©Journal of Sports Science and Medicine (2013) 12, 225-231
http://www.jssm.org

Review article

Mechanics and Learning Practices Associated with the Tennis Forehand: A Review

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Abstract
The forehand ranks closely behind the serve in importance in the sport of tennis. Yet, while the serve has been the focus of a litany of research reviews, the literature describing forehand stroke production has not been reviewed as extensively. The purposes of this article are therefore to review the research describing the mechanics of the forehand and then to appraise that research alongside the coach-led development of the stroke. The consensus of this research supports the importance of axial rotation of the pelvis, trunk, shoulder horizontal adduction and internal rotation as the primary contributors to the development of racket speed in the forehand. The relationship between grip style and racket velocity is similarly well established. However, it is also clear that there remains considerable scope for future research to longitudinally examine the inter-relationships between different teaching methodologies, equipment scaling and forehand mechanics.

Key words: Coaching, skill development, pedagogy, groundstrokes, methodology.

Introduction

The forehand ranks closely behind the serve in importance both for researchers and practitioners. Yet, while the serve has been the subject of a large number of research reviews (e.g., Elliott, 1988; Kovacs and Ellenbecker, 2011), the literature describing forehand stroke production has not been critiqued through a similar lens. Although a variety of biomechanics texts have effectively summarised forehand biomechanics (Elliott et al, 2003; Knudson, 2006; Gray, 1974; Groppel, 1992; Plagenhoef, 1970), their focus has not necessarily been to consider the tenets of skill acquisition research that may aid the contextualisation of stroke technique (i.e. Elliott et al., 2003). Further, other texts have attempted to blend theory and practice by offering a selection of coaching drills and anecdotes (e.g., Elliott et al., 2009), therein constraining the depth of any critique of the body of work describing the mechanics of the forehand. With this in mind, the purpose of this article was to first, present a contemporary peer-reviewed synthesis of the empirical biomechanics research on the forehand and second, to consider that information alongside the coach-led development of the stroke. Research papers directly related to forehand stroke production, spanning the last four decades, have variously contributed to this article's discussion of the variability, movement, grip and swing mechanics (inclusive of lower limb positioning and stance, preparatory trunk rotation and its subsequent rotation to impact, upper limb kinematics, racket trajectory, body positions at impact and racket speed) of the forehand stroke.

The consistency and rehearsal (practice) of forehand

In tennis match play, competitors must ensure their forehand stroke accommodates to diverse conditions including variations in the speed, spin and bounce of the incoming ball, as well as different target areas and amounts of psychological pressure. Yet this would appear at odds with a common practice scenario presented by Elliott et al. (2009), where coaches establish drills that involve forehands being played at the same height, with similar spin and to more or less the same location. What the coaches often intend to attain is a level of repeatability that sees any variation between successive strokes being inconsequential or even imperceptible. While it is true that there must be some stability or consistency between the strokes' movement coordination, it appears that this consistency is limited to the lower order kinematics of the distal upper-extremity joints near impact (Knudson, 1990). Conceptually, this is important for the coach, as it highlights that it is the repeatability of the end point (joint positions at impact) that is important, rather than the higher order kinematic nuance in the swing to the ball. That is, with specific regard to forehands played at similar height and to similar directions, players have been shown to exhibit variable patterns of elbow and wrist angular velocity and acceleration but relatively stable elbow and wrist angular positions at impact (Knudson, 1990). Arguably this actually fits, albeit subconsciously, with what the coach is striving to achieve in the abovementioned vignette. More broadly, it might be interpreted to support the relevance of variable and random practice of the forehand, among elite players, where some consistency in end point kinematics can be encouraged but with an almost implicit variation in the nature of the swing to impact.

Where the forehands of adult or advanced players have been shown benefit from random practice conditions (Douvis, 2005), blocked practice schedules have generally been shown as more effective than random practice in improving the forehand performance of younger or less skilled players, particularly in the immediate term (Farrow and Maschette, 1997). These data suggest that novice players need some proficiency in the task (forehand), achieved through blocked practice schedules, before benefitting from less predictable and more game-like practice schedules. Significantly, this could be considered to contrast with the tenets of the Tennis 10s campaign

Received: 31 August 2012 / Accepted: 06 December 2012 / Available online: 16 April 2013 / Published: 01 June 2013

(www.tennisplayandstay.com), recently launched by the International Tennis Federation, which encourages novice players to participate in play and more random stroke repetition immediately upon their introduction to the sport. Recent work by Farrow and Reid (2010) however, confirmed the largely positive role of modified courts and balls, which are central to the Tennis 10s program, in facilitating the learning experience for children. With respect to the forehand, players rallying on a scaled court were observed to hit a significantly larger total number of shots as well as successful shots (in to the court) than players attempting to rally on a full-sized court across a 6 week intervention period. Forehand technique was also rated for proficiency on a seven point scale by three expert coaches, with some suggestion of a general improvement in proficiency through exposure to scaled conditions following the intervention. Interestingly, the use of subjective report to rate forehand technique highlights the lack of objective assessment tools to appraise forehand mechanics in tennis. That is, ranges of acceptability have been offered for specific mechanical variables (e.g, Elliott et al., 2009) but they have not been empirically established in young children. Over the course of the abovementioned intervention, greater hitting opportunities and success were reported to lead to greater player engagement, as evaluated by an engagement scale adapted from the Flow State Scale (Jackson and Marsh, 1995). This is consistent with the creation of practice conditions that set an optimal challenge for the learner so that motivation and success are optimised and learning is maximised (Schmidt and Wrisberg, 2000). In extrapolating these findings to the development of forehand technique more broadly, these types of scaled conditions would appear to effectively constrain the performer-environment system to encourage the learning of information-movement couplings important to the forehand (Davids et al., 2008). Whether or not these conditions achieve this more effectively than normal and/or other conditions over extended periods of time remains debatable and should inform the direction of future research.

Player court movement to intercept the ball and stroke recovery

The effectiveness of any forehand involves perception of, and movement to the ball. While the data describing the characteristics of on court movement patterns in tennis lack the detail of some other sports, it is purported that ~70% of groundstrokes by elite players (including both forehands and backhands) are characterised by players covering approximately 3 - 4 m. Research has also documented that, in high level tennis, a greater percentage of strokes are played under 'time pressure' on hard courts (~ 45%) than on clay (~30%) (Weber et al., 2007). These differences are practically considered to be brought about by the differences in the frictional characteristics of the two surfaces as well as surface-specific tactics. Match notation has further illustrated that most groundstroke errors in situations of low and high time pressure were hit out ('long') and into the net respectively (Pieper et al., 2007; Weber et al., 2007). This scenario contrasts with the comparable number of errors made short and long by skilled players under consistent stroke conditions (Knudson and Blackwell, 2005). With high time pressure situations generally associated with higher incoming ball velocities or more pronounced movement to the ball, these data fit with what is commonly rehearsed in practice where errors to the net should be the exception to the rule when players have time. From the above however, it is clear that research has failed to meaningfully investigate the specific mechanical characteristics of movement to the forehand. Consequently, beyond employing the superficial understanding of court-based movement (i.e. 3-4m covered per stroke) to assist the sequencing and programming of drills on a general level, coaches and physical trainers continue to rely upon their intuition in shaping the specific practice of forehand movement technique. Examination of the mechanics that underpin effective, from performance and injury perspectives, movement to the forehand represents an important area of future research for biomechanists working in tennis.

Grip style and pressure

There are three broad classifications of forehand grip: eastern, semi-western and western. Each grip influences the kinematics of the swing and therefore the behaviour of the ball post-impact. Tagliafico et al. (2009) have also reported the type of forehand grip played a role in the wrist injury profile of non-professional players. Approximately 13% of 370 adult players monitored over a 20 month period reported injuries to the wrist that were related to the forehand grip. Injuries or pain on the ulnar and radial sides were associated with western/semi-western grips and eastern grips respectively. This fits with the data of Elliott et al. (1989) that associated increased ulnar wrist flexion with the western/semi-western grips and subsequently in the production of increased vertical racket speed. Grip position therefore needs to be considered in the diagnosis of wrist injuries as well as in any suggested remedial technique work following injury.

Historically, grip pressure was reported to have little effect on the rebound velocity of simulated forehands using a clamped racquet (e.g., Elliott, 1982). Intuitively, this fits with what is observed and encouraged by many coaches: to reduce a player's grip pressure than vice versa. Players can be asked to reduce grip pressure during the swing up to impact, where a slightly 'firmer grip' may be applied. The extent to which this can be consciously controlled is unknown; however, Knudson and White (1989) have shown that grip forces vary considerably on regions of the hand and throughout the forehand stroke, with gripping forces increasing in the 50 ms prior to impact. More recently, the idea that increases in grip pressure may be advantageous for shots not hit in the central area of the racket-head has received partial support through the study of Choppin et al. (2010), which linked a firm grip in the forehand with a reduction in the ball's flight time and trajectory following impact. Further work is clearly needed to fully understand the interaction between grip pressure and forehand shot performance, particularly with vary racket technology in mind.

Lower limb positioning and stance

The stance or feet placement used by players to hit forehands typically fall in to one of four categories. Open and closed stances exist at either end of a continuum, where the alignment of players' feet and hips are parallel with and facing the net in the open stance but almost rotated 180° away from the net in the closed stance. The *Square/neutral stance* see the feet and hips assume a side-on hitting position to the net, while the semi-open stance broadly captures any foot positioning between the square and open stances.

There is a lack of empirical data to quantify the ratios of stances used by professional players during match play, which is surprising given that stance type has been variously related to hitting kinematics, Indeed, the contention of Schonborn (1999) that ~90% of all forehands of advanced tennis players are played in an open stance position offers a rare published insight, yet the source of this assertion remains unclear. Nevertheless the relative distribution of forehand stances is likely affected by gender, age, skill level and surface. With regard to court surface, Table 1 compares the percentage of open (including semi-open), square and closed stance forehands (in accordance with the above descriptions) hit by Roger Federer and Alejandro Falla in one set of tennis played by the pair on clay (French Open) and grass (Wimbledon) courts. Notwithstanding that semi-open and open stances were grouped together, the comparisons reveal some interesting insights. For example, where the distribution of stances employed by Federer appear relatively stable across the two court surfaces, Falla was observed to play considerably fewer (~50%) forehands from an open stance but almost 3.5 times as many shots from a square stance on grass courts than on clay courts. The extension of this case study in to more thorough investigation of appropriate sample size and to a broader cross-section of ages would undoubtedly prove helpful to coaches in developing the forehand stroke. That is, although some coaching philosophies are prescriptive in the stance that they advocate for the introductory forehand, other coaches are less so. It remains dubious what, if any approach, is more effective (Alvarino, 2010).

Table 1. Percentage comparison of the stances used when hitting forehands in a set of clay court and grass court tennis in matches performed by Roger Federer (RF)-Alejandro Falla (AF).

Court	Stroke	Open		Square		Closed	
		RF	AF	RF	AF	RF	AF
Clay	Forehand	77	72	13	12	10	18
	Backhand	6	36	22	43	72	21
Grass	Forehand	72	34	19	41	9	25
	Backhand	6	10	26	48	68	42

Knudson and Bahamonde (1999) reported comparable trunk muscle activation, measured bilaterally in rectus abdominus, erector spinae and external oblique, in the open and square stance forehands hit by collegiate male and female players. Interestingly, greater peak shoulder joint internal rotation torques and greater peak wrist flexion torques have been recorded during square stance forehands (Bahamonde and Knudson, 2003), which contrasts with the perception that the open stance technique creates greater loading conditions in the upper limb.

In investigating the closed stance forehand of collegiate female players, initial knee positioning and range-of-motion have been shown to positively relate to racket velocity, as well as skill level (Nesbit et al., 2008). Efforts to augment or constrain the knee movements of the participants resulted in substantially lower racket velocities, implying that there may be optimal knee positions and ranges-of-motion for individuals. Interestingly where various investigations of serve technique have described lower limb kinematics, this study represents a rare attempt to do so similarly in the forehand. Indeed, it is likely that the lower limb will attract growing attention, with the recent work of Seeley et al. (2011) representing a case in point. These authors demonstrated a link between the peak angular velocities of dominant-side knee joint extension and plantarflexion and post-impact ball speed in the forehand. It is though probable that knee positions and lower limb drives vary depending on the height of the incoming ball and require further investigation to consolidate their inter-relationships. In practical terms, the finding of Nesbit et al. (2008) would appear to underline the pitfalls of overly constraining interventions in attempting to encourage leg drive.

Preparatory trunk rotation

In many forehands, subtle axial rotation of the trunk and backward movement of the racket elbow are the precursors to the backswing (Elliott et al., 2009). The mature backswing is characterised by the following end point positions: hip alignment and shoulder alignment rotations of ~90º and ~110º (from the baseline) respectively, and subsequent shoulder-pelvis separation angles in the transverse plane of 20 - 30º (Takahashi et al., 1996). Shot direction has also been shown to influence preparatory trunk rotations, with elite and high-performance players noted to create greater hip alignment rotations but smaller separation angles when playing balls of comfortable height down-the-line as compared cross-court (Landlinger et al., 2010a). It is unknown whether a comparison between down-the-line and cross-court forehands impacted at different heights or in response to balls with different oncoming speeds would yield similar results. Certainly, it would seem intuitive that sizeable increases in oncoming ball speed may reduce the magnitude of any differences in preparatory trunk rotation. Elliott et al. (2009) speculated that the aforementioned levels of rotation are rarely evident in young players (<10 years of age) learning the stroke and further speculated that full rotation of the shoulders is likely to precede that of the hips. These observations have scant empirical support and underline the need for a longitudinal examination of forehand mechanics among young athletes.

Trunk rotations to impact

In generalising the instruction of the forehand, there appear to be two general philosophies: *a rotational approach to building racket speed* and a *more linear approach to building racket speed,* both of which generally advocate the notion of proximal to distal sequencing (Elliott et al., 2009). The former approach emphasises the positive contribution of trunk rotation and shoulder internal rotation. It has been qualitatively observed that this emphasis tends to correspond with players using the western and semi-western grips. Conversely, the latter approach seems the preference of coaches that emphasise more eastern grips and the flattening the arc of the racket swing in the transverse plane near impact. Noteworthy is that neither approach precludes the rotation or contribution of key segments, rather they are emphasised in different ways and/or at different times. For example, Elliott et al. (2009) hypothesized that the more rotational approach appears a natural fit among players with shorter statures and 'reduced' segment moments of inertia. In practice, these two philosophies also link to the previously described stances, with the rotational approach often being associated with western grips and the linear approach related to stepping down the court (square/neutral stances).

Extension of the rear or back hip aids its movement forward as well as the rotation of the trunk in the transverse plane during the forward swing (Iino and Kojima, 2001). According to some authors, trunk rotation is a key contributor to the development of racket speed (Fujisawa et al., 1997; Seeley et al., 2011), regardless of skill level (Bahamonde, 1999). However, the force produced through axial trunk rotation, tested isokinetically, appears to lack a direct relationship with the ability to generate ball speed in the forehand (Fujisawa et al., 1997). The forward speed of the shoulder only contributes a relatively small amount (~10%) to racket speed at impact (Elliott et al., 1997) but has been shown to differentiate between the forehands of elite (3.0 ± 0.4 m·s^{-1}) and high performance (2.5 ± 0.4 m·s^{-1}) players (Landlinger et al., 2010a). However, in line with the proximal to distal sequencing of most joint rotations, trunk rotation also assists in pre-stretching the shoulder muscles that are responsible for internally rotating the upper arm, therein indirectly contributing to racket speed at impact. It is worth noting that while the percentage contributions of segment rotations to racket speed are known to vary widely throughout the stroke, the simplicity of the information has helped coaches to contextualise, perhaps incorrectly, the joint rotations that contribute to the development of racket speed (Crespo and Reid, 2009).

Upper limb rotations to impact

In the forehand, various segmental rotations of the upper limb contribute to ball speed, often varying with the direction of the shot and speed of the oncoming ball. Research has indicated upper limb and racket movement in the forehand is characterised by two generalizable coordination strategies. First identified in the 1970s (Ariel and Braden, 1979), the strategies were later termed the unit and multi-segment forehands (Elliott et al., 1989). The evolution of racket and string technology and the changes in the court surfaces upon which most tournaments are played have contributed to the increasing use of the multi-segment swing, relative to the unit swing, over the last three decades (Crespo and Reid, 2009).

• *Upper arm forward movement (horizontal flexion):* While the alignment of the upper arm in relation to the trunk (shoulder abduction) is typically affected by the player's grip, horizontal flexion at the shoulder generally contributes ~25% of the racket speed at impact. Players adopting more western grips often position their arms closer to their bodies (Elliott et al., 1997).

• *Forearm rotations about the elbow*: Elbow extension and pronation play minor roles in generating racket speed for impact (Elliott et al., 2009). The idea that pronation only contributes to racket speed marginally is somewhat incongruent with the emphasis that the authors have observed to be placed on it by many coaches. The likely reason for this is that coaches see the forearm pronating and wrist flexing towards ball impact, yet fail to appreciate that this is largely due to the preceding and interactive proximal trunk and shoulder joint torques (Hirashima et al., 2008). The level of elbow flexion is again related to the grip used and the tactical situation. Seeley et al. (2011) showed that elbow flexion angular velocity increased with ball speed, but they failed to report the grips used during testing.

• *Upper arm internal rotation:* Long-axis rotation of the upper arm is an important component of the forehand, contributing ~35% of the racket's speed at impact for strokes played from a relatively slowly fed ball (Elliott et al., 1997; Takahashi et al., 1996). It reaches its peak in the final milliseconds in the swing to impact and out of classical proximal to distal sequence (Bahamonde and Knudson, 2003; Takahashi et al., 1996). Some of the musculature responsible for internal rotation, along with other trunk and upper extremity muscles, have been shown to increase their EMG activity as hitting speed increases (Rogowski et al., 2011. Elliott et al. (2009) have hypothesised that elite players do not always use internal rotation to generate racket speed, particularly in response to fast approaching balls or shots played down the line. The assumption is that the dimensionality of the swing is reduced to produce a straighter or flatter swing trajectory and/or in response to greater time pressure. This would appear somewhat simplistic and the more likely scenario is that internal rotation still exists but with potential changes to its timing or magnitude. Contrary to these reports, however, recent research that appraised three forehands, hit with varying speed but to the same down-the-line location, reported no difference in the magnitude of shoulder joint internal rotation (Seeley et al., 2011). In a similar vein, the work of Landlinger et al. (2010a) have suggested that both elite and high performance players utilise similar maximum internal rotation angular velocities on cross court (~803-825°/s) and down-the-line (~762-780°/s) shots.

• *Hand rotations:* Approximately 25% of the racket speed at impact is produced through a combination of palmar or ulnar flexion. The nature of this combination depends on the type of grip (Elliott et al., 1997) but is independent of stance (Bahamonde and Knudson, 2003). More recently, the magnitude of wrist flexion has been shown to increase with heightened forehand hitting speed (Seeley et al., 2011). The wrist generally flexes in the late forwardswing but the hand is likely to remain hyperextended to some level at impact. The work of Rogowski et al. (2011) investigated how changes in racket velocity profile are produced and revealed that radial deviation increased racket-face vertical velocity more at impact from the flat to topspin forehand drives than did shoulder abduction. This highlights the important role of the wrist in changing the racket's trajectory and, presumably, the effect imparted to the ball. In the opinion of the authors, it also highlights a paradox of sorts, where the emphasis placed on the role of the wrist in teaching the forehand stroke seems inconsistent with the attention it has been afforded (as compared to internal rotation and trunk rotation) in the tennis biomechanics literature. To this end, and as aforementioned, it can be difficult for coaches to appreciate the role of the wrist in the context of the required rotations at other joints. Nevertheless, there would appear an opportunity for future research to evaluate wrist joint motion in forehands played in response to balls of varying speed.

Racket trajectories in the vertical plane

A flat forehand is characterised by upward swing paths at impact about 20º above the horizontal, whereas this increases to ~40º for a topspin stroke and ~70º for a topspin lob (Takahashi et al., 1996). Intuitively, this fits with the ideal that players swing with steeper, low-to-high, racket trajectories to increase the topspin imparted to the ball, yet the veracity of these findings, which subsequently form the basis of the 'guidelines' offered in coach education syllabi, have not been tested across a meaningful array of different conditions (Crespo and Reid, 2009). That intermediate players have been reported to use flatter trajectories up to impact (~20º) than more advanced players (~30º) when hitting topspin drives appears logical in that lesser skilled players would benefit from reducing their margin for error in the vertical plane. Indeed errors made 'long' are characterised by racket trajectories ~3º larger than those when errors are made to the net (Blackwell and Knudson, 2005; Knudson and Blackwell, 2005).

Body positions at impact

Stability of the head: A characteristic of many elite players is that they appear to fix their heads for impact and retain this position well into the follow through (Lafont, 2008). Interestingly, 10 of the top 100 ATP Tour Professionals in 2007, including seven from the top 25, were categorised as having a fixed head position (presumably holding their gaze position) through until the near completion of the follow through. There may be a temptation to extrapolate these observations to all high performance players, yet doing so would appear premature given the paucity of quantitative data describing head alignment and gaze behaviour in the forehand.

Trunk rotation: The shoulders rotate more than the hips during the forwardswing, such that by impact they are approximately parallel with the net (Landlinger et al., 2010a). Players' hips and shoulders are generally affected by the directionality of the shot, being more open or rotated forward in the cross-court as compared to the down-the-line stroke (Landlinger, et al., 2010b).

Hitting arm and racket angles: Players using an eastern grip generally record larger elbow angles at impact (~130º) than those that use a more western grip (~100º) (Elliott et al., 1989; 1997). Grip style also influences the alignment of the wrist at impact, particularly given the related varying contributions of palmar, ulnar and/or radial flexion. Nevertheless, as aforementioned, the wrist remains extended at impact on most forehand shots (Elliott et al., 1989; 1997). Players also generally orientate their rackets perpendicular to the court at impact, irrespective of the stroke played (Elliott et al., 1989).

Impact location: Examinations of the ball-racket at impact in the forehand of professional players shows that they attempt to strike the ball at the node point of the racket (Choppin et al., 2011). It stands to reason that timely adjustments to feet, body and/or racket position are required for this to happen regularly and that the same consistency in impact location is unlikely to be a feature of the forehands played by lesser skilled players. The height at which player impact the ball is determined by the grip used, court position and tactical intent (Crespo and Reid, 2009). Players with an eastern grip, hitting on a hard court surface, typically impact the ball about 4 cm below hip height in preferred hitting situations, whereas players who use semi-western or western grips naturally adopt higher impact locations (≥6 cm above the hip) (Elliott et al., 1989). These western grips (semi-western and western) are considered advantageous on clay courts, where the ball bounce is higher, yet become more challenging in quicker, lower bouncing conditions such as those generally experienced on grass courts.

Racket speed

The speed of the racket is similar for flat, topspin and topspin lob strokes. However, the respective horizontal and vertical velocities for flat (17 and 8 $m \cdot s^{-1}$), topspin (14 and 12 $m \cdot s^{-1}$) and topspin lob forehands (9 and 13 $m \cdot s^{-1}$) demonstrate how decreases in forward racket velocity are met with increases in vertical racket velocity as more topspin (relative to ball velocity) is presumably introduced to the stroke (Elliott et al., 1989). Interestingly, there is no quantitative data to contrast the ball spin rates of these different forehand strokes. Indeed, until recently, the literature was devoid of peer-reviewed papers quantifying the spin rates of forehands played by professional players' in-situ (e.g., Choppin et al., 2011). This work suggests that male players generate approximately 25% more post-impact ball spin with their forehands than their female counterparts. The explanation for this difference is not explicit in the current research, yet it does confirm a common anecdotal belief among coaches (Alvarino, 2010).Typically, the ability to generate forehand racket speed increases with playing level (Landlinger et al., 2010b). Lower racket speeds have been recorded for club players (21 to 24 $m \cdot s^{-1}$) (Blackwell and Knudson, 2005), while professional players have recorded higher speeds: ~33 $m \cdot s^{-1}$ (Landlinger et al., 2010a). Worth noting also is that racket speeds in forehands must be carefully calculated as custom data smoothing procedures are needed to eliminate effects of impact (Knudson and Bahamonde, 2001); the literature however suffers from a lack of consistent treatment of such data, limiting the extent to which meaningful comparisons can be made across studies/populations.

Follow-through

The follow-through is an important but poorly investigated part of the forehand stroke. The work of Knudson and Bahamonde (2003) has confirmed that trunk muscle activation in the follow-through is comparable between forehands played with square and open stances, yet other evidence-based insights are rare. Consequently, short of empirical data to inform coaches' views, many professionals talk about a 3 x 90º end point position, referring to the shoulder, elbow and wrist angles at the culmination of the follow through (Elliott and Reid, 2011). While the shoulder abduction angle and elbow angle are close to 90º, the authors have observed larger variation in the culminating wrist angle.

Conclusion

Science, particularly sports biomechanics has played a key role in assisting tennis coaches to understand the mechanical characteristics ('the what') of the forehand. Given the open nature of tennis play, these characteristics have preferentially described the cross-court and/or down-the-line strokes, often with similar impact locations, which in turn highlight scope for future investigative efforts. Further, the role that biomechanics research has played in aiding coaches to expedite the learning of the forehand or to reduce injury as it relates to the forehand is less obvious. More specifically, prospective or longitudinal insights in to the inter-relationships of different teaching methodologies, equipment scaling and forehand mechanics would meaningfully add to the existing evidence base and advance the instruction of the forehand stroke.

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Key points

- Sports biomechanics has played a key role in assisting tennis coaches to understand the mechanical characteristics of the forehand.
- Research has confirmed the largely positive role of modified courts and balls in increasing the technical proficiency, number and success of forehand shots of beginner children.
- Suggested research directions include prospective or longitudinal studies into the inter-relationships of different teaching methodologies, equipment scaling and forehand mechanics.

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