1999

ISBS '99 : XVII International Symposium on Biomechanics in Sports, June 30-July 6, 1999, Edith Cowan University, Perth, Western Australia: Tennis

Elliot Bruce (Ed.)

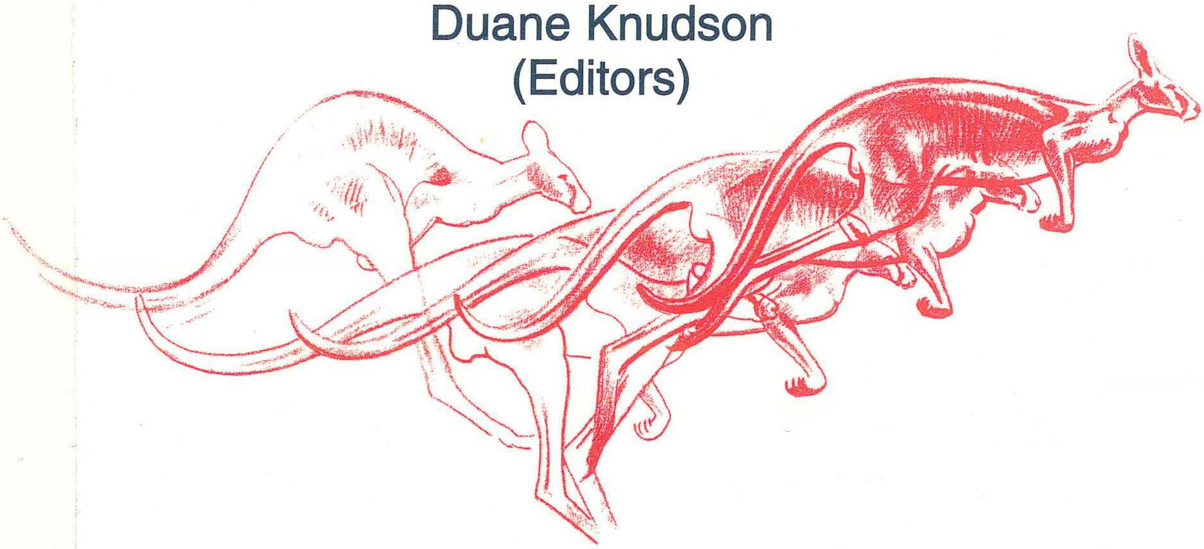
ISBS '99

INTERNATIONAL SOCIETY OF BIOMECHANICS IN SPORTS

Applied Proceedings of the XVII International Symposium on Biomechanics in Sports

TENNIS

Bruce Elliott
Barry Gibson
Duane Knudson
(Editors)



School of Biomedical and Sports Science

FREEDOM THROUGH KNOWLEDGE

EDITH COWAN UNIVERSITY
PERTH WESTERN AUSTRALIA

I S B S ' 9 9

XVII International Symposium
on
Biomechanics in Sports
June 30 - July 6, 1999
Edith Cowan University
Perth, Western Australia

EDITH COWAN UNIVERSITY
PERTH WESTERN AUSTRALIA

APPLIED PROCEEDINGS:

TENNIS

Bruce Elliott
University of Western Australia
Barry Gibson
Edith Cowan University
Duane Knudson
California State University
(Editors)

School of Biomedical and Sports Science
Edith Cowan University,
Perth, Western Australia

Applied Proceedings of the XVII ISBS Symposium, 1999: Tennis

Editors: Bruce C. Elliott; Barry J. Gibson; Duane Knudson

Publisher: School of Biomedical and Sports Science, Edith Cowan University, Perth, WA

Printing: PK Print, Hamilton Hill, Western Australia

ISBN: **0-7298-0456-9**

PREFACE

The International Society of Biomechanics is Sports (ISBS) and the School of Biomedical and Sports Science, Edith Cowan University, are pleased to present the proceedings on tennis from the applied program of the XVII International Symposium on Biomechanics in Sports.

The papers comprising these proceedings were written by international experts in tennis research. The International Society of Biomechanics in Sports is confident that this and future publications will contribute to the major goal of the Society, that is, to 'bridge the gap between sports biomechanics researchers and practitioners in teaching, coaching, training and rehabilitation'.

Perth, June 1999

Ross H. Sanders (ISBS'99 Symposium Convenor)

Barry J. Gibson (Head of the School of Biomedical and Sports Science, Edith Cowan University)

ORGANISATION

ORGANISING COMMITTEE

Ross Sanders (Chair)
Barry Gibson
Jerry Linsten
Elizabeth Rose
Lesley Sanders

SECRETARIAT

Eileen Baker
Angela Johnson

ISBS EXECUTIVE COMMITTEE

Hans Gros	President
Stuart Miller	Secretary General
Manfred Vieten	Treasurer
Julie Steele	Vice President/Publications
Tony Bauer	Vice President/Conferences
Renato Rodano	Vice President/Public Relations
Larry Noble	Vice President/Research and Projects
Eugene Brown	Vice President/Awards

TABLE OF CONTENTS

SPORT SCIENCE RESEARCH: IMPLICATIONS FOR THE TENNIS COACH

Bruce Elliott
The Department of Human Movement and Exercise Science
The University of Western Australia, Nedlands, Western Australia

KEY WORDS: biomechanics, tennis, sport science

INTRODUCTION:

Successful development of tennis performance requires a mix of player talent, the art of good coaching and an understanding of those aspects of sport science pertinent to tennis. This paper will briefly outline the role that, **sport psychology, exercise physiology, perceptual motor skills, motor learning** (pedagogy) and **biomechanics** play in coaching tennis and outline key sources of information. The paper, however, is primarily aimed at 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. There are many tennis books that provide guidance to the coach in this endeavour (such as Weinberg, 1988; Groppel, Loehr, Melville and Quinn, 1989). Gould and Damarjian (1998) listed a number of topics that have been shown to be of importance to both elite athletes and their coaches. The importance of effective communication between the coach and player was also identified as being critical to player development. Each of the following topics must be integrated into a program (both on- and off-court) for player development.

- visualisation – imagery
- concentration – attention
- relaxation strategies
- self talk strategies
- arousal strategies
- stress management

Exercise physiology must play an integral role in player development, particularly from adolescence onwards. Aerobic and anaerobic training (including periodisation of these attributes such that development not overtraining is achieved), the role of plyometric training, the need for a good diet, fluid replacement and strength/endurance/power training all must be planned if a player is going to be given the best opportunity to develop. While much of this training can be performed on-court, it is also important that off-court training is fully integrated into any training program. Many of the metabolic demands of tennis are discussed by Bergeron et al. (1991) and Hollman et al. (1994). A general approach to exercise physiology and tennis is presented by Ann Quinn in Groppel et al. (1989) and by Hohm and Klavora (1987).

The training of **perceptual motor skills** (Abernethy, Wann and Parks, 1998) has not been well used in the preparation of tennis players. The concept of cuing (perception) a key mental skill, must be taught from a relatively young age. While experts and lesser skilled players may pick-up different information from cues, there is no general agreement in the literature as to whether there are differences in the eye movement patterns for players of varying skill levels. However, skilled players must be able to "look" at the right cues and "see" the information these cues provide (Abernethy and Russel, 1987). A chapter on "Training Perceptual – Motor Skills for Sport" (Abernethy et al., 1998) provides an overview of the general area of training motor skills.

Motor learning combined with **pedagogy** (teaching methodologies) are the sciences that deal with how people learn new skills. While the use of teaching cues is widely used tennis coaches have not been particularly well served by science in providing evidence as to the superiority of one teaching methodology as opposed to another. The general concept of learning and tennis (such as feedback, when to teach new techniques, tennis drills) is discussed in the book by Groppel et al. (1989), while a multitude of coaching books (such as Braden and Bruns, 1980) based on professional experience are published.

Biomechanics is a key area in coach education and player development because all tennis strokes have a fundamental mechanical structure. Successful achievement of each of these strokes is greatly affected by the technique the player employs. An individualised model for performance must then be structured with due consideration to the key mechanical features of each skill, while allowing the flair and physical characteristics of a player to be taken into consideration when developing stroke production. The coach who understands the key mechanical features of a stroke, can analyse movement and is also able to communicate, will provide the best opportunity for optimal player development. A comprehensive review of tennis stroke production (Elliott, 1999) can be found in the recent publication The IOC Book on Tennis Medicine.

Coaches often challenge athletes to change technique, in order to enhance racket and consequently ball speed. An increase in stroke power can be achieved by considering five aspects of stroke production.

BIOMECHANICS OF STROKE PRODUCTION:
The Use of Coordinated Movements: There are two major strategies of coordination used in tennis (Table 1). 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 racquet 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).

Table 1 Coordination Strategies in Tennis

POWER STROKE (such as the service)		PRECISION STROKE (such as the volley at net)	
Leg drive and Trunk rotation	⇒ shoulder speed	Forward step of left leg (RH player) and shoulder rotation	⇒ shoulder speed
+		+	
Upper arm elevation and flexion	⇒ elbow speed	Forward movement of upper limb and racket (minimal movement in joints)	⇒ racquet speed
+			
Forearm extension pronation and upper arm internal rotation	⇒ wrist speed		
+			
Hand flexion	⇒ racquet speed		
(Elliott et al., 1995)		(Elliott et al., 1988)	

Recent studies on the serve (Elliott et al., 1995) and the forehand drive (Elliott et al., 1997) have provided coaches with an appreciation (Table 2) of the role of individual segments in developing racquet velocity.

Table 2 **Approximate Contributions to Impact Racquet Velocity (%)**

	Service	Topspin Forehand (Forward Direction)
Shoulder	10	10
Upper Arm		
Horizontal flexion	15	25
Internal rotation	40	40
Forearm		
Extension	0	3
Pronation	5	2
Hand		
Flexion (palm)	30	15
Flexion (radial/ulnar)	0	5

The above table shows that a number of segments, if coordinated correctly, lead to an effective stroke. Such information, however, must be treated very carefully as the action of some segments (such as the legs in the service) play and important role prior to impact, while others act in a way that enable other segments to operate more effectively. The high percentage attributed to the upper arm, particularly in the service action, in part reflects energy transferred up the kinetic chain from the lower extremities and trunk.

The Distance Over Which Speed Can Be Developed: One of the main reason for having a backswing is to increase the distance over which velocity can be developed during the forward swing. The potential to generate racket speed, over this increased distance, will only occur if the time needed to perform the movement does not increase proportionately. In groundstrokes it was commonly taught that "the racquet should be pointed at the back fence", whereas today advanced players frequently rotate the racket 45° beyond this point for the forehand (Elliott et al., 1989a; Takahashi et al., 1996) and 90° beyond this point ("parallel with back fence") for a backhand groundstroke (Elliott et al., 1989b).

The tendency to keep the racket behind, yet away from the back in the service action or to position the racket passed the hitting-shoulder in preparation for a volley at the service-line are 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 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) is partially recovered such that the concentric phase (shorten) is enhanced. This is also supported by the fact that the concentric action begins with the appropriate muscles under higher tension than could be created purely concentrically. 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: A subtle coaching point in maximising power in the serve is the timing of the "leg-drive" with the racquet preparation. The eccentric 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 racquet. 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, place 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 and then shorten phases of the motion. The benefit of this stored energy is reduced if a delay occurs between these phases of the movement. In the bench press, after a period of approximately 1 s, 55% of the stored energy was lost (Wilson, Elliott and Wood, 1991). A recent study by Elliott, Baxter and Besier (1999) showed that speed of internal rotation of the upper arm was approximately 20% increased for a no-pause compared to a 1.5 s pause condition. In tennis it is therefore essential that a short or no pause at all occurs between the backswing and forward swing phases of stroke production. "Prepare early" so often taught in groundstrokes, while good advise 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.

The Role of Muscle Performance: Endurance, Power and Strength: There are a number of different domains of muscular performance. While a discussion of these domains is beyond the scope of this chapter it is appropriate to state that muscle strength, endurance and power must all be addressed if performance is to be enhanced and the incidence of injury reduced (Gambetta, 1998). While Kleinöder (1990) has shown that a specific training program can enhance racquet speed it is questionable as to whether more strength will naturally lead to more power. 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. It has also been shown that explosive lifting of smaller loads maximises the training of rate of force development and muscle power (Wilson, Newton, Murphy, and Humphries, 1993), physical attributes that are critical in effective stroke production.

Up until puberty the emphasis in player preparation should be on stroke production and enjoyment of the game. Those players post-puberty, who wish to develop their game fully, must integrate off-court strength/endurance/power training into their program. The use of pulleys, plyometrics, medicine ball drills and so on that incorporate a stretch-shorten action should form a part of this training.

THE ROLE OF EQUIPMENT DESIGN:

A discussion of this topic is beyond the scope of this paper and the reader is directed to the chapter by Brody (1999) in the IOC Book on Tennis Medicine. There is no doubt that modern designs have enabled the ball to be hit with a higher speed than was possible with previous designs. How these changes in racket design have affected players technique and the risk of injury are important topics for coaches and scientists to address in the future.

CONCLUSION:

The applied tennis sections to follow discuss in greater depth how to analyse stroke production and the various aspects of sport science as they apply to tennis.

REFERENCES:

Abernethy, B. & Russel, D. (1987). The relationship between expertise and visual search strategy in a racquet sport. *Human Movement Sciences*, **6**, 283-319.

Abernethy, B., Wann, J. & Parks, S. (1998). Training perceptual motor skills for sport. In B. Elliott (ed) *Training In Sport: Applying Sport Science*, London: Wiley Publications, 1-55.

Bergeron, M., Maresh, C., & Kraemer, W. (1991). Tennis: A physiological profile during match play. *International Journal of Sports Medicine*, **12**: 474-479.

Braden, V. & Bruns, B. (1980). *Teaching Children Tennis The Vic Braden Way*, Toronto: A Sports Illustrated Book, Little, Brown and Company.

Brody, H. (1997). *Tennis Science for Tennis Players*. Philadelphia: University of Pennsylvania Press.

Elliott, B.C. Overheu, P. & Marsh, P. (1988) The service line and net volleys in tennis: a cinematographic analysis. *The Australian Journal of Science and Medicine in Sport,* **20,** 10-18.

Elliott, B., Marsh, T. & Overheu, P. (1989a) A biomechanical comparison of the multisegment and single unit topspin forehand drives in tennis. *International Journal of Sport Biomechanics,* **5**, 350-364.

Elliott, B., Marsh, T. & Overheu, P. (1989b) The topspin backhand drive in tennis. *Journal of Human Movement Studies,* **16**, 1-16.

Elliott, B.C., Marshall, R.N. & Noffal, G. (1995) Contributions of upper limb segment rotations during the power serve in tennis. *Journal of Applied Biomechanics,* **11**, 433-442.

Elliott, B., Takahashi, K & Noffal, G. (1997). The influence of grip position on upper limb contributions to racket head velocity in a tennis forehand. *Journal of Applied Biomechanics,* **13,** 182-196.

Elliott, B. (1999). Biomechanics of tennis, In P. Renstrom (ed). *IOC Book on Tennis Medicine*, London: Blackwells Scientific Publications, (in press).

Elliott, B., Baxter, K., & Besier, T. (1999) Internal rotationof the upper arm segment during a stretch-shorten cycle movement. Accepted Journal of Applied Biomechanics.

Gambetta, V. (1998). How much strength is enough? *Sports Coach*, **21**(1), 7-9.

Gould, D., & Damarjian, N. (1998). Mental skills training in sport, In B. Elliott (ed). *Training in Sport: Applying Sport Science*, London: Wiley Publications, 70-111.

Groppel, J., Loehr, J., Melville, D. & Quinn, A. (1989). *Science of Coaching Tennis*. Champaign: Leisure Press.

Hohm, J. & Klavora, P. (1987). *Tennis, Technique, Tactics, Training: Play to Win the Czech Way*. Toronto: Sport Books Publishers.

Hollmann, W., Strüder, H., Ferrauti, A. & Weber, K. (1994). Metabolic demands in tennis. In H. Krahl, H. Pieper, B. Kibler and P. Renström (eds). *Tennis: Sports Medicine and Science*. Essen: Society of Medicine and Science in Tennis.

Kleinöder, H.K. (1990) The effect of tennis specific powertraining towards an increase of service speed and speed of leg movements. PhD thesis, The German Sports University, Cologne, Germany (unpublished).

Takahashi, K., Elliott, B. & Noffal, G. (1996) The role of upper limb segment rotations in the development of spin in the tennis forehand. *The Australian Journal of Science and Medicine in Sport,* **28**, 106-113.

Wienberg, R.S. (1988). *The Mental Advantage*. Champagne, Illinois: Leisure Press.

Wilson, G.J., Elliott, B.C. and Wood, G.A. (1991) The effect on performance of imposing a delay during a stretch-shorten cycle movement. *Medicine and Science in Sport and Exercise,* **23**, 364-370.

Wilson, G.J., Newton, R.U., Murphy, A.J. and Humphries, B.J. (1993). The optimal training load for the development of dynamic athletic performance. *Medicine and Science in Sport and Exercise*, **25**, 1279-1286.

USING SPORT SCIENCE TO OBSERVE AND CORRECT TENNIS STROKES

Duane Knudson
California State University-Chico,
Chico, CA, USA

The qualitative analysis of tennis strokes is a demanding task because of the complexity, speed, and dynamic nature of most tennis strokes. Coaches are likely to be more effective if they integrate information from all the sport sciences using a comprehensive model of the qualitative analysis process. This model of qualitative analysis (Knudson & Morrison, 1997) is summarized and illustrated for several tennis strokes. Coaches can improve their qualitative analysis of tennis players by focusing on the evaluation of both strengths and weaknesses of performance, diagnosing the causes of poor performance, carefully prescribing a single intervention, and continuing to qualitative analyze the player's performance.

KEY WORDS: qualitative analysis, interdisciplinary, evaluate, diagnose, intervention

INTRODUCTION:

Twenty-first century qualitative analysis: Tennis coaches and teachers strive to help tennis players improve performance. Whatever the goals of the athlete, a primary method of improving technique is based on the coaches ability to qualitatively analyse the movement of the player. Unfortunately, there has been a lack of training in this important professional skill. Many coaches are forced to develop skill in qualitative analysis essentially through on the job experience. Most coaches approach this process by comparing a mental image of the correct stroke technique to the movement visually observed, detecting errors in technique, and prescribing corrections. Extensive qualitative analysis and sport science research indicates that this approach is inadequate (Arend & Higgins, 1976; Hay & Reid, 1988; Knudson & Morrison, 1997; McPherson 1996; Norman, 1975). This paper will summarise a comprehensive approach to the qualitative analysis of tennis strokes.

A comprehensive vision of qualitative analysis requires the coach to simultaneously integrate information from all the sport sciences. This interdisciplinary approach to qualitative analysis requires the coach to be a continuous student, by studying the game, coaching, and the sport sciences throughout their career. The qualitative analysis model proposed by Knudson and Morrison (1997) will be used to illustrate this larger vision of qualitative analysis. Knudson and Morrison (1997:4) define qualitative analysis as "the systematic observation and introspective judgment of the quality of human movement for the purpose of providing the most appropriate intervention to improve performance". This difficult skill can be conceptualised in a four task model (Figure 1). The coach prepares for the live qualitative analysis by gathering information about the activity, player, and preparing an observational strategy. Second, the analyst observes the player using all relevant senses to gather information about performance. The third task, involves two important steps, the evaluation of the strength and weaknesses of performance and the diagnosis of the movement problem from the many symptoms observed. The fourth task of qualitative analysis is some intervention by the coach, that in on-court coaching situations is immediately followed up by further observation of subsequent practice/performance. The rest of this paper illustrates these important tasks in analysing tennis strokes.

METHOD:

The first task of qualitative analysis is preparation. Here coaches integrate many kinds of background information to equip themselves for qualitative analysis. In preparation for qualitative analysis a tennis coach must weigh information from both experience and the sports sciences. Good preparation within qualitative analysis involves weighing many sources of information on the activity, the performers being analysed, and an appropriate observational strategy.

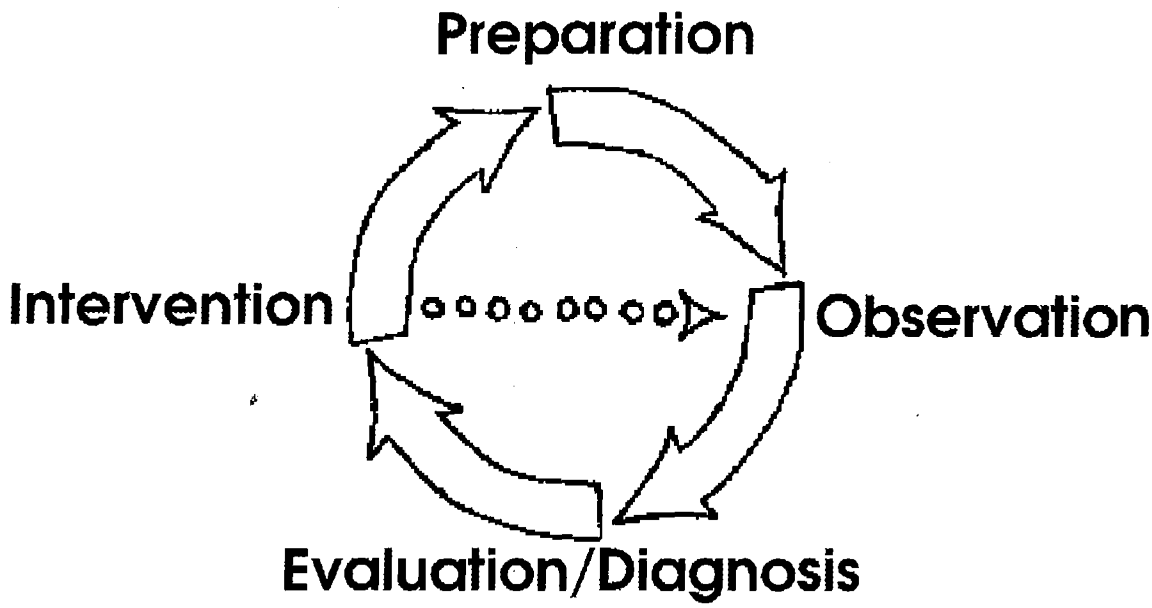


Figure 1 - The Knudson & Morrison (1997) model of qualitative analysis. In on-court analysis the professional will return immediately to observation after providing intervention to the player.

When preparing for qualitative analysis, tennis professionals must integrate and judge the quality all the potential sources of tennis information. The two major sources of information that must be combined are experience and the scientific literature. There is no substitute for professional experience, but coaches can maximise this experiential body of knowledge by attending coaching conferences and networking with peers. Remember that experience provides good information that is athlete and context specific. Care must be taken not to infer too much from a success or failure with a certain athlete or intervention. The lessons of professional experience must therefore be weighed against the scientific literature. Research in the sport sciences has the advantages of experimental control of extraneous variables and statistical tests on the likelihood of the observations. The conclusions from a consensus of tennis research are likely to create more valid information than experience alone. The advantage of sport science research is that its conclusions are more likely to lead to better analysis and intervention, but the weakness is that all the experimental control tends to limit the generalisation of these results to different situations or players.

DISCUSSION:

A major improvement in recent years has been the increase in the amount of sport science research, tennis specific sport science, and its availability to coaches. This has been especially effective in countries like Australia, Canada, Holland and the USA where national efforts to improve coaching are a model for the world. There are several excellent tennis-specific sport science publications (Brody, 1987; Elliott and Kilderry, 1983; Groppel, 1992; Groppel, Loehr, Melville, & Quinn, 1989). The United States Tennis Association publishes the newsletter *Sport Science News*. It is also important for tennis coaches to search out current sport science research that may not specifically focus on tennis but is quite relevant to the sport. Examples of places to obtain good sport science information include the *Sportscience News* web site (http://sportsci.org/) and professional publications like *Sport Coach*, *SPORTS Science Periodical on Research and Technology in Sport*, *Strategies*, and *ACSM Health & Fitness Journal*. Coaches should certainly seek out continuing education in human movement and exercise science departments at local universities and courses related to coaching certifications. Sport science needs to be available to coaches and coaches need to be available to sport scientists. Only cooperative efforts and both parties striving to learn from the other will significantly advance qualitative analysis and instruction in tennis.

A major area of prerequisite information is related to the activity itself. Tennis professionals must continuously gather information on the strokes, equipment, training, rules, and strategy of the sport. This vast amount of information must be continuously integrated and organised by the coach. A particularly effective strategy for integrating information on a particular skill is the establishment of critical features. *Critical features* are the key features of a movement that are necessary for optimal performance. Critical features are the most invariant aspects of a movement that are required for safe, efficient, and effective accomplishment of the goal. Tennis professionals should strive to synthesise the hundreds of details and cues they know about a skill into a few critical features. These critical features will be the primary foci of teaching and qualitative analysis and must be translated into cues relevant to the specific performer.

Critical features should normally be described as actions or movements, but can be any factor affecting a movement. A common critical feature in the volley for some players is a *confidence or control of a fear* of being hit by the ball. This critical feature may not be a major instructional point in the volley, but a good analyser notices these problems and adjusts practice and reinforces the player to decrease these fears. Critical features should always be expressed in a few, simple words. The use of simple cue words or phrases makes it possible for the athlete to remember the key action they are tying to create. For example, Knudson (1991) recommended that four critical features be focused on in the qualitative analysis of the topspin forehand drive from the classic square stance. The first critical feature is the degree of *readiness* and unweighting the body so the athlete can move to intercept the ball. The second critical feature was as *early and simple racket preparation.* The third critical feature was the correct *body rotation and stroke path.* The final critical feature was a *moderate and high follow-through.*

These simple cues usually have more extensive descriptions attached to them. The *early and simple racket preparation* feature includes the traditional unit turn (body rotates sideways to the net) and a small loop backswing pointing the racket to the back fence. This is the beauty of well designed cues. Players can focus on one thing or be reminded of one word, and a flood of related information can be attached to this one cue or phrase. In the analyst's mind, these more extensive descriptions should also include the *range of correctness* that is appropriate for each critical feature. This defining of how much is too much or too little accommodates physical differences between players and simplifies the following evaluation task of qualitative analysis.

Good analysts also strive to gather relevant information about their clients and appropriate observational strategies. Professionals need to be aware of physical and mental characteristics of their clients with specific reference to age, gender, and competitive goals. Tennis professionals can give clients various performance and fitness tests to document their physical and mental abilities. Results of these tests also inform the evaluation of performance by documenting physical and mental strengths and weaknesses of a performer relative to the competition. There are several good sources for norms of various physical and tennis-specific tests (Buti, Elliott, & Morton, 1984; Elliott et al., 1989, 1990; Groppel, Loehr, Melville, & Quinn, 1989; Kibler, McQueen, & Uhl, 1988; Kraemer et al., 1995; Newton et al., 1995; Roetert, Piorkowski, Woods, & Brown, 1995). Analysts can use this information to help prepare an observational strategy. Knowing what to look for and planning how to gather this information in a systematic observational strategy are the bridge to the next task of qualitative analysis, the observation of performance.

Beyond visual observation: Once a coach has a thorough knowledge of the sport and performer, they must execute an effective observational strategy. The task of observation in qualitative analysis is more than just visual observation because good observation is systematic and utilises all relevant senses. An observational strategy is a systematic plan to gather all the relevant sensory information about the performance of a tennis stroke or skill.

Remember that the purpose of observation is to gather all the relevant information that can be gathered. Relevant information can often be gathered efficiently from many sources. A professional feeding balls to a client's forehand can get information on the spin or heaviness of their strokes by volleying or stroking the client's shots back. This kinesthetic information can be easily gathered without disrupting the visual information on the client's stroke technique. Most professionals are well aware of the speed and spin information in the sound of impact. The sound of impact or the marks of footwork on a clay court can provide a great deal of information for the analysis of movement. Tennis professionals should experiment with various sensory sources of information about the performance of a variety of clients. To simplify the rest of this section I will focus on visual observation, although the information is also relevant to the other senses.

Tennis coaches usually rely on vision to gather the most information about a movement. It is important for coaches to remember that the visual perception of movement is severely limited as movement speed increases. The visual tracking of racket and upper extremity in ballistic strokes like the serve and forehand is extremely difficulty. These limitations of visual perception of motion have been summarised by Knudson and Kluka (1997). To get the most information out of an overloaded visual system, analysts should plan and execute an observational strategy.

Research has shown that there are many ways to organise an observational strategy (Knudson and Morrison, 1997). How you plan to observe the backhand may depend on the performer, situation, and your own perceptual style. Observational strategies fall on a continuum between a gestalt (overall impression of whole movement), to a more structured plan of observational focus. A common strategy is to organise observation based on the *phases of the movement*. The analyst plans to use sound and vision to observe preparatory movements in the first few backhands, followed by focusing on the forward stroke and follow-through in subsequent trials. Other analysts feel more comfortable organising the observational strategy around *balance* or the base of support, or around on their own rating of *importance of the critical features*. At the less organised end of the continuum is a gestalt approach or planning to observe from *general to specific*. By focusing on general impressions of a few trials (presumed to be information greater than the sum of individual parts), the analyst can then focus on specific aspects of the movement in later trials. Whatever strategy you choose to use, it is important that you approach observation consistently so that relevant information is not missed.

Other key elements of a good observational strategy are attention to the situation being analysed, the number of trials observed, vantage points, and the potential need of extended observational power. By planning the situation and exact nature of the task performed the coach can be assured that the performance is as similar as possible to actual competition. Observing serves without the pressure of a return or match conditions may not be very relevant. Professionals also need to plan to observe several trials based on the kind of skill and the skill level of the player. Novice players are highly inconsistent in stroke performance and the errors they make. As skill increases strokes are performed with greater consistency, but no movement is perfectly consistent. A minimum number of trials to be observed to reduce the risk of focusing on insignificant variations in technique is usually between 5 and 8 (Knudson & Morrison, 1997). The observational strategy should also specify several vantage points since most movements are three dimensional. The appropriate vantage point is perpendicular to the plane of motion to be observed. For example, the distance away from the body the ball is contacted in the forehand should usually be observed from behind. Observation needs to be extended with the use of shuttered video when the movement of interest is fast. The major benefits of videotaping in tennis are the abilities to repeat and slow down the fast actions of strokes. A shutter setting of 1/1000 of a second is usually necessary to prevent blurring of the images. Pause and jog-shuttle controls on the VCR playback unit will allow the analyst to review the 25 or 30 video frames captured each second. Considerable movement detail beyond live observation can be detected by slow-motion and stop-action review of videotape replay.

Evaluation and diagnosis: The third task of qualitative analysis involves two very important steps. The analyst first evaluates the performance, identifying both the strengths and weaknesses. This is immediately followed by diagnosis. Diagnosis is the identification of the underlying causes of poor performance from the observed strengths and weaknesses. These two steps may be the most difficult parts of qualitative analysis. This task is such a challenge because of the multifaceted nature of human movement and the need to integrate all the sport sciences and experience in these decisions.

Unfortunately, many coaches do not use this interdisciplinary approach to evaluation and diagnosis of movement. The traditional approach is to just *detect movement errors* that are then corrected with some form of feedback. Evaluation of movement is more than detecting differences in our mental model of a movement and what the performer executed. Evaluation involves the careful judgments of identifying the strengths and weaknesses of performance. The careful documentation of the range of correctness of critical features makes it easier to judge what aspects of performance are acceptable or weak. Suppose a player has a good overall one-handed backhand but tends to contact the ball too close to the body. Evaluating this situation as an error in stroke technique or contact point may be short-sighted. A thorough evaluation may result in a judgment that the basic weight transfer, arm action, and stroke path are all strengths of this backhand. The weakness may lie in other areas such as preparatory movements and perception of the spin of the ball being returned. Another example would be the evaluation of a young player's attempts to serve at a higher velocity. The coach must weigh information about the biomechanics of their serve, the athlete's strength and endurance, serving percentage, opponents, and the personality and psychology of the athlete. The many factors that interact to affect human movement are why evaluation of the performance is so difficult.

Once the strengths and weaknesses of performance have been identified, the analyst faces the challenge of determining what one intervention is most appropriate. This diagnosis of the underlying causes of poor performance is usually attacked by prioritizing the effect of the possible interventions. Knudson and Morrison (1997) have identified six different rationale or approaches to diagnosis: *relating actions to previous actions*, *maximizing improvement*, in *order of difficulty*, in the *sequence of the movement*, from the *base of support* up, and *critical features* first. These rationale can also be combined to form an effective diagnostic approach.

Suppose a player has been evaluated as weak in generating racket speed through the contact zone on the forehand. An analyst could combine the relating actions to previous actions and maximizing improvement rationale to diagnosis the performance. He/she first asks themselves if there are previous actions (backswing, forward swing technique, timing, strength) that might be related to the problem (slow racket through impact). If the performer has good timing and adequate strength for this skill, the analyst must decide if intervention on racket preparation or forward stroke technique would be most effective in improving performance.

Unfortunately there is little scientific literature to determine which rationale for diagnosis is related to the most improvement. Another approach to simplify diagnosis of performance in most teaching situations is for the professional to determine the importance of the critical features of the movement based on their teaching experience and the sport science literature. For example, in analyzing the serve for beginners, Knudson, Luedtke, & Faribault (1994) proposed six critical features in order of importance (Table 1). For the purpose of illustration, this approach to analyzing the serve will be used as the basis for discussion of prioritizing possible intervention.

Table 1 Diagnosis of the Tennis Serve by Importance of Critical Features

Critical Feature	Rationale
1. Grip	Determines the path of the racket and forearm/wrist action
2. Toss	Determines timing and proper racket path
3. Racket Preparation	Affects timing and speed of the racket
4. Continuous	Determines effective ball trajectory Upward Motion
5. Followthrough	Maximizes racket speed and protects the body
6. Stance	Affects balance, accuracy and development of racket speed

*Knudson, Luedtke, & Faribault (1994)

Stick figures of the serve of a typical beginner are illustrated in Figure 2. Imagine the player also has a typical reaction of, "Help coach, what can I do to get my serve to go in?" This player has asked the critical question the analyst must answer in the diagnosis task of qualitative analysis. Assume the observation of several serves shows similar actions and results to that illustrated in Figure 2. Assume the athlete uses a continental grip and a complete follow through. Evaluation of the performance indicates that the grip, stance, and the follow through are strengths. The critical features of toss, racket preparation, and continuous upward motion are weak. Almost impossible to identify in this figure is that the racket preparation is long and slow. This combined with a high toss and the arm not near extension at impact limits the velocity and trajectory of the serve.

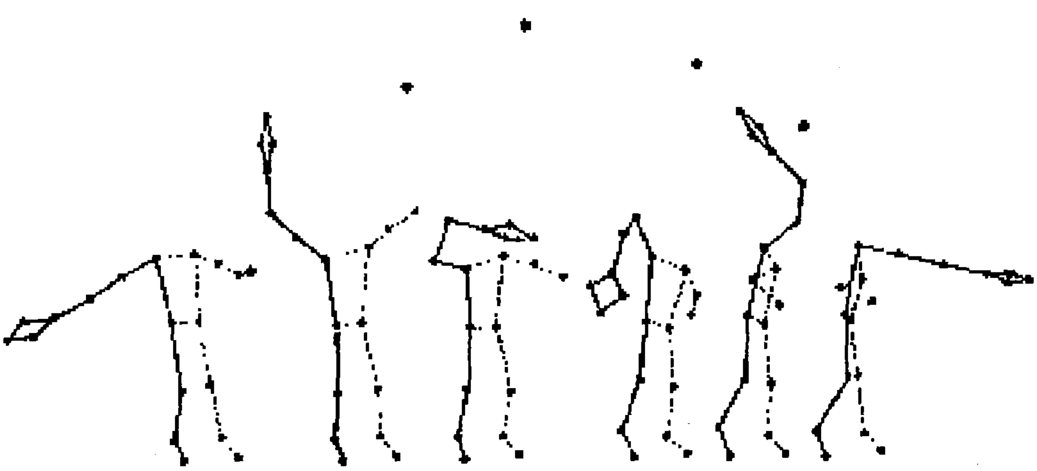


Figure 2 - Stick figure representation of a typical serve of a beginning player horizontally spaced to prevent overlapping positions. Space and time between images is not uniform. Evaluate these images to determine the strengths and weaknesses of this performance.

The diagnosis of this person's serve, however, depends on the ultimate goal for improvement. The student is interested in short-term results, while most coaches and the Knudson et al. (1994) system are focused on long-term service ability. Coaches must communicate to athletes the long-term nature of goals and potential improvement. Given the three weaknesses identified, the Knudson et al. (1994) system proposes that modification of the toss might lead to the most improvement. Focusing intervention on a slightly lower toss might force the person to speed up racket preparation to make contact with the ball. This diagnosis is based on a hypothesized relating of an action (long preparation and low hitting action) to a previous action (high toss).

Not all tennis professionals would agree with this diagnosis, and another approach might be to focus the player's attention on a correct upward hitting action. Some coaches might believe in motor development studies indicating that people with immature overarm throwing patterns often adopt this elbow extension dominated hitting action in the serve. These analysts might emphasize the correct hitting action that theoretically will lead to greater success and might force the person to speed up racket preparation to use the current high toss. Using the science of biomechanics in relating actions to other actions may work backward in time. Unfortunately, biomechanical modelling studies have not been able to give many clear cut answers to segmental and muscular contributions to movement on which to base decisions relating actions to other actions. Even if a technique point could be unambiguously attributed to other actions, this information would still have to be integrated with developmental and motor learning research to make the correct diagnosis of performance.

Intervention: Good tennis coaches find many ways to intervene in the learning process to help players improve performance. Intervention is more than providing the traditional feedback or corrections. The intervention task of qualitative analysis involves the administration of any change in training that serves to improve performance. Despite having a variety of tools of the trade, the best coaches carefully select a single intervention based on their diagnosis of the situation. Providing the single best intervention maximises the performer's success and prevents "paralysis by analysis." This is dramatically different than the novice coach who typically has a correction complex. A poor analyst freezes a performer with information and guilt by giving the player feedback on many things (Figure 3) they are doing wrong, without usually providing information on what to do. This section will summarise the several techniques of intervention to improve tennis strokes.

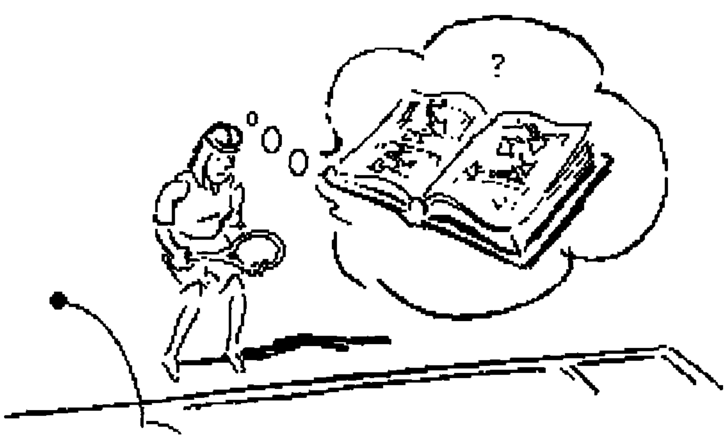


Figure 3 - Too much intervention may cause paralysis by analysis in the athlete.

The sport sciences of motor learning and pedagogy provide extensive research on how tennis coaches should intervene to improve performance. Most of this research has been focused on feedback. Feedback to a performer serves to reinforce correct actions, motivate, and guide the performer is more appropriate technique. Some principles to follow when using feedback as intervention are to focus on specific and corrective feedback, use cue words or phrases, minimise the delay between the movement and the feedback, and use a variety of approaches if unsuccessful. Research suggests that feedback about the actual movement (knowledge of performance) is more powerful intervention than outcome information (knowledge of results). Another important technique to maximise the effect of feedback is to use the sandwich technique. This approach sandwiches corrective feedback between two reinforcements (praise or compliments) of effort or critical features performed well. Knowledge of psychology and the performer are key for analysts knowing when athletes will negatively react to corrections or is need of positive reinforcement.

There are several methods of intervention beyond providing traditional feedback. Knudson and Morrison (1997) have identified several of these methods. One intervention strategy that is particularly effective in situations were athletes have difficulty in making a change in technique is *overcompensation or exaggeration*. Novice players often tend to hit downward on their serves, but this is effectively remediated by instructing players to attempt to hit the ball straight to the back fence. This exaggeration of intention usually results in the appropriate vigorous and upward hitting action of a good serve. This is the intervention that might be chosen by the coach whose diagnosis of the server in figure 2 is based on the belief that a continuous upward hitting action is the most important critical feature of the serve.

Another effective strategy is to use a *visual model* for correct performance. Chalk can be used to draw a visual model for the correct footwork or racket path for a particular stroke. Videotape replay of the performer's technique and desirable technique is an effective visual modelling approach to intervention. A coach may also choose to intervene by *modifying the task*. A player having trouble handling high service returns might need to be put in a practice situation where this skill is repeatedly practiced. A practice set with one serve per point could be arranged between this player and another with a good twist serve. This is also an example of changing the *environment* of practice or training. A good professional customises the environment to the level and needs of the player. Practice with more or fewer serves per point, or using the wind to force a player to modify technique are good examples of the strategy of modifying the environment.

Three other effective intervention strategies are *modifying practice*, *manual guidance*, and *conditioning*. The art and science of *modifying practice* schedules and selecting practice tasks is an area with great potential effective intervention. It would be difficult to summarise all the sport science information on designing practice, but several generalisations can be applied. Beginners tend to benefit from a more blocked practice schedule (repetition of same movement in simplified conditions) and with increasing skill level random practice schedules (practice with rapid changes between a variety of skills and activities) These methods seem to create greater and more permanent learning. For example, a tournament player would benefit most from service return practice using several drills on both sides of the court or playing points, compared to returning 100 first serves in the add court. Coaches often use *manual guidance* as a way to get performers to feel the correct movement (Kernodle & Turner, 1998). This kinesthetic feedback is often useful with novice performers where the initial feel of the correct movement has not been found. Coaches can easily help players move through the correct motion slowly. Remember that manipulation of dynamic motion is dangerous and should be used with caution. The feel of the racket touching the fence (volley drill with the player next to a fence) is a good approach to kinesthetic feedback on the volley. The coach blocking or pulling on the racket during dynamic movement is dangerous for the coach and the athlete. An often overlooked form of intervention is the prescription of conditioning. Some tennis techniques require greater strength, explosiveness, and flexibility than others. Improvement might come quicker if serious practice on a technique is postponed until some *conditioning* (e.g. grip strength, stretching) is performed. This is especially relevant for athletes that tend to rush a comeback from an injury.

CONCLUSION:

Effective qualitative analysis involves the integration of information from all the sport sciences and a broader vision of the process than has traditionally developed with professional experience alone. Tennis professionals will be more effective analysts if they strive to implement a four task model of qualitative analysis (Knudson & Morrison, 1997). Important features of comprehensive qualitative analysis to focus on includes: evaluating both strengths and weaknesses of performance, diagnosing the cause of limited performance, careful prescription of a single intervention, and continuing the process of qualitative analysis.

REFERENCES:

Arend, S., & Higgins, J.R. (1976). A strategy for the classification, subjective analysis, and observation of human movement. *Journal of Human Movement Studies*, **2**, 36-52.

Ariel, G., & Braden, V. (1979). Biomechanical analysis of ballistic vs. tracking movement in tennis skills. In J. Groppel (Ed.), *A national symposium on the racket sports*. (pp. 105-123). Urbana-Champaign: University of Illinois Press.

Birrer, R.B., Levine, R., Gallippi, L., & Tischler, H. (1986). The correlation of performance variables in preadolescent tennis players. *Journal of Sports Medicine*, **26**, 137-139.

Brody, H. (1987). *Tennis science for tennis players*. Philadelphia, PA: University of Pennsylvania Press.

Buti, T., Elliott, B., & Morton, A. (1984). Physiological and anthropometric profiles of elite prepubescent tennis players. *Physician and Sportsmedicine*, **12**(1), 111-116.

Elliott, B.C. (1988) Biomechanics of the serve in tennis--a biomedical perspective. *Sports Medicine*, **6**, 285-294.

Elliott, B.C., Ackland, T.R., Blanksby, B.A., Hood, K.P., & Bloomfield, J. (1989). Profiling junior tennis players Part 1: Morphological, physiological, and psychological normative data. *Australian Journal of Science and Medicine in Sport*, **21**(3), 14-21.

Elliott, B.C., Ackland, T.R., Blanksby, B.A., & Bloomfield, J. (1990). A prospective study of physiological and kinanthropometric indicators of junior tennis players. *Australian Journal of Science and Medicine in Sport*, **22**, 87-92.

Elliott, B., & Kilderry, R. (1983). *The art and science of tennis*. Philadelphia, PA: Saunders College Publishing.

Elliott, B.C., Marshall, R.N., & Noffal, G.J. (1995). Contributions of upper limb segment rotations during the power serve in tennis. *Journal of Applied Biomechanics*, **11**, 433-442.

Elliott, B.C. , Marsh, T., & Overheu, P. (1989). A biomechanical comparison of the multisegment and single unit topspin forehand drives in tennis. *International Journal of Sport Biomechanics*, **5**, 350-364.

Groppel, J.L. (1992). *High tech tennis* 2nd ed. Champaign, IL: Leisure Press.

Groppel, J.L., Loehr, J.E., Melville, D.S., & Quinn, A.M. (1989). *Science of coaching tennis*. Champaign, IL: Leisure Press.

Groppel, J.L, & Roetert, E.P. (1992). Applied physiology of tennis. *Sports Medicine*, **14**, 260-268.

Hay, J.G., & Reid, J.G. (1988). *Anatomy, mechanics, and human motion*. Englewood Cliffs, NJ: Prentice-Hall.

Kernodle, M.W., & Turner, E.T. (1998). The effective use of guidance techniques in teaching racquet sports. *Journal of Physical Education, Recreation and Dance*, **69**(5), 49-54.

Kibler, W.B., McQueen, C., & Uhl, T. (1988). Fitness evaluations and fitness findings in competitive junior tennis players. *Clinics in Sports Medicine*, **7**(2), 403-416.

Knudson, D. (1991). The tennis topspin forehand drive: technique changes and critical elements. *Strategies*, **5**(1), 19-22.

Knudson, D. (1990). Intra-subject variability of upper extremity angular kinematics in the tennis forehand drive. *International Journal of Sport Biomechanics*, **6**, 415-421.

Knudson, D., & Kluka, D. (1997). The impact of vision and vision training on sport performance. *Journal of Physical Education, Recreation and Dance*, **68**(4), 17-24.

Knudson, D., Luedtke, D., & Faribault, J. (1994). How to analyze the serve. *Strategies*, **7**(8), 19-22.
Knudson, D., & Morrison, C. (1997). *Qualitative Analysis of Human Movement*. Champaign, IL: Human Kinetics.
Kraemer, W.J., Triplett, N.T., Fry, A.C., Koziris, L.P., Bauer, J.E., Lynch, J.M., McConnell, T., Newton, R.U., Gordon, S.E., Nelson, R.C., & Knuttgen, H.G. (1995). In-depth sports medicine profile of women college tennis players. *Journal of Sport Rehabilitation*, **4**, 79-98.
McPherson, M.N. (1996). Qualitative and quantitative analysis in sports. *American Journal of Sports Medicine*, **24**, S85-S88.
Norman, R.W. (1975). Biomechanics for the community coach. *Journal of Physical Education, Recreation and Dance*, **46**(3), 49-52.
Plagenhoef, S. (1979). Tennis racket testing related to tennis elbow. In J. Groppel (Ed.), *A national symposium on the racket sports*. (pp. 291-310). Urbana-Champaign: University of Illinois Press.
Roetert, E.P., Garrett, G.E., Brown, S.W., & Camaione, D.N. (1992). Performance profiles of nationally ranked junior tennis players. *Journal of Applied Sport Science Research*, **6**, 225-231.
Roetert, E.P., et al. (1996). Fitness comparison among three different levels of elite tennis players. *Journal of Strength and Conditioning Research*, **10**, 139-143.
Roetert, E.P., Piorkowski, P.A., Woods, R.B., & Brown, S.W. (1995). Establishing percentiles for junior tennis players based on physical fitenss testing results. *Clinics in Sports Medicine*, **14**(1), 1-21.

PRODUCING AN 'EXPLOSIVE' FOREHAND AND BACKHAND

Rafael Bahamonde
School of Physical Education
Indiana University-Purdue University Indianapolis, Indiana

The pattern or sequence of motions performed during a forehand or backhand stroke is called technique. The motions that produce a specific technique are the result of the internal and external forces acting on a player's body. Coaches as well as athletes need to understand what these forces are and how they are related to the performance of tennis strokes. A good understanding of these biomechanical principles will help coaches to better analyse and improve athletic performance and to determine why certain movements or techniques are better than others. The purposes of this paper are to explain the basic biomechanical principles used to develop explosive forehand and backhand strokes and to review the latest biomechanical research available on the forehand and backhand strokes.

KEY WORDS: forehand, backhand, tennis, and biomechanics

INTRODUCTION:

Do what the pros do? One of the most common mistakes made by coaches and athletes is to imitate the techniques of professional players. Hay (1993) called this practice "copying the champions." Hay (1993) suggested that many professional players succeed because of their physical attributes not because of their optimal techniques. In other cases, players develop idiosyncrasies - unique aspects of the players' strokes that do not contribute to the strokes (Groppel, 1992). As coaches, teachers, and athletes we should look for the basic skills that players use to perform tennis strokes (i.e. trunk rotation, leg action, etc.) that are the result of the physical laws of motion. We must keep in mind that although the physical laws of motion govern basic tennis skills, there are different mechanisms for the application of these laws. In tennis, this can be seen in the different stroke techniques used by tennis players. Also, we must be aware that there is not one "single perfect way" to swing a racket.

Basic biomechanical principles: A coach or player with a basic understanding of the biomechanics of stroke production would be more effective in the evaluations of new techniques and in observing, analyzing, and correcting errors in performance. Therefore, it is essential to review the biomechanical concepts used in the performance of the forehand and backhand strokes. For this paper, these concepts have been classified as external (dealing with forces acting on the player's body) and internal (dealing with muscular actions produced by the players).

External: The first concept is the *Law of Inertia*. *Inertia* is the quality of a body to resist changes to its state of motion. Carr (1998) best described it as the enemy of an athlete who wants to get moving because the athlete's mass resists his/her acceleration. Once in motion, the athlete's inertia wants to keep him/her going. These two characteristics of inertia, resist and persist, not only occur in linear motion, but they also occur in rotational motion.

The second concept is the *Law of Acceleration*. This law states that a force applied to a body (racket, ball, human being, etc.) causes an acceleration of that body of a magnitude proportional to the force, in the same direction of the force, and inversely proportional to the mass of the body. For instance, for a player to accelerate a racket he must apply a force to the racket. For a given racket, the larger the force, the greater the acceleration of the racket. If the player uses a heavier racket (greater mass) and assuming he is able to apply the same force, the acceleration of the racket will be less. The *Law of Acceleration* also occurs in rotational motion. In many situations, such as an off-centre impact (see Figure 1), forces are applied off-centre, which tend to produce a rotary effect or torque. Therefore, for a given *moment of inertia* (the amount of mass and how is distributed relative to an axis of rotation) the greater the torque, the greater the angular acceleration (rotation).

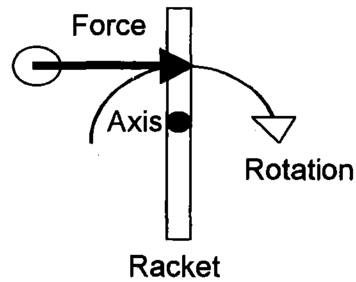


Figure 1 - Off-centre impact

The third principle is the *Law of Action and Reaction.* This law states that for every action there is an equal an opposite reaction. This is one of the most important laws in tennis because it is the foundation of all tennis strokes. For a player in the ready position to initiate a forehand or a backhand, he/she must make forces against the ground. According to the *Law of Action and Reaction* the ground pushes back on the player with an equal and opposite force. This ground reaction force is used to overcome the inertia of the player and initiate movement and to develop the linear and rotational momentum of the body.

Internal: The amount of force a player is able to develop during a forehand or backhand stroke is not only dependent upon the external forces but also is dependent upon internal factors associated with the mechanics of muscle contraction. Muscles can produce different types of contractions: *isometric*, no change in the muscle length; *concentric*, contraction involving shortening of the muscle; and *eccentric*, a contraction involving a lengthening of the muscle. It is known that the amount of force produced by a muscle depends on the type of contraction and the velocity of the contraction (see Figure 2). It is also known that human muscle is able to produce larger forces under eccentric contraction than under concentric contraction. Therefore, it should be advantageous for a tennis player to try to develop eccentric muscular contractions during the forehand and backhand strokes.

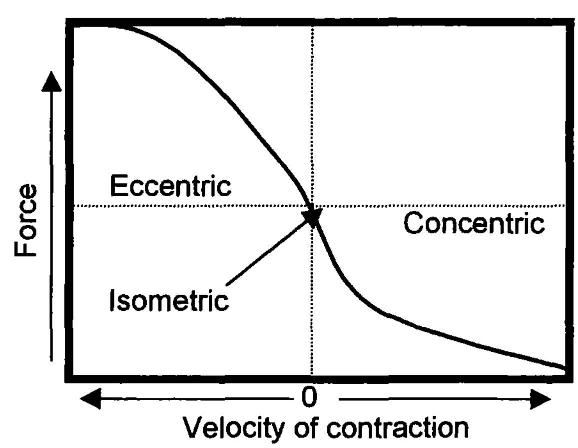


Figure 2 - Force-velocity relationship

Have you ever wondered why in many high performance activities (serve, forehand, and backhand) athletes use a sequence in which the muscles are first lengthened and then shortened instead of just shortening the muscles? This sequence is called the *stretch-shortening cycle*. By using this sequence of eccentric-concentric muscular contractions, players are able to produce more muscular force than with just simple concentric contractions. This extra force is the result of the elastic energy stored in the muscle.

Muscles tend to behave like rubber bands. The energy is stored in the elastic tissue of the muscle when stretched is and released during the shortening phase of the sequence. Researchers have shown that the ability of the muscle to release the stored elastic energy is affected by the time, magnitude, and the velocity of the stretch. Wilson et al. (1991) showed that the longer the delay between the eccentric and concentric phases, the greater the loss of elastic energy. After a one second delay, 55% of the energy was lost, and after a two second delay, 80% of the energy was lost. A player who executes a backswing too early is forced to pause between the end of the backswing and the start the forward swing and will lose some of the elastic energy stored in the muscles. Elliott (1995) suggested that for maximum efficiency players, must practice a smooth flow from backswing to forward swing. The magnitude of the stretch also affects the amount of elastic energy released. Too much pre-stretching of the muscle could be detrimental (Eldnam, Elzinga, & Noble, 1978). Finally, it has been shown that the greater the velocity of the stretch, the greater the storage of elastic energy (Rack and Westbury, 1974).

METHOD:

How to Produce an Explosive Forehand and Backhand:

Equipment: One of the most revolutionary changes in tennis has been the improvement in racket technology. Many people believe that the improvements in racket technology are responsible for the changes in stroke mechanics (Brody, 1997). Modern rackets are considerably lighter (more than 30-40 % lighter than the classic wooden rackets) due to the use of new composite materials. But the new rackets are head heavy because most of the weight has been removed from the handle and shaft. Players now have the advantage lighter rackets with about the same swing weight "punch" as heavier rackets (Brody, 1995). Other advantages of the new racket frames are that they are wider and stiffer. A wider racket has more stability when the impact is off-centre due to its larger *moment of inertia*. Stiffer frames have more power than flexible frames since less energy is wasted in bending the racket at impact. How can these new racket frames help a tennis player hit an explosive forehand and backhand? By reducing some of the racket twist from off-centre hits, the ball's erratic path is reduced and more of the ball rebound speed is maintained (See Figure 3) which gives the player more power and a larger margin of error in the stroke (more forgiving) (Brody, 1995, 1997).

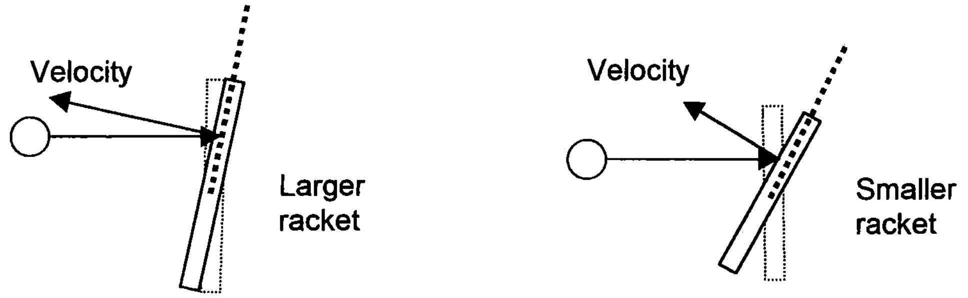


Figure 3 - Diagram of racket twist as a function of racket size

Grip: Over the years the topic of grip firmness has created a great deal of controversy for coaches and researchers. Statements such as, "A firm grip will add the arm's weight to the racket weight hence giving the player more power" can still be found in the tennis literature (Brody, 1995). There are numerous studies that have shown that grip firmness is not an important factor in determining the ball velocity of central impacts (Baker and Putnam, 1979; Elliott, 1982; Brody, 1995). In contrast, during off-centre and/or off-axis impacts, the ball rebound velocity is affected by grip firmness (Elliott, 1982; Grabiner et al., 1983). During off-centre impacts some of the energy of the ball is used to rotate the racket. Therefore, a firm grip is important for off-centre impacts because a tight grip reduces the tendency of the racket to rotate and provides more impulse and control. How do players actually prepare their grips for impact? To answer this question Knudson and White (1989) and Knudson (1991) studied grip preparation and firmness during the forehand and one-handed backhand strokes. Sensors placed on the racket handle at the level of the hypothenar eminence (fleshy part of the palm of the hand, little finger side), the base of the index finger, and/or the thenar eminence (fleshy part of the palm of the hand, thumb side) were used to measure forces pre and post-impact. All subjects tightened their grips before impact by increasing the forces at the hypothenar sensor for the forehand and at the thenar sensor for the backhand. Although pre-impact forces showed a consistent pattern, post-impact forces were variable, ranging from 4 to 309 N and from 6 to 124 N for the forehand and backhand respectively. The variability of the post-impact forces was the result of factors such as vibration forces transmitted through the racket, ball and racket impact velocity, and impact location.

Open vs. Closed Stance: The speed of today's game and the power developed in groundstrokes and serves force players to react faster; they must make forehand and two-handed backhand strokes on the run and use open stances. With the traditional closed stance, the body is turned sideways to the net and as the ball approaches, the player takes a step forward toward the ball to develop linear momentum (the quantity of linear motion that a body possesses). Linear momentum is developed through forces (*Law of Action and Reaction*) generated from the ground as a player steps forward and the body weight is shifted from the back leg to the forward leg (for closed stance footwork). In the open stance, the player takes a slight step sideways toward the sideline. Although the traditional closed stance takes longer to execute, it seems to generate linear momentum and angular momentum. Angular momentum, the quantity of angular motion that a body possesses, is also developed from the ground reaction forces and tends to produce a sequence of body rotations (legs, hips, trunk, upper limb, and racket). If you look at the open stance, there is little or no transfer of linear momentum since the step is taken sideways, and only segmental rotations (legs, hips, trunk, and upper arm) are used to generate power for the forward swing (Groppel, 1992). Although explanations of how linear and angular momenta are used in tennis strokes have been provided by sport scientists, little research has been done to explain exactly how they are developed, transferred, and/or synchronized (Groppel, 1992; Bahamonde, 1998). In two recent studies Bahamonde and Knudson (1998a, 1998b) analyzed the kinematics and kinetics of the two types of hitting stances during the forehand stroke. Results showed that the joint actions used to generate the forward swing were similar in both stances. However, both group of players, teaching professionals and intermediate players, generated larger joint torques at the shoulder and elbow and greater angular velocity of the trunk when using the closed stance, which resulted in greater racket velocities at impact. What stance should a player use to hit explosive forehand and two-handed backhands? From the literature available (Groppel, 1992; Bahamonde and Knudson, 1998a, 1998b) and from the biomechanical perspective, the closed stance seems to be better because it utilizes the linear and angular momentum generated by the players more effectively. Why are so many players using the open stance? Groppel (1992) explained that most players use the open stance not because it is more effective, but because it is faster to execute or because they are too lazy to prepare for the closed stance.

Backswing: The different styles of racket backswing and the belief that some backswings provide more racket velocity and control than others have been another point of controversy among players, coaches, and tennis professionals. It was thought by coaches and players that the traditional straight backswing provided more control (ability to keep the ball in play), and the loop (large and small) backswing provided greater racket velocity. The straight backswing has been popular because it is easy to teach and learn and because of tradition. In the old days, an average player needed to perform a long straight backswing to accelerate the heavier racket. According to Brody (1997), this gradual acceleration gave a player the control needed to hit the ball in a consistent spot. Keep in mind that the sweet spots were considerably small on these old rackets. Sport scientists have shown that the large-loop backswing increases racket velocity, but racket control and timing are more likely to be affected negatively (Groppel, 1992). In contrast, the small-loop backswing seems to increase racket velocity without affecting the timing and control of the stroke (Groppel, 1992; Pecore, 1979). It might be more difficult to hit the ball exactly in the same location with the loop-backswing, but the characteristics of the new rackets and the topspin imparted to the ball give players greater margin of error. For more power and efficiency, the transition between the backswing and forward swing should be a fluid motion regardless of the type of backswing used since it enhances the player's ability to use the *stretch-shortening cycle*.

Forehand Forward Swing: The types of forward swings have also been modified by the quest of players to generate more topspin and power. Many professional and amateur players are using a multi-segment forehand technique in which individual segments (upper arm, forearm, and hand) of the upper extremity are moved relative to each other to generate racket velocity. In contrast, the conventional forward swing calls for the segments of the upper extremity to move as a single unit pivoting from the shoulder. Research by Elliott et al. (1989) showed no major differences in the type of grip or initial footwork preferred by players using either type of forehand swings. However, clear differences were observed during the backswing phase as the multi-segment group had a more compact arm as the result of less shoulder abduction and more elbow flexion. At impact, the multi-segment group generated higher racket velocities (22.5 m/s) than the single-unit group (19.3 m/s), which resulted in higher ball velocities. The higher racket velocities of the multi-segment group were attributed to more movement at the elbow and wrist joints prior to impact.

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 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 (Brody, 1987). In the vertical plane, the trajectory angle has been measured as ranging between 17° and 47° from the horizontal (Groppel, 1992). The optimum angle of the racket in the vertical plane has been suggested to be 28° (Knudson, 1991; Groppel, 1992). This angle provides good spin production and speed when the ball is struck properly. Smaller angles tend to produce less spin, while larger angles sacrifice ball speed and depth of the shot. Changes in footwork and the type of forward swing can influence the stroke arc. For instance, the multi-segment forehand swing produces a smaller stroke arc and a steep vertical trajectory at impact (47°), which might lead to more timing errors and smaller racket horizontal velocities (Elliott, 1989). A small stroke arc reduces the margin of error due to a small swing radius (distance from ball and racket position to pivot point of the arm). For example, a player using the wrist as a pivot point to swing the racket will increase his chances of making an error due the short swing radius. Keeping the wrist firm and using the shoulder as the pivot point (longer radius) would tend to reduce the errors associated with timing (see Figure 4) (Brody, 1987). Players and coaches can further reduce this margin of error by maintaining the racket path in a straight line, following the intended path of the ball. Most researchers agree that hitting with an open stance is not more efficient but results from a lack of preparation time for the forehand stroke (Knudson, 1991; Groppel, 1992). Research by Knudson and Bahamonde (1998) showed that the closed stance allowed a group of teaching professionals to maintain a more accurate racket path in the horizontal plane. But when the players used an open stance it resulted in a 60% reduction in the window of time during which the ball could successfully be hit on the racket face in the horizontal plane. Regardless of the grip, stroke arc, swing, and footwork, proper execution of a topspin forehand stroke requires a nearly vertical or a slightly closed-face (slightly tilted forward) (7°) racket at impact (Elliott et al., 1987).

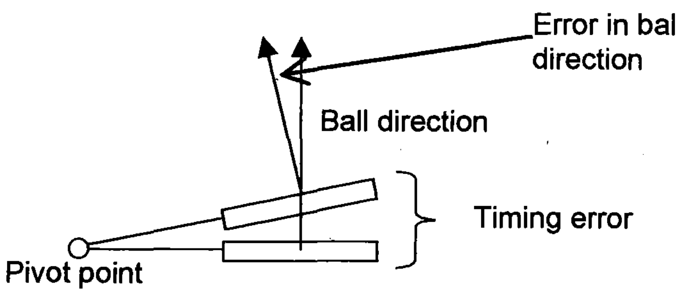


Figure 4 - Diagram of angle error and swing radius

Backhand Forward Swing: The biggest change in the backhand stroke mechanics has been the development of the two-handed backhand. Most backhands are hit with a closed stance, therefore the same mechanical principles (development of linear and angular momentum) explained earlier for the forehand stroke can be applied to the backhand stroke. A two-handed backhand can be performed with an open stance, but once again the player will not benefit from the development of linear momentum. Is one type of backhand better than the other? To date, there is no conclusive research data showing that a two-handed backhand is better than a one-handed backhand. Groppel (1992) suggested that both types of backhand, if executed properly, are conducive to optimal performance. But he also believes that the two-handed backhand could be an extremely powerful and useful shot for several reasons. It is easier to learn because it uses fewer body parts (arms work as a unit), is easier for the development of topspin, requires less strength, and the reach is similar to the one-handed backhand when properly positioned. In a study by Giangarra et al. (1993) the electrical activities of selected forearm muscles were recorded during the performance one and two-handed backhand strokes of two groups of 14 players. Surprisingly, no significant differences in the muscle activities were found between the two styles of backhands with the exception of increased activity of the pronator teres muscles during the acceleration phase of the two-handed backhand.

Regardless of the type of backhand used, there are certain motions that players can do to increase the power of the stroke. Elliott et al, (1989) have shown that racket and shoulder alignment at the end of backswing seems to be crucial in the development of trunk rotation. Observations of professional players by Elliott (1995) have shown that many of them prepare for the backhand by positioning the racket near parallel to the fence. This extreme twisting of the trunk could be useful in the development of more angular momentum and thus racket velocity. For the one-handed backhand, elbow joint rotation seems to play crucial role in the development of racket velocity. Studies by Elliott et al. (1989, 1995) showed that elite players extended their elbows very rapidly prior to impact during the topspin and backspin backhands. In the backspin backhand, elbow extension accounted for approximately 25% of the racket velocity at impact (Elliott et al., 1995). EMG studies of the elbow and shoulder functions have shown moderate activity of the triceps, middle deltoid, supraspinatus, and infraspinatus muscles during the acceleration phase of the one-handed backhand (Morris et al., 1989; Richard et al., 1988). During the backswing phase, all these muscles together with the trunk muscles are stretched then followed by concentric contractions during the forward swing, thus enhancing the production of force and leading to greater segmental rotations and more velocity.

Developing effective trunk rotation: One of the most important elements of the forehand and backhand strokes is the development of optimal trunk rotation. What is the secret of developing optimal trunk rotation? Imagine a player trying to hit a forehand on ice. The player can exert large muscular contractions to rotate the trunk, but in the absence of friction the lower body would tend to rotate in the opposite direction (*Law of Action and Reaction*) resulting in an ineffective forehand. In contrast, if the player's feet are firmly in contact with the court, the reaction forces are all transmitted to the ground. Now the player makes forces against the ground which cause the ground to make forces on the player. These forces produce linear movement and initiate a sequence of rotations starting with the legs and travelling upward to the trunk and finally to the racket.

Optimal trunk rotation also facilitates the production of maximal muscular force at the shoulder (see Figure 5).

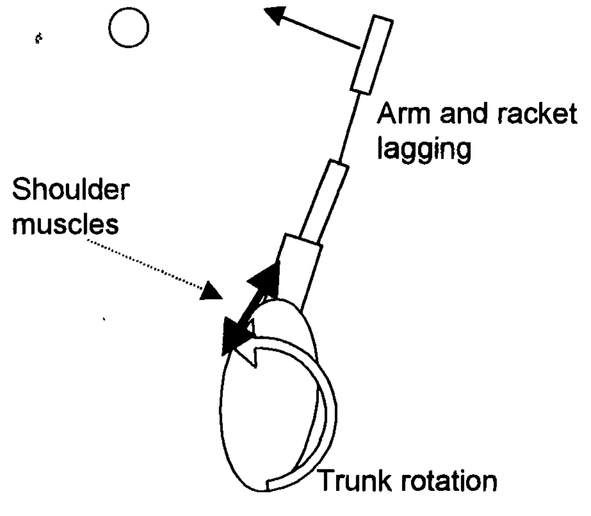


Figure 5 - Relationship between trunk rotation and shoulder muscles

When the trunk rotates, the racket and arm tend to lag behind. This lagging of the arm and racket stretches the shoulder musculature. At the same time, these muscles are contracting possibly exerting eccentric or slow concentric contractions. Figure 2 shows that muscles are able to produce greater contractile force during slow concentric or eccentric contractions. Therefore, the rotation of the trunk tends to keep the shoulder muscles stretched during the forward swing, which enhances their capacity to generate more force. If the trunk does not rotate and it stays fixed, the shoulder muscles would tend to produce fast concentric contractions which results in less force.

Bahamonde and Knudson (1998b) investigated the relationship between trunk rotation (angular velocity) and racket velocity for a group of teaching professionals and intermediate players. As expected, the professional players generated greater trunk rotation and racket velocity at impact than the intermediate players. Regardless of the type of stance used, trunk rotation was highly correlated with the racket velocity of the players (see Figure 6).

Follow-through: What is the importance of the follow-through? If we observe a group of players hitting groundstrokes, we are going to see a variety of follow-throughs. Most players do not realize the importance of the follow-through. There are several factors that warrant the performance of a follow-through. First, a complete follow-through would allow the player to continue the acceleration of the racket through impact. The lack of or a short follow-through would cause the racket to slow down prior to impact. Second, the follow-through should make the racket follow the intended path of the ball as long as possible. Coaches are always giving tips to their players about the importance of this second factor. Tips such as "make the strings follow the ball as long as possible" or "think of hitting a sequence of balls" help players to develop effective follow-throughs. And third, a complete follow-thorough may reduce the chances of injuries. Imagine if you try to hit a normal speed forehand without a follow-through! You develop large contractions of the muscles used to swing the racket forward, but to slow down the momentum of the arm and racket, the opposite group of muscles must forcefully contract to stop the arm. During this period of time these muscles are also being stretched, therefore they may be forced to produce rapid eccentric contractions that may lead to injuries.

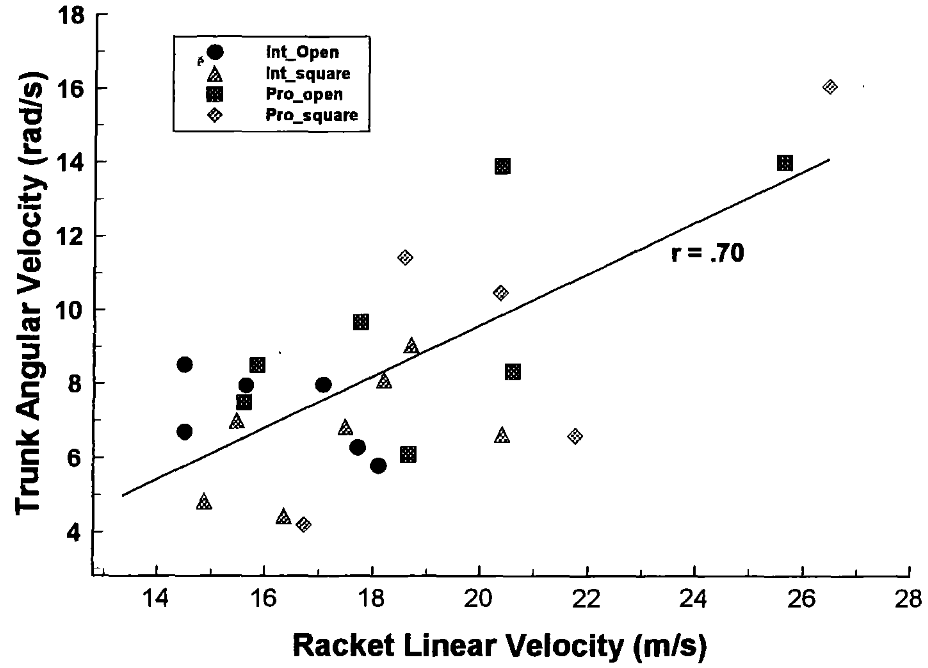


Figure 6 - Relationship between trunk rotation and racket velocity

CONCLUSION:

What can coaches or players do to produce explosive forehands and backhands? Coaches and players need to understand the basic biomechanical principles and how to apply them to the different components of the strokes. The evaluation of popular techniques should be based on the results of scientific data and not on the popularity of the technique. Based on the scientific information in this paper the following suggestions are presented. 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 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 closed stance whenever possible, not only does it seem 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, one vs. two-handed backhand) that best suits the player's physical and motor skill abilities. Regardless of the type of forward swing, stress the importance of generating trunk rotation during the forehand and backhand strokes. Explain to players the importance of a proper follow-through.

REFERENCES:

Bahamonde, R.E. (1998) Angular momentum changes during the tennis serve. (In review).

Bahamonde, R.E. & Knudson, D.V. (1998a). Upper extremity kinetics of the open and closed stance forehand. 4th International Conference on Sports Medicine and Science in Tennis, Coral Gables, FL.

Bahamonde, R.E. & Knudson, D. (1998b). Kinematic analysis of the open and square stance tennis forehand. *Medicine and Science in Sports and Exercise.*, **30**(5):s29.

Baker, J.A. & Putnam, C.A. (1979). Tennis racket and ball responses during impact under clamped and freestanding conditions. *Research Quarterly.*, **50**:164-170.

Brody, H. (1997). The influence of racket technology on tennis. *TennisPro.*, **5**:10-11,Sept-Oct.

Brody, H. (1995). How would a physicist design a tennis racket. *Physics Today.*, 26-31, March.

Brody, H. (1987) *Tennis science for tennis players.* Philadelphia: University of Pennsylvania Press.

Carr, G. (1997). *Mechanics of Sports.* Champaign, IL: Human Kinetics

Eldnam, K., Elzinga, G. & Noble, M. (1978). Enhancement of mechanical performance by stretch during tetanic contractions of vertebral skeletal muscle fibers. *Journal of Physiology.*, **424**, 133-149.

Elliott, B.C. (1982). Tennis: the influence of grip firmness on reaction impulse and rebound velocity. *Medicine and Science in Sports and Exercise.*, **14**:348-352.

Elliott, B.C, Marsh, T. & Overheu., P. (1989). A biomechanical comparison of the multi-segment and single unit topspin forehand drives in tennis. *International Journal of Sports Biomechanics*, **5**:350-364

Elliott, B.C., Marsh, T. & Overheu, P. (1987). The mechanics of the Lendl and conventional tennis forehands: A coach's perspective. *Sports Coach*, Oct/Dec:4-9.

Elliott, B.C. (1995). The biomechanics of stroke production. *Science and Racket Sports*, edited by Reilly, Hughes, & Less. London: Chapman & Hall.

Giangarra, C.E., Conroy, B. Jobe, F.W., et al. (1993). Electromyographic and cinematographic analysis of elbow function in tennis players using a single and double-handed backhand strokes. *American Journal of Sports Medicine.*, **21**(3):394-399.

Grabiner, M.D., Groppel, J.L., & Campbell, K.R. (1983). Resultant tennis ball velocity as a function of off-centre impact and grip firmness. *Medicine and Science in Sports and Exercise.*, **15**:542-544.

Groppel, J. (1992). *High tech tennis.* Champaign, IL: Leisure Press

Hay, J. (1993). *The biomechanics of sports techniques.* Englewood Cliffs, NJ: Prentice Hall

Knudson, D.V. & White, S.C. (1989). Forces on the hand on the tennis forehand drive: Application of force sensing resistors. *International Journal of Sport Biomechanics*, **5**:324-331.

Knudson, D.V. (1991). Forces on hand in tennis one-handed backhand. *International Journal of Sport Biomechanics.*, **7**, 282-292.

Knudson. D. & Bahamonde, R.E. (1998). Impact kinematics of the open and square stance tennis forehand. 4th International Conference on Sports Medicine and Science in Tennis, Coral Gables, Florida.

Morris, M., Jobe, F., Perry. J, et al. (1989). Electromyographic analysis of elbow function in tennis players. *American Journal of Sports Medicine.*, **17**(2):241-247.

Pecore, L. (1979). A cinematographic analysis of the one-handed backhand drive as used by skilled and unskilled performers. In Proceedings of a National Symposium on the Racquet Sports (edited by J. Groppel), pp. 420-476. Champaign, IL: University of Illinois Press.

Rack, P. & Westbury, D. (1974). The short range stiffness of active mammalian muscle and its effect on mechanical properties. *Journal of Physiology.*, **240**, 331-350.

Wilson, G.J., Elliott, B.C. & Woods, G.A. (1991). The effect of performance of imposing a delay during a stretch-shorten cycle movement. *Medicine and Science in Sports and Exercise.*, **23**, 364-370.

WHERE DO HIGH SPEED TENNIS SERVES COME FROM?

Guillermo J. Noffal
Division of Kinesiology and Health Promotion
California State University, Fullerton, Fullerton, CA, USA

KEY WORDS: serve, speed, biomechanics.

INTRODUCTION: The power serve in tennis has received much attention from many researchers from around the world. Part of its popularity may be due to the continuous effort to identify the factors associated with enhancing its speed. There are several aspects, such as, the characteristics of both the racquet and player that may affect one's ability to serve at high speeds. It is of no coincidence for instance that the highest recorded serve speeds to date come from individuals of above normal stature.

Fastest Serves in History

WOMEN

Name	Mph	Km/h	Year	Stature	
Venus Williams	119	191.5	1998	6'1"	185 cm
Brenda Schultz-McCarthy	114	183.4	1994	6'2	188 cm
Venus Williams	112	180.2	1997	6'1"	185 cm
Debbie Graham	109	175.4	1995	5'10"	175cm
Jana Novotna	108	173.8	1997	5'10"	175cm
Steffi Graf	107	172.2	1995	5'10"	175cm
Steffi Graf	107	172.2	1996	5'10"	175cm

MEN

Name	Mph	Km/h	Year	Stature	
Greg Rusedski	143	230.1	1998	6'4"	193cm
Mark Philippoussis	141	226.9	1997	6'4"	193cm
Richard Krajicek	135	217.2	1997	6'5"	196cm
Marat Safin	135	217.2	1998	6'4"	193cm
Alex Radulescu	134	215.6	1996	6'1"	185cm
Goran Ivanisevic	132	212.4	1996	6'4"	193cm
Richard Krajicek	132	212.4	1996	6'5"	196cm
Pete Sampras	132	212.4	1996	6'1"	185cm

There are two main characteristics that are linked to power in a tennis racquet, its mass and composition. Racquets manufacturers have changed the design and composition of the racquet to improve playability and performance. Some of the changes in the composition have been the progression from wood to metal to fibre-reinforced to composite materials. Design changes have progressed from a larger head to a wide-body to extra-long racquets. Waite (1997) has reported that players may be able to immediately increase their power potential by switching to a more power producing racquet. There are two factors regarding racquets that can increase their power producing potential: stiffness and weight. A stiffer racquet provides more power because less of the ball's kinetic energy is absorbed by frame deformation (Ashley, 1993). Stiffer racquets (either the older wide-bodies or the more modern racquets that are thinner but less flexible) allow you to hit the ball "heavier" without really hitting it harder. Each racquet manufacturer has its own scale for measuring the racquet's power level. They, unfortunately, have not been standardized among all manufacturers. Suffice it to say that you need to read the manufacturer's literature or consult a racquet professional (e.g. certified stringer) to understand the relative stiffness of the racquet you are considering. If you desire more power without changing your stroke length or without having to strain to hit the ball harder, the stiffer racquet will certainly help (Waite, 1997).

Adding lead tape to the head of your current racquet (usually at the 3 and 9 o'clock positions) will increase the mass of your racquet. If you are able to maintain the same swing speed with the added mass then the result will be a more powerful serve. However, it should be noted that adding this lead tape would change the balance and "feel" of the racquet. It will take some time for your muscles and mind to adjust to the change. If you look closely at many of the pros' racquets, you will see that they often have lead tape on the heads. Pete Sampras ads lead tape to an already heavy frame, bringing the total weight to 15 or 16 ounces! (about two to four ounces heavier than most conventional racquets). Anecdotally his opponents report the sensation of returning a "heavy" serve.

In addition, racquet manufacturers claim that longbody frames (28 inches or longer) impart more power to the ball. While this may be strictly true, longbody racquets are deliberately manufactured lighter. Thus, the power benefit of the length may be offset by the reduced weight. Therefore, longbody racquets are not inherently more powerful.

The question of whether extra-long racquets produces faster serves has been partially addressed by Tennis magazine in 1997. The magazine conducted an experiment that challenged Mark Philippoussis to hit his first serve with three different racquets: his normal 27-inch-long frame, a 29 ¼ -inch Superlong and an unused wood model. The results indicated that while the maximum speeds did not differ dramatically (127, 127, 124 mph respectively), the accuracy from a total of 15 serves did (52, 80, 60% respectively). This is indicative that serving power does not come from longer racquets but from a player's technique and physical strength.

Strings: The function of strings are to absorb much of the incoming ball's kinetic energy and then return some fraction of that energy back to the ball (Brody, 1995). Recent research has confirmed player's perceptions that looser strings yield more power while tighter strings allow more control and accuracy over the ball (Knudson, 1997).

Perhaps the best method of increasing power in your present racquet is by altering the strings. Two aspects of strings will affect the overall power of the racquet: tension and elasticity. Simply put the lower the strings tension the more power potential the racquet will have. (If you went too low with the tension however, the racquet would actually have less power). Just lowering your string tension 5 or 6 pounds can make a noticeable difference in your racquet's power level. Elasticity refers to the ability of the string to stretch and then return to its original state. Natural gut and "soft" synthetic strings are more elastic, and thus, give the racquet more power potential. However, elastic strings do tend to wear out more quickly. Fortunately, modern string technology is such that synthetics like Gamma's TNT series offer a great blend of power, control and durability. These strings cost a little more, but are well worth the price to the player seeking more power (Waite, 1997). In addition thinner strings are more elastic and they would have a greater ability to store and return energy. Gut strings are again the preferred material as they are able to retain their elasticity at higher tensions, while many synthetic materials begin to lose their elasticity as the string tension is increased leading to a stiff feel when shots are hit hard (Brody, 1995).

Segment rotations: Using the whole body in a fluid and integrated manner can really improve the power of your strokes. A good stroke production begins at your feet, flows up your knees and legs, uses the hips and body weight and then allows the upper body and arms to stroke the ball. We call this efficient use of all body parts in stroke production the kinetic chain.

Racquet Head Size (square inches) and String Tension (lbs) of Top 10 Men and Women

Women	Size	Tension	Men	Size	Tension
Lindsay Davenport	95	65	Pete Sampras	85	75
Martina Hingis	98	60	Marcelo Rios	95	70
Jana Novotna	95	62	Alex Corretja	95	62
Arantxa Sanchez-Vicario	95	60	Patrick Rafter	97	69
Venus Williams	110	62	Carlos Moya	98	57
Monica Seles	130	90	Andre Agassi	107	61
Mary Pierce	85	62	Tim Henman	95	69
Conchita Martinez	95	62	Karol Kucera	95	65
Steffi Graf	95	62	Greg Rusedski	95	48
Nathalie Tauziat	110	56	Richard Krajicek	90	59

Leg drive produces a stretch shorten cycle as the shoulder is driven upwards and the racquet moves downward. This increase in the range of motion allows the player to create more impulse by applying force over a longer period of time.

The kinematics of the upper limb during the execution of a flat tennis serve for maximum velocity have been reported in various studies (Elliott et al., 1986; Noffal, 1997). Segment endpoint velocities increase from proximal to distal and follow a shoulder-to-elbow-to-wrist-to-racquet-center sequence.

Much like throwing, serving a flat serve requires movement of the entire upper limb (upper arm, forearm and hand) which occurs during a short period of time. The shoulder for example rotates externally prior to internally rotating. The range of motion during this rotation is approximately 80 degrees (Noffal, 1997). The external position of the upper arm can only be reached dynamically and it is also observed in other throwing actions. This cocked position serves to place the internal rotation muscles on stretch. The forearm also rotates rapidly in the acceleration phase of the serve moving through a range of approximately 52 degrees. The role of this pronation is to correctly position the racquet head in preparation for impact and not to substantially contribute to racquet velocity. The wrist extends in the cocking phase and then rapidly flexes in the acceleration phase. This flexion of the wrist has been reported to be a major contributor to racquet velocity (Elliott et al., 1995). The wrist also moves from a radial deviated position to an ulnar deviated position at impact. This ulnar deviation seems to be a natural continuation of the wrist flexion movement and it also aids the racquet in reaching a more vertical position.

Shoulder and elbow loads in a tennis serve:
Noffal and Elliott (1998) calculated the resultant joint forces and moments present in the shoulder and elbow joints during the tennis serve. An appreciation of these forces will allow inferences that relate the kinetics of the movement to the mechanical properties of the structures reported to be frequently damaged. With this information, it may then be possible to modify technique or develop equipment to reduce ligament, capsule and muscle stress.

The kinetic analysis of the tennis serve is intended to quantify the resultant joint forces and moments present in the execution of the movement. Furthermore, the resultant values were further partitioned into anatomical directions reflecting muscle groups or soft tissue responsible for producing such movements. This may be of particular interest to the physician and coach, as those phases of the movement associated with high loading conditions can be identified

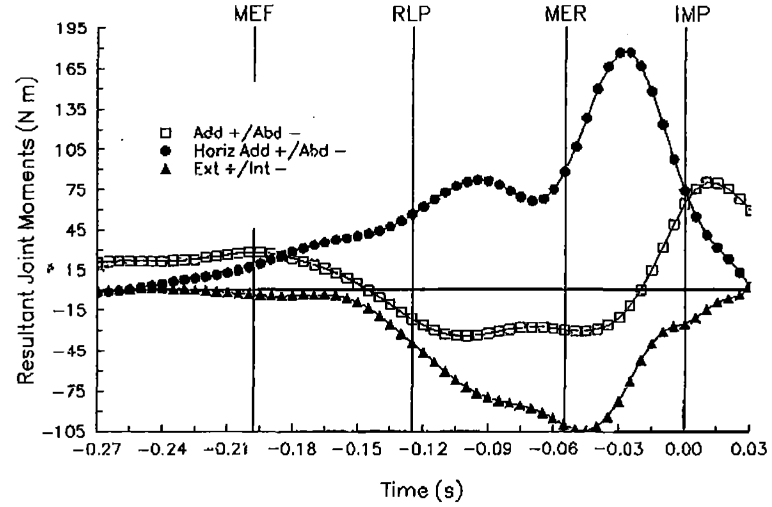


Figure 1 - Shoulder torques during a flat tennis serve of a representative subject

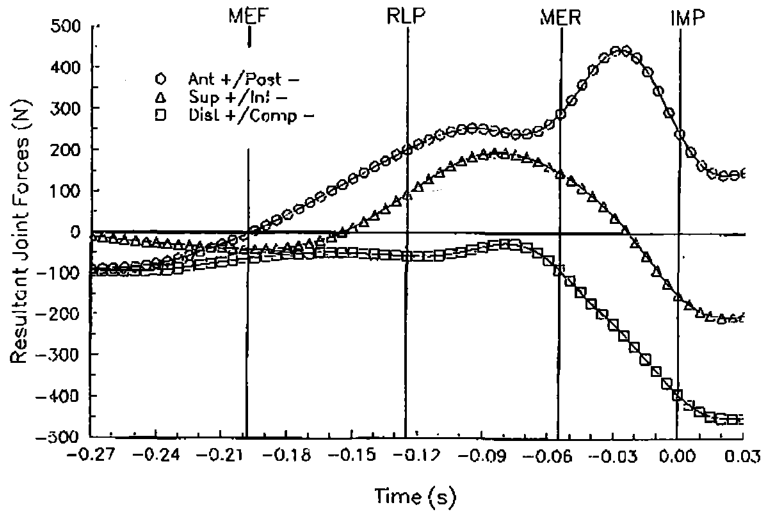


Figure 2 - Shoulder forces during a flat tennis serve of a representative subject

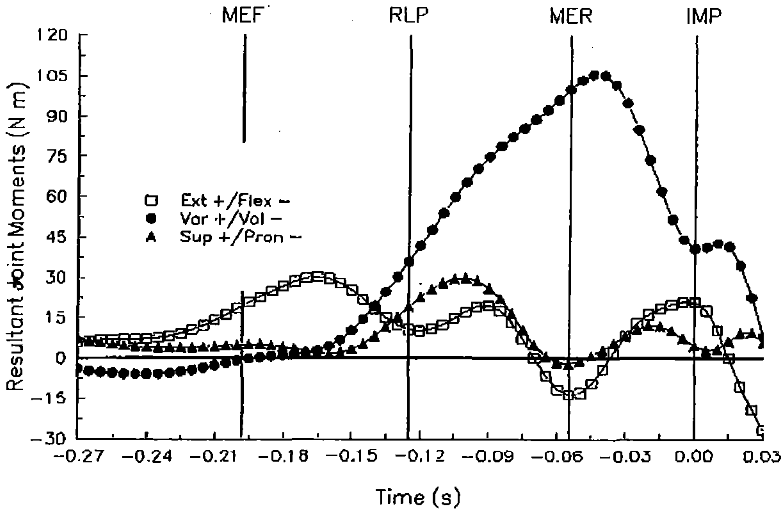


Figure 3 - Elbow torques during a flat tennis serve of a representative subject

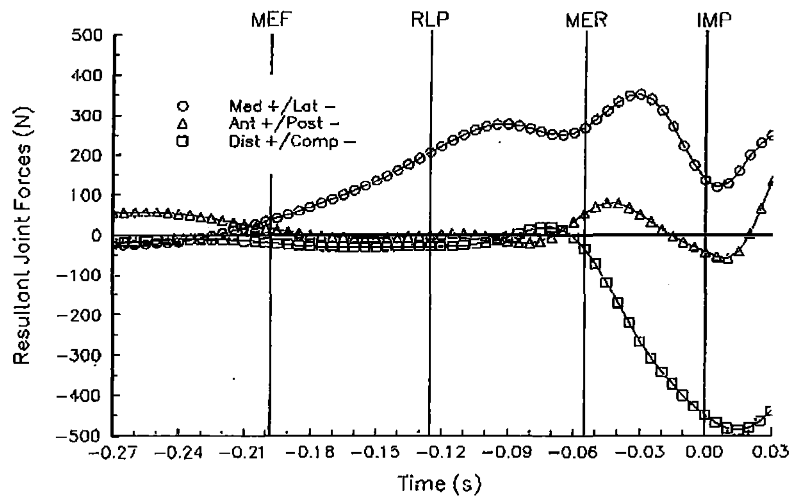


Figure 4 - Elbow Forces during a flat tennis serve of a representative subject

Forces of Interest

- Largest forces were observed during the acceleration phase and also in the follow-through.
- Anterior force at the shoulder reached a maximum of 445 N shortly after MER.
- Superior force maximum of 142 N most likely linked to supraspinatus muscle abducting the arm.
- Compressive forces (352 N) refrained the humerus from subluxing.
- At elbow, medial forces reached 320 N.
- Compressive maximum of 423 N found at the elbow.

Torques of Interest

- Abduction max 50 N m prior to MER used to elevate the arm.
- Adduction max of 82 N m after impact in the follow-through phase.
- Internal rotation max of 94 N m just after MER associated with an eccentric contraction of the internal rotator muscles (pectoralis major, latissimus dorsi, subscapularis).
- Horizontal Adduction torque in the acceleration phase prevented upper arm lag as trunk rotated toward the net.
- Negligible forearm extension and pronation torques signify small muscular contributions.
- Maximum Varus torque of 106 N m in the acceleration phase is linked to shoulder internal rotation torque.

Implications for Injury

- Greater abduction than baseball may produce subacromial impingement.
- Also lower inferior forces in the tennis serve which may be associated with the humeral head translating upwards.
- Reaching extreme ranges of motion during the cocking phase may stress the anterior and inferior portions of the joint capsule and attenuate the inferior glenohumeral ligament.
- Medial epicondylitis may be the result of the repetitive valgus stress.

Injury prevention: While the high upper arm internal rotation velocities of the flat serve have been correlated to developing high racquet velocities the player is cautioned that further increases in the speed of this movement (through training the internal rotator musculature such as the latissimus dorsi and the pectoralis major) should also take into account what structures are responsible for the deceleration of the upper arm (teres minor and infraspinatus muscles). Caution should equally be exercised with attempts to increase wrist flexion velocities, as several injuries to this area are recently becoming more apparent.

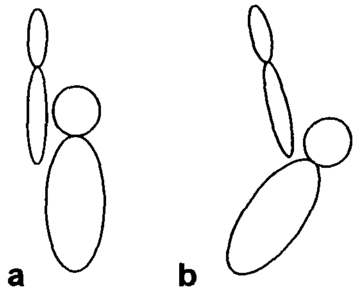


Figure 5a and 5b - Alignment of the upper limb to the trunk

In an attempt to reach a high impact point certain players may adopt a similar position as that described in Figure 5a above. However the correct alignment of the upper limb to the trunk should not be 180 degrees but more like 90 to 100 degrees (Figure 5b) therefore not placing the shoulder in a harmful position (Ellenbecker, 1998).

Ball spin: Any ball spin will take away from the overall power effect of the ball's impact. Now, in a strict sense, it is impossible to hit a truly motionless ball (all strokes produce some spin). However, some balls are hit in a relatively flat manner (small ball rotation). Flat shots are the fastest and heaviest shots. The flat serve is, perhaps, the modern player's biggest weapon.

Yandell (1998) found that there is no such thing as a "flat" ball in professional tennis and provided the data below from two of the best servers in the present time.

	First Serve MPH	RPM	Second Serve MPH	RPM
Philippousis	123	2198	99	4018
Sampras	120	2699	85	4623

Close to 5000 RPM on the second serve equates to more than 60 rotations before reaching the receiver.

However it was also found that even a 120 MPH serve slows to approximately 55 MPH by the time the receiver hits the ball. Air resistance during the flight of the ball and friction of the bounce on the court both act to reduce the velocity of the ball.

CONCLUSION:

Choose a racquet that reflects your swing pattern, remembering that the greater the mass or "swing weight" the more speed may be imparted on the ball. If off-center hits are frequent then a wider body head, which tapers, to its top edge may also be beneficial.

Choose thinner gut strings as these are more elastic and are able to maintain their elasticity at high tensions. In addition lowering your string tension may also allow you to add more power to your game, keeping in mind that there exists a point of diminishing returns when the chose tension becomes too low.

Remember that the serve is composed of a sequence of body rotations and a fluid motion is more desirable than attempting to increase the velocity of a specific segment. The serve has been associated with shoulder injuries and these injuries may be a result of muscle imbalances and the repetitive overload nature of the game. Special attention should be paid to maintaining shoulder stability by retaining muscular function (strength and flexibility) in the shoulder and scapular regions.

REFERENCES:

Ashley, S. (1993). High-tech racquets hold court. *Mechanical Engineering*, 50-55.

Brody, H. (1995). How would a physicist design a tennis racquet? *Physics Today*, 26-31.

Ellenbecker, T. (1998). Shouldering the load. *Sport Science News.* The USTA Newsletter on the Science of Tennis, Fall issue, 4-5.

Elliott, B., Marsh, T. & Blanksby, B. (1986). A three-dimensional cinematographic analysis of the tennis serve. *International Journal of Sports Biomechanics*, **2** (4), 260-271.

Elliott, B., Marshall, R., & Noffal, G. (1995). Contributions of upper limb segment rotations during the power serve in tennis. *Journal of Applied Biomechanics*, **11** (4), 433-442.

Knudson, D. (1997). Effect of grip models on rebound accuracy of off-center tennis impacts. *Biomechanics in Sports XV*, 483-487.

Noffal, G. (1997) Three-dimensional kinetics of the shoulder and elbow joints in the high performance tennis serve: Implications for injury. *Unpublished Doctoral Dissertation.* The University of Western Australia.

Noffal, G. and Elliott, B. (1998). Three-dimensional kinetics of the shoulder and elbow joints in the high performance tennis serve: Implications for injury. *Proceedings of the 4th International Conference of Sports Medicine and Science in Tennis*, Coral Gables, Florida.

Waite, R. (1997). Power to the people. *Turbo Tennis.* http://www.tennisserver.com.

Yandell, J. (1998). Spin is in! *Sport Science News-* The USTA Newsletter on the Science of Tennis, Fall issue, 4-5.

PERFORMANCE IMPLICATIONS OF PHYSICAL AND MENTAL GROWTH OF THE YOUNG ATHLETE

Barry Gibson
Edith Cowan University, Perth, Western Australia

The extensive involvement in sport and physical activity is an integral part of western society. On many occasions sport has been described as a major social institution. The adult controlled sporting mediums largely caters for young people in the age range of 10-18 years off age and involves millions of children world wide. There are proponents of junior sport who view it as a miniature life situation where children can learn life-long skills that will enable them to tackle the tasks of later life more competently. Critics on the other hand counter by pointing out that the excessive physical and psychological demands placed on the young people in these programs are primarily designed to satisfy the egos of coaches and parents. In order to gain a balanced point of view one needs to carefully consider the physiological and psychological development of children in this age range and ensure that these factors are taken into account when designing and conducting sporting programs for the young children.

KEY WORDS: Physical Development, Psychological Development, Performance, Youth Sport

INTRODUCTION:

Many factors must be taken into account when considering the growth and maturation of the human body and the readiness of children to compete successfully and without fear of injury in a sporting competition. It is well documented that children participate in competitive sport at many levels, ranging from free play through to the highly organised competitive league. This exposure provides sport with significant power and influence in young children's lives.

In many countries interschool sport and inter club competitions are an everyday occurrence and could be classed as a way of life. These sporting competitions are not without their problems and short comings, and in a number of instances there is opposition to the "institutionalised" type of organisation that sport displays. Some issues include the readiness of the children, appropriateness of the physical contact, the early specialisation, parental pressures, and the suitability of the game for children. Other concerns include the early talent identification programs that are being established and the intensive training and demand the sports are placing on the growth and development of the young bodies. One only has to look at the intensity of the training programs that are required for elite level women gymnasts to appreciate what damage can be done. This example is parallel to the program for young tennis players, where boys and girls train and play virtually all year round on a variety of hard surfaces. The impact on the body in both of these sports is significant and could have an effect on the growth of joints and limbs. While evidence shows that growth plate injuries due to excessive training are not common, care should be taken during the period of most rapid gain in height (on average 14 to 15 in boys and 12 to 13 in girls), where severe injury to the end of long bones could threaten the growth plate.

PHYSICAL DEVELOPMENT:

Physical growth and maturation: Children grow at different rates at different ages, and different children also develop at different rates, so there will be early and late developers. Not only are the rates of growth different, but also the changes in the body proportions can vary, and this will directly affect the ability to perform. Teachers and coaches are well aware of the young student who has a rapid growth spurt and develops into a gangly type of individual, lacking power and co-ordination. Then, as puberty is reached, there are the differences in body shapes and proportions that become apparent between the sexes, and these changes will also cause problems to arise and difficulties to be experienced. One of the greatest problems experienced by those having a growth spurt is the lack of muscular structure to support and assist with the co-ordination.

Effect of training and exercise on growth and development: Because of the lack of standardisation in research techniques, samples and variables selected for observation, it is very difficult to conclude whether exercise has a negative, positive, or no effect at all on skeletal development. With the simultaneous effects of normal growth, and a variety of other factors, it is very difficult to accurately attribute growth to exercise. While it has been difficult to separate maturation and training effects on performance, one facet of skeletal growth that is affected is the bone density. Bone density is found to increase with physical activity and decrease with inactivity. Evidence of this has been found in tennis players where the bone of the dominant arm has a higher density than the non-dominant arm.

Aldridge (1996, p.61) concludes that, "there appears to be a sports specific relationship between skeletal development maturation and success. This relationship is probably not produced by the different training required for different sports, but is more probably an inherited characteristic in the individual". It therefore follows that the late developer is probably more suited to gymnastics while the early developer is more suited to sports involving contact, strength and speed.

Regular physical activity is believed to have a favourable influence on the organism during growth and development. Studies have shown that physical activity is also a significant factor in controlling weight and in the growth of skeletal and muscular tissue. While training can reduce body fat and increase muscle bulk, it has been demonstrated that regular activity has no apparent effect on stature, skeletal proportions and physique, or biological maturation as commonly assessed in growth studies (Malina, 1980, 1983a).

Studies undertaken comparing young athletes of local, national and international calibre with the general population generally indicated that young athletes, on average, grow and mature in a similar manner to non-athletes, that is, the training and stress of competition does not advance or delay the growth and maturation of the active young athlete (Malina,1984; Malina, Meleski, & Shoup, 1982). Although some variation during adolescence exists due to individual differences in the timing of the adolescence growth spurt, the individual's somatotyping is relatively stable during growth and is not significantly influenced by intensive training, except for local changes associated with heavy resistance training. This may not be sufficient to markedly alter an individual's somatotype (Malina and Bouchard, 1991).

Patterns of physical growth: Significant material has been produced outlining the growth patterns of children from birth through to full maturity. Research studies have shown that the most rapid period of growth occurs immediately after birth, and then the growth rate slows to a modest steady process during childhood. This is followed by an adolescent growth spurt and then by a deceleration until the growth pattern finally stops. A similar pattern is noted in the relative growth patterns of both boys and girls during childhood, with boys being slightly taller and heavier than girls at the same age. This difference is seen as no real significance in terms of sport performance. Boys will experience their adolescent growth spurt about two years later than girls. Following a rapid gain in height there is a period of maximum gain in weight. This will be due to a large increase in body fat in girls with a relatively small increase in muscle tissue, whereas with boys it is due to a decrease in body fatness and a significant increase in muscle mass. This means that post adolescent girls have only about two thirds as much muscle as their male counterparts and about twice as much body fat.

As the age at which the adolescent growth spurt occurs from one individual to another, there will also be a variation in the readiness of being able to compete in sports events against their peers. The significant differences in age that the growth spurts can occur means that in sports programs matched on age, a number of the competitors will be disadvantaged if they are late maturers. In the childhood years, both boys and girls have the potential to develop strength and increased ability to perform motor skills prior to puberty. During adolescence, boys will develop greater strength and show an increase in performance and endurance than girls. This extends into early adulthood.

The tendency for girls' performances to plateau around the time of puberty has often been attributed to the physical changes that occur, such as the increase in the percentage of body fat. There are however, other reasons such as social rather than biological factors that can be attributed to the decline in girls' performances. Strength is another factor that gradually increases in boys during childhood with boys being slightly stronger than girls. The boys continue to improve during adolescence whereas girls tend to decrease. The rate of increase in boys will of course vary according to their stage of maturity.

At the junior level of competition, the following question is often asked, "Should boys and girls compete against one another?". Because of the very slight differences in size and strength, there is no reason why they shouldn't be competing on the same team during the childhood years. The potential for causing injuries because of size and strength is almost non existent at that stage of development. However, as they reach adolescence the situation changes significantly, with the boys possessing more height, weight and muscle mass, and thus having an advantage in the physical contests and therefore safety and fairness becomes a concern.

Smith , Smoll and Smith (1989, p.56) have recommended that "after the age of eleven, boys and girls should have their own competitive opportunities in those sports in which body size and strength are determinants of proficiency and injury and risk". It is during the adolescent growth spurt that the long bones increase their length by activity of the specialised cells located in the growth plate at either end of the shaft. The cartilage composition of the growth plate is the weakest point in the shaft and is susceptible to injury. If injured, this could cause problems with future growth of the long bones. The Academy of Paediatrics' Sports Medicine Committee has recommended that intense athletic activities such as long distance running and weight training be restricted and, in fact, discouraged during childhood until the rapid growth phase in early adolescence has been completed.

The early and late maturer: The problems associated with early and late maturation are many and varied, and these seem to be particularly relevant in the cases of boys where strength and weight can be important. The early maturer has the advantage in sports where size, speed and physical strength play a major role in success. It has often been noted that the early maturer is able to excel in several major sporting codes. These individuals often enjoy a decided advantage over their team mates and opponents throughout primary school and into the first three years of high school. The early success can have long reaching effects as parents, coaches and the individuals themselves begin to place all their energies into their training to the detriment of their academic program and all round development.

Problems quickly arise when the peer group starts their growth spurt and begins to catch up in terms of strength and speed, and the advantage that the early maturer had is lost. Bewildered and despondent, the youngster is left with an uncomfortable feeling of failure and in some instances rejection as those around him start to have the success that he previously had experienced. To prevent this problem from arising, it is important to provide the early maturer the opportunity to compete with those of a similar maturity, not of the same chronological age. This can be done in both team and individual sports.

Conversely, the late maturer has the problem of experiencing little or no success during those years leading up to adolescence. The late maturer will be small in stature and have less strength, endurance and speed than their average peers. If sport is important to these individuals, it is imperative that they be directed to those activities that are not primarily dependent on size and strength for success. They could also be persuaded to postpone their entry into the competitive arena until such time as they felt comfortable to compete. This may mean waiting until 16 years of age to start participating in competitive sport. This will enable the youngsters to avoid the negative sporting experiences that come with delayed maturity which could be a 'turn off" from sport for life.

Parents and coaches should be aware of the implications of delayed development and establish their expectations accordingly. Given encouragement and the correct management, there is no reason why the late maturer cannot develop and enjoy a successful sporting experience in the senior years of high school.

CONCLUSION:

The question of physical development remains a complex issue, and research has shown that it is affected by many factors. While it is essentially genetically controlled, it is also affected by environmental conditions. The influence of training on the developmental process is still open to debate, and more research is necessary before definite conclusions can be reached. A sound knowledge of processors of growth and development will enable coaches and teaches who are working with children, to organise the training programs that will be more beneficial to the children from a physical and psychological perspective.

PSYCHOLOGICAL DEVELOPMENT

Why is the mental development of the young athlete so important? Millions of children throughout the world are involved in school and extra curricular physical activity programs. Gould and Martens (1979) found that on average children participate intensely in organised sport 11 hours weekly for an 18-week season. A later study by Martens (1986) revealed that in the United States alone 25 million children under the age of 18 years are involved in organised physical activity programs. Given this involvement, the implications for the contributions of sports psychology and the consideration of the mental development of young children is most important.

The psychology literature has highlighted the significance of the social development and the changes in self-esteem that take place throughout the growth of the young child. Given that sports participation peaks around 12 years of age, the sporting experiences in those early years can be critical in determining the attitude that the young children adopt towards sport and physical activity. Contrary to many beliefs, participation in organised sport is not always beneficial and in fact can have a negative impact when it comes to sportsmanship and human relationships. Martens (1978) points out that character development, sportsmanship and achievement orientations do not necessarily occur through just participating.

Psychological and sociological considerations: In between the ages of 7 and 12 years of age, the children are emerging from the dominance of parents to where the peer group influence increases in importance (Spink, 1990). It is in this period of growth that the children develop a sense of identity and an ability to socialise (Harter, 1978). Sport, and in particular team games, provides a median or opportunity through which this development can take place. Often these games are seen to be most beneficial if they are organised and run by the children themselves, away from the influence and direction of adults. This format gives the children feedback about themselves and indicates clearly their performance level as compared to their peer group (Passer, 1988).

Stages of psychological development: Harter's (1981) study investigated the dimensions and development of self-esteem and found that eight year old's do not distinguish between cognitive and physical competence whilst children between the ages of 8-12 years clearly differentiate between the five salient domains: scholastic competence, physical appearance, peer acceptance, and behavioural conduct. With adolescence, four dimensions emerged, these were: close friendships, romantic relationships, job competence and morality.

The results from Harter's study have demonstrated that with the changes in cognitive and physical maturity, changes will also occur in the various competence or behavioural domains. Passer (1996) examined the three psychological issues relevant to guidelines for children's participation in youth sport. The three issues were: motivational readiness, cognitive readiness and potential harmful consequences of participating.

The first issue of when children are in a state of motivational readiness is closely linked to their social comparison behaviour. From a sporting viewpoint, social comparisons occur when children become attracted to, seek out and take advantage of opportunities to compare their physical performance and abilities with others. Studies by Roberts (1980) and Sherif (1976) have indicated that very young children do not compete because they are either incapable of or uninterested in social comparison. It is therefore important to assess the age at which children's social comparison motivation begins to occur.

Naturalistic observational studies have shown that children pass from a stage of autonomous achievement orientation at about two to three years of age (Veroff, 1969; White, 1959), to a stage where children increasingly act to maximise their self-gain from three to five years of age (Pepitone, 1980). At this age level, children will simply act to acquire something they value but will not compete for it in the true sense of social comparison competition (Pepitone, 1980). Other studies performed by Butler (1989) and Pascuzzi (1981) have also supported these findings.

The social comparison motivation has been found to significantly develop during the early years of primary school. Frey and Rubble (1985), in classroom observation studies, found that there was a sharp increase in children's social comparison related to performance assessment once the children began first grade. The research has indicated that children develop an interest in social comparison as a means of determining where they are ranked and how they are performing by comparison with their peers. The major factors that were listed by both primary and secondary school students as focal points for comparison included social comparison interests, physical and athletic ability (Alder, Kless, & Alder, 1992; Buchanan, Blankenbaker & Cotten, 1976). It is therefore to be expected that as children reach this age group they will look to sport and physical activities to develop their skills and make comparisons with their peer group.

If motivational readiness is to be used as a guide for participation in sport and physical activity, it would appear that participation should be around seven to eight years of age, and then it should be carefully monitored to ensure that the children are coping with the competitive situation.

The second issue identified by Passer (1996) is the children's cognitive readiness for competition, and more specifically their information-processing abilities. It is important for young athletes to be able to attend to and remember considerable amounts of information in order to successfully perform the skills required in a specific sport or activity. At pre-school age the children tend to have a short span of attention and are easily distracted, whereas once they progress through the primary school they are able to concentrate for longer periods of time and focus on the tasks required (Ruff & Lawson, 1993). The children also become much more adapt at gathering relevant information and ignoring task-irrelevant information. In addition, the children's memory capabilities improve as they grow older and they are able to store and process information at a much faster rate and are much more flexible in their thinking. They also display other cognitive abilities during this stage, these being simple logical reasoning, problem-solving skills and language comprehension. It has been proposed that children's cognitive abilities are such that they do not develop a mature overall understanding of the competition process until they are about 12 years of age (Coakley, 1986; Roberts, 1980).

Coakley (1986) proposes that it is around 10-12 years of age that children finally develop the capacity to recognise other viewpoints, while adapting and making allowances for group perspectives. There still is some debate amongst researchers as to the specific ages at which these perspective-taking abilities develop, as some more recent studies have shown children as young as three years of age adopting another child's perspective at simple tasks (Shaffer, 1993). However, as Coakley (1986) points out, children as young as seven years of age playing a team game often appear completely oblivious to what the other team members are doing and are only interested in the ball and themselves. Observation of children of this age will support this viewpoint put forward by Coakley.

Passer (1996) identified psychological harm as the third potentially harmful consequence that children risk when they participate in organised sport at a very young age. Research has shown that sport competition can have negative psychological effects if it is mismanaged and is inappropriate for the age group. There is always the danger of a lack of motivational and cognitive readiness for competition being a problem with young children. While many may be able to enjoy the playing of sport, they may not like the competitive nature of the games and, as a result, they will be likely to drop out at the first opportunity. Parental pressure and continual peer group evaluation can place additional stress on young athletes and result in an unnecessary competitive component being created which again causes the young athletes to turn away from the sporting scene. When children also just participate to please their parents, high competitive stress has been found to be created (Scalan and Lewthwaite, 1984). McGuire and Cook (1983) have also found that children who participate in youth sport programs with the purpose of pleasing their parents, are less likely to be satisfied with their own sports experiences and are more likely to discontinue with their involvement.

It is important for parents, coaches and administrators who are responsible for children's sport to appreciate that young children do not fully understand the complexities of causal relationships and, as a result, may form inaccurate assessments of their physical skills competence based on their success or failure rate in sports. This can lead to children gaining inaccurate perceptions of their performance outcomes and can lead to them developing unrealistic expectations and misplaced judgements.

Children are very sensitive to the response that they receive from adults, and in many cases adults do not realise this is the case. This response can be a verbal response, which may be either positive or negative, or it may just be in the form of body language, which is interpreted in a particular way by the child. Examples of this include the way in which a child may misinterpret the lack of action, facial expressions or constructive mild criticism from an adult. As a result of how they interpret this response they may become distressed or apathetic. Research has shown that young children are more likely than older children to infer someone's emotion based on a simple outcome such as a remark, a gesture or a facial expression (Gross and Baliff, 1991).

This finding must be kept in mind in the context of sport, where young children are consistently under the eye of coaches and parents, and will be very sensitive to any gestures and responses from these individuals. The children are forever on the lookout for adult responses and feedback with regard to their performance outcomes. Because of their relatively limited cognitive skills, younger children will also experience difficulty in interpreting instructions as well as older children. This problem may lead to children becoming frustrated and unduly stressed along with the parents and coaches. Careful planning, and an appreciation by adults of the situation confronting the young children, can go a long way to avoiding unrealistic expectations of their cognitive and physical abilities. Task demands and level of speech, adjusted to correspond with the developmental level, should assist in making participation in sport a more enjoyable experience for the children.

Why do children participate in youth sports? A significant amount of research has been performed over the past 20 years to provide a wealth of data on why children and adolescents participate and drop out of sport (Wankel and Sefton, 1989; Weiss and Chaumeton, 1992; Weiss and Petlichkoff, 1989). From their studies, these researchers have proposed the following reasons for participating:

- competence (learning and improving skills);
- affiliation (being with and making new friends);
- team identification (being part of a group);
- health and fitness (getting and staying fit);
- competition (excitement, demonstrating skills);
- just having fun.

While the reasons cited are basically intrinsic rather than extrinsic in their orientation, there is little doubt that as the children become older and participate in a more competitive environment, the extrinsic values such as trophies, winning and premierships become a primary motivational factor.

It is important to understand that the children's reasons for participation will be largely influenced by psychological and physical development. Harter's competence-motivation theory (1978, 1981) identifies components contributing to the development of self-perceptions, affect and motivation. According to this theory, children are motivated to become competent in their environment, and will participate with the aim of gaining mastery of tasks. Their motivation will however, be influenced by their level of self-esteem and how they perceive their own performance, particularly with reference to their peer group. The information that children use to judge their competence varies with age. Researchers (Horn, 1991; Horn and Hasbrook, 1986, 1987; Horn and Weiss, 1991) conducted several studies to investigate the nature of the preferences of young children. The results indicated that younger children (ages 8-9) used adult feedback and evaluation whilst the older children (10-14) relied more on the feedback gained from peer group evaluation. In later adolescence there was a tendency for the use of internal and multiple criteria such as goal achievement, self-improvement, speed, ease of learning new skills, and enjoyment of the activity.

Why do children drop out of sport? Children's sports participation peaks between the ages of 10-13 years and then consistently declines to the age of 18, where a relatively small percentage of individuals remain in competitive sport (Ewing and Seefeldt, 1989). The reasons given for discontinuing participation are many and varied. The following reasons for withdrawing were cited by Whitehead (1997), boredom, having other things to do, lack of success, too much pressure, poor coaching, embarrassment, ridicule, rejection, friends leaving, expense, injury, work and other commitments. Many of these reasons correspond to the results from previous studies that have been carried out to investigate reasons for the youth drop out rate in organised sport. These include studies by (Duda, 1992; Ewing and Seefeldt, 1989; Gould, Feltz, Horn, & Weiss, 1982; Gould and Petlichkoff, 1988; Watson, 1986).

Children's interpretation of success will ultimately influence their feelings about a sport and will influence their enjoyment and their behaviour in that environment. Success and enjoyment should encourage them to persevere; however, this is not always the case and other opportunities and external factors could cause them to take on other activities.

What are the effects of organised sports?: Highly structured competitive sport can place a tremendous importance on winning. This emphasis can carry over into the children's sporting domain via the parents, coach, teachers and peer group. With the development of sport at the junior level, children are being exposed to a competitive environment at a very young age. With the high exposure of sport in the media today children often watch skilled senior players executing feats and behaviour patterns that are beyond the younger athletes capabilities. These high profile athletes may in turn be set up as role models for the youngsters, resulting in unachievable goals being established.

The basic problem stems from the fact that children's sport is usually organised by adults and this takes away the spontaneity that exists when children organise their own games. With most children relying on feedback from adults, it is important that this is positive and encouraging otherwise motivation, self-esteem and perceived ability may suffer.

The supporters of competitive sport would argue that the playing of organised sport prepares the child for the competition they will experience in later life. It plays an important part in the socialisation process, and brings children in contact with social values. Sport is viewed by many as an anticipatory model of society which prepares children to take their place in society.

There are however, critics of sport competition who believe that too much emphasis is placed on winning, resulting in the development of anti-social behaviour such as, aggression and cheating. The problem stems from adults failing to appreciate that they are dealing with children and not miniature adults. Scanlan (1985) and Passer (1982) have documented the stress factors that children feel in competitive sport. They have found that those who are higher in competitive trait anxiety perceive greater state anxiety in competitive environments. In addition, children with low self-esteem experience greater stress compared to children with high self-esteem. Those children who have a low expectancy of success will also experience greater competitive stress, while those who lose often will experience greater immediate stress than those who regularly win.

Sporting myths: Over the years a number of arguments have been offered to support competitive sport as an important medium for children. It was commonly believed that children's competitive sporting programs produced better athletes. Kemp (1985) stated that in some sports, international performances occur at a very young age and therefore it is essential that basic training occurs during childhood or early youth. Examples of sports that come under this category would include gymnastics, swimming, skating, tennis and rhythmic gymnastics. There are, however, many sports where there is no positive relationship between an early beginning to training and success. These include such sports as football, basketball, cricket and rugby. Because of the physical demands of these activities, it may be advantageous to allow the young athletes to learn the basic skills via minor games in the early stages of their physical development rather than the formalised competitive situation. Studies carried out by Clough, McCormack and Traill (1993), Robertson (1982, 1991), and Robinson and Carron (1982), have all reported a high drop out rate of young athletes who became disillusioned with the formal rigours of organised sport.

The question of sport providing additional play opportunities has been put forward to support the argument for competitive sport. However, the importance placed on competitive sport and the time it takes away from other leisure activities may also lead to children turning away from organised sport. In addition, the nature of competitive sport does not allow for the majority of children to experience success. With winning being emphasised, only the top few will be rewarded for their efforts, while the majority of children who need the physical activity will choose to move away from the area. According to Alexander (1991), a number of children will take on the spectator role and never participate in any further physical activity.

The belief that children will need to compete in later life and that sport provides the perfect medium for learning has often been raised in defence of organised competitive sport. Eitzen and Sage (1986) have pointed out that there is no documentation to demonstrate that children are worse off for not competing in competitive sport at a young age. It is not just the competing that is the problem but the intensity of competition; and the associated stress and anxiety that is detrimental to performance and participation (Martens, 1977; Scalan and Lewthwaite, 1984; Scalan and Passer, 1979).

Other factors have been suggested as reasons that actually discourage children from continuing in physical activity through to later life. These include the poorly trained coaches who may mean well but are not sensitive to the needs of youngsters, and have little experience in developing these needs. A second major reason is the lack of control that children have over their sporting environment. Adults direct the competition and this competition may not resemble the competitive experiences that they have later on in life where they are more in control of the competitive situation.

It is evident that some children may be positively reinforced by the competitive experiences, whereas there are a majority of children who will be alienated and not wish to compete or participate in physical activity in later life.

What can coaches do? Sport can be a training ground for life-long achievement, and given the significant time that sporting coaches have with the children during both training and match days, there are numerous opportunities for the coach to ensure positive benefits arise from the sporting experiences. Classic research about coaching children has been conducted by Smoll and Smith (1980) at the University of Washington. The results of their studies revealed a strong correlation between instructional techniques, positive reinforcement, mistake-contingent technical instruction and the high rating received from the children. An experimental study was also conducted by these researchers, whereby coaches were trained to exhibit desirable coaching behaviours such as encouraging remarks and positive feedback to the children. The children in the experimental coaching group indicated a greater liking for their coach, and showed significant positive changes in their self-esteem when compared with children who were coached by coaches from a control group, who had not had any guidelines to assist them with their coaching techniques. These results clearly demonstrate the effect that positive coaching behaviours can have on the psychological development of children. Other studies by Black and Weiss (1992), Horn (1985) have found that remarks from coaches that are sincere, positive, and encouraging after a good performance frequently lead to effectiveness, competence and enjoyment. One can conclude from these results that coaches need to be given guidance about both the physical and psychological development of children and how best they can adapt their teaching to gain maximum benefits. The major factors that need to be considered in developing sound coaching techniques include positive feedback, encouragement, developing realistic expectations, and creating an environment that is free from fear where new skills can be developed.

What can parents do? Numerous researchers including Horn (1991), Horn and Hasbrook (1986, 1987), Horn and Weiss (1991), have emphasised the importance that the young children place on feedback from parents, coaches and teachers. Sensitivity towards the children regarding their performance is therefore of paramount importance. Self-comparison and feedback will occur in all situations, but it is important that adults are more understanding and place the importance of sport and its related achievements in the true context of importance. In other words, the children should be made to realise that failure to win a competition does not mean that there is little hope for them in life. The emphasis first and foremost should be placed on having fun, participation and developing skills. While most children want to play sport for enjoyment and fun, parents can inadvertently turn the activities into a pressurised situation where the competitive element is over-emphasised. Parents can also fall into the trap of comparing their children's performance with others instead of encouraging skill development. It is important that the children are made aware that physical and skill development do occur at different times for different individuals and this will help them to appreciate why they are not performing at the same level as others. This is important in terms of the child's self-esteem and development of self-worth.

CONCLUSION:

Competitive experiences are an important part of a child's development, and correctly managed it can be a very positive training ground for teaching one to compete successfully in the numerous areas that will confront them throughout life. The real value of competition will depend on how it is conducted. Parents and coaches have a very important role to play in ensuring that development and transition occurs in a manner that will maximize the young athletes' inherent potential and provide an enjoyable learning experience along the way.

REFERENCES:

Adler, P.A., Kless, S.J. & Adler, P. (1992). Socialization to gender roles : Popularity among elementary school boys and girls. *Sociology of Education*, **65**, 169-187.

Alexander, K. (1991). Seeking change in school physical education : Learning from a negative result. *The ACHPER National Journal*, Summer.

Black, S.J. & Weiss, M.R. (1992). The relationship among perceived coaching behaviors, perceptions of ability, and motivation in competitive age-group swimmers. *Journal of Sport and Exercise Psychology*, **14**, 309-325.

Buchanan, H.T., Blankenbaker, J. & Cotten, D. (1976). Academic and athletic ability as popularity factors in elementary school children. *Research Quarterly*, **3**, 320-325.

Butler, R. (1989). Mastery versus ability appraisal : A development study of children's observations of peers' work. *Child Development*, **60**, 1350-1361.

Chafel, J.A. (1986). A naturalistic investigation of the use of social comparison by young children. *Journal of Research and Development in Education*, **19**(3), 51-61.

Clough, J., McCormack, C. & Traill, R. (1993). A mapping of participation rates in junior sport. *The ACHPER National Journal*, Winter, 4-7.

Coakley, J. (1986). When should children begin competing? A sociological perspective. In M.R. Weiss & D. Gould (Eds.), *Sport for children and youths* (pp.59-63). Champaign, IL: Human Kinetics.

Duda, J.L. (1992). Motivation in sport settings : A goal perspective approach. In G. Roberts (Ed.), *Motivation in sport and exercise* (pp.57-91). Champaign, IL: Human Kinetics.

Eitzen, D.S. & Sage, G.H. (1986). *Sociology of American sport.* (2nd ed.). Dubuque, IA: Wm.C. Brown.

Ewing, M.E. & Seefeldt, V. (1989). *Participation and attrition patterns in American agency-sponsored and interscholastic sports : An executive summary.* Final Report. North Palm Beach, FL: Sporting Goods Manufacturer's Association.

Frey, K.S. & Ruble, D.N. (1985). What children say when the teacher is not around : Conflicting goals in social comparison and performance assessment in the classroom. *Journal of Personality and Social Psychology,* **48**, 550-562.

Gould, D., Feltz, D., Horn, T. & Weiss, M. (1982). Reasons for attrition in competitive youth swimming. *Journal of Sport Behavior,* **5**, 155-165.

Gould, D. & Martens, R. (1979). Attitudes of volunteer coaches toward significant youth sport issues. *Research Quarterly,* **50**(3), 369-380.

Gould, D. & Petlichkoff, L.M. (1988). Participation motivation and attrition in young athletes. In F. Smoll, R. Magill & M. Ash (Eds.), *Children in sport* (pp.161-178). (3rd ed.). Champaign, IL: Human Kinetics.

Gross, A.L. & Ballif, B. (1991). Children's understanding of emotion from facial expressions and situations : A review. *Developmental Review,* **11**, 368-398.

Harter, S. (1978). Effectance motivation reconsidered. *Human Development,* **21**, 34-64.

Harter, S. (1981). A model of intrinsic mastery motivation in children : Individual differences and developmental change. In W.A. Collins (Ed.), *Minnesota Symposium on Child Psychology : Vol.14* (pp.215-255). Hillsdale, NJ: Erlbaum.

Horn, T.S. (1985). Coaches' feedback and changes in children's perceptions of their physical competence. *Journal of Educational Psychology,* **77**, 174-186.

Horn, T.S. (1991, October). *Sources of information underlying personal competence judgments in high school athletes.* Paper presented at the AAASP Annual Conference, Savannah, GA.

Horn, T. & Hasbrook, C. (1986). Informational components influencing children's perceptions of their physical competence. In M. Weiss & D. Gould (Eds.), *Sport for children and youths : Proceedings of the 1984 Olympic Scientific Congress* (pp.81-88). Champaign, IL: Human Kinetics.

Horn, T. & Hasbrook, C. (1987). Psychological characteristics and the criteria children use for self-evaluation. *Journal of Sport Psychology,* **9**(3), 200-221.

Horn, T. & Weiss, M. (1991). A developmental analysis of children's self-ability judgments in the physical domain. *Pediatric Exercise Science,* **3**, 310-326.

Kemp, N.G. (1985). Ready or not : The real winners in children's sport aren't necessarily the medalists. *Sports Science Periodical on Research and Teaching in Sport*, April, 1-5.

Malina, R.M. (1980). Physical activity, growth and functional capacity. In F.E. Johnston, A.F. Roche & C. Susanne (Eds.), *Human physical growth and maturation* (pp.303-327). New York: Plenum.

Malina, R.M. (1982). Physical growth and maturity characteristics of young athletes. In R.A. Magill, M.J. Ash & F.L. Smoll (Eds.), *Children and sport* (pp.73-96). Champaign, IL: Human Kinetics.

Malina, R.M. (1983). Human growth, maturation and regular physical activity. *Acta Medica Auxologica*, **15**, 5-23.

Malina, R.M. (1983). Menarche in athletes : A synthesis and hypothesis. *Annals of Human Biology,* **10,** 1-24.

Malina, R.M. (1984). Physical growth and maturation. In J.R. Thomas (Ed.), *Motor development during childhood and adolescence* (pp.2-26). Minneapolis: Burgess.

Malina, R.M. (1986). Readiness for competitive youth sport. In M.R. Weiss & D. Gould (Eds.), *Sport for children and youths* (pp.45-50). Champaign, IL: Human Kinetics.

Malina, R.M. (1996). The young athlete : Biological growth and maturation in a bioculture context. In F.L. Smoll & R.E. Smith (Eds.), *Children and youth in sport : A biopsychosocial perspective* (pp.161-186). Dubuque, IA: Brown & Benchmark.

Malina, R.M. & Bouchard, C. (1991). *Growth, maturation and physical activity.* Champaign, IL: Human Kinetics.
Malina, R.M., Meleski, B.W. & Shoup, R.F. (1982). Anthropometric, body composition and maturity characteristics of selected school-age athletes. *Pediatric Clinics of North America,* **29**, 1305-1323.
Martens, R. (1977). *Sport competition anxiety test.* Champaign, IL: Human Kinetics.
Martens, R. (1978). *Joy and sadness in children's sports.* Champaign, IL: Human Kinetics.
Martens, R. (1986). Youth sports in the USA. In M.R. Weiss & D. Gould (Eds.), *Sport for children and youths* (pp.27-33). Champaign, IL: Human Kinetics.
McGuire, R.T. & Cook, D.L. (1983). The influence of others and the decision to participate in youth sports. *Journal of Sport Behavior,* **6,** 16.
Pascuzzi, D.L. (1981). Young children's perception of success and failure. Abstract in *Psychology of Motor Behavior and Sport (1981)*: 97.
Passer, M.W. (1981). Children in sport : Participation motives and psychological stress. *Quest,* **33**, 231-244.
Passer, M.W. (1996). At what age are children ready to compete? Some psychological considerations. In F.L. Smoll & R.E. Smith (Eds.), *Children and youth in sport : A biopsychosocial perspective* (pp.73-86). Dubuque, IA: Brown & Benchmark.
Roberts, G.C. (1980). Children in competition : A theoretical perspective and recommendations for practice. *Motor Skills : Theory into Practice,* **4**, 37-50.
Robertson, I. (1982). Sport in the lives of South Australian children. In T. Orlick, J.T. Partington & J.H. Salmela (Eds.), *Mental training for coaches and athletes* (pp.61-63). Ottawa: Sport in Perspective Inc and The Coaching Association of Canada.
Robertson, I. (1989). The coach and the drop out. *Sports Coach*, April-June, 8-14.
Robinson, T. & Carron, A. (1982). Personal and situational factors associated with dropping out versus maintaining participation in competitive sport. *Journal of Sport Psychology,* **4**, 364-378.
Ruff, H.A. & Lawson, K.R. (1990). Development of sustained focused attention in young children during play. *Developmental Psychology,* **26**, 85-93.
Scanlan, T.K. (1995). Social evaluation and the competition process : A developmental perspective. In F.L. Smoll and R.E. Smith (Eds.), *Children and youth in sport : A biopsychosocial perspective* (pp.298-308). Dubuque, IA: Brown & Benchmark.
Scanlan, T. & Lewthwaite, R. (1984). Social psychological aspects of competition for male youth sport participants: I: Predictors of competitive stress. *Journal of Sport Psychology,* **6**, 208-226.
Scanlan, T. & Passer, M.W. (1979). Sources of competitive stress in young female athletes. *Journal of Sport Psychology,* **1**, 151-159.
Shaffer, D.R. (1993). *Developmental psychology : Childhood and adolescence.* (3rd ed.). Pacific Grove, CA: Brooks/Cole.
Smith, R.E., Smoll, F.L. & Smith, N.J. (1989). Parents complete guide to youth sports. Costa Mesa, CA: HDL Publishers.
Smoll, F.L. & Smith, R.E. (1980). Psychologically oriented coach training programs : Design implementation and assessment. In C.H. Nadeau, W.R. Halliwell, K.M. Newell & G.C. Roberts (Eds.), *Psychology of motor behaviors and sport — 1979*. Champaign, IL: Human Kinetics.
Spink, K.S. (1990). *Give your kids a sporting chance : A guide for parents*. Melbourne: Sun Books.
Veroff, I. (1969). Social comparison and the development of achievement motivation. In C.P. Smith (Ed.), *Achievement-related motives in children* (pp.46-101). New York: Russell Sage Foundation.
Wankel, L. & Sefton, J. (1989). A season-long investigation of fun in youth sports. *Journal of Sport and Exercise Psychology,* **11**, 355-366.

Watson, G.G. (1984). Intrinsic motivation and competitive anxiety in sport : Some guidelines for coaches and administrators. *The Australian Journal of Science and Medicine in Sport*, December, 14-20.
Weiss, M.R. & Chaumeton, N. (1992). Motivational orientations in sport. In T.S. Horn (Ed.), *Advances in sport psychology* (pp.61-99). Champaign, IL: Human Kinetics.
Weiss, M.R. & Petlichkoff, L.M. (1989). Children's motivation for participation in and withdrawal from sport : Identifying the missing links. *Pediatric Exercise Science,* **1**, 195-211.
White, R.W. (1959). Motivation reconsidered : The concept of competence. *Psychological Review,* **66**, 297-334.
Whitehead, J. (1997). Why children choose to do sport — or stop. In M. Lee (Ed.), *Coaching children in sport : Principles and practice* (pp.109-120). New York: E. & F.N. Spon.

ENDURING A FIVE-SET SINGLES MATCH (AND THE NEXT MATCH): PHYSIOLOGY OF PREPARATION, COMPETITION AND RECOVERY

Michael A. Christmass
The Department of Biochemistry and The Department of Human Movement and Exercise Science, The University of Western Australia, Nedlands, Western Australia, Australia.

Successfully enduring a 5-set tennis match demands a sustained high level of technical, tactical, physiological and psychological capacity in often hostile environmental conditions. In terms of physiology, success is likely to depend on the player's ability to repeatedly generate power for explosive stroke production and for rapid court movement during extended matches. This paper outlines the effect of metabolic factors, and of playing in hot environments, on fatigue and tennis performance as well as physiological preparation to minimise these effects. Fitness training, nutrition and hydration are discussed and strategies are presented to help sustain physiological performance during a match and to optimise preparation for the next match.

KEY WORDS: tennis, performance, endurance, metabolism, dehydration, recovery.

INTRODUCTION:

The margin between winning and losing a 5-set tennis match is frequently small. At the end of a match played over several hours differences in physiological performance between opponents of similar technical and tactical ability may be crucial to success. In long matches, the demand for energy to sustain work levels, imposed in a hot environment, provokes considerable physiological strain. To successfully endure tournament competition tennis players must be sufficiently prepared to meet this physiological challenge on several consecutive occasions. This paper discusses the scientific background to physiological performance in tennis and in particular the effect of metabolic factors, and of hot environments, on fatigue in tennis. Scientific findings are presented as the basis for recommendations on fitness training, nutrition and hydration to help players prepare and compete in extended matches and to recover during tournament competition. In each case scientific background is followed by a summary of specific recommendations for coaches and players.

THE SCIENTIFIC BACKGROUND TO OPTIMUM PHYSIOLOGICAL PERFORMANCE IN RELATION TO ENERGY METABOLISM, HOT ENVIRONMENTS AND FATIGUE:

High performance tennis is an extremely competitive environment. The small improvements in performance crucial to success are gained through increasingly sophisticated and specialised training and preparation techniques. For success in this atmosphere coaches and players need reliable information, based on scientific evidence, to continually improve training and preparation strategies. But in tennis the availability of direct scientific data is limited. Scientific information from other sports and studies of laboratory exercise must be interpreted and translated to the conditions of competitive tennis. This is a necessary, but imperfect process in establishing sound recommendations for training and preparation.

Seeking scientific information to establish the factors critical to limiting physiological performance is a first step in this process. These factors provide a target to focus training and preparation strategy. But before searching for the factors which might limit physiological performance, the actual nature of the performance must be established. For example, for the highly trained athlete successful endurance in a marathon involves sustaining an optimum running speed, whilst for the less trained competitor the concern is often with completing the distance (Williams and Chysanthoupolus, 1997).

What Constitutes Endurance in Tennis?

Successfully enduring a 5-set tennis match demands a sustained high level of technical, tactical, physiological and psychological capacity in often hostile environmental conditions. For example, the the 1988 US Open best of five set men's singles final lasted 4.9 h (Chandler, 1995) and the 1994 Australian Open was played in 38°C (100°F) heat with centre-court surface temperature frequently 54°C (130°F; Bergeron, Armstrong, & Maresh, 1995). Under these conditions tennis players must accelerate, decelerate, change direction, move quickly, maintain balance and generate optimum stroke production repeatedly (Chandler). Aspects of physical fitness important here include cardiovascular endurance, flexibility, body composition, muscular endurance, strength and power as well as more specific factors such as acceleration, agility, balance and response time.

Physiological endurance is generally defined as the longest period that submaximal work (i.e. continuous jogging) can be sustained continuously (Sahlin, 1992). But in tennis the work level can be intense and is not constant (or continuous) so this definition is probably not relevant. In modern tennis effective stroke production involves explosive force particularly for groundstrokes and the serve (Elliott, 1999). In turn, rapid court movement is an essential response to the power developed on serve and groundstrokes by both players. These factors suggest that power output is a key physiological component in optimum tennis performance. The technical and tactical options available at any stage of a match may depend on the capacity to generate explosive bursts of power. As a result, success in the decisive rallies at the end of a long and demanding tennis match could be determined by the ability to repeatedly generate effective power output. Endurance in tennis may be defined by the ability to sustain effective power output through the 2-5 h length of a competitive match.

Endurance in Tennis Matches: Does Fatigue Limit Performance?

Recently, several studies have provided scientific evidence to support the common observation that fatigue impairs tennis performance through effects on stroke production and court movement. McCarthy, Thorpe, & Williams, (1997) studied the effect of a maximal tennis performance test (30 ball feeds$\cdot$min^{-1}; 4 min work, 40 s recovery) to exhaustion (35.4 ± 4.6 min) on stroke production. Groundstroke accuracy declined from the beginning to 75 % of the performance test and at exhaustion. Backhand groundstroke (crosscourt) and service accuracy (right court) were lower after, compared to before, the maximal performance test. Mitchell, Cole, Grandjean, and Sobczak (1992) found that serve velocity was reduced following a 3 h competitive match. Recently a standardised testing procedure has been developed to determine the effect of fatigue on stroke production in situations specific to competitive tennis (Vergauwen, Spaepen, Lefevre, & Hespel, 1998). A strenuous standardised 2 h on-court training session (Vergauwen, Brouns, & Hespel, 1998) resulted in an increase in the percentage of errors on first serves (due mainly to errors on "wide", rather than "down the centre" serves). For groundstrokes, fatigue was most conspicuous when players were in a defensive (rather than neutral or attacking) rally situation and resulted in a 9 % increase in error rate with more frequent errors on the backhand. As well as an increase in errors, the quality of successful strokes decreased with fatigue. Court movement is also affected by fatigue since the number of balls that could not be reached increased by 6 % (Vergauwen, Brouns, et al., 1998). As well, the time to complete tennis pattern shuttle-runs increases with fatigue (Mitchell et al.; Vergauwen, Brouns, et al.). These results support the notion that improving physiological endurance, by minimising the effects of fatigue, is likely to benefit tennis performance. The following section outlines the scientific background to the factors which could limit physiological endurance in tennis (i.e. the capacity for repeated powerful efforts). As mentioned earlier, an appreciation of these factors will focus recommendations for training and preparation strategies.

Fatigue and Metabolism in Tennis:
Several factors involving metabolism/nutrition (i.e. the supply of energy for muscle work) have been suggested as causes of fatigue: decreased muscle "immediate energy" (i.e. phosphocreatine) stores, increased muscle acidity, decreased muscle carbohydrate (i.e. glycogen) stores, a low blood glucose level and an increase in the ratio free tryptophan:branched chain amino acids in the circulation (Newsholme, Blomstrand, & Ekblom, 1992). The ratio of free tryptophan:branched chain amino acids may cause fatigue at the level of the brain (i.e. central fatigue) whilst the other factors are likely to contribute at the muscle level (i.e. peripheral fatigue; Newsholme et al.). All these factors are involved in some way with metabolism and the supply of energy for muscle work (i.e. the energy producing metabolic pathways). But the contribution of each factor to fatigue in tennis is unknown. To appreciate the potential significance of any one of these factors, it is important to determine how energy is supplied for muscle work in tennis.

The Role of Energy Producing Metabolic Pathways for Tennis - in Theory: Energy for muscle work is provided by instantaneous breakdown of the small amount of ATP present in the muscle cell. However, the muscle store of ATP can only provide energy for intense work of short duration (1-2 s) and hence ATP must be continuously supplied during exercise. Supply of ATP for brief, intense exercise is provided by metabolism of: stored muscle phosphocreatine to produce creatine (the phosphocreatine system); and stored muscle glycogen to produce lactate (the glycolytic energy system). Supply of ATP in prolonged, less intense exercise is accomplished by aerobic metabolism of glycogen and fat stored in the muscle and also supplied to the muscle from the circulation. Phosphocreatine provides an instant reservoir for resupply of ATP (Newsholme, 1986). This energy system serves as the main source for ATP during single intense muscle contractions (Green, 1997). In theory these features, combined with the need for rapid movement and explosive stroke production implicate phosphocreatine as a key component of energy supply in tennis.

The Role of Energy Producing Metabolic Pathways in Tennis - in Practice: Conclusions from scientific studies concerning the role of the different energy producing metabolic pathways in singles tennis are conflicting (Christmass, Richmond, Cable, Arthur, & Hartmann, 1998). Contradictions as to the overall metabolic response (Bergeron et al., 1991; Christmass et al., 1998) and the level of lactate accumulation (Copley, 1984; Bergeron et al.; Therminarias, Dansou, Chirpaz-Oddou, Gharib, & Quirion, 1991; Christmass et al., 1998) are probably due to the lack of scientific studies on metabolism in singles tennis. There is little definite scientific information on the contribution of the energy producing metabolic pathways and the use of various fuels (phosphocreatine, carbohydrate, fat) for energy supply during a match. The potential of metabolic factors to influence fatigue in tennis must be interpreted on the basis of theory and of practical scientific information from laboratory studies, studies of related sports and the few available studies on tennis.

Metabolism and Fatigue - the Relevance of Metabolic Factors to Fatigue in Tennis: In theory, physiological performance in tennis could be limited by a decrease in power due to a fall in muscle phosphocreatine levels. Hultman and Sjoholm (1986) showed that direct stimulation of muscle (to avoid central fatigue) resulted in a rapid decline in power along with a decrease in phosphocreatine. Phosphocreatine levels return to about 50 % within 60 s of intense exercise resulting in near complete depletion but may take 5 min to fully recover (Soderlund & Hultman, 1991). International Tennis Federation rules allow 20 s recovery between rallies and 90 s between the change of ends. Generally a single rally would be unlikely to severely deplete the muscle phosphocreatine store but several consecutive intense rallies could perhaps reduce phosphocreatine levels enough to impair power output.

The conversion of muscle glycogen stores to lactate during intense exercise results in an increase in muscle (and blood) acidity. Increased muscle acidity is commonly associated with reduced muscle power, although the precise mechanism is unclear (MacLaren, Gibson, Parry-Billings, & Edwards, 1989). Generally, lactate levels and hence muscle acidity are thought to remain low during tennis (Bergeron et al., 1991; Copley, 1984) and contribute little to fatigue (Therminarias et al., 1991). However, increases in circulating lactate levels in tennis can occur (Christmass et al., 1998) and could influence fatigue in some cases (i.e. court surface, match characteristics).

The close association between fatigue and low muscle glycogen levels in prolonged continuous exercise is well established (Saltin & Karlsson, 1971). In humans the high rates of glycogen metabolism needed for power are not affected by glycogen levels when muscle glycogen stores are high (Vandenberghe, Hespel, Vanden Eynde, Lysens, & Richter, 1995). But when glycogen stores are low (i.e. 20-30 mmol·kg^{-1} w.w.; Costill, 1988) the supply of ATP from glycogen is reduced. This has relevance in soccer where low (9 mmol·kg^{-1} w.w.) muscle glycogen contents have been recorded at the end of a match, and players with low pre-match muscle glycogen stores spend more time walking and less time sprinting (Saltin, 1973). There is little direct information concerning the rate and extent of muscle glycogen depletion during singles tennis. However, carbohydrate intake has been found to improve explosive strength (Sargent jump) after 2 h of tennis (Burke & Ekblom, 1984). Low muscle glycogen levels could theoretically reduce optimum physiological performance in prolonged tennis.

In tennis, blood glucose levels do not decrease significantly (Mitchell et al., 1992) and in most cases actually increase (Christmass, Richmond, Cable, & Hartmann, 1995; Therminarias et al., 1991; Bergeron et al., 1991). Hypoglycaemia (i.e. low blood glucose) *per se* is therefore unlikely to be a factor in fatigue during tennis.

An increase in the ratio of (free) tryptophan:branched chain amino acids in the circulation could affect central drive and mood through changes in the level of neurotransmitters in the brain (Blómstrand, Celsing, & Newsholme, 1988). Four hours of singles tennis increased the (free) tryptophan:branched chain amino acid ratio more than 2.5-fold (Struder, Hollmann, Duperly, & Weber, 1995) suggesting that central fatigue (i.e. motivation, perception) could limit performance in long matches.

Fatigue and Dehydration in Tennis:
Tennis is typically played in warm or hot environments. Many players probably compete with some deficit in the normal range of body water content (Bergeron et al., 1995). This condition is known as hypohydration (Sawka, 1992) but will be referred to by the more common term "dehydration". Few studies have systematically examined the effect of levels of dehydration on performance in tennis (Bergeron et al.). But dehydration is known to impair general exercise performance (Sawka and Pandolf, 1990). For a detailed review of fluid and electrolyte balance during tennis, and for the effects of dehydration on general exercise performance the reader is referred to Bergeron et al. (1995) and Sawka and Pandolf, respectively. Briefly, exercise performance is typically impaired by dehydration with increased effects with greater dehydration (Sawka and Pandolf) and at higher environmental temperatures (Sawka). Parameters of exercise performance potentially important to tennis such as muscular endurance, maximal aerobic power and physical work capacity are all adversely affected by dehydration (Sawka and Pandolf). Dehydration may also affect mental performance in tennis since short-term memory, arithmetic and motor speed and attention are all impaired in proportion to the degree of dehydration (Gopinathan, Pichan, & Sharma, 1988). Importantly, only a small degree of dehydration (1-2 % body weight) may be needed to affect physical (Craig & Cummings, 1966) and mental performance (Gopinathan et al.).

RECOMMENDATIONS FOR OPTIMUM PHYSIOLOGICAL PERFORMANCE:
The scientific background to physiological performance in tennis and the limitations to this performance provide a framework and focus for strategies to optimise pre-match preparation,

competition and recovery. But in the same way it is important for specific recommendations and strategies to also be based on scientific evidence. Again, the lack of direct scientific information (metabolism/physiology) on tennis necessitates interpretation of data from laboratory studies and related activities. The following section outlines recommendations for preparation, competition and recovery for improved tennis performance. The scientific background to the strategies is outlined and is followed by a summary of practical recommendations.

Pre-match Preparation - Fitness Training and Acclimatisation for Long Matches in Hot Conditions:
In terms of physiological fitness tennis players must be sufficiently powerful, and capable of rapid recovery between rallies. Acclimatising to hot environments may also benefit performance.

The Phosphocreatine Energy System: Since powerful stroke production and explosive movement are important factors in modem tennis (Elliott, 1999) a considerable proportion of fitness training should be focussed on developing the phosphocreatine energy system. The net use of phosphocreatine may be quantitatively small (Bangsbo, 1994), but it is important for producing and repeating rapid, powerful movements (Newsholme et al., 1992).

The Aerobic Energy System: Once power has been developed, the capacity to recover and to repeatedly generate power (i.e. endurance in tennis) is most likely to depend on high levels of aerobic fitness.

Recovery of phosphocreatine: Recovery of phosphocreatine stores after exercise stops when oxygen supply is blocked (Sahlin, Harris, & Hultman, 1979). The availability of oxygen is therefore probably a limiting factor for recovery of phosphocreatine levels (Sahlin et al., 1979). Since tennis players have a finite recovery time between rallies, effective oxygen delivery to muscle due to a high aerobic fitness level is likely to improve the ability to recover and repeat powerful efforts.

Lactic acid accumulation and muscle acidity: As mentioned earlier, lactic acid accumulation (and muscle acidity) are in most cases unlikely to contribute to fatigue in tennis (Therminarias et al., 1991). However, increased lactate levels result from longer work period durations in intermittent type exercise (Ballor & Volovsek, 1992) and also tend to occur in tennis players with more intense patterns of footwork (Christmass et al., 1998; i.e. take more steps per time). A combination of these effects (i.e. matches on slow surfaces such as clay) could conceivably result in an increase in lactate accumulation (and muscle acidity). Of importance here is that high aerobic fitness levels (and hence effective blood supply to muscle) enable more efficient buffering of muscle acidity (Newsholme et al., 1992) minimising possible effects on performance. Certainly, higher aerobic capacity is associated with greater recovery of muscle force as well as higher phosphocreatine and lower lactate levels after repeated bouts of heavy exercise (Jansson, Dudley, Norman, & Tesch, 1990).

Preserving muscle glycogen stores: In endurance exercise a high level of aerobic fitness results in an increased reliance on fat as a fuel which will help to spare glycogen reserves (Holloszy, 1990). The situation is less clear for intermittent exercise such as tennis. Higher rates of carbohydrate use occur in the presence of low muscle oxygen availability when work periods (i.e. rallies) are longer during intermittent treadmill exercise (Christmass, Dawson, & Arthur, 1999). More research is needed to determine whether increased aerobic fitness can spare muscle glycogen stores in long tennis matches.

Tolerating exercise in hot conditions: A high level of aerobic fitness and physical training in a cool environment improve physiological responses to exercise in a hot environment (i.e. a "partial" heat acclimation; Piwonka & Robinson, 1967; Pandolf, 1979). Therefore, increased aerobic fitness may benefit tennis performance in hot conditions when a period of acclimatisation is not possible.

Acclimatising for Tennis in Hot Conditions:
The following recommendations are based on the reviews by Terrados and Maughan (1995), Sawka (1992) and Murray (1992). The adverse effects on physiological and performance variables as result of exercise in hot environments can be reduced by regular exposure (i.e. acclimatising) to the conditions (Terrados and Maughan). The principal adaptations are largely complete within 6-8 days of exposure to the new conditions (Armstrong and Maresh, 1991) including daily training or competition (Wenger, 1988). For specific details of an overall conditioning program for tennis the reader is referred to Chandler (1995).

Pre-match Preparation - Nutrition and Hydration for Prolonged Matches in Hot Conditions:
Maintaining an adequate diet in general as well as appropriate nutrient and fluid intake in the days prior to important matches is likely to benefit tennis performance.

The Tennis Player's Diet: Clearly sustaining physiological performance in tennis will be improved by high levels of physical fitness for the reasons outlined above. Such preparation generally requires large volumes of on- and off-court training for which an adequate diet is essential (Coyle, 1991). For a review of athlete nutrition and sports performance the reader is referred to C. Williams (1995) and Clarkson (1996). Briefly, a diet consisting of a wide range of foods in which 60-70 % of total energy intake is derived from carbohydrate, 12 % from protein and the remainder from fat is optimal for most sports (Devlin & Williams, 1991). A high level of carbohydrate intake is recommended on the basis of the demand placed on glycogen stores during training and competition and the relationship between depletion of these stores and fatigue (Costill & Hargreaves, 1992). Recommended dietary protein requirements for most athletes can be achieved within a balanced diet (Lemon, 1991a). Reducing fat intake to extremely low levels is not recommended on the basis that some lipids (i.e. essential fatty acids) are important to general health (C. Williams, 1995). Alternatively, consuming excess fat reduces the opportunity to maintain the recommended carbohydrate intake (C. Williams, 1995) and may have detrimental long-term effects on health (Clarkson, 1996).

Should Tennis Players Carbohydrate Load? The positive effect of a high carbohydrate diet in the days prior to competition on endurance in prolonged submaximal exercise is well established (Karlsson & Saltin, 1971). This effect is also apparent during brief high intensity continuous exercise (Maughan et al., 1997) as well as during intermittent exercise (Bangsbo, Norregaard, & Thorsoe, 1992). A gradual decrease in the volume of training in the week prior to a tournament combined with an increase in carbohydrate content of the diet (i.e. 3 days on a mixed diet containing 50 % carbohydrate, followed by 3 days on a high carbohydrate diet containing 70 % carbohydrate) has been recommended as an effective carbohydrate loading regime (Sherman, Costill, Fink, & Miller, 1981). The practice of dietary carbohydrate loading is relatively common for endurance events lasting more than 1-2 h and could be of benefit for tennis tournaments involving 5-set (i.e. long) matches. On the other hand, increases in muscle water content with carbohydrate loading can cause feelings of heaviness and stiffness (Fox & Mathews, 1981) which may impair tennis performance in some cases. There is little specific information to support or refute the benefits of carbohydrate loading in tennis. Short-term high fat diets have been suggested to improve endurance performance, however this has not been definitively confirmed and in general results indicate a possible detrimental effect on performance (Sherman & Leenders, 1995).

Pre-match Nutrition: The timing and composition of nutrient intake on the day of competition will also affect performance in prolonged exercise (Wright, Sherman, & Dernback, 1991). For sports in which the level of glycogen stores may impair performance ingestion of a high carbohydrate meal (200-300 g) 3-4 h before exercise is generally recommended (Coyle, 1991). High carbohydrate meals are usually easily and rapidly digested and absorbed compared to meals high in fat and protein (Williams & Chyssanthopoulos, 1997). In this context, a high fat meal 3-4 h before exercise should be avoided because digestion is slow which increases the potential for gastrointestinal distress (Williams & Chyssanthopoulos).

Carbohydrate Snacks: Irregular scheduling of matches during tournament tennis competition often makes it difficult to precisely time the pre-match meal. In this situation, supplementary carbohydrate snacks may be necessary. In the past, carbohydrate consumed in the hour prior to exercise has been suggested to reduce endurance capacity (Foster, Costill, & Fink, 1979), increase muscle glycogen depletion and cause a fall in blood glucose at the beginning of exercise (Costill et al., 1977). However, since these early findings several studies have found carbohydrate ingested in the hour before exercise does not result in increased muscle glycogen use and has either no effect, or improves, endurance performance (for review see Coyle, 1991). On this basis, Coyle (1991) concluded there was minimal support for the concept that carbohydrate ingestion in the hour prior to exercise impairs endurance performance. However, on the basis of possible differences between individuals in metabolic response to pre-exercise carbohydrate ingestion, experimentation with variations in pre-exercise carbohydrate intake during training is recommended (Costill & Hargreaves, 1992). In terms of the effects on blood glucose, the decrease at the onset of exercise may not reach levels associated with hypoglycaemia (2.5 mM; Chryssanthopoulos, Hennessy, & Williams, 1994) and in any case is frequently not perceived by athletes (Ferrauti, Weber, & Struder, 1997; Williams & Chyssanthopoulos, 1997) and does not cause muscle weakness (Coyle, 1991). Blood glucose concentration decreases significantly at the beginning of exercise in tennis with (Ferrauti et al., 1997) or without (Bergeron et al., 1991) carbohydrate ingestion immediately before activity. Despite the points outlined above Ferrauti et al. noted that some tennis players may perceive this response adversely (i.e. complain of hypoglycaemic symptoms) and suggested that players perform an extensive warmup so that any potential fall in blood glucose occurs in the pre-match period.

Pre-match Hydration: Players should consume 300-500 ml of water before a 5-set (i.e. long) match on the basis of an exercise duration of 1-3 h and provided a carbohydrate-electrolyte drink is consumed during the match (Gisolfi & Duchman, 1992; see below).

Recommendations for Coaches and Players:

- Fitness training should develop the phosphocreatine energy system. Training emphasis particularly in precompetition and competition phases. Agility, response time, acceleration training using tennis-specific pattern running with 1 : 6-10 (work : recovery), 2-8 s duration, maximum effort. Power training (i.e. plyometrics, weight training) should follow hypertrophy phases as an adjunct to the tennis-specific pattern running.
- Develop and maintain a high level of aerobic fitness. Training emphasis particularly in general preparation phase. High intensity 5000 m running, 1000 m repeats (i.e. x 5-6), fartlek.
- Acclimatise to hot conditions. Allow 6-8 days in new conditions including daily training.
- General dietary energy intake 60-70 % carbohydrate, 12 % protein, with remainder from fat.
- Dietary carbohydrate loading *may* be beneficial but this should be based on individual experience.
- High carbohydrate (200-300 g) meal 3-4 h before the match.
- Pre-match nutrient intake should be high carbohydrate, low fat, low protein to avoid gastrointestinal distress. There is little evidence that carbohydrate snacks in the hour before exercise impair endurance. For best results experiment with variations in pre-exercise carbohydrate intake in training.

- Hydrate with 300-500 ml of water before the match. (Assuming a 1-3 h match with a carbohydrate-electrolyte drink consumed during the match).

During the Match - Nutrition and Hydration:
Carbohydrate supplementation and fluid replacement during exercise are important in delaying fatigue (Maughan & Shirreffs, 1997). This is also likely to be the case for tennis players.

The Effect of Carbohydrate-Electrolyte Drinks on Tennis Performance: Consumption of carbohydrate-electrolyte drinks during competition will contribute to delaying fatigue due to dehydration but may also improve performance (Williams and Chryssanthopoulos, 1997). For example, in endurance exercise supplementation with carbohydrate can delay fatigue (Coyle et al., 1983) and may improve sprint performance at the end of prolonged exercise (Hargreaves, Costill, Coggan, Fink, & Nishibata, 1984). The effect of a carbohydrate beverage on tennis performance has been investigated although with contradictory findings (Burke & Ekblom, 1984; Mitchell et al., 1992; McCarthy, Thorpe, & Williams, 1995; Ferrauti et al., 1997; Vergauwen, Brouns, et al., 1998). Ferrauti et al. (1997) and Burke and Ekblom (1984) showed an improvement in court speed following supplementation with a carbohydrate drink in prolonged (4 h and 2 h, respectively) tennis matches although Mitchell et al. and McCarthy et al. (1995) found no effect. Ferrauti et al. (1997) concluded that the absence of an effect in these latter studies was due to too few subjects (McCarthy et al., 1995) and an inadequate testing procedure (Mitchell et al.). In terms of stroke production, several studies have found no effect of carbohydrate beverages (Ferrauti et al.; McCarthy et al., 1995; Mitchell et al.). However, Vergauwen, Brouns, et al. (1998) tested stroke production in specific situations relevant to match conditions. For example, comparisons were made with "down the centre" and "wide" serves and groundstrokes were compared across neutral, defensive and offensive rally situations (Vergauwen, Brouns, et al., 1998). In general this study showed that carbohydrate supplementation enabled players to produce more powerful and more accurate stroke production as well as to reduce error rate. On the basis of findings for prolonged continuous and intermittent exercise, and for tennis, it is possible that performance will benefit from consumption of a carbohydrate-electrolyte drink during 5-set tennis matches. However, the precise composition of a suitable carbohydrate-electrolyte drink is dependent on several factors (see review by Gisolfi and Duchman, [1992]).

Composition of Carbohydrate-Electrolyte Drinks: On the basis of a 5-set (i.e. prolonged) singles match, tennis players should follow the guidelines for fluid replacement for exercise durations from 1-3 h outlined by Gisolfi and Duchman (1992). Briefly, 800-1600 $ml{\cdot}hr^{-1}$ of a 6-8 % carbohydrate solution (5-15 °C) including 10-20 mM of sodium is recommended (Gisolfi, & Duchman). The rationale for the carbohydrate content has been reviewed previously (Lamb & Brodowicz, 1986) and this level satisfies the recommendations from Coyle (1991). The suggested volume range is large and some players may experience gastrointestinal discomfort with a volume more than 1.25 $l{\cdot}hr^{-1}$ (Coyle, & Montain, 1992). Precise volumes will depend on sweat rate which will vary between individuals (i.e. large males, small females) and with differences in environmental conditions.

During the Match - Physiological Considerations for Strategy and Tactics:
International Tennis Federation rules provide for maximum standard recovery in tennis (see above). The recovery of muscle metabolism is partly a time-dependent process (Harris et al., 1976). On this basis it can be assumed that optimum physiological performance will benefit from securing complete advantage of available recovery time. Again, the finding that higher lactate levels occur with longer work periods in intermittent exercise (Ballor & Volovsek, 1992) and with more intense footwork patterns in tennis (Christmass et al., 1998),

provides some support for the perception that players may modify match strategy to "preserve energy" late in 5-set (i.e. long) matches. Specifically, match strategy to limit the length of rallies is understandable from a perspective of maintaining physiological performance. Players with intense footwork patterns may also benefit from tactics to modify this characteristic at particular stages in prolonged matches. For example, in baseline rallies, limit footwork recovery to a court position related to the opponent's specific technical/tactical options rather than repeated recovery to the central baseline position.

Recommendations for Coaches and Players:

For matches lasting 1-3 h consume 800-1600 $ml \cdot hr^{-1}$ of a 6-8 % carbohydrate solution (5-15 °C) including 10-20 mM of sodium content. Volume range is large and many tennis players may find an upper limit for comfort at 800 $ml \cdot hr^{-1}$. Precise volume will depend on individual sweat rates and environmental conditions.

Match strategy to reduce the length of rallies and to modify characteristically intense footwork patterns (limit unnecessary footwork) could benefit physiological performance late in long matches.

Between Matches - Recovery for Repeated Performance:
Success in a tennis tournament involves winning several consecutive matches frequently separated by less than 24 h. Tennis players must develop effective strategies for post-exercise recovery so that high level performance can be repeated. In addition to restoration of fluid and electrolyte balance and energy stores, post-exercise recovery may include the use of massage (Cafarelli & Flint, 1992), hydrotherapies (i.e. float tanks, contrast temperature baths), sauna and decompression chambers as well as electrical physiotherapy modalities (Calder, 1990). However, there is relatively little scientific data concerning the effectiveness of most of these techniques with the exception of nutritional strategies for recovery (Burke, 1996; Maughan & Shirreffs, 1997). For a review of general processes available for recovery, and specifically the role of massage, the reader is referred to reviews by Calder and Cafarelli and Flint, respectively. The current paper will focus on recommendations for fluid and nutrient recovery in the post-exercise period.

Nutrient Recovery: Nutritional recovery includes replenishment of glycogen stores which may be depleted in prolonged matches (Bergeron et al., 1995), restoration of fluid and electrolyte balance, and repair of cell/tissue damage (Burke, 1996). The relationship between glycogen stores, carbohydrate supplementation and performance (see above) emphasises the importance of replacing glycogen stores in the post-exercise period. On average 20-24 h are required to restore normal muscle glycogen levels following exhaustive exercise (Coyle, 1991). Costill and Miller (1980) originally hypothesised that inadequate carbohydrate intake during repeated days of exercise would result in gradual loss of glycogen stores and reduced endurance performance. Although this hypothesis has been the subject of debate, current nutritional recommendations promote a high carbohydrate diet during periods of prolonged competition to support maximal recovery of glycogen levels (Burke). Coyle has suggested that the rate of glycogen storage is generally optimised by consuming 50 g of glucose (carbohydrate with a high glycaemic index) every 2 h in the early stages of recovery (total > 600 g for a 70 kg body mass). The rate of glycogen storage is more rapid in the initial 2 h post-exercise period (Ivy, Katz, Cutler, Sherman, & Coyle, 1988b) but this is unlikely to be physiologically significant (Burke). Instead the recommendation that carbohydrate intake commence as soon as practical following a match is based on maximising available recovery time for glycogen storage (Coyle). Provided total carbohydrate intake is adequate, muscle glycogen storage is apparently not influenced by the frequency and size of carbohydrate meals (Costill et al., 1981; Burke et al., 1996). Therefore, in cases where consumption of carbohydrate every 2 h in the time between matches is impractical (i.e. sleep) a low fat, low protein meal containing sufficient carbohydrate for the period without food will suffice (i.e. 50 $g \cdot 2h^{-1}$, Coyle). Moderate to high glycaemic index foods should form the basis of carbohydrate intake post-exercise (Coyle). Since appetite is often lower in the period immediately post-exercise, carbohydrate intake in the form of fluids may be useful at this time (Keizer, Kuipers, van Kranenburg, & Geurten, 1986).

Fluid-Electrolyte Recovery: Recent research indicates that the provision of fluids is likely to be as important as carbohydrate for maintaining exercise performance (Below, Mora-Rodriguez, Gonzalez-Alonso, & Coyle, 1995). A planned program of fluid intake is important (particularly when recovery is limited and dehydration may be ~ 2-5 % body mass; Burke, 1996) because of the combined effects of failure to rehydrate when fluids are readily available (i.e. "involuntary dehydration"; Nadel, Mack, & Nose, 1990) and continued loss of fluid through sweating and urination after exercise (Burke). Generally, the volume of fluid consumed for rehydration must be larger (i.e. 1.5-2.0 fold) than the volume lost in exercise to allow for fluid lost as sweat and urine in post-exercise recovery (Shirreffs, Taylor, Leiper, & Maughan, 1996). However, fluids with a low sodium content (i.e. water) will cause high urinary losses so that even consumption of large volumes (i.e. 2.0-times the exercise sweat loss) will not sustain fluid balance in recovery (Shirreffs et al., 1996). Rehydration drinks should generally contain moderately high levels of sodium (50 mM) and perhaps some potassium (Maughan & Shirreffs, 1997). For optimum rehydration, when sodium is the sole electrolyte source consumed, increasing the sodium content of rehydration fluids above that of commonly available drinks (i.e. Gatorade™ 20 mM; Gonzalez-Alonso, Heaps, & Coyle, 1992) may be beneficial (Maughan & Leiper, 1995). Finally, water may suffice for rehydration when solid food, consumed during recovery, adequately replaces electrolytes (Maughan & Shirreffs).

Recommendations for Coaches and Players:

- Commence consumption of carbohydrate as soon as possible in post-match recovery.
- Consume 50 g carbohydrate (high glycaemic index) every 2 h (total > 600 g for 70 kg body mass).
- A fluid intake program should be planned to optimise post-match rehydration.
- Consume 1.5-2.0 fold the estimated exercise sweat loss to account for urinary and sweat losses in recovery (i.e. exercise sweat loss calculated from the difference between pre- and post-match nude, dry body mass).
- Rehydrate with fluid containing moderate-high sodium content (50 mM).

Supplementary Information:
The availability of dietary supplements is frequently of interest to athletes seeking improvements in performance. Several supplements, not on the International Olympic Committee (IOC) list of banned substances, may enhance athletic performance (Anderson, 1993).

Creatine Supplementation: At present creatine does not appear to have adverse effects and is not banned by the IOC (Clarkson, 1996). Oral creatine supplementation can increase muscle levels of creatine and phosphocreatine (Harris, Soderlund, & Hultman, 1992) as well as increasing the recovery of phosphocreatine after intense exercise (Greenhaff, Bodin, Soderlund, & Hultman, 1994) which would be expected to improve and help maintain power output (see above). Balsom, Ekblom, Soderlund, Sjodin, and Hultman (1993a) showed that creatine supplementation improved performance during brief, high-intensity, intermittent cycling. In general, research supports an ergogenic effect of creatine supplementation in high-intensity intermittent exercise (M.H. Williams, 1995). Dietary creatine supplementation has been shown to improve performance in prolonged (80 min) intermittent, intense exercise (Preen et al., 1997) and therefore might improve tennis performance in long matches.

Presently, there is no evidence of an effect in tennis and research is also needed to determine whether effective creatine supplementation regimes can be developed for the specific conditions of tournament tennis.

Caffeine Supplementation: Caffeine is a stimulant drug and is restricted by the IOC (Clarkson, 1996). Research suggests that long duration aerobic performance is improved by caffeine supplementation at levels below current IOC regulations (Graham and Spriet, 1991). Caffeine supplementation in low doses has been shown to improve visual choice reaction time (Lieberman, Wurtman, Emde, Roberts, & Coviella, 1987) which might be expected to contribute to improved tennis performance. In the study by Vergauwen, Brouns, et al. (1998) carbohydrate compared to placebo supplementation improved tennis performance (see above). However compared to carbohydrate only, carbohydrate plus caffeine supplementation did nôt alter the decline in stroke quality observed at fatigue or add to the ergogenic effect of carbohydrate for shuttle run performance (Vergauwen, Brouns, et al., 1998). Ferrauti et al. (1997) studied the effect of supplementation with carbohydrate and caffeine separately on tennis performance. In this study post-exercise urinary caffeine levels were below IOC limits and there was no effect of caffeine on shuttle run performance (Ferrauti et al.). Caffeine had no effect on stroke production or playing success in male subjects although performance improved in female players (Ferrauti et al.). At present, caffeine supplementation appears to have minimal ergogenic benefit for tennis.

Clarkson (1996) and M.H. Williams (1995) have presented general reviews of the numerous dietary supplements suggested as possible ergogenic aids for athletes. In most cases results are equivocal as to an ergogenic effect and further research is needed (Clarkson; M.H. Williams, 1995). The previous discussion is presented with the intention of directing coaches to current scientific opinion in this controversial field rather than an advocacy for nutritional ergogenic supplementation. The reader is referred to M.H. Williams (1994) for discussion of the ethical issues involved in the use of nutritional ergogenic aids in sport.

SUMMARY AND CONCLUSIONS:

Fatigue impairs tennis stroke production and court movement and hence improving physiological performance is likely to benefit players. In terms of physiological performance, successfully enduring a 5-set (i.e. long) tennis match is likely to depend in part on the capacity to repeatedly generate power across several hours of play. Fitness training for tennis should focus on developing the phosphocreatine energy system (i.e. various forms of training for power). But a high level of aerobic fitness is also crucial to facilitate recovery between rallies and to a lesser extent to improve tolerance of hot conditions in non-acclimated players. Hot environments and dehydration impair physical and mental performance variables relevant to tennis. Where necessary, players should acclimatise by training daily for 6-8 days in the hot environment. Pre-match dietary carbohydrate intake to maintain glycogen stores is important but dehydration may cause fatigue before glycogen stores are depleted. Carbohydrate drinks during competition may improve physiological performance and will also contribute to delaying fatigue due to dehydration. Recent evidence indicates that carbohydrate-electrolyte drinks may improve tennis-specific performance. For long matches (3 h) players should consume 800-1600 $ml{\cdot}h^{-1}$ of a 6-8 % carbohydrate solution containing 10-20 mM sodium (this volume range is large and specific intake will depend on individual sweat rate and environmental conditions). For effective post-match recovery players should begin consumption of carbohydrate (50 $g{\cdot}2\ h^{-1}$, total > 600 g for 70 kg body mass) and fluid (sodium content 50 mM; 1.5-2.0-fold the exercise fluid loss) as soon as possible after the match.

REFERENCES:

Anderson, O. (1993). Creatine propels British athletes to Olympic gold medals: is creatine the one true ergogenic aid ? *Running Research News*, **9** (1), 1-5.

Armstrong, L.E., & Maresh, C.M. (1991). The induction and decay of heat acclimatisation in trained athletes. *Sports Medicine*, **12**(5), 302-12.

Ballor, D.L., & Volovsek, A.J. (1992). Effect of exercise to rest ratio on plasma lactate concentration at work rates above and below maximum oxygen uptake. *European Journal of Applied Physiology*, **65**, 365-69.

Balsom, P.D., Ekblom, B., Soderlund, K., Sjodin, B., & Hultman, E. (1993a). Creatine supplementation and dynamic high-intensity intermittent exercise. *Scandinavian Journal of Medicine and Science in Sports*, **3**, 143-49.

Bangsbo, J. (1994). The physiology of soccer. *Acta Physiologica Scandinavica*, **151**(S 619), 1-155.

Bangsbo, J., Norregaard, L., & Thorsoe, F. (1992). The effect of carbohydrate diet on intermittent exercise performance. *International Journal of Sports Medicine*, **13**(2), 152-57.

Below, P.R., Mora-Rodriguez, R., Gonzalez-Alonso, J., & Coyle, E.F. (1995). Fluid and carbohydrate ingestion independently improve performance during 1 h of intense exercise. *Medicine and Science in Sports and Exercise*, **27**, 200-10.

Bergeron, M.F., Armstrong, L.E., & Maresh, C.M. (1995). Fluid and electrolyte losses during tennis in the heat. *Clinics in Sports Medicine*, **14**(1), 23-32.

Bergeron, M.F., Maresh, C.M., Kraemer, W.J., Abraham, A., Conroy, B., & Gabaree, C. (1991). Tennis: A physiological profile during match play. *International Journal of Sports Medicine*, **12**, 474-79.

Blomstrand, E., Celsing, F., & Newsholme, E.A. (1988). Changes in plasma concentrations of aromatic and branched-chain amino acids during sustained exercise in man and their possible role in fatigue. *Acta Physiological Scandinavica*, **133**, 115-21.

Burke, E.R., & Ekblom, B. (1984). Influence of fluid ingestion and dehydration on precision and endurance performance in tennis. In N. Bachl, L. Prokop & R. Suckert (Eds.), *Current Topics in Sports Medicine* (pp. 379-388). Vienna: Urban & Schwarzenberg.

Burke, L.M. (1996). Nutrition for post-exercise recovery. *The Australian Journal of Science and Medicine in Sport*, **29**(1), 3-10.

Burke, L.M., Collier, G.R., Davis, P.G., Fricker, P.A., Sanigorski, A.J., & Hargreaves, M. (1996). Muscle glycogen storage following prolonged exercise: effect of the frequency of carbohydrate feedings. *American Journal of Clinical Nutrition*, **64**, 115-19.

Cafarelli, E., & Flint, F. (1992). The role of massage in preparation for and recovery from exercise. *Sports Medicine*, **14**(1), 1-9.

Calder, A. (1990). Recovery: restoration and regeneration as essential components within training programs. *Excell*, **6**(3), 15-19.

Chandler, T.J. (1995). Exercise training for tennis. *Clinics in Sports Medicine*, **14**(1), 33-46.

Christmass, M.A., Dawson, B., & Arthur, P.G. (1999). Effect of work and recovery duration on skeletal muscle oxygenation and fuel use in sustained intermittent exercise. *European Journal of Applied Physiology* (In Press).

Christmass, M.A., Richmond, S.E., Cable, N.T., Arthur, P.G., & Hartmann, P.E. (1998). Exercise intensity and metabolic response in singles tennis. *Journal of Sports Sciences*, **16**, 739-47.

Christmass, M.A., Richmond, S.E., Cable, N.T., & Hartmann, P.E. (1995). A metabolic characterisation of singles tennis. In T. Reilly, M. Hughes & A. Lees (Eds.), *Science and Racket Sports* (pp. 3-9). London: E & FN Spon.

Chryssanthopoulos, C., Hennessy, L., & Williams, C. (1994). The influence of pre-exercise glucose ingestion on endurance running capacity. *British Journal of Sports Medicine*, **28**, 105-9.

Clarkson, P.M. (1996). Nutrition for improved sports performance. *Sports Medicine*, **21**(6), 393-401.

Copley, B.B. (1984). Effects of competitive singles tennis playing on serum electrolyte, blood glucose and blood lactate concentrations. *South African Journal of Science*, **80**, 145.

Costill, D.L. (1988). Carbohydrates for exercise: dietary demands for optimal performance. *International Journal of Sports Medicine*, **9**, 1-18.
Costill, D.L., Coyle, E.F., Dalsky, G., Evans, W., Fink, W., & Hoopes, D. (1977). Effects of elevated plasma FFA and insulin on muscle glycogen usage during exercise. *Journal of Applied Physiology*, **43**, 695-9.
Costill, D., & Hargreaves, M. (1992). Carbohydrate nutrition and fatigue. *Sports Medicine*, **13**, 86-92.
Costill, D.L., & Miller, J.M. (1980). Nutrition for endurance sport: carbohydrate and fluid balance. *International Journal of Sports Medicine*, **1**, 2-14.
Costill, D.L., Sherman, W.M., Fink, W.J., Maresh, C., Witten, M., & Miller, J.M. (1981). The role of dietary carbohydrates in muscle glycogen resynthesis after strenuous running. *American Journal of Clinical Nutrition*, **34**, 1831-6.
Coyle, E.F. (1991). Timing and method of increased carbohydrate intake to cope with heavy training, competition and recovery. *Journal of Sports Sciences*, **9**, 29-52.
Coyle, E.F., Hagberg, J.M., Hurley, B.F., Martin, W.H., Ehsani, A.A., & Holloszy, J.O. (1983). Carbohydrate feeding during prolonged strenuous exercise can delay fatigue. *Journal of Applied Physiology*, **55**, 230-5.
Coyle, E.F., & Montain, S.J. (1992). Carbohydrate and fluid ingestion during exercise: Are there trade-offs ? *Medicine and Science in Sports and Exercise*, **24**, 671-678.
Craig, F.N., & Cummings, E.G. (1966). Dehydration and muscular work. *Journal of Applied Physiology*, **21**, 670-74.
Devlin, J.T., & Williams, C. (1991). Foods, nutrition and sports performance: A final consensus statement. *Journal of Sports Sciences*, **9**, (Suppl.), iii.
Elliott, B.C. (1999). Biomechanics of tennis. In P. Renstrom (Ed.), *The IOC Book on Tennis Biomechanics*. London: Blackwells. In Press.
Ferrauti, A., Weber, K., & Struder, H.K. (1997). Metabolic and ergogenic effects of carbohydrate and caffeine beverages in tennis. *Journal of Sports Medicine and Physical Fitness*, **37**, 258-66.
Foster, C., Costill, D.L., & Fink, W.J. (1979). Effects of pre-exercise feedings on endurance performance. *Medicine and Science in Sports and Exercise*, **11**, 1-5.
Fox, E.L., & Mathews, D.K. (1981). *The physiological basis of physical education and athletics*. Philadelphia: Saunders College.
Gisolfi, C.V., & Duchman, S.M. (1992). Guidelines for optimal replacement beverages for different athletic events. *Medicine and Science in Sports and Exercise*, **24**(6), 679-87.
Gonzalez-Alonso, J., Heaps, C.L., & Coyle, E.F. (1992). Rehydration after exercise with common beverages and water. *International Journal of Sports Medicine*, **13**, 399-406.
Gopinathan, P.M., Pichan, G., & Sharma, V.M. (1988). Role of dehydration in heat stress-induced variations in mental performance. *Archives of Environmental Health*, **43**, 15-17.
Graham, T.E. & Spriet, L.L. (1991). Performance and metabolic responses to a high caffeine dose during prolonged exercise. *Journal of Applied Physiology*, **71**(6), 2292-2298.
Green, H.J. (1997). Mechanisms of muscle fatigue in intense exercise. *Journal of Sports Sciences*, **15**, 247-56.
Greenhaff, P., Bodin, K., Soderlund, K., & Hultman, E. (1994). Effect of oral creatine supplementation on skeletal muscle phosphocreatine resynthesis. *American Journal of Physiology*, **266**, E725-30.
Hargreaves, M., Costill, D.L., Coggan, A., Fink, W.J., & Nishibata, I. (1984). Effect of carbohydrate feedings on muscle glycogen utilization and exercise performance. *Medicine and Science in Sports and Exercise*, **16**(3), 219-22.
Harris, R.C., Edwards, R.H.T., Hultman, E., Nordesjo, L.-O., Nylind, B., & Sahlin, K. (1976). The time course of phosphorylcreatine resynthesis during recovery of the quadriceps muscle in man. *Pflugers Archives*, **367**, 137-42.
Harris, R.C., Soderlund, K., & Hultman, E. (1992). Elevation of creatine in resting and exercised muscle of normal subjects by creatine supplementation. *Clinical Science*, **83**, 367-74.

Holloszy, J.D. (1990). Utilization of fatty acids during exercise. In A.W. Taylor, P.D. Gollnick, H.J.
Green, C.D. Ianuzzo, E.G. Noble, G. Metivier & J.R. Sutton (Eds.), *Biochemistry of Exercise VII* (pp. 245-259). Champaign: Human Kinetics.
Hultman, E., & Sjoholm, H. (1986). Biochemical causes of fatigue. In N.L. Jones, N. McCarney & A.J. McComas (Eds.), *Human Muscle Power* (pp. 215-238). Champaign: Human Kinetics.
Ivy, J.L., Katz, A.L., Cutler, C.L., Sherman, W.M., & Coyle, E.F. (1988b). Muscle glycogen synthesis after exercise: effect of time of carbohydrate ingestion. *Journal of Applied Physiology*, **65**, 1480-5.
Jansson, E., Dudley, G.A., Norman, B., & Tesch, P.A. (1990). Relationship of recovery from intense exercise to the oxidative potential of skeletal muscle. *Acta Physiologica Scandinavica*, **139**, 147-52.
Karlsson, J., & Saltin, B. (1971). Diet, muscle glycogen and endurance performance. *Journal of Applied Physiology*, **31**, 203-206.
Keizer, H., Kuipers, A.H., van Kranenburg, G., & Geurten, P. (1986). Influence of liquid and solid meals on muscle glycogen resynthesis, plasma fuel hormone response, and maximal physical working capacity. *International Journal of Sports Medicine*, **8**, 99-104.
Lamb, D.R., & Brodowicz, G.R. (1986). Optimal use of fluids of varying formulations to minimise exercise-induced disturbances in homeostasis. *Sports Medicine*, **3**, 247-74.
Lemon, P. (1991a). Effect of exercise on protein requirements. *Journal of Sports Sciences*, **9**, (Suppl.), 53-70.
Lieberman, H.R., Wurtman, R.J., Emde, G.G., Roberts, C., & Coviella, I.L.G. (1987). The effects of low doses of caffeine on human performance and mood. *Psychopharmacology*, **92**, 308-12.
MacLaren, D.P.M., Gibson, H., Parry-Billings, M., & Edwards, R.H.T. (1989). A review of metabolic and physiological factors in fatigue. *Exercise and Sports Science Reviews*, **17**, 29-66.
McCarthy, P.R., Thorpe, R.D., & Williams, C. (1995). The influence of a carbohydrate-electrolyte beverage on tennis performance. In H. Krahl, H.G. Pieper, W.B. Kibler & P.A. Renstrom (Eds.), *Second International Conference of Sports Medicine and Science in Tennis* (pp. 210-18). Dusseldorf: Rau.
McCarthy, P.R., Thorpe, R.D., & Williams, C. (1997). The influence of fatigue on tennis performance. *Journal of Sports Sciences*, **15**, 17.
Maughan, R.J., Greenhaff, P.L., Leiper, J.B., Ball, D., Lambert, C.P., & Gleeson, M. (1997). Diet composition and the performance of high-intensity exercise. *Journal of Sports Sciences*, **15**, 265-75.
Maughan, R.J., & Leiper, J.B. (1995). Sodium intake and post-exercise rehydration in man. *European Journal of Applied Physiology*, **71**, 311-19.
Maughan, R.J., & Shirreffs, S.M. (1997). Recovery from prolonged exercise: Restoration of water and electrolyte balance. *Journal of Sports Sciences*, **15**, 297-303.
Mitchell, J.B., Cole, K.J., Grandjean, P.W., & Sobczak, R.J. (1992). The effect of a carbohydrate beverage on tennis performance and fluid balance during prolonged tennis play. *Journal of Applied Sport Science Research*, **6**(2), 96-102.
Murray, R. (1992). Nutrition for the marathon and other endurance sports: environmental stress and dehydration. *Medicine and Science in Sports and Exercise*, **24**(9, Suppl.), S319-23.
Nadel, E.R., Mack, G.W., & Nose, H.N. (1990). Influence of fluid replacement beverages on body fluid homeostasis during exercise and recovery. In C.V. Gisolfi & D.R. Lamb (Eds.), *Perspectives in Exercise Science and Sports Medicine Vol 3. Fluid Homeostasis during Exercise* (pp. 181-205). Carmel: Benchmark.
Newsholme, E.A. (1986). Application of principles of metabolic control to the problem of metabolic limitations in sprinting, middle-distance, and marathon running. *International Journal of Sports Medicine*, **7**(Suppl.), 66-70.

Newsholme, E.A., Blomstrand, E., & Ekblom, B. (1992). Physical and mental fatigue: Metabolic mechanisms and importance of plasma amino acids. *British Medical Bulletin*, **48** (3), 477-95.
Pandolf, K.B. (1979). Effects of physical training and cardiorespiratory physical fitness on exercise-heat tolerance: recent observations. *Medicine and Science in Sports and Exercise*, **11**, 60-65.
Piwonka, R.W., & Robinson, S. (1967). Acclimatization of highly trained men to work in severe heat. *Journal of Applied Physiology*, **22**, 9-12.
Preen, D., Dawson, B., Goodman, C., Lawrence, S., Beilby, J., & Ching, S. (1997). The effect of oral creatine supplementation on 80 minutes of repeated sprint exercise. In *Proceedings of The Australian Conference of Science and Medicine in Sport* (pp 276-277). Bruce: Sports Medicine Australia.
Sahlin, K. (1992). Metabolic factors in fatigue. *Sports Medicine*, **13**(2), 99-107
Sahlin, K., Harris, R.C., & Hultman, E. (1979). Resynthesis of creatine phosphate in human muscle after exercise in relation to intramuscular pH and availability of oxygen. *Scandinavian Journal of Clinical and Laboratory Investigation*, **39**, 551-58.
Saltin, B. (1973). Metabolic fundamentals in exercise. *Medicine and Science in Sports and Exercise*, **5**, 137-146.
Saltin, B., & Karlsson, J. (1971). Muscle glycogen utilization during work of different intensities. In B. Pernow & B. Saltin (Eds.), *Muscle Metabolism during Exercise* (pp. 289-299). New York: Plenum Press.
Sawka, M.N. (1992). Physiological consequences of hypohydration: exercise performance and thermoregulation. *Medicine and Science in Sports and Exercise*, **24**(6), 657-70.
Sawka, M.N., & Pandolf, K.B. (1990). Effects of body water loss on physiological function and exercise performance. In C.V. Gisolfi & D.R. Lamb (Eds.), *Perspectives in Exercise Science and Sports Medicine, Vol 3: Fluid Homeostasis During Exercise* (pp. 1-38). Indianapolis: Benchmark.
Sherman, W., Costill, D., Fink, W., & Miller, J. (1981). Effect of exercise-diet manipulation on muscle glycogen and its subsequent utilisation during performance. *International Journal of Sports Medicine*, **114**, 114-18.
Sherman, W.M., & Leenders, N. (1995). Fat loading: the next magic bullet ? *International Journal of Sport Nutrition*, **5**, (Suppl.), S1-S12.
Shirreffs, S.M., Taylor, A.J., Leiper, J.B., & Maughan, R.J. (1996). Post-exercise rehydration in humans: effects of volume consumed and drink sodium content. *Medicine and Science in Sports and Exercise*, **28**(10), 1260-71.
Soderlund, K., & Hultman, E. (1991). ATP and phosphocreatine changes in single human muscle fibres after intense electrical stimulation. *American Journal of Physiology*, **261**, E737-41.
Struder, H.K., Hollmann, W., Duperly, J., & Weber, K. (1995). Amino acid metabolism in tennis and its possible influence on the neuroendocrine system. *British Journal of Sports Medicine*, **29**(1), 28-30.
Terrados, N., & Maughan, R.J. (1995). Exercise in the heat: Strategies to minimize the adverse effects on performance. *Journal of Sports Science*, **13**, S55-S62.
Therminarias, A., Dansou, P., Chirpaz-Oddou, M.F., Gharib, C., & Quirion, A. (1991). Hormonal and metabolic changes during a strenuous tennis match. Effect of aging. *International Journal of Sports Medicine*, **12**, 10-16.
Vandenberghe, K., Hespel, P., Vanden Eynde, B., Lysens, R., & Richter, E.A. (1995). No effect of glycogen level on glycogen metabolism during high intensity exercise. *Medicine and Science in Sports and Exercise*, **27**(9), 1278-83.
Vergauwen, L., Brouns, F., & Hespel, P. (1998). Carbohydrate supplementation improves stroke performance in tennis. *Medicine and Science in Sports and Exercise*, **30**(8), 1289-95.
Vergauwen, L., Spaepen, A.J., Lefevre, J, & Hespel, P. (1998). Evaluation of stroke performance in elite tennis players. *Medicine and Science in Sports and Exercise*, **30**(8), 1281-88.

Wenger, C.B. (1988). Human heat acclimatization. In K.B. Pandolf, M.N. Sawka & R.R. Gonzalez (Eds.), *Human Performance Physiology and Environmental Medicine at Terrestrial Extremes* (pp. 153-197). Indianapolis: Benchmark.

Williams, C. (1995). Macronutrients and performance. *Journal of Sports Sciences*, **13**, S1-S10.

Williams, C., & Chryssanthopoulos, C. (1997). Pre-exercise food intake and performance. In A.P. Simopoulos & K.N. Pavlou (Eds.), *Nutrition and Fitness: Metabolic and Behavioural Aspects in Health and Disease. World Review of Nutririon and Diet,* **82** (pp. 33-45). Basel: Karger.

Williams, M.H. (1994). The use of nutritional ergogenic aids in sports: Is it an ethical issue ? *International Journal of Sport Nutrition*, **4**, 120-31.

Williams, M.H. (1995). Nutritional ergogenics in athletics. *Journal of Sports Sciences*, **13**, S63-74.

Wright, D., Sherman, W., & Dernback, A. (1991). Carbohydrate feedings before, during, or in combination improve cycling endurance performance. *Journal of Applied Physiology*, **71**, 1082-88.

THE ATTRIBUTES OF THE COACH — COACHING JUNIOR TENNIS PLAYERS FROM NOVICE TO ELITE.

John Thorpe
Vice President, Tennis Coaches Australia, Perth

THE ATTRIBUTES OF A GOOD TENNIS COACH - GENERAL:

As a participant in sport, either as a coach or player , we can experience a very good training ground for life in general. We learn the skills of dealing with victory and accepting defeat as well as the discipline of training and working in a team. A good tennis coach will maximise this learning opportunity for themself and also the player.

The role of the tennis coach is crucial within the game of tennis. A good coach will be competent in many areas including the following:

- Biomechanics of stroke production
- Basic teaching principles
- Instilling enthusiasm in players
- Teaching the virtues of good sportsmanship
- Understanding progression in learning
- Flexibility and innovation

Parents will encourage their children to participate in a sport they feel positively about. As tennis coaches it is essential to nurture the enthusiasm of our junior players brought about by current successful Australian players. The responsibility of the tennis coach becomes increasingly important to improve the image and profile of the game. Tennis has been accused of having little development support from the average ATP and WTA Touring Professional. At the championship level, tennis is a big money sport and this has bred a somewhat selfish attitude that is contrary to the spirit of sportsmanship. It can be argued that this has reduced the development of tennis at a club level. The tennis coach is now the "front line" and we need to be more professional than previously. Coaches should participate in lifelong learning, and be prepared to move out of their immediate environment and maintain currency with the latest methodologies. With this attitude it will be possible to approach the new millennium with an excellent growth opportunity.

When we look at the role of the tennis coach we can simplify our analysis by looking at different groups of players. For easy analysis the coaching role has been divided into four categories of players:

1. The novice player
2. The early competition player
3. The advanced competition player
4. The elite player

It is highly unlikely that a coach has expertise in all four areas. Most good coaches are able to perform adequately in all four areas but are likely to do excel in a maximum of two categories. As an example, the national coach is more effective dealing with elite athletes than he or she would be coaching a young player in the first tennis lesson. This is not to say that the national coach can not teach the novice player well, but only that this is not the normal every day work, and therefore their current experience level is depleted.

All of our students like to think that they can progress to the top as tennis players. Unfortunately the reality is that as we test more difficult skills, less players will succeed.

Figure 1 is representative of the tennis population as the skill level becomes more advanced. The world's number one player could be represented as a minute dot at the top of the triangle.

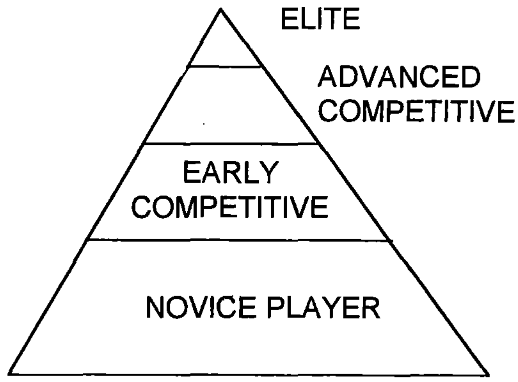


Figure 1 - Pyramid of players and skill level.

Figure 2 represents the game of tennis divided into the four basic teaching areas. As a player improves in skill they are challenged in more areas. In the event of reaching the advanced competition stage, they are challenged in all areas.

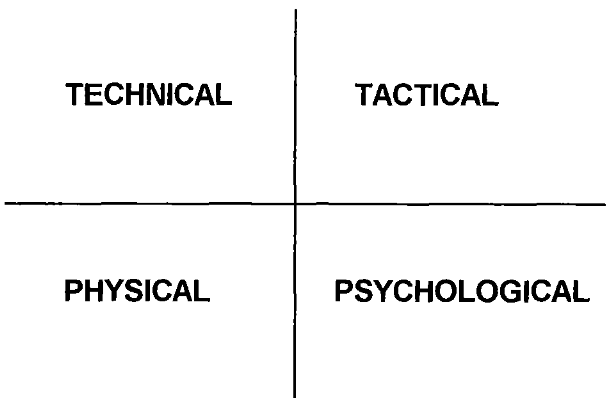


Figure 2 - The four basic teaching areas of tennis

COACHING THE NOVICE PLAYER:
Coaching the novice player can be one of the most satisfying coaching experiences. There is little doubt that this player can show the most accelerated development of all learners participating in a continuous programme. As the coach of a novice player a relaxed atmosphere must be created where the player is not intimidated and will look forward to the fun and challenge of hitting tennis balls.

The emphasis of coaching in this situation is the core fundamental mechanics of making tennis strokes. A small physical component will be necessary when coaching this player, but it is little more than the basic movement skills to a typical ballfeed by the coach. Excessive concentration on movement skills will complicate the learning process and should only be included as the player approaches the early competition stage. Coaching should emphasise the areas of grips and simple racquet swings that are controlled by the larger muscles of the body.

The player should have a clear understanding of the correct grips and a clear visual image of what their strokes should look like. As coaches it is important not to make the mistake of trying to impress the student with our own ability to play or extensive knowledge. If the student can answer positively the following questions then we can assume that the task has been satisfactorily completed.

1. Can the player demonstrate accurately the correct swing in shadow format? [no ball present]
2. Does the player feel good about themself?
3. Does the player have increasing enthusiasm to play tennis?

COACHING THE EARLY COMPETITION PLAYER:

Coaching the early competition player requires special skills and patience. Attention to detail is very important because the player is likely to be playing considerably more tennis than at the novice stage. Technique tends to become more established at this level and is important to ensure an acceptable manner is achieved. Coaching is still heavily based on swing mechanics while the physical component should also being covered. An emphasis on the need for sound footwork and training of correct footwork patterns is also essential.

In many ways the coach of the early competition player does the hard work. The development of a full court game is difficult at a young age, but is essential in order for the player to progress with a variety of options in their future game. The early competition player must develop a competent volley and approach shot. In the case of the two handed backhand player, a slice backhand will be essential. Tactical coaching is also introduced at this level. This player must begin to understand the concepts of when to defend, when to rally, and when to attack, and must be made aware of how to play different shots in order to vary their game.

One of the biggest challenges for the coach is to teach the player to keep winning and losing in perspective. It is important to develop an attacking game, however, there is often a period of time early in the development process where winning will be difficult because of the time that it takes to develop an attacking game. The coach must call on all skills at this time in order to convince the young players to adhere to a long term plan, even if losses are suffered in the short term. The coach must remind the player that an attacking game is essential if they are to progress to the elite level. There is significant evidence to suggest that early success in terms of winning is often not sustained into the later areas of development. Often the coaches can set goals for the player that do not necessarily include winning. For example, player A can be a winner by playing a balanced mixture of attacking, rallying, and defensive balls against player B. This player could be classified as a winner because of the variety of strategies and strokes being used, even if the match is lost.

To progress to the next stage a player must develop a correct understanding in the following:

- Correct grips - especially on serve
- Correct swing pattens
- Correct footwork pattens
- An all court game
- Adhere to a coaching plan - winning is not the main goal at this stage
- Tennis is fun — keep it that way !

COACHING THE ADVANCED COMPETITION PLAYER:
Coaching the advanced competition player is particularly challenging. The coach must now include an even balance between mechanical, psychological, tactical, and physical training. Winning is now an important issue for the player. The coaches must assist the players to "get over the line" at this stage of their development. The best way for this to be done is for the coach to act as Head Coach while being prepared to involve other experts in certain coaching roles. This would involve including a trained Exercise Physiologist to conduct the physical tests and construct a training programme for the player. The coach may then oversee this physical programme. It is essential that the coach of the advanced competitive player has the skills to work in a team and to cooperate with other member of the coaching team. This would include state and regional coaches, medical experts and specialists in other coaching fields. The coach should always remain the central figure, but not be too proud to seek special expertise to assist in player development.

Managing the coach/parent relationship is also an issue that can involve a challenge. It is important for the coach and parent to have a firm understanding of their roles and responsibilities. The state of this relationship needs to be regularly reviewed. It has even been recommended that the coach suggest an official contract with a parent in order to manage the coaching role (Loehr and Kahn III, 1987). While this may seem extreme, a contract is essential for coaches who are particular about having no parental involvement in the coaching role. It is of interest that the authors recommend a contract that can govern the parent/player relationship. The coach may even have to be a mediator in disputes arising from this document.

The coach must ensure that the player has developed a particular style of game and that it is compatible with the player's physical profile. Power strokes are important and the coach must coordinate with strength advisers on the best strokes to work with and how best to achieve this goal. It is necessary to teach the players correct habits in order to manage their preparation for competition. This will include setting goals, managing diet, having rest periods from training, and maintaining equipment.

To move up from this category, the coach must ensure that the player has achieved in the following areas.

- Hold a very high state ranking
- Hold at least a mid level national ranking
- Technically sound in all areas of the game
- Be very successful in physical testing for speed , endurance and strength
- Have very good work ethic
- Show courage

COACHING THE ELITE COMPETITION PLAYER:
Coaching the elite competition player is often seen as the pinnacle of the coaching challenge. This coach often has had an elite playing background. This is an obvious advantage because the coach has insight into the difficulties and challenges that face the player. There have, however, been some celebrated cases in which the coach has come from a very modest playing background to be very successful in the coaching of an elite performer.

Coaching is often dominated by the physical, tactical and psychological components. The competitive edge is often found in these areas and the coach must deliver the coaching message effectively for the player concerned. This can be particularly difficult if the coach is involved with several athletes who are likely to have different approaches to accepting coaching advice. The successful delivery and player management will be the ultimate test for the coach.

Technique is generally not adjusted at this stage. An exception to this can be minor alterations to stroke production in order to prevent injury. At this level of play the strain on the muscles and joints can be extreme and the coach must always be aware that they may have to formulate a plan in this area. Modern tennis is a power game and it would be assumed that the player has a power serve and power groundstrokes. The coach must assist the player to achieve the maximum from these potential weapons. This can involve tactical coaching designed to make the best use of these winning shots. It could also involve the coordination of a strength programme to make these shots more powerful. The unique issue about coaching at this level is that the coach must have a totally individual approach to each player. Because of the variation in player needs, the coach must show good flexibility and innovation.

It is important to be able to regulate the volume and intensity of coaching. There are many individual considerations here, and the task will be complicated if the coach is responsible for several athletes. It is likely that as players become competitive internationally, they could have a personal coach and not be involved in a group situation.

At this stage the player must learn to cope with the difficulties of national and international travel, while the coach must also be prepared to travel and work irregular hours. The coach and player must also learn to deal with sponsors, media, tournament directors, and other coaches and association bodies.

Results are everything at this stage of development. The player must learn to attain results and the coach's success will be measured by those results.

CONCLUSION:

Coaching the junior tennis player from the novice stage through to the elite requires diversity in the role of the coach and the expectations of the player. Tennis is a game, and in the end must remain a game. It is important to keep in perspective the tennis commitment. The player must relish the challenge that the game presents and the coaches should always put themselves in a position where they are continually learning.

REFERENCES:

Loehr, J.E. & Kahn III, E.J. (1987). *Net results Ñ Training the tennis parent for competition.* Lexington, Ma: Stephen Green Press.