (no intervention). Following the

educational training, a study investigator performed a pre-scripted scenario of a patient

incorrectly using a MDI. All students, regardless of group, visually observed the MDI

technique and documented any steps that were performed incorrectly. MDI technique

was based on a 12-step procedure; each step was accompanied with specific instructions.

Ultimately, web-based learning was shown to be just as effective as classroom instruction

in evaluating a mock patient exhibiting incorrect MDI technique.[84]

This study is not without its limitations. First, the sample size for each group was

relatively small and may be a reason as to why group differences were not seen within

this sample of participants. Future research should employ a larger sample of observers.

Second, there was no randomization technique employed between the two groups. Third,

the learning styles of the observers were not considered when allocating the participants

to one of the two groups. Future studies should incorporate a two-phase training module

regardless of group allocation when teaching health care providers and tennis

professionals how to evaluate serve mechanics using the OTSA.

Conclusion

Our findings suggest that the OTSA is a reliable tool among novice users and can

be taught using either a classroom or computer based module. A computer-based module

may impact health care professionals and tennis coaches around the world as this mode of

training allows for mass education. Node 5 was shown to be consistently unreliable and

should be removed from the final version of the tool, as it is difficult for HCPs and

coaches to see this movement.

Chapter 5: Validity of the Observational Tennis Serve Analysis Tool

Introduction

The serve is the most predominant stroke during the service game and is thought to be the most important shot as it initiates the start of each point.[3] An effective serve requires the generation of energy flow through the kinetic chain.[6] The quality of energy flow from the trunk to the hand has a direct relationship with upper extremity joint kinetics and serve velocity.[6] This concept has been described and examined with three-dimensional (3D) analysis;[6] however, this type of analysis is not readily available to all health care professionals (HCP) and coaches. Effective and efficient methods for assessing tennis serve mechanics on court without the presence of 3D laboratory equipment may be valuable as players train to improve serve velocity and decrease injury.

Authors have developed an observational analysis method for evaluating serve mechanics that requires two standard video recording devices. The analysis method is called the Observational Tennis Serve Analysis (OTSA) tool and is broken down into nine components. (Table 4.1) The components are associated with efficient force production responsible for creating maximal energy and optimal ball speed with minimal energy expenditure and joint loading.[4,6,54] The first eight components are evaluated at maximal knee flexion (trophy stage) while the last component is assessed during the entire service motion. The first eight components are defined as nodes, and represent a body position at a specific joint and have been compiled through 3D motion analysis studies.[2,4,11,13,14,55,57,64,71] The ninth component evaluates the composite motion of the entire service motion. The tool has been shown to have moderate to substantial inter-

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observer reliability among its creators and among a group novice users not involved in the tools development. (Chapter 3 & 4)

While this OTSA has established properties of reliability, the construct validity of the tool is still unknown. The aim of construct validation is to establish a tools relationship with one or more variables.[106] In regards to tennis, a commonly used variable to quantify skill is ranking levels. Both the International Tennis Number (ITN) and United States Tennis Association National Tennis Rating Program (USTA NTRP) rank a player based on a 6-category system (forehand, backhand, serve, volley, special shots, and playing style). The USTA NTRP is on a scale of 1.0-7.0 (7.0 representing a world class player) and is commonly used in the United States, while the ITN is on a scale of 1-10 (1 representing a world-class player) and is well known internationally. Both scales incorporate the same criteria and may be used interchangeably.[107] (Appendix A)

Several authors have investigated the relationship between joint kinetics and serve efficiency between different ranked tennis athletes.[13] Professional players (USTA NTRP 6.0-7.0) were more efficient than advanced players (USTA NTRP 4.5-5.0) as they maximized ball velocity with lower upper extremity joint kinetics.[13] As a result, Martin et al.,[13] concluded that advanced players may use improper serve technique that could overload the joint and increase the risk of injury. Since significant relationships between serve efficiency and ranking levels are being seen when using 3D motion tracking it would be reasonable to suggest that the more nodes achieved on the OTSA should be positively associated with a higher ranking level. Therefore the purposes of this study were twofold. First, we hypothesized that all the components on the OTSA would be

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able to discriminate between different high and low ranked tennis players. Second, we hypothesized that the OTSA total composite score (9 components summed together) would be positively associated with NTRP level. A positive and strong correlation between the OTSA and NTRP would provide convergent validity indicating that higher OTSA scores are correlated with higher ranked tennis players.

Methods

Participants

Thirty-nine tennis players were recruited from a sample of convenience from the local tennis community. Players were considered eligible if they participated in tennis at least once a week, had a USTA NTRP, and were not under medical care for a musculoskeletal condition that affected tennis play. Players were excluded if they had been diagnosed with a neurological disorder, or had a history of fracture or surgery within the past year. Players were categorized using the USTA NTRP and placed into one of two groups: high ranked players were considered a 5.0 or above while low ranked players were considered a 3.5 and below according to the USTA NTRP.[107] (Appendix A) Low ranked players were considered 3.5 and below as these players are still developing the service technique according to the USTA NTRP operational definitions. Players ranked as 4.0 or 4.5 are considered to have developed 1st and 2nd serves. However, there were only 4 players that possessed a ranking of 4.0 or 4.5; therefore these players were not categorized into a group due to the small sample size. Demographic data from thirty-five male and female tennis players is presented in Table 5.1.

Table 5.1: Player characteristics

	High Ranked USTA Players (n=18)	Lower Ranked USTA Players (n=17)
Sex		
Male	10	7
Female	8	10
Age*	20 ± 2 years	43 ± 14 years
Height*	179 ± 11 cm	170 ± 9 cm
Weight*	162 ± 24 lbs.	157 ± 24 lbs.
Weekly Participation*	5 ± 1 days	3 ± 1 days

Abbreviation: United States Tennis Association
*Data represented with mean ± standard deviation
cm = centimeters
lbs = pounds

Before participation players were verbally informed of the study and voluntarily read and signed an informed consent form if over the age of 18 or assent form if under the age of 18. The University of Kentucky Institutional Review Board approved the study.

Procedures

All participants underwent a standardized 10-minute warm-up period that included jogging, lower and upper extremity dynamic mobility drills, and 10 practice serves from the deuce court. Following the warm-up, players were asked to serve three flat first serves from the deuce court while being videotaped. In order to capture the service motion one digital camera (Panasonic DMC-TS25) was positioned anteriorly to the participant, 20 feet from the baseline "T" of the court at a 20° angle. A second digital

camera (Panasonic DMC-TS25) was positioned posterolateral to the participant, 14 feet

from the baseline "T" of the court at a 45° angle (Figure 5.1). (Myers et al., in review)

Figure 5. 1: Anterior and posterior camera position on tennis court

Tennis serve mechanics were assessed using the observational tennis serve

analysis (OTSA) tool. The OTSA is accompanied by operational definitions describing

both "good" and "bad" mechanics for each of the nine components (Table 5.2).

Table 5.2: The Observational Tennis Serve Analysis Tool

	Good Mechanics	Bad Mechanics
Node 1: Foot	Good: rear foot stays behind front foot	Bad: rear foot stays in front of front foot
Node 2: Knee	Good: substantial knee bend (both knees to bend greater than 15°)	Bad: none to minimal knee bend (both knees bend less than or equal to 15°
Node 3: Counterhip Rotation	Good: The hip on back side is rotating away from the net	Bad: The hip on back side is not rotating away from the net
Node 4: Posterior Hip Tilt & Loading	Good: The hip on back side is dropping towards the ground and the back leg is loaded	Bad: The hip on back side is not dropping towards the ground and the back leg is not loaded
Node 5: Forward Hip Lean	Good: The hip on front side is not leaning forward towards the net	Bad: The hip on front side is leaning forward towards the net
Node 6: X-angle	Good: x-angle describes the relationship between the shoulders and the hips and should be approximately equal to 30°	Shoulders rotate to far or don't rotate behind the hips Bad: the x-angle is greater than 30° Bad: the x-angle is less than 30°
Node 7: Trunk	Good: Trunk rotation around a vertical axis	Bad: No trunk rotation around a vertical axis
Node 8: Arm	Good: Shoulder in line with the plane of scapula	Bad: Hypercocking – shoulder behind the plane of scapula; Hypococking – shoulder in front of plane of scapula
Motion 9: Kinetic Chain	Good: Used knee flexion and back leg drive to maximize ground reaction forces that push the body upward from the cocking position into ball impact	Bad: Use trunk muscles to pull the trunk and arm from cocking into ball impact
*Note: Evaluate nodes 1-8 at maximum knee bend. Kinetic chain node to be evaluated throughout entire motion.		

Each node was graded separately as good or bad for the three service trials. To receive a "good" grading for a node, the player had to exemplify good mechanics two out of the three trials. If a node was graded as "good" a score of 1 was recorded for that particular node, whereas a 0 was recorded if a node was graded as "bad." Additionally, each player received a composite score. Taking the sum of the nodes for each player generated the composite score; therefore a score of nine represented excellent mechanics. The lead author graded all serve mechanics using the guidelines from the OTSA. One of the OTSA developers trained the lead author how to use the observational method. Training took place on three separate days for a total time of 3 hours of instruction. The lead author was exposed to a series of videos exemplifying efficient and inefficient mechanics for each of the 9 nodes. To determine intra-observer reliability, the lead author used the OTSA to evaluate 13 videos of professional tennis players serving. Videos were viewed a week apart using slow-motion and freeze-frame during maximal knee bend. Intra-observer reliability using this method is displayed in table 5.3.

Table 5.3: Intra-observer reliability within one experienced sports medicine professional evaluating 13 professional players serve videos

Node	Percentage of Observed Agreement (%)	Kappa Coefficient	95% Confidence Intervals
Node 1: Foot Position	100	1.00[a]	1.00, 1.00
Node 2: Knee Position	92	0.75[b]	0.29, 1.21
Node 3: Counterhip Rotation	92	0.63[b]	-0.07, 1.33
Node 4: Posterior Hip Tilt & Loading	92	0.75[b]	0.29, 1.21
Node 5: Forward Hip Lean	92	0.83[a]	0.51, 1.15
Node 6: X-angle	85	0.65[b]	0.20, 1.10
Node 7: Trunk Position	100	1.00[a]	1.00, 1.00
Node 8: Arm Position	92	0.75[b]	0.29, 1.21
Motion 9: Kinetic Chain	85	0.58[c]	0.05, 1.11

[a]Indicates almost perfect level of agreement
[b]Indicates substantial level of agreement
[c]Indicates moderate level of agreement

Statistical Analyses

Discriminant validity was assessed by comparing the components of the OTSA between two different tennis ranking levels.[108]   Nine separate chi-square test for independence were implemented to determine the tools discriminant capabilities.[109,110] However, in situations where more than 20% of the 2x2 contingency table cells had expected values <5, a Fisher exact test was utilized.[111]   An effect size for each significant node was determined using The Phi value (φ). A φ value of 0.1 is considered a small effect, 0.3 a medium effect, and ≥ 0.5 a large effect.[112]

Convergent validity was assessed using a Spearman Rank-Order Correlation to determine the level of association between the total composite score on the OTSA and player ranking. The Spearman-Rank is a non-parametric correlational analysis. The analysis was performed using Statistical Program for the Social Sciences (SPSS) version

21.0 (IBM Corp. Armonk, NY, USA). A α level of p < 0.05 was considered significant

for statistical analysis.

Results

Six of the nine nodes were able to discriminate between high and low ranked

players. Nodes 2 thru 4 and 6 thru 8 of the OTSA demonstrated significant relationships

with ranking level. (Table 5.4) Nodes 1 and 5, and motion 9 were unable to discriminate

between high and low ranked players, as the percentages of players exhibiting efficient or

inefficient mechanics were similar in both groups. (Table 5.4)

Table 5.4: The observed counts and percentages of high and low ranked players exhibiting both efficient and inefficient mechanics for all 9 nodes

Nodes	Efficient Mechanics		Inefficient Mechanics		P-value	ES
	High Ranked	Low Ranked	High Ranked	Low Ranked		
Node 1	12/18	14/17	6/18	3/17	0.44	-
	67%	82%	33%	18%		
Node 2	18/18	2/17	0/18	15/17	<0.001	0.89
	100%	12%	0%	88%		
Node 3	14/18	1/17	4/18	16/17	<0.001	0.73
	78%	6%	22%	94%		
Node 4	5/18	0/17	13/18	17/17	0.04*	0.40
	28%	0%	72%	100%		
Node 5	4/18	6/17	14/18	11/17	0.47*	-
	22%	35%	78%	65%		
Node 6	9/18	0/17	9/18	17/17	0.001*	0.57
	50%	0%	50%	100%		
Node 7	14/18	0/17	4/18	17/17	<0.001	0.79
	78%	0%	22%	100%		
Node 8	13/18	1/17	5/18	16/17	<0.001	0.69
	72%	6%	28%	94%		
Motion 9	5/18	1/17	13/18	16/17	0.17*	-
	28%	6%	72%	94%		

Each node is accompanied with a p-value and φ effect size (ES)
*Fisher exact test used due to violation of assumption with chi square test
Node 1 = foot position
Node 2 = knee position
Node 3 = back hip counter-rotation
Node 4 = back hip posterior tilt & load
Node 5 = forward hip lean
Node 6 = x-angle

Node 7 = trunk rotation
Node 8 = arm position
Motion 9 = composite motion of kinetic chain

There was a strong positive correlation between the composite score of the OTSA and ranking level which was statistically significant, $r_s = 0.74$, $p = 0.01$ (Figure 5.2).

Figure 5.2: Represents the strength of association between OTSA scores and USTA ranking levels for all 39 tennis players
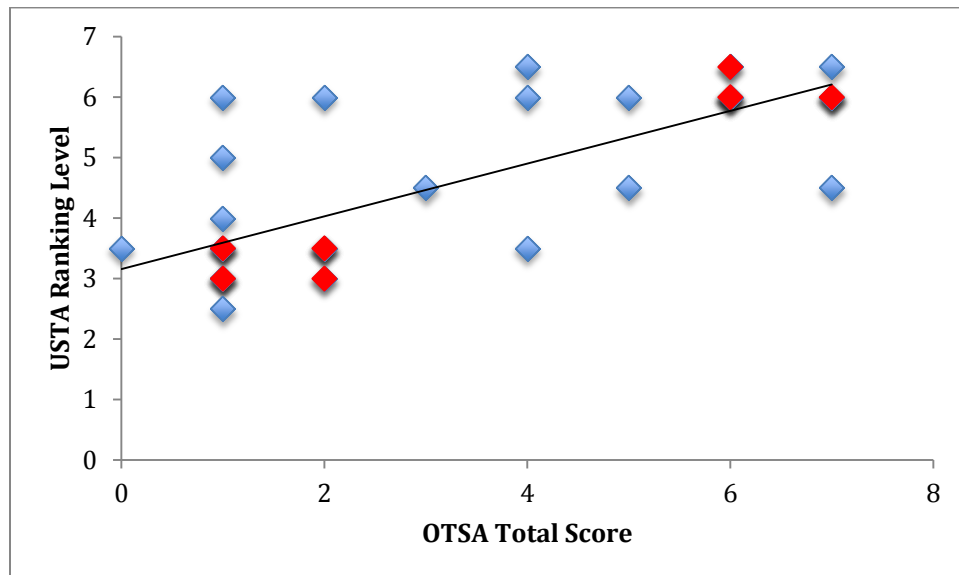
Blue diamonds represent a single player ranking and OTSA score. Red diamonds represent multiple players with the same OTSA score.

Discussion

This study aimed to determine the discriminant and convergent validity of the OTSA. A discriminative instrument (such as the OTSA) should be able to discriminate between different ranking levels.[113] It was demonstrated that several of the nodes were able to discriminate high ranked players from low ranked players; thus partially supporting our initial hypothesis. Convergent construct validity for the OTSA was supported by the strong significant relationship with the USTA NTRP, supporting our secondary hypothesis.

These data provide tennis professionals and HCPs an idea of the common mechanical errors that are seen in both high and low ranked tennis players. For example, the majority of lower ranked players in this sample did not engage the lower extremity and trunk during the early preparation phase of the service motion. Previous research has determined that the absence of distal segment contributions during the serve are detrimental to velocity and upper extremity joint integrity.[2,4,6] As such, lower ranked players may need to undergo additional training to improve serve mechanics which may positively impact performance and possibly diminish the risk of injury, especially to the upper limb. Though an appropriate training intervention has not been investigated in tennis players, Lephart et al.,[114] established an 8-week golf specific training intervention that assessed swing mechanics along with other musculoskeletal variables. The intervention was found to have positive effects on swing velocity and body position. It is reasonable to suggest that a similar intervention could potentially have a positive impact on serve mechanics.

This clinical measure for assessing serve mechanics between different ranking levels yields similar results to the laboratory findings between different skill level tennis players. The majority of the 3D biomechanical literature is specific to serve mechanics at the elite level. Several authors have suggested that proper serve technique may lead to fewer injuries and better serve efficiency in the professional levels of play. Martin et al.,,[13] found that professional players (ITN 1) were more efficient than advanced players (ITN 3 & 4) as they maximized ball velocity with lower upper extremity joint kinetics. 3D kinematic analysis has also revealed that non-injured players rotated the pelvis and trunk earlier in the service motion resulting in reduced joint kinetics and higher ball

velocities compared to injured players.[2] Additionally, injured players left the arm in horizontal abduction for too long during the cocking phase compared to non-injuries players.[2] All but one of the non-injured players in Martin et al.,[2] study had a player ITN ranking of 1 (professional status) while more than 50% of the players in the injured group had a ITN of 3 or 4 (advanced status). Consequently, advanced players seem to demonstrate mechanical flaws within the service motion putting them at risk for potentially damaging loads.[13]

There were three nodes of the OTSA that did not discriminate between ranking levels. Most of the players in this sample demonstrated forward hip lean (node 5). This may be due to the uneven distribution of force transfer between the legs prior to push off. If more force is generated through the front leg, it may cause the front hip to protrude towards the net, resulting in misaligned and inefficient mechanics throughout the rest of the kinetic chain segments. On the contrary, forward hip lean may be corrected if more force transfer is generated through the back leg, as authors have suggested that utilizing back leg drive is the basis for proper motion and subsequent acceleration.[73] The kinetic chain position did not discriminate between ranking level. High ranked players are more likely to use the entire kinetic chain during the service motion than low ranked players; however, the data within this sample suggests that the majority of players do not use the chain as efficiently as they could. Lastly, foot position was correctly demonstrated in the majority of players. While it did not discriminate it is still an important node as it is the key starting position for the rest of the service motion. This finding is critical; as the authors believe that incorrect foot position will produce a ripple effect of inefficient mechanical positioning throughout the kinetic chain. In fact, the majority of players that

did not demonstrate good foot position were unable to appropriately rotate the back hip and trunk away from the net during the preparation phase of the motion.

This study is not without its limitations. First, this study did not investigate the mechanical trends within a player categorized as a 4.0 or a 4.5 on the USTA NTRP. Future research should be done to investigate if the OTSA is sensitive enough to discriminate between smaller windows of players if an adequate number of subjects are obtained. Ability to discriminate between a single level would represent a very sensitive instrument. Second, this study examined the discriminant validity that each individual node on ranking level, but this study did not examine combinations of nodes. Future research examining which combination of nodes are necessary to best predict ranking levels, serve velocity, and serve accuracy need to be investigated. Third, the USTA NTRP was used to validate the OTSA and is commonly used in order to rank USTA players, but to our current knowledge the NTRP has not been validated. Other validated measures such as 3D kinematics should be used to validate the OTSA further. Future research examining the tool's criterion validity are needed to fully account for the OTSA tool's accuracy in assessing tennis serve mechanics.

Conclusion

This study investigated the discriminant and convergent validity of nine components associated with the OTSA, and was the first to evaluate tennis serve mechanics among different skill level tennis players using a field-based tool. Given the results, the majority of the nodes were able to discriminate between ranking level. Low ranked players exhibited more mechanical deficits within the lower extremity and trunk than high ranked players. If not addressed these deficits could have future implications on performance and injury risk.

Chapter 6: Summary

The first purpose of this dissertation was to determine the inter-observer reliability for each node between the two health care professionals that helped to create the observational tennis serve analysis (OTSA) tool. The second purpose was to determine the intra and inter-observer reliability of the OTSA in a group of coaches and health care professionals undergoing two different forms of instructional training. The third purpose of this project was to investigate the discriminant and convergent validity of the OTSA.

Hypotheses and Findings for Specific Aim 1

Hypothesis 1: The inter-observer reliability will be moderate ($\geq$0.41) or higher for the majority of the nine components associated with the OSTA.

Finding: This hypothesis was accepted, as results show moderate to almost perfect inter-observer reliability in 8 out of the 9 nodes.

Hypotheses and Findings for Specific Aim 2

Hypothesis 1: The reliability of all novice users (coaches and HCPs) will be moderate ($\geq$0.41) or higher for the majority of the nine components associated with the OSTA

Finding: This hypothesis was accepted, as results showed moderate to substantial intra and inter-observer reliability in 8 out of the 9 nodes.

Hypothesis 2: The reliability results will be equal among the novice participants receiving computer-based instruction and classroom instruction for all nine components associated with the OTSA.

Finding$_1$: This hypothesis was fully supported, as there were no statistical differences in the intra-observer reliability values between the two instructional training groups when considering all the observers, only HCPs, and only coaches.

Finding$_2$: This hypothesis was partially supported, as inter-observer kappa values for nodes 7 and 1 were significantly higher in the classroom instructional group compared to the computer-based group when considering all 8 observers and all 4 coaches, respectively. Kappa values were significantly higher in the computer-based group for node 5 and node 6 when considering all 8 observers and all 4 coaches, respectively when compared to the classroom instructional group.

Hypotheses and Findings for Specific Aim 3

Hypothesis 1: Nine components associated with the OTSA will be able to discriminate between high and low ranked tennis athletes as categorized by the United Stated Tennis Association National Tennis Rating Program (USTA NTRP).

Finding: This hypothesis was partially supported as node 2 thru 4 and 6 thru 8 were associated with ranking level, and were able to discriminate between those ranked high and low.

Hypothesis 2: The total composite score (9 components summed together) of the OTSA will be positively associated with USTA NTRP ranking level.

Finding: There was a strong positive correlation between OTSA and ranking level, which was statistically significant supporting OTSA convergent validity with the NTRP

Synthesis and Application of Results

The overall purpose of this dissertation was to determine the reliability and validity of a field-based observational assessment used to assess tennis serve mechanics.

It was determined that the majority of the components associated with the observational tennis serve analysis (OTSA) tool were reliable and valid. The most important findings were that the OTSA was reliable amongst a group of novice users unfamiliar with the OTSA method of assessment, and that the OTSA can be successfully taught during a traditional classroom or computer based setting. These results would seem to indicate that health care providers and tennis professionals are able to consistently agree on specific body positions during the preparation phase of the tennis serve following a standardized training session.

To determine the validation of the OTSA, both discriminant and convergent validity were assessed. Six out of the nine nodes were able to discriminate between high and low ranked tennis players. Additionally, there was a strong correlation between the OTSA and the USTA NTRP, indicating that there is convergent validity and supports the construct of the OTSA as deficits in the service motion are associated with ranking of tennis players. Before we can definitively conclude that these six nodes are the best discriminators of ranking level, a larger sample and variation of players should be recruited. It is currently unknown if the nodes on the OTSA are sensitive enough to detect changes in players who demonstrate closer rankings on the USTA NTRP; for example, differences between players categorized as 4.0-5.0 and 5.5-7.0.

The results of these dissertation studies warrant consideration for reducing the nodes associated with the OTSA. Forward hip lean (node 5) was consistently the weakest node throughout all three studies within this dissertation. Reliability results were poor among the creators and novice users, and the node was unable to discriminate between high and low ranked players. Furthermore, after additional consideration it was

determined that a player demonstrating a good x-angle (node 6) will inevitably demonstrate good trunk rotation (node 7). In fact, in a random sample of 6 observers these two nodes had a strong positive point-biserial (pb) correlation (range $r_{pb} = 0.62 - 0.83$ P=0.01). Thus, it may be reasonable to suggest that only one of these two should remain as a node. While both nodes were able to discriminate between ranking levels intra and inter-observer reliability were consistently higher for node 7. Observers demonstrated a higher level of agreement when evaluating node 7 compared to node 6. Consequently, the OTSA should likely only retain 7 nodes instead of 9 during future research (Appendix B). This would further simplify the OTSA and make it more user friendly likely without affecting reliability or validity of the system.

The findings of these studies have several clinical implications. First, this tool provides health care providers and tennis professionals with an assessment tool used to detect body positions essential for superior serve performance while also minimizing joint load to the upper extremity and trunk. Second, the OTSA is portable, cost-effective, and can be used on-court without the presence of expensive laboratory equipment.

In conclusion, the studies in this dissertation provide insight into how a tennis serve can be assessed using an observational field-based method. In chapters 3 and 4, the methodological utility of using the OTSA tool to evaluate serve mechanics was confirmed by demonstrating good reliability for the majority of all nodes. The results of Chapter 4 also indicate that multiple teaching strategists can be employed for teaching users how to use the OTSA when evaluating serve mechanics. While a majority of the nodes associated with the OTSA were reliable, the OTSA also demonstrated both discriminant and convergent validity as confirmed in Chapter 5. Future research should

determine if there is a relationship between the nodes on the OTSA and musculoskeletal

function, serve performance, and trunk or upper extremity injury.   Additionally,

researchers should explore if a comprehensive intervention program could positively

impact serve mechanics.

Appendices

Appendix A: Criteria Rankings for the International Tennis Number and United States Tennis Association National Tennis Rating Program

ITN	USTA NTRP	Forehand (FH)	Backhand (BH)	Serve or Return of Serve	Volley	Special Shots	Playing Style
10.1 10.3	1.0	The player is just starting to play tennis					
10	1.5	The player has limited experience and is still working primarily on getting the ball into play					
9	2.0	Incomplete swing, lacks directional intent	Avoid BH, erratic contact, grip problems, incomplete swing	Incomplete service motion; double faults common; toss is inconsistent, return of serve erratic	Reluctant to play net; avoids BH; lacks footwork		Familiar with basic positions for singles & doubles; frequently out of position
8	2.5	Form developing; prepared for moderately paced shots	Grip and preparation problems; often chooses to hit FH instead of BH	Attempting a full swing; can get the ball I play at slow pace; inconsistent toss; can return slow-paces serve	Uncomfortable at net, especially on the BH side; frequently used FH racquet face on BH volleys	Can lob intentionally but with little control; can make contact on overheads	Can sustain a short rally of slow pace; modest consistency; weak court coverage; usually remains in the initial doubles position
7	3.0	Fairly consistent	Frequently prepared;	Developing rhythm; little	Consistent FH volley;	Can lob fairly consistently	Fairly consistent on
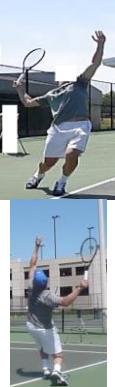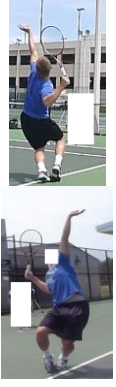
		with some directional intent; lacks depth control	starting to hit with fair consistency on moderate shots	consistency when trying for power; 2nd serve is often considerably slower than 1st serve; can return serve with fair consistency	inconsistent BH volley; has trouble with low and wide shots	on moderate shots	medium-paces shots; most common doubles formation is still one up, one back; approaches net when play dictates by weak in execution
6	3.5	Improved consistency & variety on moderate shots with directional control; developing spin	Hits with directional control on moderate shots; has difficulty on high or hard shots; returns difficult shots defensively	Starting to serve with poster; developing spin; can return serve consistently with directional control on moderate shots	More aggressive net play; some ability to cover side shots; uses proper footwork; can direct FH volleys; controls BH volley but with little offense; difficulty in putting volleys away	Consistent overhead on shots within reach; developing approach shots, drop shots, and half volleys	Improved consistency of moderate shots with directional control; improves court coverage; starting to look for the opportunity to come to the net; developing teamwork in doubles
5	4.0	Good consistency;	Directs the ball with	Places both 1st and 2nd serves,	Depth and control on FH	Can put away easy	Good consistency

		hits with depth and control on moderate shots; may try to hit too good a placement on a difficult shot	consistency and depth on moderate shots; developing spin	often with power on first serve; uses spin; dependable return of serve; can return with depth in singles and mix returns in doubles	volley; can direct BH volleys but usually lacks depth; developing wide and low volleys on both sides of the body	overheads; can poach in doubles; follows aggressive shots to the net; beginning to finish point off; can hit to opponent's weaknesses; able to lob defensively on difficult shots and offensively on set-ups	on ground strokes with directional control and depth demonstrated on moderate shots; not yet playing good percentage tennis; teamwork in doubles is evident; rallies may still be lost due to impatience
4	4.5	Very good consistency; uses speed and spin effectively; controls depth well; tends to over-hit on difficult shots; offensive on moderate	Can control direction and depth but may break down under pressure; offensive on moderate shots	Aggressive serving with limited double faults; uses power and spin; developing offense; on 2nd serve frequently hits with good	Can handle a mixed sequence of volleys; good footwork; has depth and directional control on BH; developing touch; most common error is	Hits approach shots with good depth and control; can consistently hit volleys and over- heads to end the point	Very good consistency; more intentional variety in game; is hitting with more pace; covers up weaknesses well; begin-

		shots		depth and placement; frequently hits aggressive service returns; can take pace off with moderate success in doubles	still over hitting		ning to vary game plan according to opponent; aggressive net play is common in doubles; good anticipation; beginning to handle pace
3	5.0	Strong shots with control, depth, and spin; uses FH to set up offensive situations; has developed good touch; consistent on passing shots	Can use BH as an aggressive shot with good consistency; has good direction and depth on most shots; varies spin	Serve is placed effectively with intent of hitting to a weakness or developing an offensive situation; has a variety of serves to rely on; good depth, spin, and placement on most 2nd serves to force weak return or set up next shot; can mix	Can hit most volleys with depth, pace and direction; plays difficult volleys with depth; given an opportunity volley is often hit for a winner	Approach shots and passing shots are hit with pace and high degree of effectiveness; can lob offensively; overhead can be hit from any position; hits mid-court volleys with consistency	Frequently has an out-standing shot, consistency, or attribute around which game is built; can vary game plan according to opponent; this player is "match wise," plays percentage tennis and "beats himself or herself" less than the

			aggressive and off-paced service returns with control, depth, and spin			4.5 player; solid teamwork in doubles is evident; game breaks down mentally and physically more often than the 5.5 player
2	5.5	This player is capable of hitting dependable shots in stress situations; has developed good anticipation; can pick up cues from such things as opponent's toss, body position, backswing, preparation; 1st and 2nd serves can be depended on in stress situations and can be hit offensively at any time; can analyze and exploit opponent's weaknesses; can vary strategies and style of play in a competitive situation.			
1	6.0 – 7.0	The 6.0 player typically has had intensive training for national tournament competition at the junior level and collegiate levels and has obtained a sectional and/or national ranking. The 6.5 player has a reasonable chance of succeeding at the 7.0 level and has extensive satellite tournament experience. The 7.0 is a world-class player who is committed to tournament competition on the international level and whose major source of income is tournament prize winnings.			

Appendix B: Observational Tennis Serve Analysis Tool

Nodes	Operational Definitions for Good Mechanics	Picture of Good Mechanics	Operational Definitions for Bad Mechanics	Picture of Bad Mechanics
1: Foot Position	Rear foot stays behind or equal to the front foot		Rear foot stays in front of front foot	
2: Knee Position	Substantial knee bend (Both knees bend > 15°)		None to minimal knee bend (both knees ≤ 15°)	
3: Counterhip Rotation	The hip on the back side is rotating away from the net		The hip on the back side is not rotating away from the net	
4: Posterior Hip Tilt & Loading	The hip on the back side is dropping towards the ground and back leg is loaded		The hip on back side is not dropping towards the ground and the back is not loaded	
5: Trunk Rotation	Trunk rotation around a vertical axis		No trunk rotation around a vertical axis	
6: Arm Position	Shoulder in line with the plane of scapula		**Hypercocking:** shoulder behind plane of scapula	

				Hypococking: shoulder in front of plane of scapula	
Motion 7: Composite Motion of Kinetic Chain	Uses knee flexion and back leg drive to maximize ground reaction forces that push the body upward from the cocking position into ball impact			Uses trunk muscles to pull the trunk and arm from cocking into ball impact	

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<div align="center">**Vita**

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<u>*Education*</u>
Doctor of Philosophy, Rehabilitation Sciences, University of Kentucky, Lexington, KY
(Anticipated Graduation Date: May 2017)
Graduate Certificate in College Teaching & Learning, University of Kentucky,
Lexington, KY
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Master of Science in Athletic Training, California University of Pennsylvania,
California, PA
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Bachelor of Science in Athletic Training, Elon University, Elon, NC
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<u>*Work Experience*</u>
Fall 2015   **Adjunct Professor,** Eastern Kentucky University, Richmond, KY
                     PHE 212 Care & Prevention of Athletic Injury
                     ATR 201 Clinical Lab Preceptor

Spring 2015   **Teaching Assistant,** University of Kentucky, Lexington, KY
                     AT 690 Orthopaedic Evaluation & Rehabilitation of the Upper

Extremity

Aug. 2009-May 2013 **Lecturer,** The University of North Carolina, Pembroke, NC
                     ATH/L 3050 Therapeutic Exercise Lecture & Lab
                     ATH 1040 Introduction to Athletic Training
                     PED 3480 Kinesiology
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                     ATH 2010 Clinical Education II
                     PED 3490 Anatomy and Physiology

Aug 2009–May 2013   **Assistant Athletic Trainer/Clinical Preceptor,** UNC-Pembroke,
                     Pembroke, NC
                     Served as an athletic trainer for Wrestling, Softball, Cross Country,
                     and Men's & Women's Golf; responsible for athletic training
                     inventory

Aug 2008-May 2009   **Graduate Assistant Athletic Trainer/Clinical Preceptor,**
                     California University of Pennsylvania, California, PA
                     Served as an athletic trainer for Women's Soccer and Softball

Professional Development
Publications: Peer Reviewed Journals

Oct 2016   Kibler WB, Cunningham TJ, **Myers NL**, Uhl TL. *Do Scapular Kinematics Alter During the Performance of the Scapular Assistance Test and Scapular Retraction Test: A Pilot Study:* JSM Anatomy & Physiology.1(1): 1-8, 2016.

July 2016   **Myers NL**, Sciascia AD, Kibler WB, Uhl TL. *Development of a Volume-Based Interval Training Program for Elite Level Tennis Players*: Sports Health. EPub. Acceptance Date July 1, 2016 DOI: 10.1177/1941738116657074.

June 2016   **Myers NL,** Capilouto GJ. *A Model for Rehabilitation Adherence in Athletes Demonstrating Different Attachment Styles*: International Journal of Athletic Therapy & Training. 12(4): 12-17, 2016.

April 2016   Moore-Reed SD, Kibler WB, **Myers NL**, Smith B. *Acute Changes in Passive Glenohumeral Rotation Following Tennis Play Exposure in Elite Female Players*: International Journal of Sports Physical Therapy. 11(2): 230-236, 2016.

Dec 2015   **Myers NL**, Toonstra JT, Smith JS, Padgett CA, Uhl TL. *Sustained Isometric Shoulder Contraction on Muscular Strength and Endurance: A Randomized Clinical Trail*. International Journal of Sport Physical Therapy. 10(7): 1-11, 2015.

Oct 2015   **Myers NL,** Sciascia AD, Westgate P, Kibler WB, Uhl TL. *Increasing Ball Velocity in the Overhead Athlete: A Meta-Analysis of Randomized Controlled Trials:* Journal of Strength and Conditioning Research. 29(10): 2964-79, 2015.

July 2015   Sciascia AD, **Myers NL**, Kibler WB, Uhl TL. *Return to pre-injury levels of play following arthroscopic labral repair in overhead athletes***,** Journal of Athletic Training 50(7): 767-777, 2015

In Review   **Myers NL**, Kibler WB, Lamborn L, Smith BJ, English T, Jacobs C, Uhl TL. *Validity and Reliability of a Biomechanically Based Analysis Method for the Tennis Serve.*

In Progress   **Myers NL,** Kibler WB, Westgate PM, Smith BJ, Uhl TL. *The Impact of Court Surface and Ranking Level on Serve Volume in Women's Professional Tennis Players.*

Publications: Non-Peer Reviewed Journals

In Press   Myers NL**, Kibler WB, Uhl TL.** *Serve Volume: How Important is it?*
                  TennisPro Magazine

Sept 2015   Myers NL**, Kibler WB.** *Let Your Body do the Work: The Tennis Serve*
                  Nodes. Physically Speaking: WTA Sports Science Education Program.
                  Page 6-7: 2015

Publications: Books & Chapters

In Review   Kibler WB, **Myers NL**, Scapulothoracic Evaluation & Treatment in
                  Tennis Players, Tennis Medicine: A Complete Guide to Evaluation,
                  Treatment, and Rehabilitation.

In Review   Kibler WB, **Myers NL**, Core Stability in Tennis Players, Tennis
                  Medicine: A Complete Guide to Evaluation, Treatment, and
                  Rehabilitation.

In Review   Kibler WB, **Myers NL**, Pathophysiology of Tennis Injuries: The Kinetic
                  Chain, Tennis Medicine: A Complete Guide to Evaluation, Treatment, and
                  Rehabilitation.

In Review   Uhl TL, **Myers NL,** Total Shoulder Arthroplasty, In Placzek JD, Boyce
                  DA (eds) Orthopaedic Physical Therapy Secrets. (3rd) Elsevier,
                  Philadelphia, 2015

In Review   Uhl TL, **Myers NL,** Scapulothoracic Pathology, In Placzek JD, Boyce
                  DA (eds) Orthopaedic Physical Therapy Secrets. (3rd) Elsevier,
                  Philadelphia, 2015

Presentations: Abstracts

June 2016   **Myers NL,** Sciascia AD, Kibler WB, Uhl TL. *Development of a Volume-*
                  Based Interval Training Program for Elite Level Tennis Players,
                  Baltimore, MD
                  Free communication poster presentation. National Athletic Trainers'
                  Association Convention

June 2016   Lamborn L, **Myers NL,** English T, Jacobs C, Kibler WB, Uhl TL: Trunk
                  Performance in players with Good and Poor Serve Mechanics, Baltimore,
                  MD (presented by Leah Lamborn) Free communication oral presentation.
                  National Athletic Trainers' Association Convention

| June 2015 | **Myers NL**, Padgett CA, Smith JS, Toonstra JT, Butterfield TA, Uhl TL: Effects of Sustained Muscle Contraction on Shoulder Muscle Endurance, Baltimore, MD
Free communication oral presentation. National Athletic Trainers' Association Convention |

Presentations: International

March 2017	**Keep serving till the basket is empty! When does load become overload in teenage shoulders?** Monte-Carlo, Monaco Will present at the IOC World Conference on Prevention of Injury & Illness in Sport
May 2015	**Increasing Serve Velocity in Tennis Players.** Rome, Italy Lecture presented at The Society of Tennis Medicine & Science World Congress
May 2015	**The Effect of Tennis Play on Glenohumeral Rotation in Female Athletes.** Rome, Italy Lecture presented at The Society of Tennis Medicine & Science World Congress

Presentations: National

Dec 2017	**Development of a Volume-Based Stroke Interval Training for Elite Level Tennis Players**. Amelia Island, FL Lecture presented at The Society of Tennis Medicine & Science World Congress
Dec 2017	**Trunk Performance in players with Good and Poor Serve Mechanics.** Amelia Island, FL Lecture presented at The Society of Tennis Medicine & Science World Congress
June 2016	**Development of a Volume-Based Stroke Interval Training for Elite Level Tennis Players**. Baltimore, MD Poster presentation at The National Athletic Trainers' Association Convention
June 2015	**Training & Performance: Increasing Ball Velocity in the Overhead Athlete,** St. Louis, MI Lecture presented at The National Athletic Trainers' Association Convention (Mini-Course)

June 2015	**Effect of Sustained Muscle Contraction on Shoulder Muscle Endurance,** St. Louis, MI
	Lecture presented at The National Athletic Trainers' Association Convention

June 2015	**Establishing a Movement Profile: Science to Practice,** St Louis, MI
	Learning Lab Assistant at The National Athletic Trainers' Association Convention

June 2010	**The Relationship Between the Amount of Educational Training & Utilization of Joint Mobilization Implemented by the Certified Athletic Trainer,** Philadelphia, PA
	Poster Presentation at The National Athletic Trainers' Association Convention

Presentations: State/Regional

April 2016	**Development of a Volume-Based Stroke Interval Training for Elite Level Tennis Players,** Lexington, KY
	Poster presentation at Center for Clinical & Translational Science Conference

March 2015	**Increasing Ball Velocity in the Overhead Athlete: A Meta-Analysis of Randomized Control Trials,** Atlanta, GA
	Lecture presented at The Southeastern Athletic Trainers' Association

Sept2014	**Increasing Ball Velocity in the Overhead Athlete: A Meta-Analysis of Randomized Control Trials,** Lexington, KY
	Lecture presented at Kentucky Physical Therapy Association

March 2014	**The Effect of Tennis Play on Glenohumeral Rotation in Female Athletes,** Lexington, KY
	Poster presentation at Center for Clinical & Translational Science Conference

External Funding
Work for Hire

Nov 2016	**Stroke Volume during Practice & Tournament Play in Junior Elite Tennis Players**
	United States Tennis Association
	Investigators: **Myers NL,** Kibler WB, Uhl TL
	Amount: &10,000.00

October 2014	**Serve Volume in Professional & Junior Elite Tennis Players**

United States Tennis Association
Investigators: **Myers NL**, Sciascia AD, Kibler WB, Uhl TL
Amount: $9,585.00

Mentorship

Fall 2016-Spring 2017	Lexi Axtell Undergraduate Research Student
Fall 2015-Spring 2017	Gabby Sombelon ATC Thesis Title: Relationship Between Upper Extremity and Trunk Injury and Tennis Serve Volume
Fall 2014-Spring 2016	Leah Lamborn MS, ATC Thesis Title: Lower Extremity and Trunk Performance in Players with Good and Poor Serve Mechanics

Certifications

June 2008-present	National Athletic Trainers' Association Board of Certification: Certification #060802070 Kentucky Licensed Athletic Trainer, License #AT1087 National Provider Number: 1861886616
March 2009-present	NASM Performance Enhancement Specialist: Certification #1352609
August 2016-2018	American Heart Association Basic Life Support (CPR/AED)

Peer Reviewer Assignments
Peer Reviewer: Clinical Journal of Sports Medicine – March 2016
Peer Reviewer: International Journal of Sports Physical Therapy – Summer 2015, April 2016, July 2016
Peer Reviewer: Journal of Athletic Training – October 2015
Peer Reviewer: Journal of Sports Rehabilitation – January 2015, September 2015

Organizations
National Athletic Trainers' Association – 2008 to present
Southeastern Athletic Trainers' Association – 2013 – present
Kentucky Athletic Trainers' Society – 2013 - present

Honors
Patty and Chuck Kimmel Scholarship – Summer 2014
Rhodes-Ford Sports Medicine Scholarship – Fall 2006 and Spring 2008
Most Valuable Athletic Training Student – Fall 2007 and Spring 2008

Service
Habitat for Humanity ReStore, Lexington, KY – Spring 2016

Crave Food & Music Festival, Lexington, KY – Summer 2015
Salvation Army Angel Tree, Lexington, KY – Winter 2014
Special Olympics Winter Games (Athletic Trainer), Johnstown, PA – Winter 2009
UNC – Pembroke Committee on Substance Abuse Prevention, Pembroke, NC – Fall
2011 - Spring 2013