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coaching & sport science review

The official coaching and sports science publication of the International Tennis Federation

editorial

Welcome to issue 24 of the ITF Coaching & Sport Science Review – the second issue of 2001.

This issue is dedicated to the biomechanics of tennis stroke and movement production. We have asked some of the world's leading sports, but more particularly tennis-specific, biomechanists to contribute to this issue in an attempt to update our knowledge in this very important area. We hope tennis coaches, trainers and players alike find this issue of interest and to the benefit of their coaching, training and/or playing of tennis. If you have other topics that you would like covered in future monographic issues please feel free to suggest them.

The 12th ITF Worldwide Coaches Workshop will be held in conjunction with the LTA of Thailand at the Intercontinental Hotel, in Bangkok, Thailand from Sunday, October 28 to Thursday, November 1, 2001. It will be the first time that this educational forum is held in Asia. We are pleased that Thai Airlines have agreed to support the workshop and that participants will be able to receive a 75% discount off their normal ticket prices. Please look inside for more information including the tentative programme. We hope to see you there!

The ITF has recently published the Spanish and French versions of the "ITF Competition Formats Manual". These are now available for purchase on the ITF website www.itftennis.com. We will shortly be publishing in English a booklet entitled "The Tennis Volunteer" in commemoration of 2001 being the Olympic Committee's International Year of the Volunteer.

In this issue we are again including details of the new system for subscribing to the ITF Coaching & Sport Science Review. Please note that subscriptions are accepted at anytime. Subscribers taking their subscription part way through the year will receive the back issues from the beginning of the year in question and the appropriate amount of future issues.

Juan Carlos Ferrero participating in an ITF Biomechanics Investigation.

We hope that the articles in ITF Coaching & Sport Science Review continue to generate considerable discussion among coaches worldwide and with the addition of the link to the ITF Coaching & Sport Science Review in the "Coaches News" section of the ITF website, www.itftennis.com, this information is becoming increasingly accessible. We continue to welcome your comments on any of the articles published, and if of interest, they too may be published. Similarly, if you have any material that you think relevant and worthy of inclusion in a future issue, please forward it to us for consideration.

We would like to thank all the experts who have contributed articles for this issue of ITF Coaching & Sport Science Review and extend a special thanks to Professor Bruce Elliott, Head of the Department of Human Movement and Exercise Science of the University of Western Australia, and Machar Reid, ITF Development Assistant Research Officer, for their efforts in the compilation of this issue.

We hope you enjoy our 24th issue.

Dave Miley
Executive Director, Tennis Development

Miguel Crespo
Research Officer, Development

contents

biomechanics and stroke production: implications for the tennis coach

By Bruce Elliott, Professor and Head of the Department of Human Movement and Exercise Science
The University of Western Australia, Australia

SUCCESSFUL tennis performance requires a mix of player talent and player development. This development requires a coach to understand those aspects of sport science pertinent to tennis if a player is to ever reach an optimal level of performance. This introductory article briefly explains the role **sport psychology** (mental aspects) **and exercise physiology** (fitness**)** play in tennis development, before outlining in more detail the role of **biomechanics** in stroke production**.** However, the article is primarily aimed at setting the scene for an understanding of the biomechanics of stroke production.

The importance of **sport psychology,** particularly mental skills training, in tennis performance is well accepted. While this is clearly acknowledged at the elite level, it should also play an integral role in player development from a young age. The following topics are just some that must be integrated into a program (both on- and off-court) for player development.

- visualisation – imagery
- concentration – attention
- relaxation strategies
- stress management

The training of perceptual motor skills is also important in the preparation of tennis players and therefore cuing (perception), a key mental skill, must be taught from a relatively young age.

Exercise physiology also plays an integral role in player development, particularly from adolescence onwards. Tennis specific aerobic and anaerobic training (including periodisation of these attributes such that improvement not overtraining is achieved) is essential for player development. The role of plyometric training, a good diet and appropriate fluid replacement strategies should also be incorporated into player development. Strength/endurance/ power training, along with flexibility training, must also be planned if a player is going to be given the best opportunity to succeed. While much of this training can be performed on-court, it is also important that off-court training is fully integrated into any program.

Biomechanics is a key area in coach education and player development because all tennis strokes have a fundamental mechanical structure. Successful achievement of each stroke is greatly affected by the technique the player employs. When developing stroke production an individualised model for performance must then be structured with due consideration to the key mechanical features of each skill, while considering the flair and physical characteristics of a player. The coach, who **understands the key mechanical features** of a stroke, **can analyse movement** and **communicate**, will provide the best opportunity for optimal player development. This coach will also provide a player with the best opportunity to play the game with **minimal risk of injury.**

Coaches often challenge athletes to change technique, in order to increase racket and consequently ball speed. An appreciation of the first 3 of these 5 factors is essential prior to reading the individual articles on each stroke.

Developing Power Strokes in Tennis

The Use of Coordinated Movements: There are two major strategies of coordination used in tennis. In strokes where power is required (such as the service and groundstrokes) a number of body segments must be coordinated in such a way that a high racket-speed is generated at impact. Where precision is needed, you reduce the number of segments and move segments more as a unit (such as the volley at the net). This concept is generally introduced to the coach as the "kinematic chain". While this is a logical way to view how racket-speed is generated it is better to appreciate that a **flow of movements from the ground, via the trunk to the racket-arm** is required for effective stroke production. Remember that to remove an action from this chain (e.g. the rotation of the shoulders in the serve) may hinder flow while also reducing the number of segments used to generate racket-speed (see use of segments below).

Francisco Clavet viewing footage of his serve.

Distance and the Development of Racket-Speed: One of the main reasons for having a backswing is to increase the distance over which speed can be developed during the forward swing. In groundstrokes it was commonly taught that "the racket should be pointed at the back fence", whereas today advanced players frequently rotate the racket 45° beyond this point for the forehand and 90° beyond this point ("parallel with back fence") for a backhand groundstroke.

The tendency to keep the racket behind, yet away from the back in the service action is further evidence of players increasing the distance of the forward swing to impact. This increased backswing also links to the storage of elastic energy and pre-tensing of muscles as discussed below.

The Use Of Elastic Energy/Muscle Pre-tension: In a stretch-shorten-cycle movement elastic energy stored during the eccentric phase of the action (the stretch in the backswing) is partially recovered such that the forward swing phase (muscles shortening) is enhanced. This is also supported by the fact that the forward swing begins with the appropriate muscles on-stretch. Research has shown that the benefit to performance from these two factors is critical to success in sports such as tennis. Examples from selected strokes are:

Service: The stretch of the shoulder muscles is maximised by a vigorous "leg-drive" that is combined with the effects of gravity and the inertia of the racket. The off-centre "leg-drive" also helps to rotate the trunk forward (flexion, shoulder-over-shoulder and rotation) in preparation for impact.

Groundstrokes: Rotation of the shoulders greater than the hips and the positioning of the upper limb relative to the trunk during the backswing phase of these strokes, places appropriate muscles on stretch. In the backhand groundstroke this is why the racket is rotated such that it is parallel to the baseline (rotated through approximately 270° from the ready position) in preparation for the forward swing.

Volley/Service Return**:** The split-step, an integral part of the volley actions and service return, places the quadriceps muscle (extensor of the knee joint) on stretch thus permitting quick movement to either side of the body in preparation for the subsequent stroke.

The key to the recovery of the elastic energy is the timing between the stretch (backswing) and then shorten (forward swing) phases of the stroke. The benefit of the stored energy is reduced if a delay occurs between these phases of the movement. A "rule of thumb" is that racket-speed can be increased by approximately 20% if a pre-stretch occurs and 50% of this benefit will be lost if there is a pause of 1s between backswing and forward swing phases of the stroke. In tennis it is therefore essential that a short or no pause occurs between the backswing and forward swing phases of stroke production. "Prepare early" so often taught in groundstrokes, while good advice to beginner players, may not be appropriate for those seeking optimal performance. The timing of the backswing in the forehand for instance, should be such that there is sufficient time to reach an extended backswing position thus putting muscles on stretch, prior to flowing immediately into the forward swing phase of the stroke so that impact can occur at the appropriate time. Some players prefer to prepare early and then quickly take the arm back further prior to the forward swing to impact.

The Role of Muscle Performance: Endurance, Flexibility, Power and Strength: There are a number of different aspects of "muscle training" that must be considered. While a discussion of these domains is beyond the scope of this series of articles, it is appropriate to state that muscle strength, flexibility, endurance and power must all be addressed if performance is to be enhanced and the incidence of injury reduced. While it has been shown that a specific training program can enhance racket-speed, it is questionable as to whether more strength/power will naturally lead to an increase in racket-speed. Players must obviously develop sufficient muscle strength (on- and off-court) to perform effectively in a long match or over a large number of efforts. An increase in muscle strength means that a lower percentage of total strength is needed for each stroke

Up until puberty the emphasis in player preparation should be on developing stroke production, enhancing coordinative ability and enjoying the game. Those players post-puberty, who wish to develop their game fully, must integrate off-court strength/endurance/power training into their programs. The use of pulleys, plyometrics, medicine ball drills and so on, that incorporate a stretch-shorten action should form a part of this training. Flexibility training methods should be a permanent feature of player preparation to maintain the appropriate muscular length-tension relationship that provides for injury prevention and optimal power generation.

The Role of Equipment Design: There is no doubt that modern racket designs have enabled the ball to be hit with a higher speed and with greater control than was possible with previous designs. How these changes have affected players' technique will be outlined within this series of papers.

Conclusion:

The applied tennis articles to follow discuss in greater depth how to analyse stroke production and incorporate biomechanics into tennis stroke and movement production.

the serve

By Bruce Elliott, Professor and Head of the Department of Human Movement and Exercise Science
The University of Western Australia, Australia

THE success of many players on the men's and women's circuits (eg, Pete Sampras, Richard Krajicek, Mark Philippoussis, Greg Rusedski, Venus Williams or Lindsay Davenport) is at least in part due to their powerful serves. While court surface plays a role in reducing the effectiveness of these serves, a mechanically sound serve should be considered an integral part of all player development.

There is no single technique used in the tennis serve, a point that is clearly illustrated by viewing the top professionals. However, critical mechanical features integral to a successful service action are common to the majority of players with an effective serve. It can also be stated that "ineffective service actions" are generally the result of poor development of one or more of these critical features. The general structure used in this discussion may be applied to the power serve along with the slice and kicker serves.

The approach I will take with reference to service development is to look at how racket-speed can be developed from "the court-up". Coaches may not always analyse performance in this way, but it is a logical process to follow.

Preparation:

Most players start their service routine with a pre-serve ritual of bouncing the ball. At this stage they are deciding where to serve, and how to set up the point. During this phase the player should relax and visualise the intended serve.

The front-toe is generally pointed at an angle to the baseline to allow the rotation of hips and shoulders and the feet are a comfortable distance apart. The trunk should be approximately perpendicular to the net with initial weight distribution an individual characteristic. However, regardless of where the weight is initially positioned it will always move forward for impact such that it is forward of the front-toe, regardless of the service type.

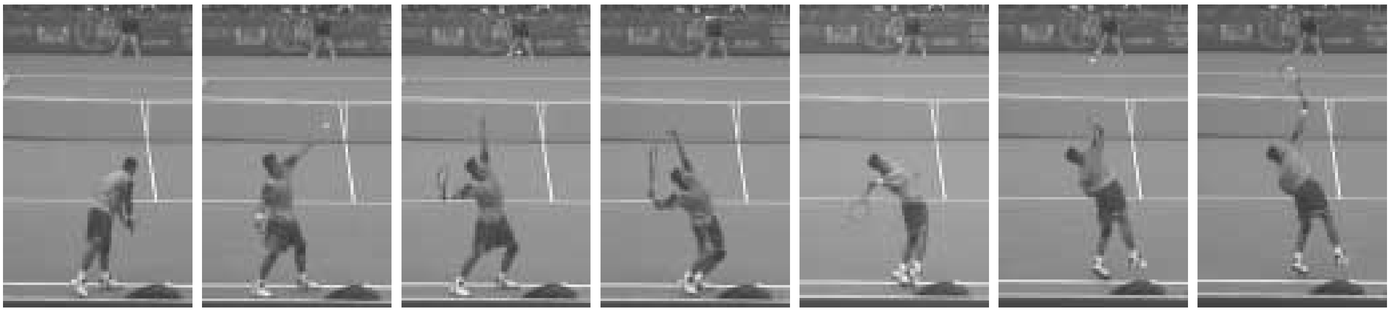
Ball Toss and Leg Drive:

Ball toss:

- The ball should be "pushed" into the air using the "straight forward and up" technique or using the "rotary style". There should be full extension of the tossing arm with the shoulders tilted and weight leaning forward. At this time the hips and shoulders rotate to enhance the ability to generate racket-speed. The rotary style toss obviously enhances trunk rotation, but is generally more difficult to control from the perspective of an accurate ball toss.
- The toss should be positioned such that it is in front and marginally to the left of the front foot at impact. This allows an effective development of racket-speed near impact. Individual player preference and type of serve will alter this location between marginally to the left, to marginally to the right of the front foot. The kicker-serve will usually be hit from a toss positioned further to the left for a right-handed player, while a slice should be hit from a similar toss to the power-serve.

Knee bend:

- Players may adopt either a "foot-back"



or a "foot-up" service style. That is some players bring the back leg forward (foot-up technique) creating a "platform" to explode up with both legs. In using this technique ensure that your back-foot is not positioned in front of the front-foot as this will generally impede the timing of the rotation of the hips. This technique generally produces a better "up-and-out" hitting action, while others leave the back foot near its original position to drive upward and forward (remember that the back foot must play a role in this drive). Players may adopt a foot position in between these 2 extremes as this aspect of the "leg drive" is a matter of choice. This leg drive is essential for first and second serves as well as with all types of serve. It is difficult to "choke" if a player has an effective leg drive.

An effective drive in conjunction with trunk rotation is designed to:

- Assist in driving the racket down, behind and away, from the back (putting muscles on stretch) and increasing the distance of racket movement to the ball.
- Remember that a good drive will increase hitting height by allowing impact to occur off the court.

The Swing to Impact:

The key to an effective serve is rhythm. That is a sequence of coordinated movements produce the key ingredients of **racket-speed** (see sequence listed in accompanying table), **impact height** and **racket trajectory**. Speed of rotation of the hitting arm and impact height have been shown to be 2 key differences between elite and lesser level players so these are characteristics that should be developed. It must be stressed that a solid base and strong trunk are needed if these characteristics are to be developed to their optimal. In the early stages of the backswing the arms while moving in synchrony do not go "down-together and then up-together". The racket-arm marginally trails the ball-arm to create a tilted shoulder alignment with the racket-arm-elbow in line with the shoulders. This enhances the shoulder-over-shoulder trunk rotation discussed below. The movement of the racket-arm through a full backswing, like during the Phillippoussis serve, or a more abbreviated take-back as used by Rafter, is an individual characteristic. A full backswing however, may provide for better rhythm and decrease the load placed on the shoulder as it involves more rotational movement as opposed to an up-down structure.

Contact point: This point is slightly to the right of the head. Remember the ball is generally impacted in-line with the front foot for all types of first and second serves. The actual contact point will often vary depending upon service style and type of serve being hit. For a "kicker" serve the ball will often be impacted further to the left for a right handed player. Here, it is important for coaches to encourage players to adopt the right trunk angle (tilt of the hips) to minimize excessive hyperextension and also reduce the load on the lumbar region of the lower back. For this reason, it is probably inadvisable for coaches to teach a ball toss that is too far to the left of centre for a right hander. The leg drive, while very important for all serves, is also essential to get the up-and-out action of the kicker.

The slice serve should be hit off a similar position as for the flat serve, the ball rotation being imparted by the racket hitting the outside of the ball. In the slice serve the level of forearm pronation (rotation of the forearm) is reduced prior to impact (racket-face angled) to impart this off-centre impact to the ball.

Shoulder alignment: The alignment of the shoulders is closer to the vertical than the horizontal. This is to allow internal rotation of the trunk/shoulder to generate racket-speed at impact. Trunk rotation occurs in the 3 planes of motion.

- Minor levels of rotation about the long axis of the body, helps drive the racket backward.
- Shoulder-over-shoulder rotation (cart-wheel action) produces momentum for and prepares the body for impact.
- Forward rotation (somersault action) allows the player to produce momentum which is shifted from the trunk, to the arm and finally to the racket.
- Players who keep their shoulders relatively parallel to the court at impact must lower the impact position to gain maximum benefit from the large internal rotators of the trunk/shoulder. The ball is positioned approximately in line with the front foot such that the hitting arm and racket are not in a straight line, thus gaining height but not eliminating the effect of internal rotation prior to impact.

An up-and-out hitting action: There is a strong association between the height of impact and success in the serve. High performance players typically impact the ball just after it has begun to drop. It is important however to teach that the racket continues up to impact so that

Coordinated movement: The sequence which generally builds from the court up is as follows:

Segment Rotation	Joint Moved	Contribution to Racket –Speed at Impact
Leg drive and trunk rotation	⩾ shoulder speed	10-20%
+		
Upper arm elevation and flexion	⩾ elbow speed	≈ 10%
+		
Forearm extension, pronation and upper arm internal rotation	⩾ wrist speed	≈ 40% (Primarily internal rotation of upper arm)
+		
Hand flexion	⩾ racket-speed	≈ 30%

Coaches must be careful in interpreting the percentage contributions above as they refer to contributions to racket-speed at impact. For instance, an effective leg action actually drives the racket away from the ball but in doing so prepares the racket for the drive to the ball. It is important to understand that all the body movements are needed to produce an effective service action. The sequence above does however, highlight the need to train the muscles involved in, and that provide for, rotation at the shoulder.

some forward rotation is imparted to the ball.

Follow Through:
Internal rotation of the upper arm and pronation of the forearm both continue during the early phase of the follow through. These actions are needed to allow the racket to slow gradually and not stop abruptly, such that stress is placed on the body. The leg-drive together with the shoulder-over-shoulder and forward trunk rotation, when linked to the impact location, cause the player to land in the court with their front-foot. The racket will then generally move across the body to complete the follow through action.

the return of serve

By Heinz Kleinöder, PhD., German Sports Institute, Cologne

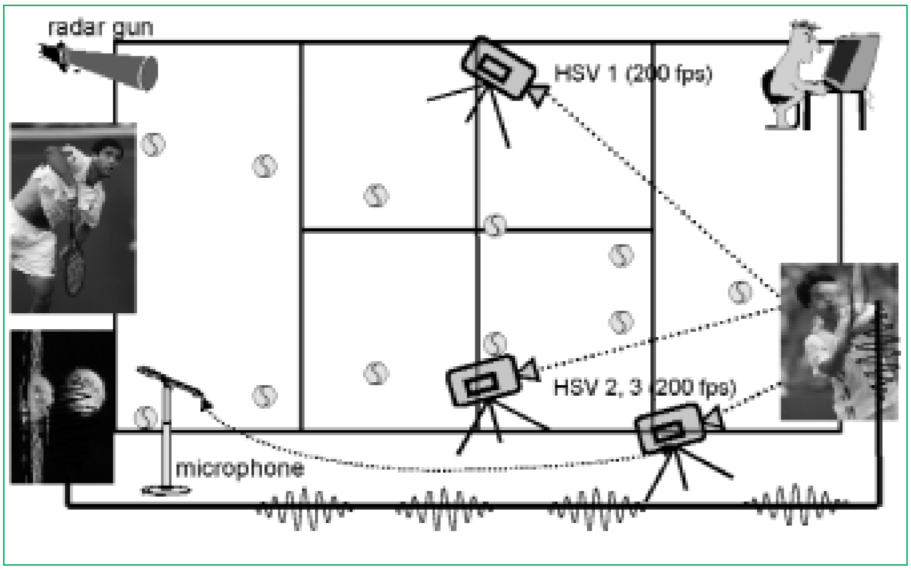


Fig.1: Experimental conditions

Introduction

As a feature of biomechanics, kinematic analysis delivers information about invisible aspects of human movement co-ordination. Such analysis is intended to support the trainer's eye with precise information in the difficult task of identifying mistakes and finding out appropriate solutions. By using high-speed cameras operating at 200 to 400 frames per second, coaches can also gain information about the total time budget of the return and the quality of the impact on the racket.

The research

The available time budget and time management of the players are the most important considerations for co-ordinating returns on the 1st and 2nd serves. To provide coaches with information about these two factors, the returns (approx. 1000 strokes) of approximately 30 professional players were filmed with 3 NAC high-speed video systems during competitive conditions at several tournaments (World Team Cup, Davis Cup) over a ten-year period. One high-speed camera, connected to a microphone, detected and signalled the time of impact of the service player to provide for the derivation of the available time budget. Another two high-speed cameras filmed the return technique of the players. Kinematic analysis was performed in laboratory at the German Sport University in Cologne (Fig. 1).

Applied findings for Coaches

Racket velocity and segment interaction

The mean initial velocity of the 1st serve was 160±15 km/h and 117±10 km/h for the second serve. There were remarkable individual differences (maximum velocities of 187±1.41 km/h and 127±5.66 km/h were recorded for the first and second serves respectively). The results indicated a mean time budget of approximately 900 ms (1st serve) and 1200 ms (2nd serve) being available for the return player on clay courts. On fast courts, the available time budget decreases by approximately 200 ms. The variation in time available (as represented by high standard deviations) on the return can be further explained by differences in the conditions of ball flight and individual returning strategies (e.g. the position of the return player on the court etc., Fig. 2).

The effects of the smaller time budget on the 1st serve return can be seen in Fig. 3. It shows velocity time curves of typical 1st and 2nd serve returns. During the time of movement regulation the players adapt their racket movement to the demands of the approaching ball. Shortly before the point of impact the synchronization of segment velocities is barely visible, which is in clear contrast to velocity generation on the serve (see Kleinöder, 1997). This means that the sequencing of maximum segment velocities (i.e. first shoulder, then elbow, wrist and racket), identified as a feature of the groundstrokes and serve, cannot be clearly seen during the return.

This can in part be explained by the

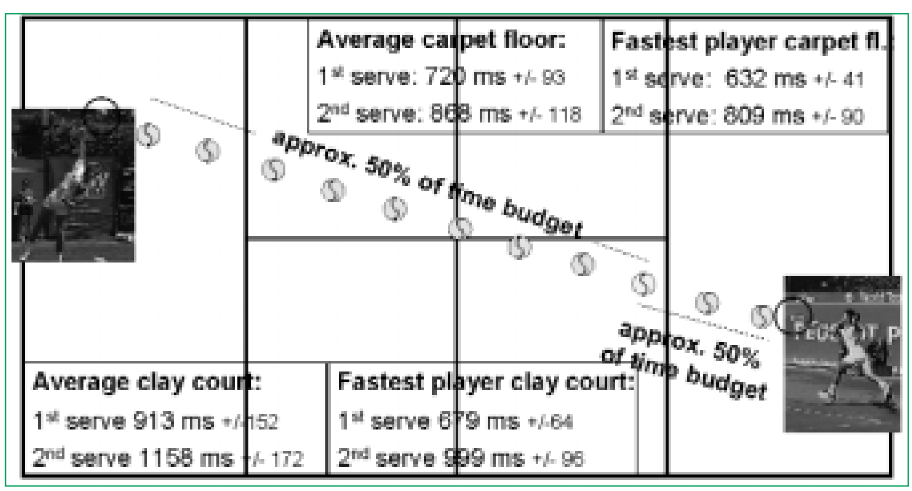


Fig. 2: Time budget of the return player on different courts

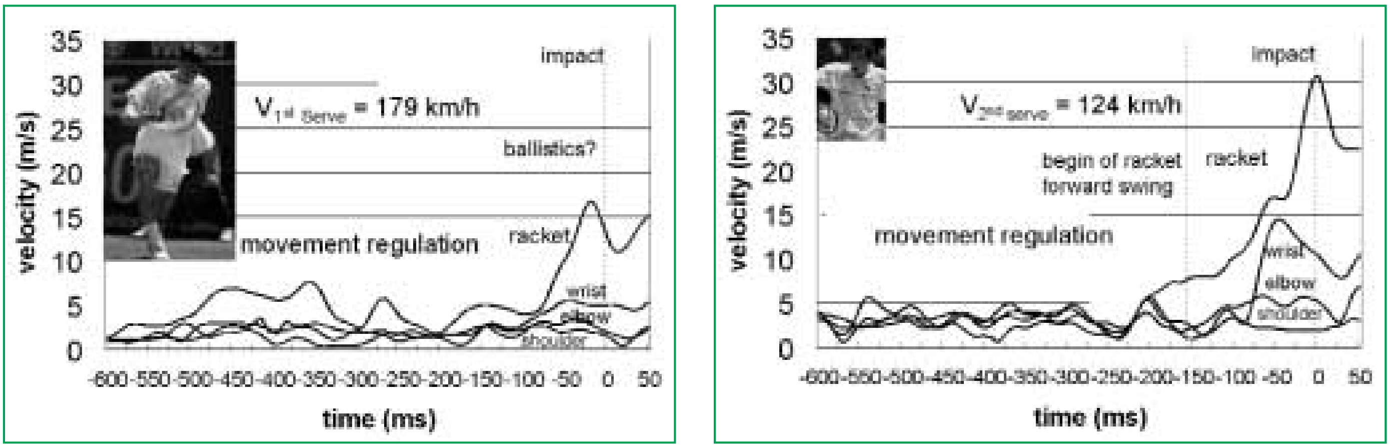


Fig. 3: Comparison of segment co-ordination at 1st and the 2nd serve return

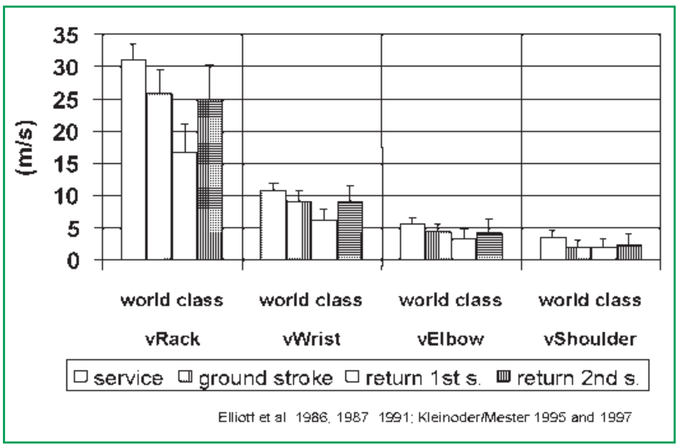


Fig. 4: Summary of racket and arm velocities during different tennis strokes

unpredictable nature of the return and the high time pressure under which players are placed, especially when returning the 1st serve. The very high demand of precision on the return is also a factor. Fig. 3 clearly shows the emphasis of the relationship between velocity and precision shifting from precision-orientation on the 1st serve return to velocity generation on the 2nd serve return. A comparison between each of the players investigated supported this conclusion (see Fig. 4).

The racket velocity at impact is much lower during 1st serve returns. This is also true for the segment velocities of the arm (shoulder, elbow and wrist). Interestingly professional players also fail to reach maximum racket velocity at impact during service returns (Kleinöder et al. 1995). That is, racket velocity decreases from 19.6±4.8 m/s to 16.7±4.9 m/s during the 1st serve return and – albeit significantly less – from 26.6±3.6 m/s to 25±5.1 m/s during the 2nd serve return. The variation in the racket velocities achieved, can once again be attributed to the variable conditions encountered during competition.

Reprogramming

Examining one of Pete Sampras' successful 1st service returns during the Wimbledon final of last year reveals a prominent feature of an effective returner. Fig. 5 illustrates that he initially incorrectly anticipates a forehand return but is able to quickly adjust and play a backhand return for a winner. This ability to reprogram an incorrect decision within a very short time interval is a very important factor on the return.

Impact

The number of off-centre impacts on the racket is another measure of the precision of the return. In professional players, this number is typically very, very low. In contrast, players of lesser standards have widespread points of impact, which may in turn contribute to injuries of the striking arm (i.e. tennis elbow). Fig. 6 shows the effect of an off-centre impact: a rapid rotation of the racket (in 35 ms, not even visible to the human eye) that can stress the muscles of the arm.

Summary

On the basis of these recent research efforts it is highly recommended to train anticipatory abilities; train returns by varying the time pressure imposed on the players in order to improve their time management; offer tasks for reprogramming (e.g. backhand to forehand return) and; work to control impact location on the racket.

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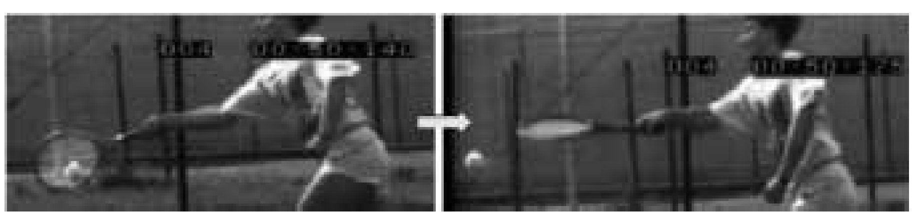

Fig. 6: An off-centre impact and its effect

Fig. 5: Incorrect anticipation but successful return by Pete Sampras

biomechanics of the forehand stroke

By Rafael Bahamonde, Ph.D., Assistant Professor of Exercise Science, Indiana University, USA

Introduction

The tennis forehand stroke has changed drastically over the last 10 years. Today's players seldom use the traditional forehand. Instead, the majority of the top amateur and professional players use the modern topspin forehand stroke. Changes in the forehand technique have been attributed to new racket designs.[1, 2] Rackets are bigger, lighter, and stiffer than the traditional wooden rackets allowing the players to hit the ball with more power and control. These changes in the forehand technique have influenced the type of grip, footwork and racket backswing and forward swing of today's tennis players.

Preparation

The Grip

The functions of the grip are to provide the proper racket orientation at impact, place the wrist in a favorable strength position, and, depending on the type of stroke used, allow for hand mobility.[1] Most researchers agree that grip firmness is a crucial factor for off-centre impacts.[4-6,10] Most tennis professionals advocate the use of a western or semi-western grip instead of the traditional eastern forehand grip. The western grips are preferred because it is easier to generate topspin and maintain racket orientation at impact. One disadvantage of the western grip is that it is difficult for players to hit low bouncing balls. Other researchers promote the use of the eastern forehand grip highlighting that it provides for greater wrist stability and allows the players to achieve the proper racket orientation at impact regardless of ball height.[1] In a study by Elliott et al.[9] the effects of using the eastern and western forehand grips on the rotational contribution of the upper limb segments to racket head velocity were investigated. Players using the western grip were able to produce higher forward (toward the court) and sideways (along the baseline) velocities than the players using the eastern forehand grip.

The stance

Today's players must react faster and are forced to hit on the run due to the power developed in the groundstrokes and the serves. Hence, they adopt an open stance. The traditional square stance takes longer to execute but it generates linear momentum; as the player steps forward toward the ball, and angular momentum; from the rotation of the legs, hips, and trunk.[10-12] In contrast, in the open stance there is little or no transfer of linear momentum since the step is taken side ways, and only the segment rotations are used to generate power for the forward swing.

The backswing

Another point of controversy among players, coaches, and tennis professionals has been which type of backswing provides more racket velocity and control. It was thought that the traditional straight backswing provided more control, and the loop (large and small) backswings provided greater racket velocity. Although a large-loop backswing has been shown to increase racket velocity, racket control and timing are more likely to be affected.[1,10] In contrast, the small-loop backswing seemed to increase racket velocity without affecting the timing and control of the stroke.[10] Regardless of the type of backswing used, for more power and efficiency, the transition between the backswing and forward swing should be a fluid motion since it enhances the player's ability to utilize the pre-stretching of the muscles.

The forward swing

The type of forward swing has also been modified by the changes in the game. Many of the top professional players use a multi-segment forehand technique in which individual segments of the upper extremity are used to generate racket velocity. In contrast, in the conventional forward swing the segments of the upper extremity move as a single unit from the shoulder. Research by Elliott et al.[14] revealed no major differences in the type of grip or initial footwork preferred by the players using multi-segment or single unit forehand swings. Clear differences were observed during the backswing phase; the multi-segment group had a more compact arm, and later, during the forward swings, generated higher racket velocities (22.5 m/s) than the single unit group (19.3 m/s) resulting in greater ball velocities.

Racket trajectory and orientation

Aside from the differences in the type of stance, grip, and/or forward swing, the key elements in the topspin forehand stroke are the stroke arc and the racket orientation at impact. The trajectory of the racket (stroke arc) can be separated into horizontal and vertical planes. Most researchers agree that the horizontal motion of the racket should resemble a flattened arc near impact.[6,13] The optimum angle of the racket in the vertical plane has been suggested to be 28°.[1,10] This angle provides good spin production and speed. Smaller angles tend to produce less spin while larger angles sacrifice ball speed and the depth of the shot. Changes in footwork and type of forward swing can influence the stroke arc. For instance, the use of the multi-segment forehand swing produces a smaller stroke arc and a steep vertical trajectory at impact (47°).[10] According to Brody a smaller stroke arc is less accurate since it reduces the margin of error due to the smaller swing radius.[6] Most researchers agree that hitting with an open stance is not more efficient but is the result of lack of preparation time for the forehand stroke.[1,10] Research by Knudson and Bahamonde[17] showed that the closed stance allowed a group of teaching professionals to maintain a more accurate racket path in the horizontal plane. When the players used an open stance it resulted in a 60%

reduction in the time in which the ball could be successfully hit on the racket face in the horizontal plane.

Linear and Angular Momentum

One of the most common concerns of tennis players is how to develop more power and control on the forehand stroke. Both power and control can be achieved through the proper development of linear and angular momentum. Linear momentum is the quantity of linear motion that a body possesses. In the forehand stroke, linear momentum is developed through the forces generated from the ground as you step forward and transfer your body weight from the back leg to the forward leg (for a closed stance footwork).[10] Angular momentum is the quantity of angular motion that a body possesses. Angular momentum is also developed from the ground reaction forces (GRF) and tends to produce a sequence of body rotations (legs, hips, trunk, upper limb, and racket).[10] Optimal trunk rotation is one of the outcomes of angular momentum. It has been shown that trunk rotation is significantly correlated with racket velocity regardless of the type of stance used or skill level (professionals or intermediates).[12] The rotation of the trunk not only contributes to the racket velocity (about 10% of final racket velocity) but is also used in the pre-stretching of the shoulder muscles to allow them to produce a larger tension.

Conclusion

What can coaches or players do to produce explosive forehands? Coaches and players need to understand the basic biomechanical principles and how to apply them to the different components of the strokes. There is no doubt that one of the most important sources of power for a tennis player comes from the racket. The new rackets not only allow the players to hit ball harder, they also provide more control. A firm grip near impact is necessary to control the racket during off-centre hits. Use a square stance whenever possible, it not only seems to be more effective in generating linear and angular momentum but it also seems to produce a more accurate racket path. Try to develop a smooth and continuous small-loop backswing. Select the forward swing (multi-segment or single unit forehand) that best suits the player's physical and motor skill abilities. Regardless of the type of forward swing, stress the importance of using trunk rotation and the legs throughout the forehand stroke and explain to the players the importance of a proper follow-through.

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biomechanics of the one and two-handed backhands

By Machar Reid, ITF Assistant Research Officer

Introduction

The backhand, so often the bane of the recreational player, comprises the nucleus of tennis stroke production along with the forehand and the serve. Traditionally coaches, players and theorists had considered a consistent topspin backhand, whether played with a single hand or in its two-handed form, necessary to complement the forehand and the serve. However, the modern game has demanded players develop backhands as penetrative and powerful as any other stroke in the game. Indeed, such has been this advancement, the backhand, and more particularly the two-handed stroke, now represents the primary weapon of some of the world's foremost players.

Any coach understands that the selection of either backhand stroke is one any prospective, or developing player for that matter, will face. I say developing, as Stefan Edberg and Pete Sampras provide two high profile examples, of players to have successfully changed their backhand technique while in their teens. Irrespective of this, the appropriateness of a player's selection, as guided by the coach, can have significant implications on his or her development. To complicate matters, it has not been until recently that researchers have gone some way to facilitate the choice confronting all players and coaches', by revealing information pertaining to the mechanical characteristics of both the modern one-handed, but more particularly two-handed stroke (Reid & Elliott, 2001). With the exception of studies performed by Groppel in 1978 and Elliott et al. in 1989, earlier descriptions tended to be experientially based, doing little to validate a coach's introspective evaluation of technique and nothing to clarify the supposed mechanical advantages and disadvantages of each backhand stroke.

The Debate – which one (or two) to choose

Among coaches, whenever a discussion of the one and two-handed strokes is to be had, there is sure to be several contentious points likely to stimulate eager debate. The proposed benefits of each with respect to velocity generation, topspin, reach, skill acquisition and disguise, will typically attract the most animated of examinations. This said, within the discussion to follow, I will endeavour to clarify these major points of issue and also touch on the application of the open stance to the backhand stroke and the mechanical variation within the two-handed technique.

1. Velocity generation:

The representation of the one-handed backhand as a multi-segmental (5) stroke has received much support (Elliott et al., 1989; Wang et al., 1998) and the recent findings were consistent with this view. Joint rotation at the shoulders, elbows and wrists of players using the two-handed technique confirmed that, in contrast to the work of Groppel (1978), the two-handed stroke is similarly multi-segmental. That is, earlier work had suggested that the two-handed technique involved a bi-segmental co-ordination of only hip rotation followed by the rotation of the trunk-limb-racket segment. In fact, the sequential coordination of four to five body segments is also required for the two-handed stroke: hip rotation, shoulder rotation and varying degrees of motion about both shoulders, elbows and wrists contribute to the production of force during a shot.

Which of the two backhand techniques is capable of producing higher racket velocities at impact? Historically, the production of high racket velocities was believed to require the radius of rotation to be as long as possible and the swinging movement to occur through the greatest arc; characteristics clearly favouring the one-handed technique. However, the shorter hitting radius of the two-handed stroke provides for greater angular velocities of the racket head at impact, and thus comparable linear velocities at the impact position. A reduction of the hitting radius is further magnified in two-handed players that incorporate the use of more elbows and wrists (ie. Venus or Serena Williams) during stroke production.

2. Topspin:

Regardless of a player's preferred backhand technique, major determinants of the type and amount of spin imparted to the ball are the trajectory and alignment of the racket at impact. While topspin is typically used to good effect in both techniques at the professional level, there has long been speculation that beginners using the one-handed stroke encounter difficulty when attempting to hit topspin due to the additional strength required to swing the racket upward at a steeper trajectory (Groppel, 1992). In contrast, imparting topspin with the two-handed shot is thought to be comparatively simple by virtue of the additional strength provided by the second hand. Findings of the recent study lend support to this view by revealing that in order to attain the high vertical velocity required to hit an effective lob, one-handed players need to decrease the horizontal acceleration of the racket up to impact. Two-handed players on the other hand, have no such trouble and can continue to build horizontal and vertical velocity right up to the impact position.

3. Reach:

While accepted that two-handed players should have the skill to release the top hand to play balls when approaching full stretch, with time to set for the shot, both one and two-handed players impact the ball at effectively the same lateral distance from the body. The longer radius of rotation of the one-handed player however, does ensure that impact is made significantly further forward (20-30cm) than in the two-handed technique, where contact is typically made over or just in front of the lead or outside foot.

4. Skill acquisition:

From a skill acquisition perspective, the hypothesised strength requirements and magnitude of the varying segmental involvement have long been thought to complicate the issue as to which of the two strokes should be taught. While coordinative ability may be the most important factor in the learning process (Schonborn, 1998), it is logical to assume that, as alluded to earlier, the one-handed backhand requires additional strength to complete the shot. This may, in turn be an influential factor in the effectiveness with which this shot can be played by the beginner or junior player.

Similarly, it would appear that the reduction in body segments used independently during the two-handed backhand (ie. different segments move together) may make preparation for impact easier than with the one-handed stroke (ie. where segments move one after the other) and facilitate the ease with which players can cope with received balls of varying height (Elliott & Saviano, 2001).

Two other factors that coaches need to consider here are the development of the backhand slice and the backhand volley. Neither of which should be forgotten if the player is to develop an all-round game.

5. Disguise:

While the literature of the late 1970's repeatedly referred to the advantage the two-handed backhand had over the one-handed stroke in terms of disguise (Patterson, 1976), quantification of the mechanical attributes that help to account for such claims had never been pursued.

However the findings from the recent study do suggest that the use of the two-handed technique may be advantageous in this regard. That is, with a shorter forward swing and more rapid horizontal and vertical acceleration to the ball, a two-handed player may provide an opponent with significantly less time to detect any kinematic variance, which in turn can supply the anticipatory information about the direction, velocity and trajectory of the shot. Additionally, although two-handed players do not noticeably employ their top hand (ie. nearest the throat) for the purposes of disguise when afforded sufficient time to set for the shot, the "flicking" of the ball cross court or over an opponent's head, is likely to be witnessed, and used to tactical advantage**,** when players have less time to balance and set-up.

6. The open stance backhand:

The ever-increasing dynamicity of the modern game and the subsequent time pressure imposed on the players has seen a proliferation in the number of players using the open stance backhand. From a tactical and movement recovery perspective, this technical adaptation helps to alleviate the time pressure and allows players to more efficiently recover their court position. Clearly, this is one of the areas in which the use of the second upper limb is of tremendous assistance to the two-handed player. The additional strength provided allows players to pivot about their outside leg, rotate their shoulders well past their hips (applying an aggressive pre-stretch to the abdominal musculature and the lat-gluteal complex), and much like players do on the forehand side, use the shot

almost exclusively when under time pressure at the back. On the other hand, one-handed players can use the stance effectively when playing with an abbreviated backswing from a relatively stationary set up (ie. the return) or to play higher bouncing balls off the back foot. Typically however, the semi-closed stance is preferred as it provides one-handed players with the combination of a longer path over which to generate racket velocity and a more favourable (in terms of stability and strength) impact position.

7. Variation in the two-handed technique:

As becomes clear when viewing players at the professional level, some mechanical variation exists between different players using the two-handed technique. This variation, typically in the segmental interaction and angular displacement of the two upper-limbs (i.e. elbow and wrist joint motion; Reid & Elliott, 2001), provides a distinction in the racket's trajectory and positioning up to and for impact. These differences are well illustrated by comparing the backhand of either Venus or Serena Williams with that of Andre Agassi or Lleyton Hewitt.

Conclusion

While recent research (and the modern game for that matter) points to the two-handed backhand holding certain advantages over the one-handed technique, coaches should continue to work with their players to find the most suitable backhand stroke for each individual. With each player's physical characteristics, coordinative ability and playing style vastly different, rather than develop a personalised backhand preference, similar to those that plagued the coaching of the past, coaches should be encouraged to assist the player develop his or her "own" backhand stroke.

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biomechanics of the volley

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THE game of tennis has seen some significant changes in the way it is played over the past 30 years. Racket technology has, at least partially, been responsible for players at the top level hitting the ball harder and with more open stances. Serves are being hit at 130 miles per hour and both forehands and backhands are used as major weapons to win points from almost anywhere on the court. In addition, most tournaments around the world are now played on hard- or clay court surfaces. Grass court surfaces are becoming more and more rare these days. So where does that leave the net game, and specifically the volley? The volley is typically played at or near the net and contact is made before the ball bounces on your side of the net. Let's take a look at some of the characteristics of the volley.

Preparing for the Volley

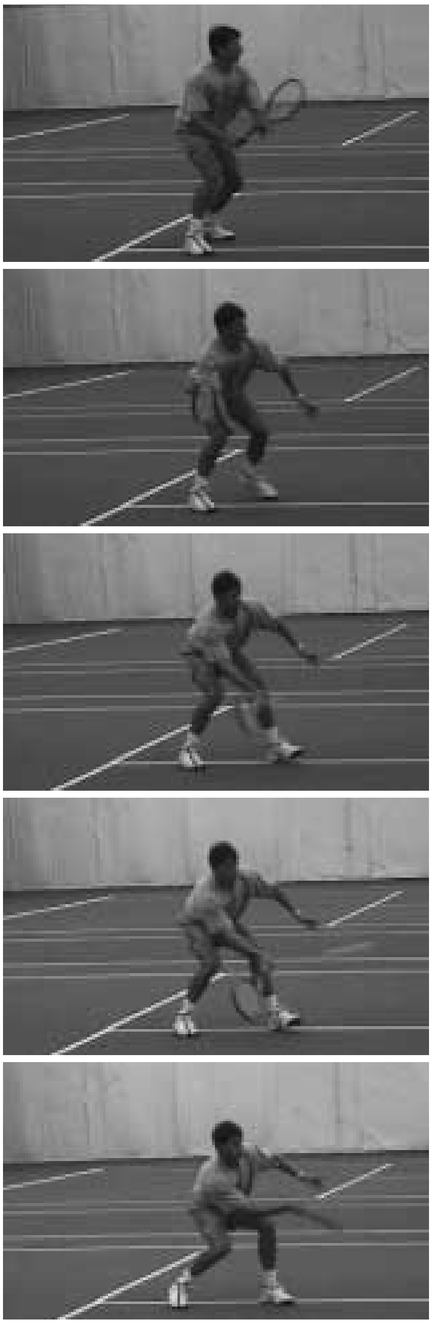
Since contact with the ball is made near the net, you will have less time to prepare for this shot than most others. Proper preparation is crucial for the volley. Poor preparation leads to a rushed stroke and therefore poor mechanics. Experienced players learn to anticipate or at least they become aware of the opponent's options in a particular situation. Reducing the number of options opponents have from five or six to two or three can make your response to the ball a lot faster. Saviano (2001) identified four major cues to help proper anticipation: 1. Your opponent's patterns and tendencies, 2. Cues from his strokes, 3. His court positioning, and 4. Proper perception of spin and trajectory.

In addition to anticipation, which mostly comes from the experience of playing many matches, players with good response time have an advantage at the net. According to Grosser et al. (2000), response time is particularly important to reach a passing shot at the net or in a volleying duel in doubles. Response time is a combination of reaction time and movement time. Reaction time is the time it takes for your brain to process the information about what type of shot is being hit and send a message to the muscles to prepare for either a forehand or backhand volley. Movement time is the actual time spent moving into position for the correct volley. Chow et al (1999) found, when studying skilled tennis players, that the average reaction times (from ball machine release to initial racket movement) for forehand and backhand were 226 and 205 ms respectively. This difference was statistically significant. The average stroke time (from initial racket movement to ball impact) ranged from 381 ms in fast speed trials to 803 ms in slow speed trials. Since it is slower to overcome inertia from a stationary position, we recommend using a split step to improve the response time in preparation for the volley.

Footwork Preparation for the Volley

Too many players practice the volley in a static situation. Van Fraayenhoven and Schapers (2001) recommend dynamic volley practice, timing the split step and focusing on balance as soon and as much as possible. Top players perform a split step before most strokes to establish a base of support and to be able to get to the next shot in the fastest and most balanced way. Most players at the club level should try to split step as the opponent initiates the forward swing, even though the very top volleyers have learned to time the split step so that they actual perform this movement the instant just after the opponent's impact. They have learned to time the split step so that it facilitates them getting to the net as quickly as possible, and still allow their brains to have enough time to process the impact and give the signal to move toward the volley position.

Performing a split step is probably most important for volleys and other shots played at the net. A split step is like the unweighting technique skiers use to make a turn. Unweighting lasts for only the split second your body is falling through the air (Groppel, 1992). The concept of unweighting can help your movement skills tremendously in tennis. By quickly decreasing and increasing your force against the ground, you can get balanced and then explode to the next shot in any direction as quickly and forcefully as possible. To perform the split step properly, your feet should be about shoulder width apart, your weight on the balls of your feet, your upper



body leaning slightly forward. Make sure you keep your racket out in front of your body. Then quickly bend your knees to get on balance and prepared to move in any direction (Roetert, 1995). Beside the fact that the split step provides for proper balance and allows for movement in all directions, the pre-stretch of specifically the quadriceps and calf (gastrocnemius and soleus) muscles helps store elastic energy to allow explosive movement upon landing.

Volley Swing Mechanics

Although the volley can be played with either a continental or eastern grip, top level players generally use a continental grip for both forehand and backhand volleys. The eastern grip necessitates a grip change from forehand to backhand side which is somewhat more time consuming, although previous research indicates that sufficient time is available (ITF, 1998). Most punch volleys are hit with an abbreviated swing, however a study by Elliott (1994) highlighted the fact that the racket was taken beyond the shoulder in the backswing of both forehand and backhand volley when hit at the service line. This type of backswing may be more specific to the first volley following a serve, as this type of volley should focus on keeping the ball deep in the opponent's court. Second volleys typically will have a shorter backswing and the focus will be more on hitting an angle. One of the primary energy sources for the volley is the transfer of weight and returning the power of the incoming shot (Williams, 2000). Chow et al (1999) found that the ground reaction forces during the stroke phase suggest that the subjects initiated lateral movement by leaning sideward when ball velocity was low and by a vigorous push-off of the contralateral foot when ball velocity was high. This weight transfer, or step does not have to be completed before contact with the ball is made. In fact, if the landing of the step occurs at exactly the same time as ball contact, accuracy of the shot may be compromised, because the step may cause the racket head to drop (this can be likened to a car slamming on the brakes, causing the nose to go down). A key coaching point for the volley therefore is to "not synchronize" the hands and feet when contacting the ball. Williams (2000) found that on lower volleys the weight transfer step usually occurs before contact, while on higher volleys the step occurs after contact.

On both the forehand and backhand volleys the racket head was found to be slightly open at contact, however, in comparing the backswings, the rotation of the upper limb laid the racket more open on the backhand side (Elliott, 1994). Although the racket head is slightly open, players should be careful not to dish the ball when volleying. Groppel (1992) found that players who "dish" the ball employ no racket head rotation prior to ball contact and that the dishing effect seen is usually a reaction to the impact; it is not a purposeful movement. As mentioned earlier, the forward swing involves a weight transfer which is initiated by the soleus, gastrocnemius, quadriceps and gluteals. Both forehand and backhand volleys typically utilize some trunk rotation (obliques and spinal erectors) although the backhand volley involves less trunk rotation. The forehand swing uses the anterior deltoid, pectorals, shoulder internal rotators, elbow flexors (biceps) and serratus anterior muscles in a concentric (shortening) fashion. The backhand volley swing uses the rhomboids, and middle trapezius, posterior deltoid, middle deltoid, shoulder external rotators, triceps and serratus anterior, also concentrically. The opposing muscle groups for each stroke contract eccentrically (lengthening action) in the follow-through (Roetert & Ellenbecker, 1998).

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improving stroke technique using biomechanical principles

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BIOMECHANICS is the sport science interested in how forces create and modify human motion. Since biomechanics is the science of technique, a primary application of biomechanics for tennis coaches is in the analysis of stroke technique. This paper will introduce tennis coaches to a larger vision of stroke analysis called qualitative

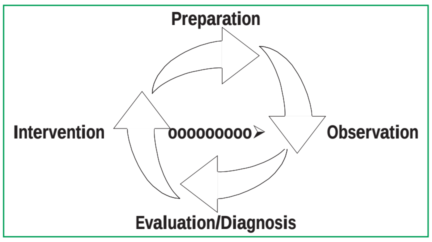

Figure 1. The four-task model of qualitative analysis proposed by Knudson and Morrison (1997).

analysis and show how a few biomechanical principles can be used to help improve tennis performance.

An expanded vision of "stroke analysis"

When a tennis coach observes a player during practice and decides on feedback or certain changes in technique they are performing the professional skill of **qualitative analysis**. Good qualitative analysis is much more than observing errors and making corrections. This section provides a brief overview of a larger vision of qualitative analysis than error detection.

Qualitative analysis of tennis strokes can be pictured in a four-task model (Figure 1). In the preparation task the coach gathers relevant knowledge about the strokes, players, and situation to be analyzed. In observation the coach systematically uses all their senses to gather relevant information about performance. In the evaluation/diagnosis task the coach has two main goals: identify both strengths and weaknesses and then prioritize the weaknesses based on their importance to performance. In the intervention task the coach selects the most appropriate strategy to help the player improve. During on-court qualitative analysis the coach can immediately return to observation to monitor progress and continue analysis.

This larger vision of qualitative analysis helps tennis coaches improve player performance much faster than traditional methods. Noting both strengths and weaknesses helps the coach get a more complete picture of a player's abilities. The diagnosis of performance focuses the coach and player's attention on the most important technique factors, limiting unproductive information overload or attention on irrelevant technique factors. The good coach is skilled at many kinds of intervention (not just verbal feedback) to help players improve. More detail and research on qualitative analysis is available in the book by Knudson and Morrison (1997).

There is another critical point in the professional qualitative analysis of tennis strokes. A tennis coach/professional should use an **interdisciplinary** approach to all the four tasks of qualitative analysis. An interdisciplinary approach is the integration of professional experience and all the sport sciences, not just biomechanics. For example, a coach noting that a young player's strokes have consistently slow racket speeds through impact might decide maturation and conditioning are more important than biomechanical changes in technique. The rest of this paper will illustrate how a few principles of biomechanics can be used to improve tennis stroke technique, but coaches should strive to integrate all the sport sciences with these principles.

Nine principles of biomechanics

One strategy to apply biomechanics to the qualitative analysis of tennis strokes is through the use of a few generic biomechanical principles. I have used nine principles (Table 1) in my biomechanics and qualitative analysis courses (Knudson, in press) as a structure for the application of biomechanics in improving human movement. These principles use coach-friendly labels rather than the specific mechanical terminology. The paper will not present an extensive discussion of all these principles but the next section will show how four of these principles can be applied in the qualitative analysis of tennis strokes. Interested coaches can read more about using principles of biomechanics in qualitative analysis in several sources (Hudson, 1995; Norman, 1975; Knudson, in press).

Table 1
Principles of Biomechanics

Balance: the degree of control over stability/instability
Coordination Continuum: organization between simultaneous and sequential action
Force-motion: forces are required to change the state of motion
Force-time: the timing/pattern of force application
Inertia: the linear and angular resistance to motion
Optimal projection: impact or release conditions that optimize performance
Range of motion: body motion used in a movement
Segmental interaction: the transfer of energy across body segments and joints
Spin: projectile rotation to stabilize flight and adjust trajectory

Principles are based on papers by Norman (1975) and Hudson (1995)

Stroke examples

The principles of *coordination* and *segmental interaction* are becoming even more relevant to tennis coaches because of recent changes in groundstroke technique. For most of the 20th century tennis was played with heavy rackets with small heads. Forehand technique involved a square stance, a weight shift followed by shoulder centered, full-arm stroke. With the lighter, larger and more powerful rackets available today many players are using more open stance and sequentially coordinated forehand techniques (Figure 2). Sequential coordination (progressive motion from larger to smaller joints tends to transfer energy through the interaction of segments) is the most effective technique for fast movement of small resistances. Recent biomechanical research on tennis groundstrokes has shown evidence of sequential coordination and stretch-shortening cycle muscle actions. Today, groundstrokes are coordinated much like the serve, with well-timed sequential actions of body segments. For example, in an open stance forehand as the speed of trunk rotation peaks this stretches the chest muscles, storing elastic energy. As trunk rotation slows (Knudson & Bahamonde, 1999) before impact some of this energy is recovered as the chest muscles accelerate the upper arm. Coaching good sequential coordination is not easy, but obvious pauses or a lack of a stretch on distal muscles as proximal segments reach peak speed are symptoms or poor coordination that coaches should work to eliminate.

The principle of *optimal projection* in tennis suggests that there are optimal angles that strokes are hit given the typical conditions (height, speed, court location). This means that certain stroke paths are more desirable than others to place the ball at typical, strategic targets. For example, virtually all serves are hit with an initially horizontal or upward trajectory. The upward swing of the racket in the serve creates topspin on virtually all serves. Research on the serves of advanced players has shown that the racket is moving upward at impact, usually about 4 degrees above the horizontal. Coaches can apply the principle of optimal projection by evaluating players for signs of "pulling down" on the serve. Beginners often tend to "hit down" on the serve, so coaches need to provide beginners with practice, cues, and the feeling of "hitting up" on the serve. Even advanced players in a hurry to the net or trying to get more weight into their serves can begin to hit their serves at too shallow an angle. Brody (1987) has reported typical "windows" or angles of successful shots for most tennis strokes.

Optimal projection is also related to the biomechanical principle of *spin*. Spin applies to all strokes because virtually all tennis shots are stroked to accommodate the spin on the ball or to impart spin that matches a strategic objective. Research has shown that "flat" strokes are a misnomer since all shots

have some spin. In general, the research shows that for typical groundstrokes the racket paths at impact for flat, topspin, and topspin lobs are about 20, 35, and 50 degrees above the horizontal. Skilled players tend to swing the racket upward near 20 degrees on most strokes, increasing the slope of the racket motion before impact in topspin strokes. Tennis coaches should know that greater topspin on a stroke comes at a cost of lower ball speed. A player using a more steep racket path through impact risks less pace, poorer depth of placement, and greater miss-hits for their heavy topspin. The good tennis coach is able to observe racket motion, ball flight, and impact sounds to evaluate if a player is using appropriate spin on their shots. Backspin strokes are usually hit with a smaller downward trajectory (15 to 25 degrees) than topspin strokes because the spin of the ball after the bounce does not have to be reversed.

A major benefit of spin that must be qualitatively assessed by the coach is the curve in the balls flight. The spinning ball creates a fluid force called lift, tending to curve the trajectory of the ball in the direction of the spin. Coaches need to weigh the strategic advantages of the trajectory and bounce of a player's spin strokes in matchplay. If the strategy is appropriate for a specific situation, is the player's technique and execution correct? Taking the pace of an opponent's strokes with underspin may be appropriate but the player might be stroking too steeply downward. This poor execution creates sitters for their opponent (shallow, slower shots, with a higher bounce).

Summary

Tennis coaches can help maximize player performance by employing an interdisciplinary approach to qualitative analysis. Biomechanics is one of the most important sport sciences for evaluating and diagnosing tennis techniques. Biomechanical knowledge can be organized into nine principles for application in the qualitative analysis of tennis strokes. For more examples of qualitative analysis of tennis strokes see Knudson (1999) or Knudson and Morrison (1997).

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racket technology and tennis strokes

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WHEN you watch tennis being played today, you immediately notice that the tennis rackets are quite different from the wooden rackets that were in use 30 or more years ago. The modern racket is larger in both head length and head width, considerably lighter, less flexible, made of a reinforced plastic material, and it is possibly an inch or so longer. When you watch the more proficient young players hitting, you also see that the style of tennis strokes has also changed over that period of time. The classic, smooth, flowing ground stokes that were displayed by the tennis champions of the first ⅔ of the 20th century have been replaced by a game that emphasizes power from the baseline and the ability to end the point with a single swing anytime the opponent is slightly out of position or hits a shot that bounces short. Is it possible that the changes in stroke mechanics are a direct result of the changes in racket technology, or did the strokes evolve independently of the racket changes? What this article will explore, is how the new technology in tennis rackets has allowed players to modify the way they hit the ball, and get away with it.

The old standard wood rackets that were used by most players up until the 1970 era, weighed at least 14 to 15 ounces, had a neutral balance, and had a small head in both length and width. Because of the structural limitations of wood, in order to fabricate a racket light enough for a player to comfortably swing, the frame could not be made very thick, which resulted in some degree of flexibility, particularly near the tip. In addition, the strength to weight ratio of wood dictated that the head could not be too large if you wanted to string it at a reasonable tension. The modern rackets are molded from a graphite-reinforced material (plus, on occasion, other exotic reinforcing materials), weigh 9 to 11 ounces, and are often handle light. It is even possible to construct rackets with a weight as low as 7 ounces, yet have a head that is quite large and produce a frame that is exceedingly stiff and durable.

The classic groundstroke used by most players up until the middle of this century was a long flowing swing with good, early preparation and a long follow through. The players stood sideways and smoothly accelerated the racket through to the hitting region as the body weight was transferred forward (you stepped into the ball). The shot was often hit flat or with some topspin, but occasionally players preferred to use a small amount of slice (underspin) on

the backhand. The modern forehand groundstroke that many players have adopted has an open stance with a semi-western or western grip. The players coil the body, and then uncoil it as the shot is hit, bringing the big trunk muscles into action. This uncoiling, rotational motion often causes the player to leave the ground during or at the end of the shot. The result is that the ball is hit with excessive topspin and usually very hard.

In today's tennis, even the youngest juniors seem to be whipping their rackets around with abandon. Years ago, probably only the exceptional player would have had the physical ability to have done that with the old, heavy wood frames. The average player and the recreational player needed the long, flowing swing to accelerate the old, heavy racket up to hitting speed. In addition, this gradual acceleration gave the player much more control of the racket head and allowed the player to hit the ball at approximately the same location on the racket face each time it was swung. This was essential, since various impact locations on the old rackets often responded quite differently (the "Sweet Spot" was small). A ball hitting an inch or so away from the desired location on the head might easily end up in the net or go long. With these old rackets, to get the ball to land consistently in the court required a consistent impact location on the strings, which could only be accomplished with a controlled swing.

With the quick, whipping swing that many players use today, it is more difficult to hit the ball at exactly the same location on the head each time the racket is swung. However, due to the characteristics of the modern racket and the heavy topspin strokes used, the resulting ball trajectory is much less sensitive to the exact location of the ball impact on the strings. (The racket is more "forgiving" or it has a large "Sweet Spot".) If there is a preferred location to hit the ball (such as the center of the strung area), the new rackets give you more latitude for error of impact location both in a direction across the racket face, and along the main axis of the frame.

Because the new frames are much wider than the old wood rackets, they are much more stable against twisting when the ball impact point is not along the principal axis. The physical property of the racket that produces this stability is called the polar or roll moment of inertia. The larger this moment, the less the racket will twist on off-center hits and the less the power degrades as the ball impact point moves off of the axis. This moment of inertia is proportional the weight of the racket and to the square of the width of the racket head. A 10-inch wide head (the size of a typical oversize racket) is 25% wider than the old 8-inch wide wooden frame, so it has a moment of inertia that is over 50% greater. This more than makes up for the 25% reduction in weight that comes with the newer rackets. This increase in polar moment reduces the racket twist on off-axis impact (hence reduces the ball's errant angle due to the twist), and keeps the rebound ball speed from changing too much on such off-center hits. Both of these effects give the player a larger margin for impact location error in the striking of the ball. In addition, the use of topspin gives the player a much larger "window" of acceptable angles to hit into, if the shot is to land in the court.

When the power of a racket is measured in the laboratory, balls are fired at the frame and the ball rebound speed is measured for various impact locations. For a typical racket, the ball rebound speed is a maximum for impacts near the throat and the ball rebound speed falls off as the impact location moves toward the tip. As a general rule, the further the impact location is from the balance point, the lower is the ball rebound speed in the lab. In addition, stiffer rackets tend to have more power than flexible rackets, particularly closer to the tip. Many of the new rackets are head heavy, which means their balance point is further up in the head. Because of this, the maximum power point moves up, away from the throat. As the racket head is made stiffer, the power degradation near the tip is reduced. These results are for a situation where the racket is not being swung, but is at rest in the laboratory.

When the racket is swung, the tip is moving somewhat faster than the throat and the ratio of these two speeds depends upon the exact nature of the swing. A very wristy, whipping motion will have a greater tip to throat speed ratio than the old classic swing. Because the tip is moving faster than the throat, the maximum power point moves up higher in the head. When the physics of all of these factors (the racket response and player swing) is combined to predict the actual playing characteristics of the racket, the new frames with the modern style of swing show a uniformity of power response over a large area of the head. This is contrasted by the old frames, coupled with the classic swing, where the ball had to be hit at exactly the same place every time to get a uniformity of response.

For the classic racket and classic swing, if the ball impacted beyond the center of the head, there was a loss of power and the ball might not clear the net. For those old wooden rackets, if the ball impacted closer to the throat than the center of the head, the result was more power, and it was likely that the shot would go over the baseline. With the modern racket and modern swing, these sorts of variations in ball impact location will result in very little variation in resultant ball speed, compared to the ball speed when the impact is at the center of the head. This means that if the ball is struck an inch or two from the center of the head, the result will still be a good shot.

If a player had the physical prowess to swing a heavy, classic racket in the modern, wristy manner, any small resulting miss-hits might end up spraying the ball all over the court. The modern rackets, due to their forgiving nature and their lighter weight, have allowed players to adopt a new style of swing and still get the ball to land in the court where they want it.

There is a second reason why strokes using the western and semi-western grips are seen more frequently these days than 30 years ago. From the beginning of tennis, the game was played on grass, which is a low bouncing, fast surface. Three of the four Grand Slam tournaments were on grass, as were many of the other tournaments. (For example, the USTA was known as the USLTA, where the L stood for lawn.) The western and semi-western grips are not optimized for fast, low bounces but are ideal for medium or slow paced, high bouncing surfaces. Today the professional grass court circuit lasts at most a month, so most players learn, practice, and play on either hard courts or clay courts. Consequently the new grips and the new types of strokes have evolved along with the new racket technology to match the predominant court surfaces.

biomechanics of movement in tennis

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WHEN investigating the biomechanics of movement in tennis, one of the first things to do is to understand the movement patterns of the sport, specifically how these patterns relate to different court surfaces. Once these patterns are understood, we can design training programs that match the individual needs of our players. Famous German tennis coach Richard Schönborn, states that the whole movement potential of a tennis player is determined by the individual's conditioning and coordination abilities and that is why these abilities must be continually integrated into tennis technique (Schönborn, 1998).

Effects of Surface on Court Movement

Tennis is the only major sport that is played on a wide variety of surface types, including at the highest levels of the game. Fortunately, with an estimated three-quarters of a million tennis courts in more than 200 countries worldwide, few would dispute the inference that the liberalism that tennis has allowed in regulating the type of material tennis is played on, has contributed to the growth of tennis internationally and greatly increased access to the sport (Coe & Miley, 2001). Much of this work has contributed to the fact that tennis courts can now be classified according to their pace characteristics, which until recently was only possible through anecdotal reports from tennis players.

A recent study by O'Donoghue & Ingram (2001) investigated elite level tennis strategy and the effect both court surface and gender have. These authors timed rallies during the four Grand Slam championships, studying footage from 252 singles matches using a computerized notational analysis system. Results of their study show rallies from women's singles matches (average 7.1 seconds per rally) to be significantly longer than rallies from men's singles matches (5.2 seconds per rally). Rallies measured at the French Open for both men and women were significantly longer than any other Grand Slam tournament, and rallies at Wimbledon were significantly shorter.

In addition to simply tabulating the amount of time of rallies for men and women during matches on different surfaces, these researchers measured the proportion of baseline rallies on each surface. This finding has significant ramifications on the dynamics and mechanics of court movement. The proportion of baseline rallies for each tournament were as follows: French Open 51% of points, Australian Open 46% of points, US Open 35% of points, and Wimbledon 19% of points. These findings clearly illustrate the different demands and strategies employed by players on the 4 different surfaces used at Grand Slam tennis tournaments.

Findings by Grosser, Kraft and Schönborn (2000) also show that in championship tennis, according to the court surface, a quarter to a third of all strokes are hit under time pressure (that is at least one stroke per point). Therefore, the influence of the various forms of speed on the result of matches is obvious.

Effect of Tennis Balls on Court Movement

New research studying the effects of the type III ball (larger) on court movement has recently been presented. Using a sample of recreational players, forehand groundstrokes were studied during rallies, with a particular emphasis on where in the court forehand groundstrokes were contacted. Results of the study showed that, with the type III ball, a greater number of forehands were struck in a position closer to the net, as compared to forehands contacted with the traditional size ball. Therefore, this research suggests that a greater amount of forward movement is required when playing with the type III ball in recreational players. Further research is needed to examine other characteristics and player responses when playing with the type III tennis ball.

Effect of Modern Technique on Court Movement

As young players developing, these authors were both taught to take the racquet back early during preparation for a groundstroke. In many cases, coaches told players to lead with the racquet as the body was rotated in a direction ultimately leaving it sideways to the net. In fact, Bill Tilden, in his book, Match Play and the Spin of the Ball (Tilden, 1925) stated that every player should:

1. Await a stroke facing the net, with the body parallel to it.
2. Play every stroke with right angles (sideways) to the net. This is true for service, drive, chop, volley, smash, half-volley and lob.

Again, recent evidence found by sport scientists and coaches during the analysis of high speed video has shown this traditional thinking of early racquet movement and side positioning to the net to be contrary to the modern controlled movement patterns of elite level players. Observations of elite players show that body rotation is actually initiated with shoulder rotation, most obvious by focusing on the movement of the dominant shoulder backward away from the direction of incoming ball, well before racquet movement takes place. Early movement to a groundstroke is occurring in the lower body, with the initial stages of shoulder rotation occurring without substantial racquet movement. This initial rotation allows the player to begin trunk and shoulder rotation without having the racquet in an awkward or inhibitory position that would interfere with court movement. Players at early levels of skill acquisition will actually attempt to run or move to a shot with the arm and racquet straight out behind them in an attempt to prepare for a groundstroke. Careful analysis and observation of a player's initiation of rotation is another important cue for coaches and players (Saviano, 2000).

Characteristics of Court Movement

It has been stated repeatedly in the tennis literature that tennis places demands on the ability of a player to move quickly in all directions, change directions often, stop and start, while maintaining balance and control to hit the ball effectively. The sprinting, stopping, starting and bending nature of tennis puts repetitive demands on the bones, ligaments and muscles to absorb the shear forces (Chandler, 1995). Therefore, proper training exercises, including flexibility and strength training, are paramount for injury prevention purposes.

In addition, to enhance performance, players have to be in the correct position to provide a solid platform from which to hit the ball. This requires agility, speed and balance. Specifically, dynamic balance, or the ability to keep the center of gravity over the base of support while the body is moving, is

important to the success of each stroke. When moving the center of gravity to the edge of the base of support, you will start moving in that direction. When responding to an opposing player's shot, your center of gravity cannot be so far outside the base of support that you are unstable or over-committed (Chu & Rolley, 2001). In tennis, the preparatory movement before such a quick change of direction is the "split step".

Mechanics of the Split Step

With continued changes in the game of tennis and the dominance of powerful exchanges from the baseline during points, players have even less time to prepare for groundstrokes during a rally. Early descriptions of the split step from the baseline, during the preparation to hit a groundstroke, reported both feet coming down from the air and landing on the court simultaneously. This maneuver enables the player to begin to move to either the forehand or backhand side to execute a shot.

More recent reports of baseline preparatory movement, however, have shown these initial descriptions of movement to be inaccurate. Elite level players have been shown to have a specific landing and foot position sequence during the split step employed from the baseline during a groundstroke rally. This information was discovered by sport scientists through analysis of high speed digital quality video of elite players during competition.

Using the example of a right handed player preparing to hit a forehand, the exact mechanism of this split step sequence will be discussed. While in the air and on the descent from the hop or upward movement at the initiation of the split step, players begin to time the landing from this upward movement by landing with the foot farthest away from the ball a split second ahead of the other foot. In a right handed player preparing to hit a forehand, this would involve landing with the left foot first. As the right foot prepares to touch the court surface, elite players actually start rotating that foot toward the direction of intended movement toward the ball. This would specifically involve pointing the right foot outward in a right-handed player. This movement pattern is performed without apparent conscious thought, as players and coaches were generally unaware that this response or pattern occurred until recently. This exact mechanism or sequence is thought to enhance a player's ability to perform a lateral or sideways movement and may actually initiate rotation of the body toward the side of intended movement.

Examining the consequences or chain of events that a "toe-out" landing position on the side nearest ball has on overall execution of a groundstroke leads to a greater understanding of the importance of this sequence of events. Positioning and landing by the lower extremity in a position of external rotation (toe-out) serves to rotate outward the lower leg bones (tibia and fibula), which consequently rotates the upper leg (femur) outward as well. This outward rotation ultimately leads to a rotation or opening up of the pelvis toward the direction of movement. This sequence of rotational events is common in nearly all human movement patterns and is termed the kinetic link principle. This sequential activation and predictable series of events confirms what sports scientists have described in sports biomechanics for many years. Clearly, much of these actions happen in a split second and can be difficult to detect with the naked eye. Therefore video analysis with stop action should be utilized by coaches and scientists to assist players in error correction and performance enhancement.

Mechanics of the Foot and Ankle During On-Court Movement

Additional information on movement mechanics for tennis comes from analysis and discussion of the specific mechanics of the foot and ankle. A common myth in tennis is that the game is played with the player on his toes or the balls of the feet. While tremendous loads are placed on the ball of the foot during walking, running and playing tennis on-court, examining any professional tennis player's feet often shows extensive callous formation on the toes and front of the feet. Slow motion video analysis clearly shows that tennis players move on the court using the same heel to toe progression as runners and other athletes.

Further analysis of how the foot and ankle move during tennis play also explains injury patterns and shoe wear patterns. Upon striking the ground, the foot is in a supinated position. Supination is a term used to describe the foot position where the foot and heel are turned inward, with a relatively high arch position. Upon landing, the foot immediately pronates or flattens (foot and ankle turn outward with arch flattening). This pronation is necessary for several reasons. First, pronation serves to absorb shock and provide shock attenuation to protect the body from the impact following heel strike. Secondly, pronation allows the foot to adapt to the court surface or slightly uneven positions, such as on a grass court or clay court.

After pronating while the foot is flat on the court surface, the foot and ankle re-supinate prior to pushing off of the ground. This is another important mechanical aspect, as failure to re-supinate prior to pushing off the court surface can lead to injury and non-efficient propulsion. Players who have very flat and pronated feet often acquire overuse injuries such as plantar fascitis, achilles tendonitis, and shin splints, due to non-optimal foot and ankle mechanics with repeated tennis play. Ensuring that players wear proper footwear and change it when needed, as well as applying orthotics (custom inserts) to the player's shoes are steps that can be taken to minimize the risk of injury during on-court movement and to enhance performance.

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Mini-Tennis

Mini-Tennis Planning (final part)

By The French Tennis Federation

MODULE 2 – The rally

This reference situation comprises two parts. The first one takes place on a 8m x 6m court, the net is 0.5 metre high and the children use rackets of type n°1 and a mini-tennis ball. The goal is to achieve the longest rally possible with a minimum of 15 shots after the bounce.

In the second part, the goal and the success criteria remain the same. The court gets bigger and now measures 12m x 6m. The rackets used are of type n°2, meaning that they are bigger and heavier.

After favouring familiarisation exercises and using the equipment and playing areas without restraint, it is essential at this stage to develop more useful skills that will allow the child to achieve his intentions. Besides, even if the exercises are still based on play, the teacher will now ensure that they are executed as correctly as possible while taking into account the individualities of the children, which can be very specific at this age.

MODULE 2 – Putting the ball in play

For this reference situation, the dimensions of the court are 12m x 6m. The net is 0.6 metres high and mini-tennis balls and rackets of type n°2 are used. The player is going to hit, in succession, 3 serves 4 metres away from the net, 3 serves 5 metres away and 4 serves 6 metres away. The returner should return the ball in the opposite half-court. The server has to win at least 5 points to succeed.

When the child starts playing, he will have to learn how to put the ball in play. The underarm serve can be used and taught, as the child is yet to master the technique of the overarm serve. Even though hitting the ball over the shoulder is difficult, the child feels a certain pleasure doing it and the ball-to-racket contact and resulting trajectories are then easier to teach. Aiming at a zone and knocking down targets are indicators of success and sources of motivation.

After the first two modules, the game gradually develops a real structure. But more than the game itself, it is the skills to acquire that are essential for the children. In fact, at this stage, they are able to string actions together. In the first module, we've seen for example that children had a go at the activity. In the second module, they are able to understand what they do and why they do it.

So what about the third module?

What changes is that children now have certain intentions. We are going to offer them various forms of games. Through these, the child will in a way acquire a player status. This means that at this stage the game becomes important, a privileged moment. This allows the teacher to check the things the children have learnt and the things they still need to acquire. From these observations, he will then draw conclusions from which he'll define new goals.

MODULE 3 – The rally

Once he has reached this stage, the child should be able to play a singles match, umpire and count the points. The dimensions of the court are 12m x 6m and the net is 0.6 metre high. Mini-tennis balls and rackets of type n°2 are used.

The serve is executed underarm in the opposite service box and the child should win 4 points to win a game. Several games can be played by the two players. Once the match is over, players and umpires swap roles.

Besides being enjoyable, the game becomes a way of putting into practice the child's acquired skills. Teaching the game is teaching how to direct the ball better, place it where the opponent is not, cover one's ground and win points against the opponent.

It is by changing the dimensions of the court and of the net and expanding the learning situations that the teacher will develop a certain degree of adaptability in the child.

Giving children the opportunity to frequently change partners during lessons and matches offers the advantage of maintaining their interest and concentration and forces them to adapt themselves to different types of games and confront others.

The teacher will need to set up specific organisations on the court. In this particular case, the children always rotate in the same direction. It is a simple and random organisation. Depending on the goals set by the teacher, other organisations are possible.

In the second example, the court is divided in two zones: the winners' zone and the losers' zone. After the match, the children who've won move one court towards the winners' zone and those who've lost move one court towards the losers'. The advantage of this type of rotation is that after a certain time the best players will play against each other in the winners' zone and the other players in the losers' zone. This specific organisation will enable the teacher to establish ability levels within the same group.

MODULE 3 – Putting the ball in play

This reference situation brings together a server and a returner.

The server's role is to serve 10 balls aiming at the outside zone and the inside zone of the same service box alternately.

The returner's role is to return the ball in the blue half-court when the ball lands in the outside zone and in the red half-court when it lands in the inside zone. The purpose of this situation is to suggest a tactical intention to the server and the returner.

By now the child should have mastered the global service action. To make further progress, the child will attempt to strike the ball with more precision, power and consistency. The teacher will look to refine the motion while simplifying it, turn the feet towards a zone and propose situations that ensure the child's success, i.e. closer to or further away from the net.

CONCLUSION

The purpose of planning before the initiation phase is to provide a lot of ideas for the teacher. The goal is now achieved. The child can now play the game tennis. What remains to be done is to improve his motions and give a personal touch to his game. And we also have to help him find his own personality.

After everything we've covered on mini-tennis it seems that there's material for many things. However, these two articles are the basis, the starting point. We should now apply those things on every tennis court with all the teachers. And of course go well beyond that.

recommended books and videos

books

World-Class Tennis Technique. E. Paul Roetert and Jack L. Groppel (Eds.). Year: 2001. Language: English. This book is written by tennis' top experts in sport science, training, equipment, and coaching. Contributors include former world-class players, national coaches, and past or current Davis Cup Captains. Together these experts present a detailed analysis of optimal technique for all the essential strokes. Beyond the strokes, the book covers every aspect of the game as it relates to technique: from rackets and equipment to court surfaces and physical and mental training. Each chapter features a technical expert matched up with a top coach from the best tennis nations in the world. The contributors are: Ron Woods and Mary Joe Fernandez, Howard Brody and Stan Smith, Andrew Coe and David Miley, Todd Ellenbecker and Craig Tiley, Donald Chu and Lynne Rolley, Ben Kibler and Dennis van der Meer, Richard Herbst and Patrick McEnroe, Jim Loehr and Tom Gullikson, Miguel Crespo and Jose Higueras, Vic Braden and Jack Kramer, Frank van Fraayenhoven and Michiel Schapers, Bruce Elliott and Nick Saviano, Paul Dent and Patrice Hagelauer, Duane Knudson and Pam Shriver. For more information contact: Human Kinetics, P.O. Box 5076. Champaign, Il. 61825-5076. USA. www. humankinetics. com.

The athletic woman's survival guide. By Carol L. Otis, MD and Roger Goldingay. Year: 2000. Pages: 264. Language: English. Level: All levels. This book is devoted to the problem of the female athlete triad. Dr. Otis is an expert on women's tennis and health issues. She is a member of the ITF Medical and Sports Science Commission, the USTA Sports Science Committee and is the chief medical advisor for the Sanex WTA Tour. Contents of the book include: Developing a positive body image. Disordered Eating. Anorexia Nervosa. Bulimia Nervosa. Amenorrhea. Osteoporosis. Teamwork for success. Preventing the triad. Price: US$17.95. For more information contact: Human Kinetics, P.O. Box 5076. Champaign, Il. 61825-5076. USA. www. humankinetics. com.

Tennis de A à Y. (Tennis from A to Y) By Jean Brechbühl et al. Swiss Association of Tennis Coaches. Year: 2000. Pages: 213. Language: French. Level: All levels. This book contains five parts: **1. Introduction. 2. The theoretical basis**: the evolution of methods, the characteristics of human behaviour, the tennis actions, the learning factors, the objective aspects of the game, the specific tennis actions, the technique of tennis, planning, conducting and evaluation of tennis training, teaching junior and senior players, stress and tennis teaching. **3. Tennis for beginners**: Beginners with and without sports experience, goals and contents of the teaching process, drills and games, analysis and evaluation of training. **4. Tennis for intermediate players**: Players with and without the possibility to improve, goals and contents of teaching, drills and training, analysis and evaluation. **5. Tennis for advanced players**: Goals and teaching contents, drills and training, analysis and evaluation, women's tennis, international standard players. Bibliography. For more information contact: Association Suisse des Professeurs de Tennis, ASPT, Talackerstrasse 5 CH-8152. Glattbrugg. Tel: 41 01 809 44 00. Fax: 41 01 809 44 01.

Learning tennis technique and tactics by playing (Iniciación jugada a la técnica y a la táctica del tenis). By Juan Pedro Fuentes and Narcís Gusí. Year: 1996. Pages: 116. Language: Spanish. Level: Beginners. Contents include 15 sessions in which the technical and tactical contents of tennis are introduced to beginners. **Tennis teaching and training** (Enseñanza y entrenamiento del tennis). By Juan Pedro Fuentes (Editor). Year: 1999. Pages: 250. Language: Spanish. Level: All levels. Contents include: Teaching methodology. Scientific foundations of tennis coaching. Tennis in High School. Physical Conditioning for tennis. Psychological training for tennis. Motor learning applied to tennis. Wheelchair tennis. **Tennis training** (Entrenamiento en tennis) By Juan Pedro Fuentes. Year: 2000. Pages: 300. Language: Spanish. Level: Advanced. Contents include: Teaching methodology. Analysis and structure of tennis. Tennis coaching. For more information contact: Universidad de Extremadura, I.C.E. Tel. 00 34 927 25 74 60.

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09.00 – 10.15 An overall vision of player development (LR) **TBD**	09.45-10.45 Important components of mental training for 14U (OC) **Paul Lubbers (USA)**	09.45 – 10.45 "Give me net or give me death" aggressive net play (OC) **Pat Cash (AUS)**	09.45-10.45 (Choose between) Special physical training on court with the racket: Eye speed reaction (OC) **Stéphane Oberer & Olivier Bourquin (SUI)** **Or** Nutrition for top performance (LR) **Page Love (USA)**	09.45-10.45 Training routines at a High Performance Centre (OC) **Alvaro Margets (ESP)**
10.15 – 10.45 Coffee-break	10.45 – 11.15 Coffee-break	10.45 – 11.15 Coffee-break	10.45 – 11.15 Coffee-break	10.45 – 11.15 Coffee-break
10.45 – 11.45 Elements/Competencies of player development for 14U (LR) **Frank van Fraayenhoven (NED)**	11.15 – 12.15 (Choose between) Working with female 14U players (LR) **TBD** **Or** Coaching on the road with juniors (OC) **Ivan Molina (ITF) & Frank Zlesak (CZE)**	11.15 – 12.15 Physical development of 18U (OC) **Paul Roetert (USA)**	11.15 – 12.15 Developing power in tennis strokes (LR) **Bruce Elliott (AUS)**	11.15 – 12.15 Issues in women's professional tennis (LR) **Kathy Martin (WTA)**
12.00 – 13.00 Tactics & technique of 12U (OC) **Anne Marie Rouchon & Bernard Pestre (FRA)**	Lunch, free time and films	12.30-13.30 Tactics under 18 (OC) **Ivo van Aken (BEL)**	Lunch, free time and films	Lunch, free time and films
Lunch, free time and films	15.00 – 16.00 ITF and Development (LR) **Dave Miley (ITF) & Frank Couraud (ITF)**	Lunch, free time and films	15.00 – 16.00 Practical applications of sports psychology for top junior and professional tennis (LR) **Ann Quinn (AUS)**	15.00 – 16.00 Doubles tactics of advanced players (LR) **Louis Cayer (CAN)**
15.00 – 16.00 (Choose between) Medical development of 14U (LR) **Babette Pluim (NED)** **Or** Player development in Thailand (OC) **TBD**	16.15-17.15 (Choose between) Technique for 14U (OC) **Helmut Hauer (AUT)** **Or** Psychological development 18U (LR) **Jiri Sledr (CZE)**	Free afternoon and evening	16.15-17.15 Physical training for top professional players (OC) **Miguel Maeso (ESP)**	16.15-17.15 The future of tennis (LR) **Richard Schonborn (GER)**
16.15-17.15 Physical development of 14U (OC) **Paul Roetert (USA)**	17.15 – 17.45 Coffee-break		17.15 – 17.45 Coffee-break	17.15 – 17.30 Coffee-break
17.15 – 17.45 Coffee-break	17.45-18.30 Questions (LR) **All speakers of the day**		17.45 – 18.45 Singles tactics of professional players (OC) **Tom Gullikson & Doug MacCurdy (USA)**	17.30-18.00 Questions (LR) **Professional tennis speakers**
17.45 – 18.30 Questions (LR) **All speakers of the day**			18.45 – 20.00 Display of Coaches' Education Material (LR) **National Associations**	18.00 Workshop wrap up and closing (LR) **Dave Miley (ITF)**
20.00 Opening Dinner				20.00 Closing Dinner

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