TENNIS RECOVERY

A Comprehensive Review of the Research

Editors:
Mark S. Kovacs, PhD
Todd S. Ellenbecker, DPT
W. Ben Kibler, MD

A United States Tennis Association Sport Science Committee Project

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Introduction

In the last two decades, physical training and competitive opportunities have increased dramatically in junior, collegiate and professional tennis. This arose due to a multitude of factors, but much of it has stemmed from an increase in knowledge and understanding of scientifically based training programs focused on improving performance. As this focus on performance has increased, the area of recovery has received relatively limited focus. Recovery is a multi-faceted paradigm focusing on recovery from training—session to session, day to day and week to week. Recovery is also vitally important during training as well as in competition between matches and between days during multi-day tournaments. As more information is needed in the area of tennis specific recovery, the Sport Science Committee of the United States Tennis Association (USTA) sponsored an extensive evidence-based review of the available literature related to eight distinct areas of tennis-specific recovery. These eight areas are:

- Nutritional Aspects of Tennis Recovery
- Heat and Hydration Aspects of Tennis Recovery
- Psychological Aspects of Tennis Recovery
- Recovery Aspects of Young Tennis Players
- Physiological Aspects of Tennis Recovery
- Musculoskeletal Injuries/ Orthopedics Aspects of Tennis Injury
- General Medical Aspects of Recovery
- Coaching Specific Aspects of Recovery

As the mission of the USTA Sport Science Department is *"to produce, evaluate and disseminate sport science and sports medicine information relevant to tennis,"* this project was a priority to help bridge the gap between the current scientific literature covering recovery in tennis and how this information may be applied practically to coaches, players and parents. The major objective of this project was to gain a greater understanding of the information currently available and provide some guidance on how tennis players should be recovering from training and competition with a specific focus on reducing the likelihood of injury as well as improving performance, health and safety.

The original goal of this project was to analyze the data that is available in the hope of illuminating potential answers to some of the following frequently asked questions by coaches, parents, tournament directors and players:

- How many matches is it appropriate to schedule in a given day for a junior (18 years old or younger) player? (Players are grouped into 12&under, 14&under, 16&under and 18&under age groups.)
- How much time should be allowed between individual matches to allow for adequate recovery - to achieve high level performance while also reducing the risk of injury?
- How many weeks in a row should players compete in tournaments (often times traveling to play in these events) before taking a break?
- How much time should be allowed between training sessions?
- What guidelines should players follow to properly refuel the body after a match/ practice to allow for recovery?

The USTA strives to base all recommendations on existing evidence-based literature, yet the literature on recovery, particularly as it relates to tennis, is somewhat limited. Recognizing we cannot answer most of these questions definitively, this project aimed to provide the "most current state of knowledge" to the tennis community using information from many areas of sport science and from other sports arenas as well. We were very fortunate to have each chapter written by leading experts in their respective fields and the information provided does showcase what is presently available, but it equally highlights many areas that are in need of further research. The hope is that this information will be used by clinicians, researchers and coaches to improve the recovery components of the competitive tennis player, with the understanding that much of the recovery literature on tennis has yet to be investigated. More research both in lab settings as well as on the court, during training and live tournaments needs to be evaluated before definitive guidelines can be made.

Sincerely,

Mark Kovacs, PhD — Todd S. Ellenbecker, DPT — W. Ben Kibler, MD

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Abstract

Fatigue is a natural response to training and stress and as such it is an essential part of the human adaptive process. However sport scientists have struggled to provide a single definition of fatigue because of the broad range of physiological, cognitive, and emotional states integral to human performances. Despite debate about what constitutes fatigue, the negative impact of it on a player's ability to train and perform optimally and consistently, is evident to both athlete and coach. There is increased awareness that the rate of recovery from fatigue is a gauge of a player's response to stress. Recognition of player fatigue and how it is managed in both training and performance contexts, is the basis of recovery. The way that fatigue is expressed reflects the type of training undertaken, the performance environment and lifestyle issues affecting the player. Selection of appropriate recovery strategies to address specific types of fatigue will depend on the recovery knowledge of player and coach, and on the availability and cost of the strategies identified.

Numerous recovery modalities are available but few have been subjected to rigorous scientific examination. Coaches and players often depend on anecdotal information from fellow coaches and other athletes for details about recovery techniques and their use. This chapter has two major aims. The first is to provide coaches and players with a systematic approach to monitoring adaptation to training and stress. The second is to review current scientific information about commonly used recovery modalities and strategies, with examples of how these can be integrated into training and performance for tennis.

Introduction

The roles and benefits of recovery

The main role of recovery is to help athletes adapt faster to training[1,2,3]. This is done by minimizing the effects of training and performance fatigue in order to enable the player to *"bounce back"* and be ready for the next session or match.[2] This process is a critical step in the "overcompensation" model.

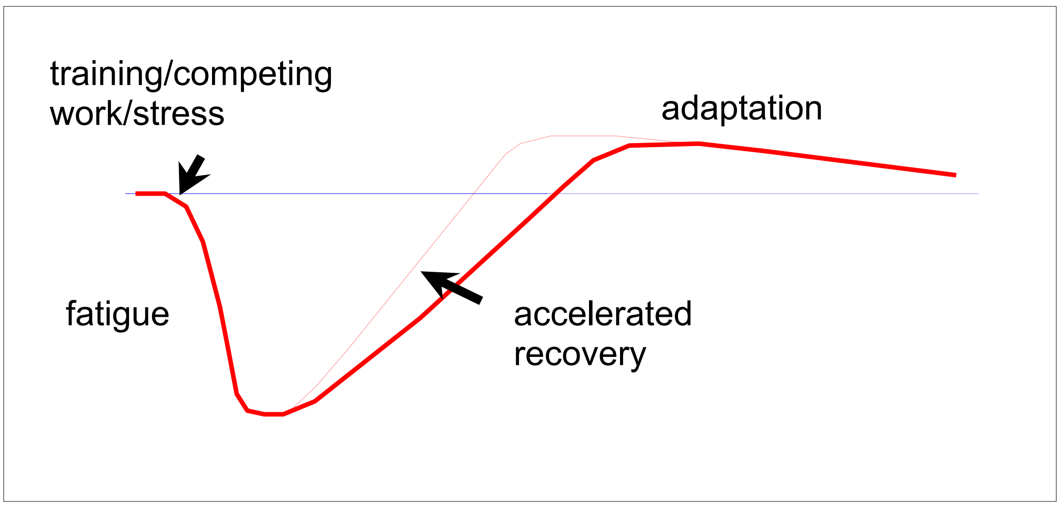

Figure 1. The principle of recovery[2]

The ensuing benefits from detecting and addressing athlete fatigue include a reduction in illnesses and injuries[5]. The conditions of overtraining [6,7] overuse[8,9,10] and burnout[11,12] are common problems for high performance athletes and can occur either independently[7] or collectively[6,11] when undertaking high volumes of training[7,11.13]. Regular monitoring of players' stress responses can help to detect problems early, thereby reducing the incidence and impact of such problems[13,14,15]. A holistic approach to managing fatigue through the use of recognized recovery practices (outlined later) promotes adaptations to training loads and stress that are natural and safe for the player. These recovery strategies provide the player with legitimate techniques to promote adaptation, unlike strategies that involve the use of banned ergogenic substances and practices, as outlined in the USTA Anti-Doping Program, that may compromise the health and wellbeing of the player.

An additional benefit for players using recovery monitoring and management strategies is the enhancement of their self-awareness and self management skills[1]. Training hard and recovering well requires careful planning and management and players who develop these competencies acquire skills that transfer to life outside the sporting environment. These attributes are invaluable for the post competitive career period when players transit into other vocations and lifestyles.

Recognizing fatigue

The fatigue experienced by players in training and competition is a necessary part of the adaptive process[2,17]. The astute coach will design programs specifically to expose the player to many varieties of fatigue in order to extend the player's skill levels and capability to perform in both fresh and fatigued states. The challenge for most coaches and players is to identify what capacity is being fatigued from these stresses[17] and then to be able to select the most appropriate recovery strategies to accelerate the restoration of the player to a normal functioning state[3,4].

Types of Fatigue

Training and competition fatigue can be categorized into four main types based on the source of the fatigue. It is important for a coach and player to be able to identify the source of the fatigue[14] so that they know how to address each type of fatigue with appropriate and specific recovery strategies[1,3]. *Metabolic fatigue* refers to fatigue resulting from imbalances in the availability and replenishment of the energy required to perform (fluids and fuels) (see chapter on Nutrition). It is associated typically with high volumes of training and competition[18,19]. This can occur as a result of demanding training sessions or matches lasting more than one hour, or as a result of several sessions a day, or training and matches over a number of days.

Much less is known about neural fatigue than metabolic fatigue. *Neural fatigue* may result from fatigue of either or both, the peripheral nervous system (PNS) and/or the central nervous system (CNS). The former occurs when there are biochemical imbalances in strong ion concentrations or neurotransmitters within the muscle cell, resulting in a reduction of localized force production[20]. PNS fatigue may occur after short but high intensity training sessions or matches even when there is no evidence of metabolic fatigue, or after long lasting but low intensity sessions[20,21]. Fatigue of the *central nervous system* can occur if the player has an inadequate diet[22] (e.g.low blood glucose levels), lacks motivation, or is injured[20]. It is characterized by a lack of drive[20] and may occur independently from or consecutively with, *psychological fatigue*. The causes of psychological fatigue are varied and may stem from within or outside the training and competition program[14,15,23]. The most common sources of this type of fatigue include competition pressures, school exams, home life stresses, and financial difficulties (see chapter on Psychology).

Environmental fatigue occurs through time spent travelling and dealing with changing weather conditions and time zones. Climate and weather conditions such as the extreme heat experienced by players at the Australian Open, can lead to an earlier onset of fatigue than would be normal for that player. Time spent travelling, particularly through one or more time zones can lead to jet-lag, so additional recovery strategies are needed to address fatigue in these circumstances[1,24,25].

All of these types of fatigue may occur together or independently depending on the amount and type of workloads and stress affecting a player. A multi-day tournament with poor weather conditions may produce all types fatigue, so a comprehensive and integrated approach to recovery requires careful planning to minimize the impact of this on performance[1,3,4].

Table 1: Training and Competition Fatigue[1]

Type of Fatigue	**Main causes for fatigue**	**Expression of this fatigue**	**Tennis examples**
Metabolic Fatigue *(Energy Stores)*	• Long training sessions e.g. of one hour or more • Playing several matches a day e.g. singles and doubles • Cumulative fatigue from training or competing over many days e.g. tournaments	• Player fatigues sooner than is normal for that player • Player struggles to complete a session or event	• Lethargy in body language • Walking slowly in the session • Slower response to chasing balls
Neurological Fatigue **PNS Fatigue** *(muscles)*	• After short high intensity sessions, e.g. weights, plyometrics, complex skill execution, etc. • After long training sessions of one hour or more, or after matches greater than two hours. • Several matches over consecutive days[26]	• Reduced localized force production e.g. slower responses, reduced power	• Slow feet • Reduced acceleration • Poor technique and co-ordination. • Abnormal number of technical mistakes • Reduced power in shots and strokes
Neurological Fatigue **CNS Fatigue**	• Low blood glucose levels • High pressured training session – especially involving rapid decision making and reactions • Poor motivation e.g.	• Lack of drive • Slower at processing visual cues	• Looses concentration quickly • Slower at decision making • Slower anticipation timing e.g. speed and placement of opponents serve or return

(brain)	monotony of training, emotional factors, injury etc.		
Psychological Fatigue *(emotional, social, cultural)*	• Lack of squad cohesion, personality conflicts etc. • Competition pressures, event venue, residential conditions, parents, coach, media, etc. • Other lifestyle stresses – home, school exams, personal relationships	• Player looses self-confidence or self esteem • Poor interaction and deteriorating communication with other players and coaches • Increased signs of anxiety, negative attitudes, etc.	• Player shows a definite lack in confidence during play and also off court • Tends to be more negative than usual especially in self-talk, and with body language • Players' communication seems different, e.g. pre occupied with matters away from tennis that affect focus and concentration
Environmental & Travel Fatigue	• Weather (e.g. wind, heat and sun) increase fatigue • Disruption of normal routines, *circadian dysrhythmia* • Disruption to sleep, waking and meal times • Sedentary and restricted body movement on long journeys, i.e. 30 min or more • Adapting to different climates and time zones	• Players are slower to start • Fatigue sooner than normal especially in the heat • Visual fatigue from bright or glaring sunlight	• Player takes longer than usual to get game together • Unforced errors in the first 15 min are well above normal • Tired eyes and eye strain • Poor tracking of the ball

Adapted from Calder[1]

Main Text

Monitoring adaptive responses to training and stress

Players will adapt to training and stress in different ways and at different rates depending on their developmental age, training experience and performance level[27]. For these reasons it is essential to monitor individual responses to work and stress, both within and outside the training and competition environment. There are three perspectives to monitoring a player's adaptation. These are through the player's own recorded perceptions[28,29,30] the coach's observations at training and in competition[4,31] and sport scientist and sport medical screening and testing assessments[32,33]. Each person involved in this process has a different role but the collective information from all parties provides a holistic view of adaptation throughout a players' long term involvement in tennis [27,28].

Of the three views, the most important is that of the player who is responsible for self-assessment on a daily basis. The coach is the next most important individual as the coach is able to monitor the player at training and often in competition. The coach's records of player performance and behavior are an invaluable source of empirical information. Sport science and sport medicine evaluations and reviews occur less frequently and are more intermittent depending on the needs of the player. These are often expensive as they require greater expertise than the personal observations conducted by player and coach.

Table 2: Monitoring Strategies for player development, experience (training age) and increased workloads and stress[27,28]

FUNdamental	Learning to Train	Training to Train	Training to Compete	Training to Win	Masters Players and Coaches
Specific Training Age: **0 years**	Specific Training Age: **1-2+/- years**	Specific Training Age: **3-7+/- years**	Specific Training Age: **8-10+/- years**	Specific Training Age: **10-12+/- years**	Specific Training Age: **1-100+/- years**
At Training (C)* *Smiley Face.* • Energy / tired • Happiness **Reminder (C)** • Toilet (hydration checks)	**Start Recording (P)** • Energy / tired • Self-esteem • Quality of sleep • Illness or injury **Reminder (C)** • Toilet checks **6-9 months (C)** • Limited field and sports specific testing	**Daily Records (P)** • Resting HR • Energy / fatigue • Self-esteem • Quality of sleep • Muscle soreness • Body weight • External stresses • Illness or injury • Menstrual cycle **Ongoing (P)** • Toilet checks **2-6 months (SS)** • Musculoskeletal checks • Sports science checks	**Daily Records (P)** • Resting HR • Energy / fatigue • Self esteem • Quality of sleep • Muscle soreness • Body weight • External stresses • Illness or injury • Menstrual cycle **Ongoing (P)** • Toilet checks **2-6 months (SS)** • Sports science & Medicine checks **6-12 months (SS)** • Musculoskeletal checks	**Daily Records (P)** *(As for the previous stage)* Individualized testing and screening varies for each athlete **(C & SS)** Access to facilities and technology, plus the intensity of the competition schedule will influence *when* and *how often* testing and screening are done	**Daily Records (P)** • Resting HR • Energy / fatigue • Self esteem • Quality of sleep • Muscle soreness • External stresses • Illness or injury • Menstrual cycle (if relevant) **Ongoing (P)** • Toilet checks **6-12 month (SS)** • Sport Science & Medical checks **Annual (SS)** • Musculoskeletal checks

*Monitoring responsibilities: **(P)** = player: **(C)** = Coach: **(SS)** = sport scientist or sport medical specialist

The Player

A responsible player will monitor training adaptations through regular recordings in a training diary or log book[30]. An essential skill for all players is to maintain a daily record of their fatigue levels and responses to stress as this enables them to learn how to recognize their current adaptive state. Recordings about the quality of sleep and a daily rating of fatigue levels are two essential variables that should be recorded daily. Some players may also like to record morning resting heart rate[34] and body weight, with the latter being a useful way of monitoring the effectiveness of any rehydration strategies following a match day, or long training session. These four variables take no more than 2 minutes a day to record and may be the first warning that the athlete is not adapting well to training and other stresses[3,14,15].

Stated simply, feeling tired after a training session or match is a normal response but feeling fatigued all the time is a sign that the body has not adapted well to stress. An elevated resting heart rate recorded first thing in the morning (i.e. 10 beats above normal) is often an indication that any training undertaken should be minimal on that day. Although many factors influence heart rate variability[34] regular recordings can be a useful physiological measure when used in conjunction with the other indicators of excessive stress. An elevated morning resting heart rate profile is more evident in developing players who are adapting to heavy training or competition, whereas more seasoned players with extensive training bases may experience a depressed morning heart rate following such workloads. Body weight is best recorded each morning before eating and after going to the toilet but some adolescent females may misinterpret this strategy as a measure of “fat” so this variable should be used very selectively in these cases. Rapid weight loss or rapid weight gain is not advisable. Unexplained weight loss is not necessarily a measure of decreased fat stores but may be an indication of poor hydration or excessive stress (see chapter on Nutrition).

In reality many players are likely to be inconsistent with recording morning resting heart rates. Research to identify effective indicators to warn of any possible onset of illness have indicated that a comprehensive set of variables, not just resting heart rate, should be monitored[12,13,19,23,24]. The frustration for many coaches is the lack of consistency with which many players record these variables. Some players will forget to record information consistently while others are unreliable at maintaining records of any kind. There are alternative strategies to deal with non-compliance. A simple and quick self-assessment method for the coach is to present a monitoring sheet to the athlete when they arrive at training. The use of the *Smiley Faces* form[5,22] (Figure 2) within a training session to indicate player well-being has proved to be most helpful for coaches of both junior and high performance players.

	☹	😐	☺
Performance			
Happiness			

Figure 2. Smiley Faces. *“Check how you feel”*

Feedback from tennis coaches after using the Smiley Faces with their players.

"The first time I used this, the players thought it was not a too serious exercise and were quite casual about filling it in. Now, however, 4 months later, when they are still filling it in every training session they can see the usefulness of it. My expectations are more "realistic" to their wellbeing rather than to the same training levels we always worked at." Peter le Surf[35]

"After what I perceived to be one heavy session, the feedback did not indicate that the session was as stressful as I had thought which brought me to the conclusion that they were more resilient than I had given them credit for. The emotional box also helped me to get an insight into how they were feeling that morning, before even talking to them. This tool is great as it is simple and a fast way for a coach to gain relevant information without delving too deep and wasting valuable time. It gives coaches a chance to adjust training sessions prior to and plan appropriate sessions based on the responses in the table." Paul Aitken[36]

The USTA has developed a more comprehensive daily monitoring form that is also simple and quick to use and ideal as a component within a training diary[37]. The aim is for players to be able to assess their responses to training and wellness on a daily basis. Consistent monitoring will help players to become more perceptive when something is outside their normal response range. With increased awareness the players are encouraged to be proactive about dealing with potential problems by contacting their coach, trainer, or medical specialist before any major issues occur.

The Coach

Each coach has a wealth of knowledge about adaptive responses based on many years of observation about tennis performance and fatigue. Frequently this knowledge is implicit in nature and based more on *mental notes* rather than formalized recorded criteria. It is important for each coach to identify what it is that they observe that is indicative of excessive stress and fatigue. The selected variables can be categorized into signs and symptoms about physical appearance, behavioral actions and interactions, performance measures and the coach's *sixth sens.*[5,6]. A quick assessment of these criteria at every coaching session enables the coach to identify non-adaptive stress responses at an early stage and then address these before they become a major issue for the player.

The Medical or Sport Science specialist

Preseason medical, musculoskeletal, vision and psychological screenings are essential. These should be addressed before any training is undertaken in order to detect any muscle imbalances, medical, and psychological issues, and to evaluate the health status and any previous illnesses and injuries[33]. While some areas require only an annual review, other assessments should be more frequent. Conditioning and performance tests are often performed every four to six weeks, and musculoskeletal assessments tend to be biannual. This regular planned screening and testing is designed to track any changes and developments in the player, and address potential medical, personal and health problems at an early stage[32]. Feedback from player, coach, and specialist perspectives should be reviewed regularly and integrated to provide an ongoing holistic assessment of the adaptation, health and well being of the player.

Rest and Recovery

Passive rest – the role of sleep

There are two major ways of resting – passively and actively. Passive rest, particularly in the form of sleep, is an area that is not well understood by either coaches or athletes. Sleep is probably the most important form of recovery for a player[38,39]. A good night's sleep of 7 to 9 hours provides invaluable adaptation time to adjust to the physical, neurological, immunological and emotional stressors that are experienced during the day. An adolescent experiencing heavy training and a growth spurt may need up to 10 hours a night and players who are sick often need more sleep as a part of their recuperation. However too much sleep can be detrimental to performance as it can slow down the central nervous system activation and lead to increased levels of melatonin[40,41].

Melatonin is a powerful hormone that is released during deep sleep. It is a chronobiotic that regulates the circadian timing system[41] and it plays an active role in recharging the immune system[40]. However excessive or insufficient amounts due to too much or too little sleep can disrupt a player's ability to train and adapt to stress as it can leave the player feeling tired and lethargic[38,39]. Melatonin levels can be disrupted by late nights, sleeping in, sleeping for long periods during the day, irregular eating habits or travelling to different time zones (*jet lag)*[25,40,41]. This extra fatigue can delay the adaptive processes particularly if disruptions to circadian patterns are frequent, as it is often the situation for players who undertake long journeys or international travel[25].

The human body also adapts to, and is partly regulated by meal times. Consequently it is important for players to plan for regular eating times whenever possible. The need for players to regulate their sleeping and eating habits does not preclude them from having a social life and enjoying the occasional late night. To cope with this, players should be encouraged to standardize their wake-up time wherever possible. Sleeping-in after a late night should be limited to 1 to 2 hours from the normal wake-up time, so there is minimal disruption to the player's sleep patterns. A brief post-lunch or afternoon nap of 15-30 minutes is popular in some countries. Research has indicated that such short naps can have a positive effect on perception[42], alertness and performance[43]. Longer naps are not as beneficial and result in sleep inertia leaving the individual feeling sluggish and groggy[44].

Getting to sleep can sometimes be difficult because of the excitement of the day's events so it is important that players develop habits to promote a good night's sleep. Practicing relaxation techniques from an early age can help the player to unwind easily. Other forms of passive rest involve techniques that help the mind to switch-off from all surrounding stimuli. Meditation, reading or listening to relaxing music are some of the other forms of passive rest.

Active rest

There are many ways to incorporate active rest strategies into a periodized training program. The end of the training session is the most obvious time to introduce active recovery activities although active rest can also be interspersed within the session or between matches. Traditional strategies for including active recovery in training involve alternating lighter and heavier workloads within the session, lighter workloads at the end of a session, lighter sessions within a week (microcycle) and lighter weeks within a four to six week training block (macrocycle). Active rest strategies can be selected to fulfill several roles including accelerating lactate recovery through a light jog, walk, swim or cycle[45,46,47] while psychological and emotional recovery can be enhanced through fun activities that are different to tennis.

Active rest and stretching

The role of stretching in sporting contexts has been the subject of considerable debate over the last ten years[48,49,50,51,52]. Stretching for sports performance has three main roles and each of these requires the use of specific techniques relevant to the aims of these roles.[50] (Table 3)

The stretching techniques selected to promote post training or post match recovery should aim to restore resting muscle length and a normal range of movement for joints, rather than aim to increase muscle length or joint range of movement[48,49]. Stretching to improve flexibility, or developmental stretching, is best done as a separate and dedicated session when the player is not fatigued as there is less chance of exacerbating any residual micro trauma in muscles following heavy workloads. Ideally players should undertake some stretching in the evening while their muscles are still warm. This is an optimal time to apply stretching techniques that are designed to increase resting muscle length and joint range of movement. Long held static stretches, assisted stretches, and Proprioceptive Neuromuscular Facilitation (PNF) are ideal techniques to improve range of movement but these techniques can leave a muscle fatigued and result in decreased power and strength for up to an hour or more[53,54,55]. As a result, they are best used at a time when the player can rest afterwards rather than being applied immediately before or after training or a match.

Table 3: Stretching roles and techniques specific to training and competition

Setting	Role / Aim	Relevant Stretching Techniques
Warm up (pre training and pre match)	Preparation to play e.g. Increase muscle temperature, rehearse motor programs, visual tracking, psychological readiness	Active movements - tennis specific e.g. increasing speed and joint range of movement gradually, to culminate in a range of dynamic match specific movements e.g. service, smash, lunge, etc.
Cool down (post training and post match)	Recover the player to a normal functioning state e.g. normal joint ROM, normal resting length for muscles	Light active movements, and a few light (short) static stretches. e.g. light movements involving all major joints, and a few light (10 second) static stretches of key joints and muscles
(off court)	Continue to recover	e.g. light swim or movements in water, light static stretch in shower, etc.
(before bed)	Several hours after playing – the body is warm, and can relax after the stretches	e.g. longer held static stretches 30 – 120 seconds, of major joints and muscles.
Improving flexibility (separate sessions)	Training flexibility for the specific needs of the player e.g. increasing ROM for a joint, improving functional flexibility, etc. NB: Player must be fresh.	Long held static stretches, assisted stretching, PNF, Pilates, eccentric loading to stretch and strengthen key muscles e.g. hamstrings, etc. NB: Developmental stretching will leave muscles fatigued and so players should avoid training or competing immediately after these sessions.

Cross training can also be used as a form of active rest provided the work intensities are moderate and the exercises undertaken are different to those normally performed in training[3,56]. For example, pool work that involves some backstroke, breaststroke, and side stroke techniques is ideal for tennis players as these are excellent forms of active stretching. Backstroke actions will extend the spine, stretch the rotator cuff and provide some conditioning work for the external rotators of the shoulder. These pool activities also have the added benefit of strengthening hip extensors and rotators and are excellent for working core stabilizers[56]. In addition low impact pool sessions provide enjoyment and variety within tennis programs and offset the high impact loads from court-based work.

Rest days

Rest days are essential. Ideally at least one day per week should be a non-training day. This allows time for physical and psychological recovery as well as time for balancing other interests such as personal relationships and family commitments. The challenge for some players is to understand that having a rest day does not preclude movement or light aerobic activity, and they should avoid sitting down and watching TV or videos for long periods. Light activities such as walking the family pet, exploring the local museum, art gallery, or sightseeing in a new place, socializing, a little shopping, or short game of golf, are suitable activities for a rest day[3]. By being active rather than sedentary the player is recovering normal movement function to prevent joints and muscles from stiffening up by being inactive.

Recovery and Nutrition

The type, timing and sequencing of fluid and fuel intake are essential considerations for players to be able to train and perform consistently well. Planning and managing these is a critical component of player recovery practices (see chapter on Nutrition).

Physical Recovery- techniques and modalities

A wide range of techniques and modalities are used by athletes to enhance recovery[1,3,4,57]. Those that are widespread and more readily available to players include water therapies, sports massage, acupuncture, and compressive clothing. Over the last 10 to 15 years an increasing number of scientific investigations have been conducted into each of these modalities. Unfortunately explanations of the physiological mechanisms about how these modalities work are often unclear, or unknown and in some cases the research findings may be influenced by a placebo effect.

Hydrotherapies

Hydrotherapies have been in use for several thousand years. Spas, pools, steam rooms, cold pools, and contrast temperature protocols were used by the ancient Greeks and Romans[57]. The two thousand year-old hydrotherapy protocols used by these ancient civilizations formed the basis for Turkish bath practices and these in turn were adapted in the mid eighteenth and nineteenth centuries for use in Scandinavia and central Europe. These traditional protocols form the basis of the hydrotherapy protocols used today.

Physiological responses to immersion in water

The immersion of a body in core-temp neutral (34°C - 36°C / 93°F - 97°F) water results in marked changes in the circulatory, pulmonary, renal and musculoskeletal systems as a result of increased hydrostatic pressures[59,60,61,62]. The effects have been shown to be most pronounced for whole body (head out) immersion rather than partial immersion as increased pressure is proportional to the size of the immersed body parts. These studies have indicated that increased hydrostatic pressure leads to a shift of blood from the lower regions of the body to the thoracic region during immersion. This results in an increase in cardiac output and stroke volume but also to a decrease in systemic vascular resistance so that there is increased muscular blood flow without an increase in heart rate. Increased pressure results in greater airways resistance so that lung volume decreases slightly and breathing requires more effort.

With temperatures below 20°C there is an increase in both heart rate and blood pressure. As water temperatures increase above core temperature, cardiac output increases and this leads to an elevation in heart rate but to a decrease in blood pressure.[59,60] The combined effects of hydrostatic pressure and water temperature amplifies these changes. Alternating from cool to warm water immersion can accelerate metabolic activity as indicated by faster clearance of blood lactate[60,61,63,64] and *creatine kinase*[65] through an increase in muscle blood flow.

Temperature Ranges

A recent review of the medical literature has recommended that a range of 10°C – 15°C for cold water is the optimal operational range for cooling soft tissues[66,67]. Colder temperatures used for long periods risk damage to soft tissues and are not recommended for sporting contexts. These recommended temperature ranges are supported by recent research findings, although the length of exposure time to these temperatures is still variable.[68] The temperature ranges for warm immersion vary from core-temp neutral (34°C-38°C)[60,61,63,68] to 42°C[68] as the upper limit with most studies employing 37°C -38°C as the examined upper temperature range[68,70].

Cold water immersion alone is sometimes used without alternating with warm water immersion[68,71]. The rationale for this protocol follows the practice of using cryotherapy for the treatment of soft tissue injuries by reducing swelling and by acting as an analgesic[66,67]. Some recent studies using cold water immersion with athletes have indicated that the procedure can reduce the sensation of DOMS[72,73] although this has not been replicated with untrained individuals[74]. Precooling the body using cold water immersion or ice vests before exercise, has been used to increase the body's heat storage capacity for performances in both neutral and warm conditions[75,76,77]. This technique is most beneficial at aiding thermoregulatory recovery following matches and performance in hot conditions[75,77,78,79].

Exposure times in water

The duration times for cold immersion, warm immersion or showering[80] vary markedly in the research. Cold water immersion times have ranged from 10 to 14 minutes[68] with the explanation that longer exposure periods necessitate a warmer temperature in order to accommodate athlete comfort. Contrast water temperature protocols use much shorter exposure times with warm immersion lasting 1 to 3 minutes and cold water immersion ranging from 1 to 2 minutes[60,68]. Some high profile tennis players have used a regimen of 45 seconds in cold water (10°C at thigh height) followed by a 1 minute period non-immersed (dryings the legs with a towel) at room temperature, with three to five repetitions. Patrick Rafter and Lleyton Hewitt have both used this protocol very effectively post-match in Grand Slam competitions[3,81].

Realistically a players comfort and compliance is a critical issue when deciding temperatures and duration protocols. If the water is too cold, or the cold exposure is too long a player may experience pain as well as boredom and may resist using hydrotherapies. Players will respond differently to cold temperatures and it is recommended that those who are inexperienced at using contrast immersion should begin by using protocols that involve shorter exposure times (30 to 60 seconds) and within the moderate temperature ranges (15°C for cold immersion and 38°C for warm) with 3 repetitions finishing on the cold immersion. A cold finish is appropriate for addressing any possible micro-trauma from training and assist with restoring normal thermoregulation. For younger players this protocol is sufficient for them to gain a benefit while older players who are more experienced in hydrotherapy practices may be comfortable using longer exposures or cooler temperatures following the guidelines outlined above.

Spas

The use of a spa for recovery after training has had minimal scientific investigation yet it is one of the most common warm water immersion modalities used by athletes. The limited research published on this topic has indicated that underwater massaging of muscles fatigued after high intensity training reduces the perception of delayed onset muscle soreness and helps to maintain explosiveness in the exercised muscles[82]. Although there are limited investigations into underwater massage, research findings have indicated that a combination of contrast immersion and underwater massage or aqua massage, could provide for both physiological and peripheral neural recovery[82] and improved mood states[83] post exercise. Like other hydrotherapy modalities the guidelines for water temperatures and exposure times have a critical effect on the fatigue levels and recovery of athletes. Exposures in warm environments for long periods of time can leave the user feeling lethargic and flat and the use of spas should be avoided if the player has any recent soft tissue injuries.

Saunas

Saunas are a type of hot dry bath and their use in training is not well understood by coaches and players. As a result saunas are often misused and can be detrimental to health and performance if a player dehydrates or experiences a severe reduction in central drive. In some Scandinavian and former Eastern Bloc countries saunas were used after periods of high intensity training when athletes experienced high degrees of central fatigue[84]. The traditional protocol involves a warm shower followed by a sauna for 5 minutes ($40^{o}C$+) with cold plunge ($10^{o}C$) for 30-60 seconds, repeated 3-5 times. The aim is to depress activity in the central nervous system to prevent over-stimulation following high intensity training, such as rapid or complex decision making in conjunction with heavy training loads. There is a lack of published research on the performance benefits of sauna use, and as many players misuse the modality it is often not recommended for use by young athletes. The Australian Institute of Sport has recognized this problem and restricted the use of saunas to athletes over 15 years of age.

Practical applications

Showering within 5 to 10 minutes at the end of a training session or match may accelerate recovery of physiological states, and assist with peripheral neural fatigue[82] (massaging showerheads). An effective post-training and post-competition routine is very important as it helps players to unwind and recover physically and psychologically[83,85]. If there is access to a pool then some active recovery (5 to 20 minutes) involving both active and static stretching is also beneficial[85,86]. Rehydration and refueling can occur concurrently with either strategy. Cold water immersion for the legs immediately after training or competition using short exposures with several repetitions[3] is beneficial, as is contrasting the cold with heat for full body immersions. However the practicalities of accessing a plunge pool, swimming pool, or spa immediately after training or a match can make some hydrotherapy options impractical. For most players a shower or an ice pack are the most accessible modalities. Players should be encouraged to use showers as often as is practical, between matches, during lunch breaks as well as after matches and training sessions.

Immediately post match some players apply ice (gel packs, a bag of frozen peas, or crushed ice or ice in a bucket of water) to key body parts to aid recovery[87]. Cooling tissue temperatures in this manner conserves energy by slowing down metabolic activity,[76,77] minimizes any post exercise edema and slows neural conductivity[87]. There are several protocols for using ice for the treatment of acute injuries[66,67] but there is no consensus about the best regimen for use in post exercise or competition situations [68, 88]. Factors that influence the duration of exposure include size of the body part to be iced, physical maturity of the player (child or adult), and the individual's sensitivity to cold e.g. Raynaud's disease, arteriosclerosis or allergy to cold. A recent review of the research literature on the treatment of soft tissue injuries indicates that intermittent 10-minute exposures are most effective[88]. Cold water immersion for a period of 15 minutes has demonstrated detrimental effects on subsequent anaerobic performances[89] so shorter time periods are recommended for post exercise situations[90]. Shorter exposure times are also influenced by the availability of facilities, amount of body area immersed, experience of the athlete, and any post competition commitments, such as media appearances and travel.

Flotation-REST

Another water based recovery strategy used separately to other training and competition hydrotherapy sessions is flotation. Flotation tanks were first designed in the 1950's as sensory deprivation chambers to enhance physical and psychological relaxation[91] reduce sensations of pain, improve concentration and sporting performance[92]. For this reason the use of flotation tanks is sometimes referred to as Restricted Environmental Stimulation Therapy or REST[91]. The tanks provide an environment with minimal stimulation by reproducing weightlessness through immersing the body in warm (34^{o}C) salty water. Tanks are enclosed to exclude light and external sounds creating an environment with little to no visual, auditory and kinesthetic stimulation. Music, videos and affirmation tapes can be used to create specific auditory and visual cues to enhance concentration or relaxation.

As a form of recovery, flotation is used with athletes who have experienced substantial physical, emotional, or cognitive stress. Flotation sessions last about 1 hour but the enclosed tank can be claustrophobic for some athletes who may need two or three trials in it before they feel comfortable. The Australian Olympic Committee has included several flotation tanks within its team recovery centers at the Sydney, Athens, and Beijing Olympic Games.

***Note**:* Any form of hydrotherapy use requires the player to follow standard health and safety guidelines. All players should be educated to have a shower before and after using a pool, spa, sauna, or other form of hydrotherapy, and to maintain their head out of the water when using a spa or plunge pool. This will minimize contact with and the spread of common water borne bacteria such as *giardia* and *cryptosporidium*. Players should avoid using hydrotherapies if they are ill particularly if they have a virus, or if they have any recent soft tissue injuries.

Sports Massage

Sports massage has gained wide acceptance by athletes and coaches over the past 30 years. Numerous claims are made about the benefits of massage but there is little empirical evidence to support many of these statements. An example of this problem is the frequent claim that massage increases blood flow in localized areas through the mechanical warming and stretching of soft tissues[93]. Most experimental evidence has suggested that massage has little influence on blood flow [94,95,96] nor does it improve post exercise muscle strength[96,97] or significantly reduce sensations of muscle soreness[98,99]. There is some research to support the idea that the warming of superficial areas through massage can provide flexibility gains temporarily[100,101]. Importantly other investigators have found that these gains are not as significant as the effects of stretching for improving flexibility[102] and have no benefit if conducted in a pre-performance context[103]. Improved mood states and enhancing feelings of well-being have also been recorded in several studies[94,104,105,106] and many athletes use massage as a means of relaxing psychologically as well as for physical treatment. One review has reported that improvements in trait anxiety from massage treatments are closely linked with the interpersonal contact between therapist and client irrespective of the skill or experience of the practitioner[107].

Perhaps the greatest benefit, but one not reported in the literature, is the biofeedback athletes receive from manipulation pressures whether these are through self administered massage[108] or treatments provided by a professional therapist or a parent[3,109]. Massage is an excellent means by which a player can become more aware of the specific muscles and tendons stressed by tennis related actions, as well as by non-sporting activities such as sitting at a desk, or in a car, or on a plane, for long periods. The ability to be able to *tune-in* to the effects of physical loading helps the player to monitor musculotendinous stresses and detect any potential problems before they become a major concern[109]. This proactive strategy is a very useful management tool to add to the players monitoring strategies.

Acupuncture and Acupressure

Acupressure is often performed as an adjunct to sports massage but acupuncture is often less accessible and more expensive than massage. Both acupressure and acupuncture focus on applying pressure or stimulus to specific reactive points along *meridians,* or lines of the body[110]. The anatomical location of these meridians varies according to the cultural and historical contexts from which they were derived, e.g. Chinese concepts of Ying-Yang, and Qi[110] and Indian concepts of Chakras[112] are the most common. There is some research to show that acupuncture influences a wide area of the brain[113] and may stimulate endogenous opiates to provide pain relief. Pressure points have a lower cutaneous electrical resistance than adjacent areas and these can be measured and evaluated[114]. However a strong correlation between acupressure points and trigger points has not been demonstrated[115].

Unfortunately the research examining acupuncture and acupressure and its effects for athletes is often published in less accessible journals[116]. At least one reputable study has demonstrated a significant relaxation response in the skeletal muscle of athletic subjects following acupuncture treatment[116]. The resulting muscle relaxation would contribute positively to recovery from strenuous exercise and to a sense of well-being and improved mood state. Acupuncture practitioners are becoming increasingly available through medical practices in western countries where acupuncture is often incorporated as an adjunct to more conventional treatments, despite the fact that the mechanisms by which it works are still unclear.

Compressive Clothing

In recent years compressive garments have become fashionable with athletes as a means to reduce injuries, benefit performance and enhance recovery[117,118,119]. The use of compressive socks and tights is no longer limited to clinical situations and air travel, as compressive garments frequently form part of post exercise recovery routines[65,117,120]. There are significant differences in compressive pressures between clinical and commercial sports compression garments[120]. Medical grade garments have a minimum pressure of 18mmHG with 3 to 4 grades of increasing pressures up to 48mmHG[121] whereas commercial sports garments have less than 18mmHG pressure[120] and are classified as “mildly therapeutic”. Both types of garments should be tailored to fit the size and shape of the athlete’s body.

The recovery benefits reported for the use of compressive garments are similar to those reported for hydrotherapy research as hydrostatic pressures perform a similar role. These benefits stem from the graduated pressures which extend medially from limb extremities towards the body core. Studies indicate that even the sports compression garments reduce post exercise edema following eccentric work and also reduce sensations of ensuing muscle soreness,[122,123] and aid recovery of soft tissue injuries.[124] There is a reduced perception of fatigue,[117,120] and n enhanced clearance of blood lactates and *creatine kinase* compared to passive recovery[65,117]. Some preliminary research has indicated cutaneous afferent and biomechanical benefits of compression on motor functionality[123]. However there is no evidence that wearing such garments during training or competition improves performance,[117,124] in fact one study claims external compression can reduce blood flow to working muscles[125] if compressive pressures are greater than is necessary.

Practical applications

A combination of hydrotherapy techniques followed by the use of compressive garments would appear to be beneficial for players between matches and post training or event[65,120] whereas either strategy on its own is less effective[126]. After cold immersion the player can use compressive socks or tights to maintain pressures on the legs and continue the benefits from the hydrotherapy protocol for several hours. The advantage of compressive garments over hydrotherapies lies in their portability and availability as players can have ready access to their own recovery tool anywhere and anytime. However as compressive garments offer no benefit during training and performance their use should be restricted to post training and match situations[65,117,120]. The compressive durability of these garments is limited and will deteriorate with constant use. Research indicates that within the main sports brands there is no measureable difference in their performance capabilities[117].

Other techniques

Although there are other recovery techniques and modalities available there is very limited, or minimal research to explain or justify their use by players[127].

Psychological Recovery Techniques

There are a number of key aspects of psychological recovery that can be integrated into the preparation and performance of a player. Debriefing, emotional control during and post match, relaxation techniques and dealing with unexpected traumatic situations (see chapter on Psychology).

Selecting and applying recovery strategies and techniques

The selection and integration of specific recovery techniques and strategies should complement the developmental age of the player (Table 3). Inexperienced and younger players can be introduced to simple strategies from the start of their involvement in tennis. These basic recovery actions form the foundation for their future development. As a player gains in experience, and training and competition workloads increase, there needs to be a corresponding expansion in the range and type of recovery strategies used to address fatigue. Information from the relevant monitoring strategies used by the player (Table 2) provides an indication of the amount and type of recovery required. Underpinning the selection of recovery strategies is the importance of identifying the specific recovery strategies to address the type of fatigue that the individual is experiencing (Table 5) plus the need to accommodate for individual preferences.

Table 3 Recovery Strategies corresponding with player development and increased workloads and stress[27,28,128]

FUNdamental	Learning to Train	Training to Train	Training to Compete	Training to Win	Masters Players and Coaches
Training Age: **0-1+ years**	Training Age: **1-2+/- years**	Training Age: **3-7+/- years**	Training Age: **8-10+/- years**	Training Age: **10-12+/- years**	Training Age: **1-100+/- years**
During Training • Rehydrate every 20-30 minutes **After Training** • Drink (water, cordial, fruit juice) & light snack (e.g. fruit, muffin, or yoghurt, etc) • Light stretch • Shower at home	**During Training** • Rehydrate every 20-30 minutes **After Training** • Post game drink & snack • Active recovery • Light stretch • Shower • Meal within 2 hours **Before bed** • Self Massage • Stretching • Relaxation (TV, book, music)	**During Training** • Rehydrate every 20-30 minutes **After Training** • Post game sports drink & snack • Active recovery • Light stretch • Contrast shower • Meal ***ASAP*** **Before bed** • Self Massage • Stretching • Relaxation *(as for previous stage) Plus:* Progressive muscle relaxation, visualization, etc. **Weekly** • Sports massage • Active recovery	**Periodized recovery** *(as previous stage) Plus:* • Compressive *skins* post training • 2 massages a week • Strategies selected to suit specific fatigue *(Table 1)* • Recovery program individualized • Competition scenarios trialed • Especially recovery from travel fatigue and adjusting to different facilities	**Periodized recovery** *(as previous stage) Plus:* • Detailed competition planning of recovery programs including nutritional needs & timing • Fine-tuning recovery strategies for different competition environments • Player has major input into the recovery program • Variation in	**During Training** • Rehydrate and refuel regularly **After Training** • Post game sports drink & snack • Active recovery • Light stretch • Contrast shower • Meal ***ASAP*** **Before bed** • Self Massage • Stretching • Relaxation movie, TV, book, music, visualization, meditation, etc. **Weekly** • Sports massage • Active recovery (e.g. pool, golf,

		(e.g. pool, golf, walk dog) • Spa & plunge pool • Stretching session	• Increased range & use of psychological recovery (e.g. flotation, meditation) • Variety of active recovery and rest day activities	recovery strategies to prevent monotony	walk dog) • Spa & plunge pool • Stretching session (eg. Yoga)

Coach and player responsibilities for recovery

At the beginning of the training year it is advisable for coaches and players to establish their roles and responsibilities for recovery from training. Both parties need to have an understanding of each others' responsibilities and both need to agree to undertake these as part of the player-coach relationship. The coach may elect to incorporate a player's responsibilities into a formal agreement, such as a contract, and assess this on an annual basis as a performance indicator for the player. (Table 4)

The coach and recovery training

The planning of workloads and appropriate work-to-rest ratios is the responsibility of the coach. In order to assess adaptation to the training loads the coach needs to monitor players (Table 2) at every training session for any signs or symptoms of non-adaptation[5,6]. Players should be familiarized with the use of a training diary or log book at the beginning of the training year and the coach should review these on a regular basis, e.g. at least once a week, and provide feedback to the player to encourage the development of self-monitoring skills. It is important to recognize any external demands placed on players such as school exams or work commitments and be able to adapt training loads to allow players to cope with these external pressures.

Many coaches will not have the knowledge or skills required to teach or deliver many recovery techniques so they may have to get other specialists to educate players about using these skills, e.g. self massage[108]. However the coach has a responsibility to reinforce this educational aspect of the training program by encouraging and reviewing the application of these techniques and activities on a regular basis.

Training programs need to be flexible so coaches have the option to change workloads relative to the adaptive responses of individual players. This flexibility also applies to the different requirements placed on players in different environments and venues. Careful planning and evaluation of player training needs and adaptive responses will ensure that coaches address the recovery training needs of their players.

The player and recovery training

Players have two major recovery responsibilities. First they need to be perceptive about any changes in their physical and psychological responses to fatigue and stress – *"listen to your body".* Secondly they need to be able to take ownership for managing this fatigue and stress as much as possible *"look after your body*". The very least a player can do to fulfill these responsibilities is outlined in Table 4.

If players learn the essential skills of self monitoring and self management, not only will they optimize their chances of adapting to heavy workloads, they will also develop effective life skills that they can use after they have finished their competitive careers. The effectiveness of these strategies is reflected in the annual review by the player and the coach through their respective performance indicators (Table 6)

Table 4: Player responsibilities for recovery

Player Self Monitoring and Self Management Responsibilities
Daily • Keep a daily record or log book recording adaptation to stress (Table 1) • Eat a balanced diet and plan appropriate meals and post training snacks • Use a shower/spa/bath after training with some cold immersion for legs after training • Stretching and self massage before bed • Practice some relaxation strategies before bed and learn to “switch off” from the day **Weekly** • Have at least one rest day a week e.g. a light non-training activity e.g. swim or other non-tennis activity • Plan some active rest e.g. yoga • Organize a massage from a professional, parent, partner, or do some self massage on legs and shoulders **Weekly Time Management Planning – plan in advance** • Prioritize all weekly commitments in advance e.g. school, work, training, domestic chores, social events, appointments etc. • Add a few varied recovery activities to fit in around these commitments e.g. movie, spa, or night out with friends

Partners and parents of players and their support for player recovery

Partners and parents can help to reinforce the recovery responsibilities of the player. By encouraging the use of a training log or diary they can help the player to learn to listen to his or her body. Parents can use the concept of the *Smiley Faces* (Figure 2) to gauge how their children are responding to training, or school, or life in general. Similarly, both partners and parents can play a useful role by learning and applying selectively massage techniques on their children. A few minutes massaging tight legs, shoulders, or back, before the player goes to bed can mean the difference between a heavy stiff body and a more relaxed body the following morning. It is essential to do simple things like preparing healthy meals, and appropriate post training snacks, and ensure the player has a drink bottle at all times.

Close family members subconsciously monitor their partner or child's responses to stress, so they are aware of the signs and cues when the player is not coping. Like the coach, partners and parents should also keep watch for excessive stress in the player and they should be able to communicate freely and openly with the coach if they suspect that the player is having difficulties adapting.

Planning recovery for training and competition

Recovery strategies and techniques for each type of fatigue can be identified in advance. (Table 5)

Table 5 Recovery strategies for different types of fatigue

Type of fatigue	Recovery Strategies
Metabolic Fatigue (Energy Stores)	• Rehydrate & refuel (including small amounts of protein as well as carbohydrates) before, during & after training • Use contrast temperature showers, pool, or spa, and active recovery activities to increase metabolism • Meal within 1-2 hours of training & monitor hydration
Peripheral Nervous System Fatigue (muscles)	• Rehydrate & refuel before, during & after training • Within 5 – 15 minutes after training use a spa or shower with jets focused on the large & fatigued muscles such as legs, shoulders and arms • After training or later in the day – massage large muscle groups & include some jostling / light shaking techniques
Central Nervous System Fatigue (brain)	• Steady & regular intake of carbohydrates during training & after training to maintain normal blood glucose levels to aid decision making • After training – unwind, listen to music, visualization

	• Rest with reduced cognitive stimulation
Psychological Fatigue (emotional, social, cultural)	• Focus on process rather than outcome performance measures • Debrief by identifying 1-3 things that worked well and 1-3 that need more work • Take mind off training with escapist or funny movie, TV. book, or socialize with family & friends • 10-15 minutes before bed – *switch-off* –from the day by using relaxation techniques
Environmental & Travel Fatigue	• Preparation planning will minimize fatigue • Stay hydrated and refueled • Stay cool in the heat - use a pool, shade, iced towels, etc. • Keep moving as much as possible on long journeys • Minimize visual fatigue by wearing sunglasses outside & limiting time on computers & play stations

Within match recovery Strategies

Preparation for within match recovery is essential and both metabolic and psychological fatigue strategies can be applied. Water, sports drinks with electrolytes and other small nutritional items should be available at court side. The allocated time for changing ends is an opportunity to do some mental recovery by using practiced routines for switching-off from the last shot, and refocusing on the next. If conditions are warm to hot, a change of shirt or socks is recommended. Andre Agassi changed tops five times when he won the Australian Open in 2003. At a post-match interview he explained that changing to a clean top made him feel like he was as fresh as he was for the start of the match – a useful psychological tool to use. These are all strategies that should be rehearsed in training so they are undertaken efficiently and automatically by the player during a match.

Post training and post match

Players need to develop simple routines for post training and game situations based on the availability of facilities and services. If these are minimal, players may have to improvise or provide for these themselves. This is in contrast to venues where optimal facilities exist, such as ready access to a physiotherapist, massage, pool or spa. In every case the post training or post event routine should follow this simple protocol. The first priority is to address any metabolic fatigue. The second priority is neural fatigue, followed by psychological recovery strategies.

The rationale for this sequence lies in the fact that metabolic fatigue can affect other types of fatigue and is best dealt with while player's metabolic rate is elevated after playing[18,19]. Low blood glucose can also affect information processing and decision making as it has an impact on the central nervous system[20,22]. This can be undertaken at the same time as hydrotherapy strategies, active recovery, or a light massage. Emotional and psychological recovery is more readily addressed as the body is starting to relax following the previous recovery strategies (Table 5).

Recovery strategies on the road[109]

The main difference between home-based competitions and travelling to tournaments is the need to identify in advance what recovery facilities may be available, and be prepared to be resourceful in using these. Essentially, recovery protocols follow the same routines as those for home-based competitions and training.

The first priority to plan for is nutritional. The amount, type, timing and availability of foodstuffs need to be identified before travelling. Prior planning will enable the player to identify what needs to be brought to the competition venue for consumption during and after the event. The availability of showers, spas, baths, pools and cold tubs, can also be identified in advance, as can the availability of massage and physiotherapy services. If none of these are available then the player can use showers and self-massage techniques and stretch in the evening before bed. Travel plans should include some relaxation activities to help the player relax when not competing.

Recovery for hot conditions

In addition to normal recovery protocols outlined above, staying cool in a hot environment will require extra attention. Hot dry conditions are easier to cope with than hot humid conditions because it is much harder to lose excess heat by sweating when humidity is high. To gauge fluid loss it is essential to monitor pre and post training/match bodyweight. Regular fluid consumption both throughout and after a match, is paramount if the player is to maintain hydration levels. Cold towels for the face, arms and legs, can be used on and off court, and cold plunge pools and showers can be used in the change rooms if they are available. Short duration pre-cooling of muscles can help conserve energy and increase reaction times[75,78,79,80]. A quick cold shower before a warm-up, or some cold towels applied to the legs and arms for a short 30-60 seconds can help to minimize energy expenditure and conserve fluid levels.

Players should stay in shady areas or air conditioned environments when not performing as this will help to conserve their energy levels and reduce the chance of heat stress. Frequent changes of socks and clothes during and between games can also help, as sweat-laden clothing can be heavy, uncomfortable and reduce evaporation. A dip in a cool pool after the match and before bed can help players relax and maintain a normal core temperature in hot conditions[71,79,109].

Summary

Every training session is important. Every training session is a chance for a player to become an even better performer. Players should aim to start each training session or match in as fresh a state as possible so that they can maximize the training benefits and experiences of the session or match. Recovery strategies are aimed at helping players and coaches to do this by focusing on reducing residual training fatigue and stress.

The coach can help educate the player to understand, plan and use recovery strategies with a view to the player learning to manage this for him or herself. Effective monitoring and recovery management will enable both the coach and player to perform better more consistently, reduce training injuries and illnesses and develop sound self-management strategies for tennis and for life after sport.

Practical Application - Integrating recovery into the annual training program

Early Preparatory Phase

The early preparation phase is the most important for developing recovery training skills. Pre-season screening is essential in order to detect any potential problems which may be exacerbated by training workloads during the year. This is also the time when players should start their self monitoring programs by using a diary or log book, and begin to learn to *tune-in* to their bodies.

Basic time management skills should be introduced at this time in order for players to learn how to plan for training, study, work, home life and still maintain a balanced social life. Some of the most essential recovery techniques should also be introduced and reinforced during this phase. These include appropriate nutrition, stretching, including postural efficiency exercises[129] hydrotherapy in the shower, self massage and one or two relaxation techniques.

Specific Preparatory / Conditioning / Pre-Competitive Phase

Training loads are often heaviest during these phases so this is an ideal time to make use of some cross training to minimize overuse problems, particularly with younger developing athletes. By now players should know how to balance their training sessions in relation to their other priorities such as work or study, and their home and social lives. The coach should be checking training diaries regularly and giving feedback to the player to encourage compliance. An increase in training loads during this phase will generate a greater need for more physical recovery strategies especially the hydrotherapies, massage, and muscle balancing exercises. The increased workloads in these phases mean that there is a need to reinforce nutrition strategies to ensure that appropriate and sufficient fuel and fluids are being consumed. Fatigued bodies tend to perform techniques inefficiently and are therefore more predisposed to injury, so adequate nutrition is critical in order to enable players to train well.

Psychological skills to promote muscle relaxation are also useful to reinforce here. Each player should practice those relaxation techniques that they plan to use during competition and spend time selecting any music they like to use in order to generate a relaxing atmosphere for the times when they will be a competition environment.

Competition phase

By this phase all recovery skills should be automated. Players should be familiar with and using, a range of self recording and self management strategies. Players should know both how and when to use all the techniques they have practiced, and be comfortable using these during intense competition. There may be a heavier reliance on psychological recovery during this phase because of competition stress. However, if the competition program is planned in advance, and players know and understand their tournament requirements, stress levels will be lower and they will have more control over their physical and psychological states.

Coaches need to plan appropriate recovery training activities around the competition schedule in order to maximise recovery from one match to the next. If the competition or tournament involves travelling away from home this involves planning the travelling time, strategies for travelling and arriving. All major activities need to be forward planned, including the wake-up times, meal times and food selection, stretching, showering arrangements, post match recovery activities, access to a pool or spa, massage availability, and planning some relaxing time-out from tennis.

It is important to organize appropriate relaxing entertainment in order to find a suitable balance between stress and relaxation. A wise coach will also have strategies in place for emotional recovery in the event that players are unsuccessful, or any serious personal incidents occur. Contingency planning reduces problems associated with situational stress and helps players to perform under challenging conditions.

Assessing the effectiveness of the recovery program

Appropriate performance indicators for assessing the effectiveness of a recovery program include a wide range of variables relevant for evaluating the training program as a whole. There are five basic questions for coaches to address in order to assess the effectiveness of a player's recovery program:

1. How much work has the player undertaken in training and competition?
2. What was the player's health status – injuries and illness for the year/training phase?
3. Did the player's performance tests and assessments improve?

4. Did the player recognize any improvements in his/her performance and ability to adapt to these workloads and matches?
5. Has the quality of the player's performances improved?

Some of the performance indicators are quantitative e.g. volume of training, while others are qualitative, e.g. quality of play.

Table 6: Performance Indicators to assess the effectiveness of the recovery program

Assessment areas	Performance indicators
Workloads completed	• Volume of work done • Intensity (training and match) • No. and scheduling of tournaments
Player's health and wellness	• Medical and musculoskeletal screening • No. of injuries • Incidence of illness • Handling pressure and stress
Player's performance results	• Fitness tests • Tennis specific tests • Competition results • Performance analysis data • Rankings
Player's evaluation of themself (player diary and/or log book)	• Wellbeing • Training performance • Match performance • Lifestyle management
Coach evaluation of the player (performance analysis data, and empirical observations)	• Skill execution • Tactical skills and decision making • Handling pressure and stress

These performance indicators should be established and benchmarked before the training year begins and then re-evaluated at the end of the season to identify and assess changes that have occurred. Specific performance indicators may also be assessed pre and post each training phase to gauge the adaptive response of the player to individual workloads and lifestyle stresses. Monitoring the effectiveness of the training program and recovery strategies on a regular basis enables both coach and player to react promptly to any adaptation problems.

This is a systematic and holistic approach to making any modifications, changes or introducing new strategies to existing recovery practices. It provides a consistent methodology for evaluating the effectiveness of the recovery program in relation to the player's adaptation to training, competition and lifestyle demands. It should ensure for a healthy well developed player who can adapt effectively to training and competition environments.

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The Physiological Basis of Recovery: Special Considerations in Tennis

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Abstract

As tennis places demand on a multitude of physiological systems, several must be considered to better identify, implement, and assess strategies to minimize fatigue and optimize recovery after competitive and preparatory events. Damage and repair processes in skeletal muscle are varied and complex in nature and are central to fatigue and recovery considerations in response to stressful bouts of physical exertion like that seen in tennis. Fatiguing demand primarily originates from motor unit activation patterns, variable environmental factors, and psychological stress that may impact readiness to play even when the competitor is physically ready.

The demands of tennis play vary according to the characteristics of match play and the characteristics of the players themselves. Factors include playing surface and implement types, competitive game play variance, temperature and humidity, and player characteristics such as age, sex, and skill level. A better understanding of the physiological basis of fatigue, how it occurs in tennis, and how it is affected by the characteristics of match play and the competitors themselves will aid in the identification and implementation of practices that strengthen the physiological systems involved in recovery. Finally, strategies to minimize fatigue and optimize recovery including proper conditioning, hydration, and nutritional strategies are discussed in conjunction with recognition of the importance of psychological recovery.

Introduction

Fatigue & Recovery

Recovery is general term referring to the short and long-term adaptive responses occurring as a result of “overloading” activity (stress) that causes fatigue. Fatigue is a term that must be defined in a highly “operational manner” as it is directly related to the external demands and physical characteristics of the person experiencing stress. Understandably, the multifaceted nature of fatigue necessitates a multifaceted conception of recovery. Before discussing the various known aspects of recovery, it is helpful to learn more about the phenomenon that creates the need for it: fatigue.

Fatigue is the consequence of “overloading” stress placed on physiological systems and is reflective of the conditions or demands of a given activity, which in turn dictates the recovery that is needed. When power output cannot be maintained or physiological homeostasis cannot be achieved in a given set of physiological systems, fatigue occurs [1]. A host of physiological mechanisms have been used to try to explain this phenomenon but many links and sites of action from central to peripheral mechanisms are believed to contribute to fatigue [2-9]. Most importantly, different demands are likely to cause and result in different forms of fatigue. As such, it is important to understand the generally accepted mechanisms of fatigue and the variables influencing the nature and extent of fatigue in each physiological system. All tennis matches possess differing demands just as all conditioning sessions vary in their fatigue and recovery profiles.

Research in the area of fatigue is important, especially when dealing with competitive athletics and their methods of preparation. In such activities, management of fatigue and recovery may play a fundamental role in achieving optimal competitive outcomes. Each distinct source of stress causes a specific type of fatigue. Consequently, if optimal recovery is to occur, fatigue must be addressed relative to the exertion it was caused by. The fatigue resulting from tennis play is largely specific to tennis. At the same time, tennis-related fatigue is likely to affect general physiological functions (e.g., cardiovascular fitness, thermoregulation, neuromuscular function, endocrine function) and tennis-specific functions (e.g., shoulder rotator cuff strength, side to side balance of muscular strength and hypertrophy, serve velocity and accuracy) [10, 11].

The Demands of Activity Determine the Fatigue Experienced And Recovery Needed

By nature, vigorous physical activity demands levels of exertion exceeding those observed in sedentary lifestyles. In order for players to realize the ultimate goal of success in tennis competition (i.e., reaching peak performance capability): regular, intense, and extensive preparation, competition, and personal sacrifice must occur [12]. Many studies have sought to establish the physical attributes that comprise and determine the ability to perform in the sport of tennis [11-18]. By comparison, few studies have explored the sources of fatigue and the role of recovery in improving performance [19].

Fatigue can be described in terms of the physiological system it impacts (e.g. muscular, neurological, nutritional, hydrational, psychological, thermoregulatory). Such systemic fatigue is believed to negatively affect performance in terms of speed, power, agility, coordination, and specialized skills (such as serving) [16]. Correspondingly, tennis players have been shown to suffer stroke accuracy decrement as high as 81% with increasing play durations [11]. Fernandez and colleagues [14] have suggested playing style, gender, training status, playing surface, ball type, and environment as the primary contributors to fatigue in tennis.

Some fatigue factors come from conditions that cannot be determined with certainty before play, such as the psychological readiness of the player in response to the match conditions and opponent. Factors that affect the demands of play commonly include varying environmental conditions such as temperature and humidity as well as strategic play-style differences between competitors. Finally, the physiological status of the player largely affects the stress experienced from a given match. Optimized recovery occurs when stress of play is minimized and rate of recovery is maximized. Therefore, emphasis is placed on practices that develop physiological resistance to fatigue and improve the physiological ability to repair damage to tissues. This is where conditioning, practice, and other preparatory strategies become exceedingly important [11, 17].

A normal fatigue to recovery response pattern takes on a type of undulating staircase pattern. Acute fatigue results in a decrease in function that is followed by a "recovery" phase back to baseline. Chronic fatigue may be a sign of functional overreaching (i.e., planned overload with withdrawal for supercompensation) in a training program or nonfunctional overreaching where mistakes are made in preparation and conditioning or the stress of competition/practice is beyond the athlete's ability to recover. Functional overreaching may be desirable if planned correctly, leading to supercompensation in affected physiological systems and a subsequent improvement in competitive capabilities (see Figure 1). Conversely, repeated exposure to non-functional overreaching (staying below the baseline without the ability to make a positive recovery response) can lead to an overtraining syndrome, which can last for months[20-23]. Thus, fatigue is a physiological event as seemingly varied as the physiological systems it can affect [24, 25]. With effective training programs (e.g., periodized resistance training) and careful management of fatigue and recovery, long-term positive adaptations can occur, even during competitive phases [12, 26].

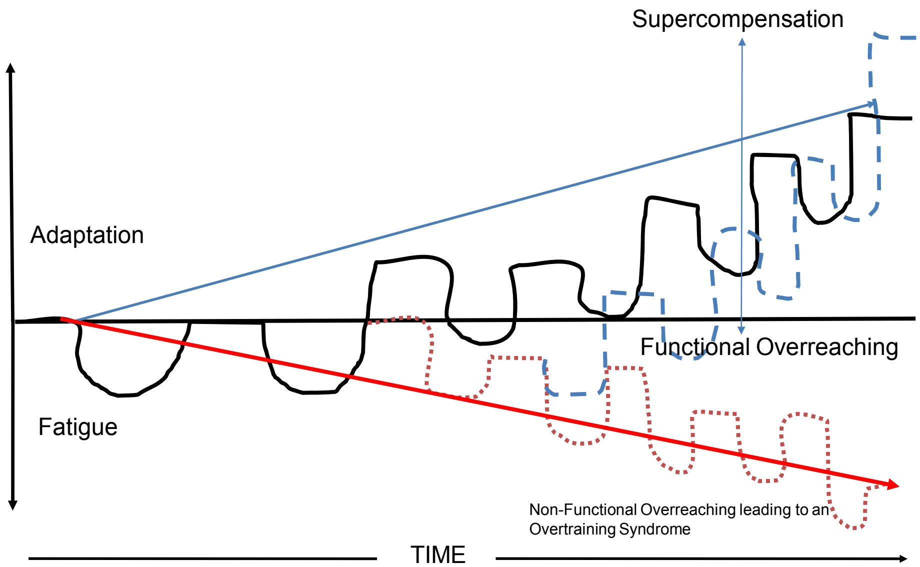

***Figure 1*.** Fatigue pushes the body's physiological status below baseline but with optimal recovery physiological status will typically return to baseline within 24-48 h. With training the baseline (solid line) will gradually increase to higher levels resulting in an upward trend in fitness level. Functional overreaching (dashed line) will intentionally push physiological status down for an extended period of time. With reductions in the volume or intensity or added rest, fitness level rebounds to a higher level. Non-functional overtraining (dotted line) will cause a downward trend in physiological status without recovery which can potentially lead to overtraining, which may take months recovery from. Overtraining typically occurs as a result of mistakes in the training program design or an excessively overloading competitive schedule.

Physiological Basis of Fatigue and Recovery

Damage and Repair

Damage

Recovery is partially related to the repair of the neuromuscular system in which damage occurs in response to force production. The extent of the disruption of motor units (i.e., motor neuron and associated muscle fibers) is related to the demands of the match (e.g., 4 hours in the heat) or the specific conditioning activity (e.g., sprint intervals vs. heavy lifting). Acute skeletal muscle tissue damage is related to “mechanical forces”, and subsequent (additional) damage is related to “chemical forces” (i.e. excessive chemical compounds and free radical scavenging etc.) which continues to break down membrane structures for several days after the mechanical stress has occurred [27-30]. The magnitude of each will be related to the specific forces the body is exposed the amount of metabolic stress (e.g., inflammatory response, noxious chemicals, high temperature, etc.), and the competitors physiological status before damaging exertion. The mechanisms involved with damage and repair represent a fertile area of research, as factors of initiation and resolution remain complex and largely unknown [31].

The amount of disruption or damage spans a continuum from normal, planned disruption as a training strategy to complete dysfunction as a consequence of serious injury (e.g., Grade II/III muscle strain). Tennis practice, competition, and strength and conditioning protocols can elicit injury across this continuum. Macro-type trauma due to injury that stops play is typically what conditioning programs attempt to prevent. The micro-trauma (microscopic tears) muscle damage/disruption caused by tennis competition, practice, or its conditioning activities are what the body is challenged to repair and recovery from. Dramatically elevated heart rates, blood lactate concentrations, and localized pH decreases are indicative of intense physical stress and may offer guidance in predicting the extent of tissue damage.

The magnitude of injury is related to the loading of muscle, most notably the eccentric component (i.e., the lengthening of muscle under load) and any subsequent chemical insults. The heavier the eccentric load the greater the potential for soreness and injury [27]. More dramatic muscle damage arises from stress with a high eccentric component (e.g., running downhill, performing a new novel exercise), and is especially pronounced when the stressed tissue has not been exposed to training stress previously. Ranges of racquet movements can result in tissue damage when outside of the trained movement patterns. Damage is proportional to the intensity of the tensile force and also depends on the biomechanical orientation of the tissue subjected to overload (e.g., stress stain curve of the involved tissue).

Damage to skeletal muscle tissue is characterized by a loss of structural arrangements in muscle, which results in loss of force production capabilities. Mechanical stress causes damage to the basic contractile unit of the muscle called the “sarcomere”, which consist of the contractile proteins “actin and myosin” along with many non-contractile proteins (e.g., titin, nebulin, Z proteins) that hold the actin and myosin in proper alignment for optimal muscle contraction (i.e., shortening of the muscle fiber). When the fiber subjected to extreme loads, especially as it elongates or contracts eccentrically, damage to the protein structure of the sarcomere can occur. Microscopically, damage to muscle tissue is easily observed in the loss of parallel positioning of Z-lines that bracket each sarcomere. This process is called Z-line streaming and results in the inability of sarcomeres to generate contractile forces. If enough sarcomeres are damaged the muscle fiber can become ineffective in producing force. When a complete muscle tear occurs, the entire muscle will lose all contractile capability.

Complete loss of muscle function as a result of exercise damage is rare, yet many athletes can experience soreness and weakness due to the demands of sport and conditioning programs. Mechanical damage initiates a cascade of inflammatory responses and noxious chemical release, which is likely to cause soreness, pain and swelling [31]. The key factors then become the amount of damage produced by the activity and the speed with which repair can take place. The greater the damage, the longer the time for repair (in worst cases, athletes may have to compete before they are fully recovered). Conversely, trained tissue will recover more quickly. Repeated bouts of overload without adequate repair may lead to chronic overuse injuries or serious musculotendonous tears. Damaged tissue may suffer reductions in its' stress-strain curve, meaning that lower amounts of force can cause the tissue to break.

Mechanical damage starts an inflammatory process that initiates the repair and healing process. This is part of recovery and the extent of its impact on training and performance depends upon the magnitude of tissue damage and the development of physiological systems that facilitate the recovery process. The inflammatory process is complex and involves multiple systems (e.g., complement system, coagulation system, fibrinolysis system), the total process of which has been well documented (see [31]. Historically, exercise physiologists spoke of "good inflammation" and "bad inflammation", meaning that inflammation took place on a continuum of severity (completely relevant to our discussion on overload). Excessive inflammation leads to excessive swelling and free radical damage. Collateral damage that cannot be stopped in a timely manner is treated with interventions that seek to reduce that amount of inflammation and speed its resolution (e.g. rest, ice, compression, elevation).

The well-known signs of inflammation are pain, redness, and swelling (edema) resulting from increased fluid flow to the area. Such fluids include blood (which carries attracted white blood cells such as leukocytes and macrophages), important proteins (e.g. fibrin), and cytokines needed in the clean up and repair of the tissue [31]. Additionally, inflammation is worsened by "chemical damage" mediated by free radicals that cause tissue membrane breakdown several days after the original mechanical overload [30]. For example, a group of reactions resulting from mechanical damage can help to form the superoxide radical that combines with iron to form reactive hydroxyl radicals that attack the polyunsaturated fatty acids in cell membranes. Such lipid peroxidation reactions are the basis of the cell membrane disruptions that occur with exercise [30] [19] suggested the use of free radical concentrations as a way to quantify the magnitude of damage from physical exertion and as a possible indicator of readiness for physical exertion.

The pain arising from the damage and repair processes associated with conditioning and competition is commonly referred to as delayed onset of muscle soreness (DOMS), a classic response to mechanical overloads or continued chemical damage arising from free radical scavenging of muscle tissue [27, 28]. The duration of DOMS is directly related to the amount of overload, amount of tissue damage, and the fitness level of the musculature affected. Delayed onset muscle soreness can last as long as 10 days with intense overloading of the muscle in untrained individuals, although trained individuals should experience DOMS for 24-72 hours after overloading eccentric exercise [27, 28]. Tennis play and conditioning activities that utilize progressive, periodized heavy resistance training should cause the tissue adaptations that reduce or eliminate DOMS resulting from competition or conditioning.

Repair

Muscle repair includes processes that range from the activation of genes to the differentiation of satellite cells and integration of myoblasts into injured fibers [31, 32]. Ultimately, the body will address and rebuild damaged tissue in addition to adding additional "damage preventing" protein. Repair is initiated by damage but some tissues (i.e., connective and skeletal muscle) will be damaged to the extent that repair is not possible and cell necrosis or death results. The repair process is initially signaled by many of the inflammatory responses occurring after exercise stress. Connective structures such as tendon tissue respond to progressive heavy resistance training with increased thickness and strength. However, the deformation and injury of such tissue is not a typical consideration of most exercise-induced repair processes. Skeletal muscle tissue is most susceptible to exercise-induced damage, which is why it is the primary focus of the damage and repair process [33, 34].

For skeletal muscle, the mechanical forces of muscular activity initiate the activation and differentiation of satellite cells found between the sarcolemma and basal lamina. Satellite cells break away from the muscle fiber and are attracted (i.e. chemotaxis) to the injured areas of fibers. Satellite cells undergo differentiation once they reach damaged muscle tissue, becoming fiber-sealing myoblast cells [32]. This repair process is important for both normal growth and heavy resistance exercise-associated muscle hypertrophy. Satellite cells can contribute daughter myonuclei, which are needed for repair and growth of muscle fibers (see Figure 2 below). If there is a large enough break in the damaged muscle fiber, the ends may not be bridged by myoblasts, and the innervated portion of the fiber will survive while the other end of the fiber will degrade. “Neural spouting” from another motor unit can provide the neural connection [35, 36] to “reengage” contractile ability.

In skeletal muscle, repair depends upon signaling from the injured tissue, interactions with cytokines (e.g., IL-1, IL-6) and hormones (e.g., IGF-I), positioning of the injured fibers, and potential rescue of fiber lengths with neural sprouting [37, 38]. The repair process operates continually in highly resistance-trained tennis players subjected to lower levels of exercise-induced muscle damage. Managing the design of the training program and optimizing other preparatory factors (such as nutrition and hydration) ensures relatively expedient recovery of tissue structures [39-42].

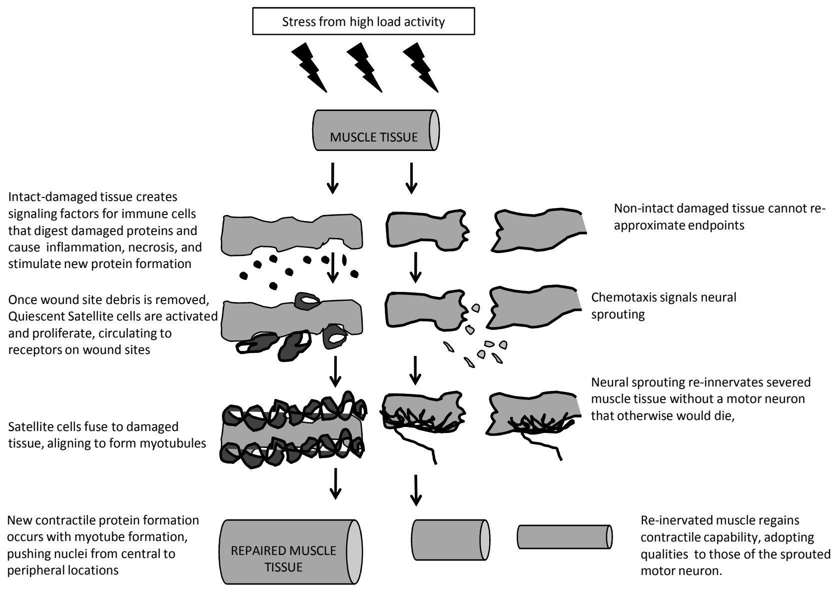

Figure 2. Muscle Damage and Repair Model – Muscle subjected to large and repetitive loads (especially eccentric) may become damaged. Different levels of damage necessitate different repair processes. Repair of damaged muscle tissue is facilitated by tissues affected by trauma and ligands present in lymph and circulatory systems that reached damaged tissues.

FATIGUE ARISES FROM THREE (3) MAJOR DOMAINS OF COMPETITIVE DEMAND

1. Motor unit recruitment to activate skeletal muscle
2. Environmental
3. Psychological demands

The number and type of motor units recruited will dictate the extent of the involvement of support systems (e.g., cardiovascular system, endocrine system, metabolic systems etc.) needed for optimal performance and recovery. For example, hitting a single serve is accomplished using highly engrained motor unit recruitment patterns, but musculoskeletal support systems involvement will be minimal if that is the only exercise performed. However, motor unit recruitment patterns while hitting a single serve at the end of a 3-hour competitive match may be very different due to alterations in available metabolic support and the amount of skeletal muscle damage that may have already occurred.

It should also be obvious that environmental stress can alter the demands of physical exertion, with heat stress being the most common challenge to both performance and recovery processes in tennis [43-45]. Psychological stress is typically related to situational stress responses (e.g., increased epinephrine concentrations prior to a match), perceptions of recovery, and the possible interference of optimal motor skills occurring in consequence [25, 46-48]. Thus, it is important to appreciate that fatigue from physical exertion is a multivariate paradigm that must be examined within the “context” of the specific set of conditions or demands the athlete is placed under.

1. *Motor unit recruitment to activate skeletal muscle*

The recruitment of motor units (i.e., one alpha motor neuron and the skeletal muscle it innervates) containing skeletal muscle fibers of various types (i.e., Type I slow twitch or Type II fast twitch fiber types), number of fibers in the motor unit, activation thresholds, and metabolic capabilities dictate the ability to meet external demands for force and power. Inherent to motor unit activation is the “size principle” developed by the research of Henneman’s group over the years [49, 50]. In some sizing factor (e.g., number of fibers, threshold level for activation, cross sectional area of muscle fibers) motor units are recruited in a set pattern to meet the demands of the skill or exercise performed. Typically, motor units are recruited from small motor neurons up the recruitment ladder to higher threshold, larger motor units. It is important to underscore the fact that small motor units (also called low threshold motor units) are almost always recruited, even in activities typically considered as being “high force” or power dominant.

With depleted metabolic substrates in the lower threshold motor units from long term repeated use, recruitment can progress to higher threshold motor units which will not be as efficient in meeting the demands of the activity. Depletion of low threshold motor unit energy substrates (e.g., glycogen) is rare in normal activities unless the duration of exercise is long (e.g., > 90 minutes of high intensity continuous exercise or high-intensity exhaustive short-term exercise) [51, 52]. Some matches in tennis may approach such levels of energy depletion and thereby impact the effectiveness of skills and power due to altered patterns of motor unit recruitment during tennis play. Thus, the recovery of skeletal muscle is partially based upon its "use" in an activity. In other words, muscle that is not recruited will not suffer fatigue. Additionally, the damage occurring with exercise is dependent upon the type of muscle action (e.g., high eccentric loads create more skeletal muscle damage) [53-55].

The continuum of stressors to skeletal muscle during a tennis match or a conditioning activity is a function of the recruitment demands and forces presented to activated muscle fibers (motor units) (Figure2). The diverse range of contractile demands in tennis results in an array of skeletal muscle insults.

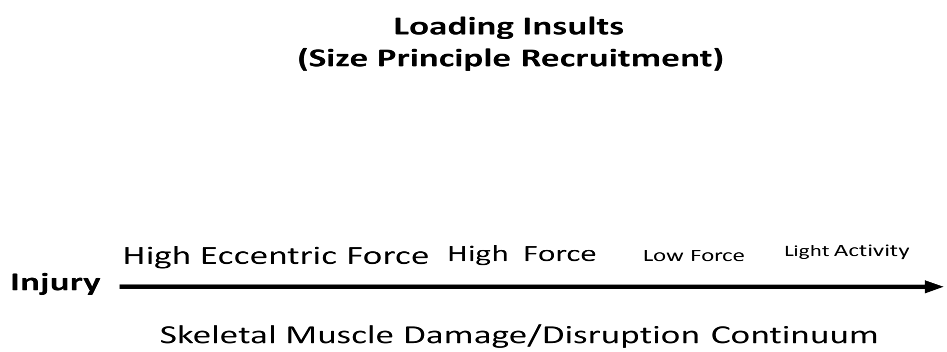

Figure 3. The recruitment of motor units will dictate how many muscle fibers are activated in training or competition. The highest forces are observed with maximal eccentric muscle actions and this type of neuromuscular demand causes the most damage to tissue. Conversely, light aerobic-based activity or every-day sedentary loading of skeletal muscle involves smallest amount of tissue activation and disruption.

2. Environmental Conditions

Environmental stress stems from factors such as temperature, humidity, playing surface, playing implements, and variables within competitive play. All activities encompass environmental factors that affect the stress of game play and the requirements for optimal recovery. In tennis, vast temperature and humidity gradients, a number of different ball types and playing surfaces, and varying styles of game-play alter the nature of fatigue - which necessitates preferential selection of recovery methodologies that most effectively target the specific systems and structures experiencing fatigue. Temperature effects are particularly important, because they may strongly affect other physiological systems and compound the net fatigue associated with tennis play. For example, in competitions where temperatures are hot and humid, dehydration and hyperthermia rapidly occur. When experiencing dehydration and hyperthermia, blood volume decreases, leading to increased heart rate and rating of perceived exertion. Nervous function decrement has been suggested, leading to diminished power, agility, speed, and coordination [19]. Additionally, the total time needed for recovery is likely to increase because of reductions in blood clearance of waste products and diminished capability to deliver recovery-enhancing hormones.

3. Psychological Demands

While difficult to measure biologically, psychological fatigue is generally accepted as a major performance-altering factor. The psychological stress from activity is addressed with close observation of athletes in conjunction with continuous feedback including surveys, informal communication, training logs, and journals that record feelings towards competitive stressors [18, 47]. Assessment of mood states may provide important insight into biological factors that are not easy to quantify, but are major determinants in competitive outcomes. Psychological state markers may include perception of effort, motivation, energy and wakefulness, anxiety levels, and changes in performance without measurable changes in biological markers of stress or fatigue [16, 47, 56].

Metabolic and Endocrine Interfaces with Fatigue and Recovery

Endocrine Interfaces with Fatigue and Recovery

The endocrine system responds to the demands placed on competitors by secreting hormones that initiate acute and long-term adaptations to stressful physical exertion [38, 57]. Prominent examples of endocrine roles in performance include the processes of cognitive excitement, metabolic homeostasis, and tissue recovery. Hormonal responses to stress depend on the nature of the stress and the physical characteristics of the individual. Men and women experience different hormonal responses to the same stressors [57]. For example, tennis has been shown to cause large testosterone responses in men [11].

Tennis has been shown to stimulate large increases in blood testosterone concentrations, which indicates that tennis is physiologically received as being moderate-highly intense at moderate volumes with a high net work [11]. Testosterone is the primary anabolic hormone for protein synthesis and neurological adaptations in men [38]. Testosterone is therefore likely to play a key role in recovery and physical capacity improvement. Less responsive individuals are likely to experience diminished recovery capability, impaired performance gains, and prolonged fatigue. In addition, the age of the individual plays a role in hormonal response to activity. Elderly individuals experience diminished hormonal responses compared to younger players participating in the same physical exercise [57] .

Metabolic Interfaces with Fatigue and Recovery

The metabolic demands of a sport are primarily determined by the duration and intensity of the activity in conjunction with the rest between and amongst bouts of exertion. Metabolic demands of a given match will dictate the recovery process, as damaged tissue is repaired through the metabolic recovery of available energy stores [13, 46, 58, 59]. The rapidity of this process will be especially important if another match is to follow. Metabolic effects of match play are difficult to assess because of variability in the physical characteristics of participants and match play (discussed later). In addition, many sports involve concurrent physical demands (i.e. heavy aerobic and anaerobic performance taking place during the same competitive event), which vary in extent depending upon the same previously stated variables. Ultimately, humans possess a sophisticated physiological ability to adapt to the metabolic stress of activity. The by-products of metabolic processes are of interest primarily because of their relationship to neural and structural damage and fatigue.

Physiological Demands of Tennis

The game of tennis has changed over the past twenty years with athletes getting bigger and equipment technology improving to match an ever increasing emphasis on "power and speed" game [14, 60]. With a game that is played with greater neuromuscular demands (power and speed incorporates high threshold motor units and forceful eccentric loads), the recovery process has become increasingly important. Prior studies have documented elite tennis matches over 1 hour and as long as 5 hours. Exercise-to-rest ratios typically range from 1:2 or 1:3. Rest periods at each end-change during competitions may last 60-90 seconds (depending on the style of play) [12, 61]. Each point is typically encompassed by 2-3 hits with an average of 4 direction changes. Elite tennis players run an average of 3 meters per shot, with 8-12 total meters per point, and 300-500 high intensity efforts per "best of 3 set" match. Point durations average 4-10 seconds while VO_2 costs and heart rates reach 50-70% and 60-80% of maximum, respectively [62]. Furthermore, heart rate and lactate concentrations increase progressively with match duration [14, 58].

In order to better understand the recovery process it is important to examine the physiological demands of the sport. Tennis has a particular demand for power and speed that can be maintained over the duration of a match. Correspondingly, tennis requires moderately high aerobic capacity in conjunction with the ability to rapidly pay off acute O_2 debt between points during a match (Chandler, 2000). High degrees of linear speed, non-programmed (visual) agility, and finely tuned coordinative abilities (e.g. serving) necessitate substantial ATP-CP energy system contributions. Tennis has been metabolically profiled as deriving 70% of its energy from high energy phosphagens (ATP-PC), 20% of its energy from glycolysis, and 10% of its energy from aerobic energy sources[12].

As a result of a diverse range of highly forceful dynamic muscle actions (e.g., sprints, starting, stopping, jumping, and rapid tennis strokes), substantial amounts of tissue disruption are likely to occur in tennis. In addition, racquet-oriented sports place unilateral stress on the shoulder and upper-back joint-musculature [10, 63, 64]. While shoulder, arm, and chronic-overuse injuries are commonly observed in tennis, many injuries involve the lower body, which has been speculated to occur as a result of hard playing surfaces [18, 65-67]. Fatigue and recovery demands will reflect behavioral practices, as poor hydration and nutritional practices will result in greater amounts of fatigue and a less efficient recovery process [40, 41].

Neurological Demands

Neurological fatigue is difficult to measure directly, but many physiologists believe that neurological fatigue primarily occurs as a result of stressful activities encompassing large amounts of power and force production. As an example, the tennis serve is a mechanically powerful movement that is likely to cause motor unit fatigue. Fatigued motor units display decreased muscle recruitment and firing frequency, which negatively impacts precision of movement and coordination.

Despite commonly accepted views on the existence of neurological fatigue, research has failed to demonstrate direct causal mechanisms. Investigators have postulated disturbances in ionic and neurotransmitter gradients, pH effects, mechanical deformation, and factors related to morphological damage as sources of neurological fatigue [1 2 19]. In addition to fatigue from repetitive muscular production of force and power, high volume work has been shown to adversely affect neurological functioning, which may indicate a high degree of stress sensitivity in the neurological system, in addition to underscoring the integrative co-functioning of all physiological systems [23].

Some scientists have proposed the existence of central nervous system (CNS) fatigue as a primary source of performance-diminishment in rigorous activities encompassing large amounts of force and power production throughout large quantities of muscle tissue. Others hypothesize peripheral nervous fatigue (localized) as the primary factor of fatigue in neurologically overloading activities. The existence of CNS fatigue has not been directly elucidated but deserves more attention and may involve psychological, skeletal, and nervous tissue mechanisms [19]. Peripheral fatigue is observable with the use of electromyography devices (commonly referred to as EMG), which show electrical activation patterns in muscle by nervous tissue. Assuming the efficacy of EMG technology, muscle activation should be higher in non-fatigued muscles than fatigued muscles, thus creating an objective assessment of recovery state (comparing pre and post activity force production characteristics).

Performance tests that measure ballistic exercises (where maximal mechanical power is generated) are preferential in determining neurological fatigue. While Performance tests are an indirect measure, their practicality, objectivity, and prescriptive ability make them valuable tools for quantification of fatigue most likely neurological in nature [19]. (See Figure for an overview of the paradigm).

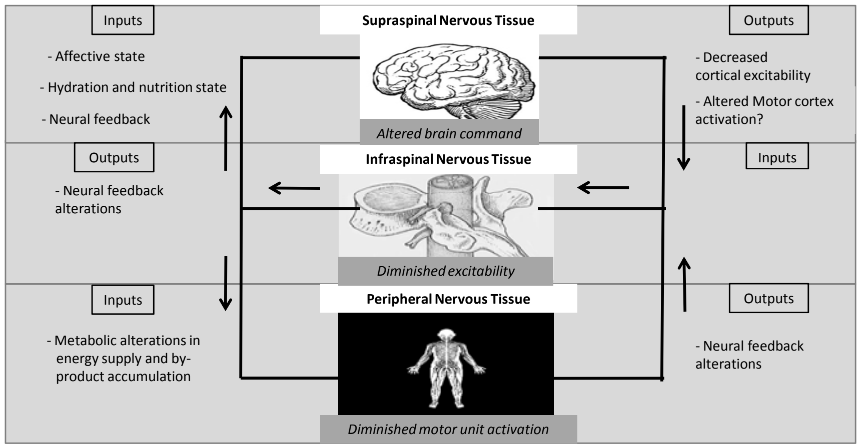

Figure 4. Neurological Fatigue Model – A proposed conceptual mapping of the neural structures involved in neurological fatigue, and possible causes and effects of fatigue between the connected components.

Thermoregulatory Demands

In tennis, thermoregulatory processes are emphasized because elevated internal temperatures are likely to diminish neural function and therefore decrease muscular rate of force production and stretch shortening cycle abilities [62]. Furthermore, dehydration and increased internal/skin temperatures can become serious health concerns if left unchecked and have also been shown to increase rating of perceived exertion during play [14, 44].

Thermoregulation takes place through peripheralization of blood flow, vasomotion effects, and ultimately increased perspiration [68]. While playing tennis, internal temperatures increase more than when running continuously. Understandably, progressive increases in the physiological cost of play with match duration explain the accompanying increase in thermoregulatory costs. Conversely, continuous running typically reaches a “steady state”, reestablishing efficiency by maximizing heat loss and minimizing energy expenditure per unit of work [44]. Thermoregulation during match play is facilitated by appropriate clothing selection, hydration, and play-style adjustments that occur between competitors [44]. Due to the absence of set constraints on play duration, exertion levels in tennis are largely competitor- selected through velocity coupling (altering velocity of shots to adjust exertion of play). Thermoregulatory development and tolerance are reflected in the skill level of competitors, which affects the stress of play.

Nutrition and Hydration Demands

Nutrition

Glycogen depletion has been a long-hypothesized source of fatigue and performance diminishment with physical exertion. However, little evidence exists to validate such claims, except in activities encompassing long durations of high exertion (such as marathon running and triathlons). The human body initiates many processes designed to prevent depletion of energy sources (barring pathological conditions that prevent optimal energy substrate generation - such as pancreatic and thyroid disorders). While glycogen depletion may be possible with extremely long matches, rate of energy expenditure may be a more important factor when considering the generation and accumulation of waste products. In metabolically demanding activities, high performance has been demonstrated and maintained with low carbohydrate diets (when acclimatization to the new diet was permitted). Such findings support the notion that optimal nutritional practices are primarily a function of adequate caloric supply when supply of calories is most relevant to competitive needs. Specifically, nutrient consumption directly before, during, and after competitive and preparatory events key to optimizing recovery and minimizing fatigue [41]. The "optimal strategy" for competitors is unknown and likely personal (or genetic) in nature. As such, the person (more so than the diet) may be the strongest factor in determining the response to a given nutritional intervention strategy [69]. If glycogen depletion does occur, replenishment is a likely prerequisite for the initiation of recovery processes [19], which underscores the importance of post-exertion feeding.

Lees suggested that carbohydrate ingestion during tennis play would delay the onset and counter the effects of fatigue (including diminished concentration, alertness, coordination, and unforced errors) [64]. The benefits of intra-competition carbohydrate ingestion is uncertain but other studies have provided rationale for experimentation with varying quantities of carbohydrates, amino acids, and water mixtures during match play [41]

Hydration

Tennis often involves hot and humid atmospheric conditions and long durations of play (as long as five hours with numerous matches per day), creating highly demanding match play in the face of progressively worsening dehydration status. The circulatory system connects all physiological systems, making hydration status (via blood volume) a key consideration in the optimization of physiological recovery. Hence, decrements in hydration as low as 2% have been shown to impair performance [40, 70-72]. Interestingly, elite athletes typically maintain performance levels despite sustained states of severe dehydration. The physical characteristics of competitors, atmospheric conditions, characteristics of play, and habitual hydration patterns affect hydration status. Most important to performance, lower hydration levels decrease blood volume, which necessitates elevations of heart rate to compensate for diminished cardiac output. Additionally, lower blood volume is likely to lead to diminished clearance of metabolic and inflammatory agents, in addition to reductions in the clearance of recovery-mediating hormones from endocrine tissues [73]. Dehydration may therefore play a more important role in recovery than previously appreciated [40].

Hydration and thermoregulatory functions may not always affect tennis stroke velocity and accuracy (especially in elite tennis players) [16]. Nevertheless, technical proficiency has been shown to suffer with progressively longer play durations and correspondingly worsened hydration states. Past research has examined the physiological effects of long-duration activity in stressful atmospheres, and it was theorized that neurological function suffered with hyperthermia and dehydration [19]. Ironically, excessive water consumption during and before game play is unlikely to enhance performance and has been shown to cause gastrointestinal stress and at the extreme, hyponatremia - both of which negatively affect performance [70].

Dehydration seems to occur regardless of hydration strategy. A "minimize the damage" mentality that emphasizes water ingestion to tolerance may promote minimization of dehydration and avoid unrealistic expectations of hydration levels during play. Minimized dehydration with the absence of cramping, nausea, and vomiting that often accompany acute hyper-hydration promotes performance and recovery concurrently. Hydration strategies may be optimized by calculation of sweat rates [70]. Furthermore, hydration strategies should seek to optimize hydration status continuously, and not solely around competition schedules [43, 70].

Psychological Demands

Kraemer and colleagues observed highly competitive NCAA division one women tennis players and determined no physiological or physical performance fatigue lasting longer than twenty-four hours after two days of match play [47]. Despite the apparent absence of physiological fatigue, psychological status was negatively altered the day after the weekend of match play. Thus, while physically ready to play after two matches, these collegiate women tennis players were not psychologically ready to play.

Psychological measures are indirect (by nature), necessitating the incorporation of surveys and scales that are assumed to accurately reflect psychological fatigue levels. Fortunately, the lack of direct biological information on psychological fatigue is countered by the ease and documented validity of perception scales in assessing psychological fatigue [62]. The level of an athlete's commitment, fatigue of other physiological systems, other "life" sources of stress, and the importance of the competitive event influence the psychological stress of competition [16].

Psychological resiliency may be a major defining factor of performance discrepancies between elite and lesser-skilled competitors. Compared to lesser-skilled players, elite players better maintain stroke velocity and play style throughout match play, even when playing under exceedingly poor conditions (extreme dehydration and substantially elevated internal temperatures). In light of the known affect of player psychology on performance, the demands of activity are better viewed from a double-edged perspective: the activity places demand on the participant, and the participant places demand on the activity.

Tissue Demands

"Stop and go" play during rallies are comprised of highly repetitive movement patterns. Such patterns emphasize rapid development of force and commonly incorporate stretch-shortening cycle muscle actions (SSC). SSC's are associated with forceful eccentric contraction of muscle followed by rapid concentric shortening of the muscle. Maximal power is enhanced by the use of the elastic component in muscle (i.e., non-contractile connective tissue) and neurological properties of forceful eccentric muscle actions and translating them immediately to rapid and forceful concentric actions with minimal pause (or amortization) between the two directional movements. These movements are part of tennis as well as the conditioning programs that are used to develop tennis specific fitness [12]. SSC's can cause significant tissue disruption and neurological fatigue. Grezios et al described the importance of the SSC in overhead stroke movements without directly considering the role of the SSC in lower body tennis movements [63]. Fatigued SSC components (muscular and neurological) will cause decreases in stroke velocity and accuracy. Mendez-Villanueva et al attributed decreasing performance to SSC fatigue caused by repetitive mechanical deformation [62].

Tennis requires exceptional mechanical power in upper and lower body movements, which necessitates the ability to activate high threshold motor units. High threshold motor units are typically associated with type II muscle fibers, forming a unit capable of quickly generating large quantities of force. Thinking back to the tissue disruption continuum and size principle, It should be apparent that high threshold motor units and their associated muscle contraction characteristics are likely to incorporate highly stressful and fatiguing tissue demands.

Girard and Millet [15] reported impaired movement, mistimed shots, and lower stroke velocities as the primary determinants of neuromuscular fatigue. Decreased muscular mechanical properties, changes in afferent feedback, ionic and neurotransmitter concentration alterations, and reduced central activation were theorized as physiological indicators of neuromuscular fatigue. Fortunately, it appears that neuromuscular tissue recovery occurs relatively quickly even with matches on consecutive days [47].

Characteristics of Play Alter Stress of Match

Tennis is especially challenging because of the range of performance characteristics it incorporates. Recovery is optimized with well-programmed strength and conditioning programs, sufficient rest (between training sessions and competitions), and behavioral practices that improve hydration and nutritional support [11, 12, 26]. Five especially prominent characteristics of play should be considered when determining the demands of a tennis match:

1. Intensity of play
2. Duration of play
3. Frequency of play (or rest)
4. Implement and playing surface characteristics
5. Environmental temperature and humidity

1. Intensity

The physiological demands of tennis vary according to the intensity of game play. Intensity in turn, depends upon the style of competitor play, level of competitor ability, and the corresponding duration of match play. Defensive play encompasses more movement and reactive ability, which is represented in play that occurs closer to the baseline. Heart rate and lactate concentrations are higher in defensive play styles. Conversely, offensive play is typically more efficient and therefore less fatiguing. Offensive players tend to move less while playing closer to the service line of the court [56].

Ultimately, competitors will couple style of play and intensity (through stroke velocity) to their opponent's style of play [13]. Competitors should prepare for both defensive and offensive play while prioritizing offensive-minded development because it is more efficient (less physiologically stressful – see Figure 5). Meanwhile, concomitant decreases in play efficiency by the defensive opponent are expected, leading to increases in fatigue level and an increasingly greater likelihood of defeat.

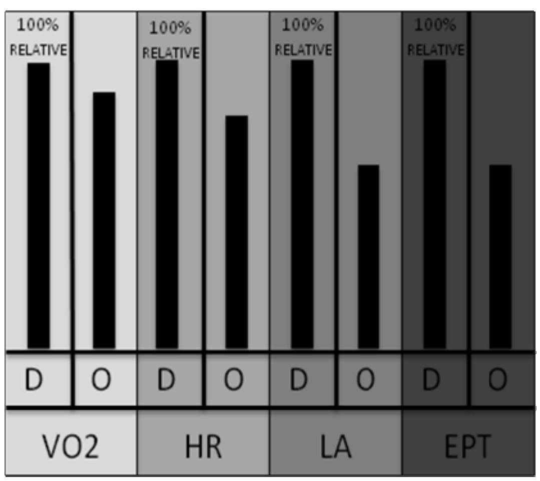

Figure 5. Physiological Cost Comparison: Defensive and offensive tennis play – Defensive (D) and offensive (O) game play compared in terms of VO2 cost

(VO2), heart rate (HR), lactic acid (LA), and effective playing time (EPT) – adapted from data presented by [61]

The main determinant of intensity is skill level. Lesser-skilled players experience a game characterized by longer rallies and greater aerobic demands. Elite tennis players experience the least aerobic demand in competition due to a “quick hit and score” playing style that is heavily anaerobic and characterizes the “power game” seen in media today. Whether play is predominantly aerobic or anaerobic, high intensity exertion will cause greater quantities of fatigue and greater need for recovery. Conditioning must develop the ability to recover from stress of similar intensity to that experienced in competitive scenarios, in addition to developing the ability to maintain stroke efficiency under conditions of fatigue [10, 13, 46].

2. Duration of Play

Effective playing time and rally duration are useful ways to gauge the stress of play as it relates to duration of play [61]. Rallies of longer duration have greater lactate responses, which is indicative of the progressive role of glycolytic metabolic contributions in tennis matches [58, 61]. Matches of longer duration cause greater quantities of fatigue and necessitate additional attention to hydration status, thermoregulation (especially in hot and humid play conditions), and nutrient supply before, during, and after the match. Correspondingly, court movement diminishes with play progression, as evidenced by greater quantities of unreached balls at later stages of play [62].

Tennis does not incorporate defined constraints on play duration. Amongst other factors such as playing surface and velocity coupling, match duration may help to indicate the difference in skill level between competitors. Matches of short duration are indicative of a larger discrepancy in skill level between competitors, including less work, less total hits, and shorter effective playing time. On the other hand, long matches represent equated competitive ability, which is likely to result in substantial fatigue for both competitors. In long matches, outcomes are often described in terms of “who lost” (or finally succumbed to fatigue), as opposed to short matches where play is referred to in terms of “who won” (or dominated). Ultimately, longer matches place greater importance on resistance to fatigue and rate of recovery.

3. Rest Between and Amongst Bouts of Exertion

Competitions incorporating numerous matches per competitor require expedient recovery between matches (or at least a superior recovery rate compared to other competitors). Despite the preference for low fatigue play (dominant, offensive), players should be physically prepared for lengthy matches. Of course, the preferential selection of skill and conditioning strategies should reflect a player’s natural strengths. Hydration, nutrition, and physical conditioning preparation are reemphasized for successful outcomes. Furthermore, the winners of elite tournament competitions are likely to possess the greatest psychological resistance to fatigue, which underscores the importance of preparation that emphasizes psychological stress-management.

4. Implement and Playing Surface Characteristics

One study observed the impact of varying ball types on game speed, and demonstrated a mean rally length duration increase of three seconds with the introduction of the slower ball type on a grass playing surface [64].

Play-speed differences are likely to affect the style of play. Slower ball speeds cause players to preferentially choose overhand swings and forehand strokes that are more accurate and precise, while traveling further to enable selection of such strokes. Faster ball speeds result in the selection of more backhand strokes. Such strokes diminish travel and result in maintenance of the "ready position" (less stray from starting position) [17]. On fast-play surfaces, court positioning takes precedence over stroke selection.

Faster game play lessens length of play, and prioritizes proficiency in hitting power, precision, accuracy, and reactive agility. Conversely, slower paced games result in longer duration of play, longer rallies, and greater aerobic fatigue. Greater than normal elevations in heart rate, blood lactate, and VO_2 costs support the profound difference of play on slower surfaces. To adapt to the actual demands of competition, competitors should prepare using implements similar to those used in an upcoming competition.

Various playing surfaces are used in tennis competitions. The most common are grass, synthetic rubber, clay, and turf (artificial grass). Playing surface dramatically affects the demands of play because of its effect on ball velocity and ground reactive forces. Hornery and co-workers suggested that playing surface does not independently affect hydration or thermoregulatory stress despite its impact on demands of play [16]. However, playing surface causes thermoregulatory concerns as a result of the different heat radiation characteristics of different playing surfaces when exposed to sunlight. More data is necessary to determine the effect of playing surface on localized atmospheric temperatures.

Murias and co-investigators documented metabolic and style of play differences on various surfaces and made a number of observations [74]. Clay courts elicited higher lactate responses. Higher lactate values seem plausible when considering the slower play, longer rally durations, and longer effective playing times on clay surfaces. Higher glycolytic energy contributions on clay is in all likelihood caused by greater total running distances, longer total playing time, and subsequently larger exercise to rest ratios relative to harder playing surfaces. Clay was also shown to incorporate more strokes per game than grass; further supporting the importance of considering playing surface when discussing the physiological costs of play and physical development strategies.

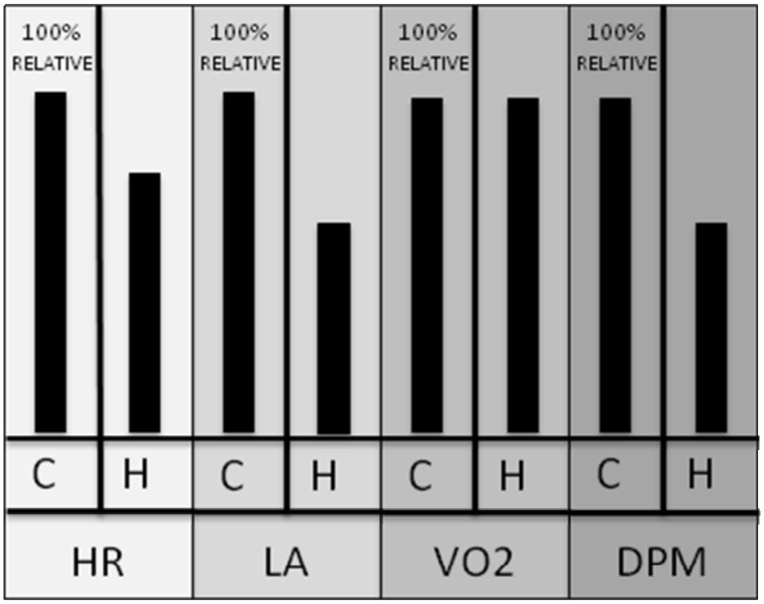

Figure 6. Costs of playing surface: clay vs. hard courts **–** Clay (C) and hard courts (H) compared in terms of relative mean heart rate (HR), mean lactic acid (LA). Mean VO2 (VO2), and mean distance ran per match (DPM). Adapted from data provided by [74]

Playing surface strongly affects the steps taken per shot. Steps per shot (SPS) is an important performance variable in tennis. Slower playing surfaces result in more movement, which shifts the demands of tennis in the direction of aerobic exertion. Greater amounts of movement allow players to make more accurate stroke selections. Faster playing surfaces, which lessen SPS, diminish the ability to make preferential stroke selections, and promote the "power game". Consequently, players are forced to make less accurate backhand strokes. A trade-off is inevitable and necessitates stroke and movement choices reflective of a player's strengths and the style of play that develops in a given match. Slow surfaces encourage "hit and run" play-style while faster surfaces encourage players to seek positioning advantages [64]. Ideally, competitors should identify the surface of the next competitive event and spend substantial time training on similar surfaces.

5. Environmental Temperature and Humidity

The environmental conditions of tennis vary extensively, which forces players to prepare for a range of playing conditions. Hot and humid atmospheric conditions are most troublesome, as lower hydration levels diminish all physiological functions, thus compounding the fatigue of play. Significantly elevated average heart rates in hot weather are one indication of the affect stressful environments can have on tennis play [11].

Tennis players seem to reach hypo-hydrated states regardless of hydration intervention technique. The principle causes of hypo-hydration in tennis are high intensity play, long play durations, and minimal rest. In addition, hot and dry atmospheric temperatures will aggravate hypo-hydration. In order for reduced stress levels and improved recovery from competition, acclimatization in a given environment must occur (i.e. training near the competitive venue). Clothing that improves heat loss should be worn in hot and humid play conditions. Such clothing would incorporate maximized convective ability ("breathing"), radiation resistance (lighter colors), and materials that dissipate perspiration effectively when perspiration rate dramatically increases (‘wicking”). Cosmetics with sunscreen and UV blocking protection can provide temporary relief from the radiation of the sun but may negatively affect or block perspiration and heat loss (eg antiperspirant deodorant).

Game Type

Players Alter the Characteristics of Play

The physical characteristics of players greatly affect the stress of a tennis match and optimal strategies for performance enhancement. Most differences in competitor attributes are reflective of innate genetic factors in addition to skills and abilities attained through practice and conditioning. Genetic factors strongly shape the realities of competition relative to the nervous system, physical size, and capability characteristics of competitors. Currently outside of human control however, genetic factors are minimally emphasized. It is important to note that tennis has evolved as with most sports to incorporate larger and stronger competitors [2, 60]. The primary competitor characteristics of interest are gender, age, skill level, heredity, and velocity coupling.

Gender

Women play “best of 3 set” matches, which decreases the total duration of play when compared to elite men paying “best of 5 set” matches in Grand Slam events (non Grand Slam events typically use a “best of 3 set” match system). In addition, women have slower stroke velocity when compared to men of similar competitive skill level. Consequently, longer rallies within shorter matches are characteristic of women's tennis play. Higher aerobic demand among women competitors is expected relative to skilled men's tennis play. Women may choose to put a slightly greater emphasis on the development of aerobic abilities when preparing for competition. Skilled men may preferentially choose to emphasize development of power/speed endurance and mechanical power while committing relatively small emphasis on aerobic capacity development. Nevertheless, aerobic capacity is optimally developed when preparation simulates competitive scenarios and addresses individual needs and goals.

Age

Age influences the demands and stress of tennis. Research data have demonstrated diminished VO2 and heart rate maximums with increasing age; therefore, older tennis players perceive higher relative play intensities [75]. Mechanical power development and maintenance is a priority for older individuals due to a higher rate of power loss as a result of sarcopenia (age–associated skeletal muscle tissue loss). Lactate tolerance and clearance ability is also diminished in older individuals, but active individuals who regularly engage in intense exercise are likely to maintain higher lactate tolerances and clearance rates than their sedentary counterparts. Older tennis players should expect increased discomfort in both competition and preparation, but should focus on the extent to which tennis and other activities will positively improve pH and lactate responses when engaging in other activities. If play-style remains “normal” in elderly tennis players, lactate responses are similar to those experienced by younger and elite tennis players. Such findings underscore the secondary role of glycolytic metabolic systems in tennis [75]. It is important to note that many elderly individuals have been shown to consume inadequate amounts of nutritional support (i.e., total calories and protein intake) compared to younger athletes, which warrants added emphasis on nutritional optimization, which can strongly affect the speed of recovery and magnitude of play-associated fatigue.

Skill Level

Tennis players of lower skill level play with lower stroke velocities, slower court movement, and slower reactive times. The highest relative VO_2 max levels are seen in both highly skilled tennis players and younger (less skilled) tennis players [61], which illustrates the lower efficiency of movement amongst lesser-skilled players compared with elite tennis players. Less-skilled competitors also suffer diminished blood glucose levels when performing consecutive matches [62]. Blood glucose remains stable in single match competition and remains most stable amongst elite players, which reflects the brief and powerful nature of exertion in elite tennis competition.

Unskilled tennis players may experience longer rally times, but lower skill level is likely to result in play characterized by relatively short durations of play, low-efficiency movement patterns, and longer rest periods in all phases of game play. Less-skilled players typically select “best of 3 set” matches that decrease the total duration of play. Lack of physiological development in combination with low skill-level reinforces the importance of diverse preparation strategies for lower skill-level participants. The fatigue associated with play may seem high in perceptual terms, while being physiologically minor due to low absolute capacity (i.e. motor units that are not recruited are not fatigued). Since fatigue is relative to physiological status, psychological fatigue tolerance and motivation may play primary roles in progressive improvement. Skill level may strongly affect psychological perception of exertion, as Morante and co-investigators observed increased fatigue tolerance amongst more highly skilled players [68]. Such tolerance was characterized by maintenance of performance with higher internal temperatures, worsened dehydration status, and highly elevated biological markers of fatigue.

Heredity

Genetic influence on fatigue and recovery from sport is an area of interest for investigators that have access to “physiogenomic” technology. Physiogenomic technology uses advanced computer modeling systems to analyze genome characteristics in hopes of determining gene functions and “phenotype” indicators (a gene that determines a physical characteristic). A participant’s genetic profile plays a strong role in the innate skill level that the participant brings into an activity and is likely to determine the development potential of the systems governing fatigue and recovery from physical exertion. As an example, athletes with large quantities or higher proportions of type II muscle will enjoy substantial advantages in power-based activities compared to athletes who are “type I dominant”.

Velocity Coupling

“Velocity coupling” is the primary competitive factor in tennis and describes the phenomenon where players adjust the speed of play to reach equilibrium of exertion. Ball speed, playing surface, and competitor dynamics affect velocity coupling, which then helps to determine the stress and fatigue experienced in competition. Specifically, Cooke and Davey showed that opponent hitting speed is the primary velocity coupling factor determining competitor exertion levels (See Figure 7 below) [13]. Smekal and co-workers postulated velocity coupling as the primary determinant of VO_2 demand during tennis play [61].

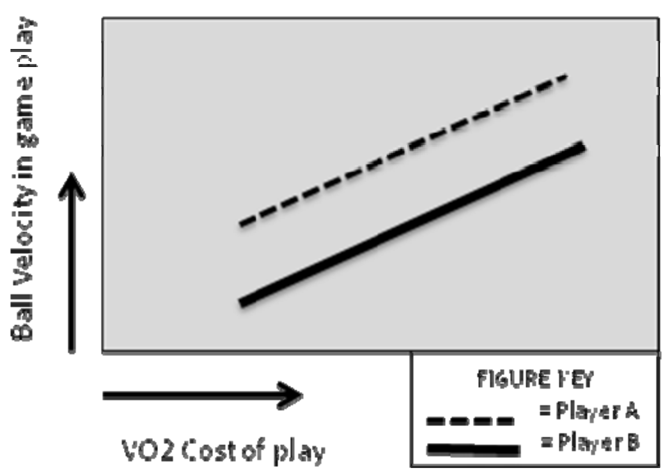

Figure 7. Velocity Coupling Effect – VO2 expenditure increases in linear fashion with stroke/ball velocity. Adapted from model provided by [13]

Intervention Strategies to Minimize Fatigue and Optimize Recovery

Several competitions per day and/or tournament are commonplace in competitive tennis. Players who can minimize and the severity of fatigue are likely to enjoy marked advantages over competitors suffering from fatigue. In highly resistance-trained NCAA Division I women tennis players, Kraemer et al documented complete recovery in many major variables of performance (grip strength, shoulder strength, stroke velocity, lower body power) following two days of match play [47]. No signs of fatigue were exhibited biologically; with cortisol levels at pre-competition resting levels. In light of such findings, further discussion of resistance training as a key consideration in the development of recovery capability is warranted.

In tennis, general conditioning or “generic specificity” physical development reflects the training of physiological systems that provide the metabolic energy needed to develop powerful skeletal muscle contractions over long durations of time. Such development typically takes place off the court when athletes are training to develop characteristics such as speed, agility, power, and aerobic endurance [11]. Conditioning should be planned to target development in the specific tennis characteristics of interest such as intensity of play, duration of play, and relevant implement and playing surface types [3, 14, 58]. In resistance training programs, exercise selection should develop biomechanical abilities reflective of those needed on the court (e.g., single leg exercises, shoulder exercises, wrist and forearm exercises) in addition to basic strength and power movements (e.g., squats, pulls, plyometrics) [11, 12, 26], which would serve as generic specificity activities (e.g. for lower body force and power production and eccentric loading tolerance).

Periodized Resistance Training

Kraemer and co-investigators demonstrated the profound ability of periodized resistance training to improve physiological abilities important in tennis [76]. The resistance training programs used in the study demonstrated the importance of using training strategies that address the needs of the individual athlete in addition to supporting the potential of non-linear periodization to meet the year-round needs of tennis players [39].

While resistance training improves strength, speed, power, and ball velocity in each stroke [39], aerobic performance may decrease if left unaddressed. One might question how much aerobic development is needed if it negatively impacts power and speed, which are much more important aspects of modern tennis play [77]. Tennis is a sport that underscores the difficulty in balancing development of antagonistic physiological systems. Non-linear periodized resistance training permits variability of work (addressing wide spectrums of physiological demand), while improving the ability to tolerate stress with minimized psychological fatigue [39]. Of equal importance, non-linear periodization emphasizes recovery by altering stress levels regularly; helping participants get the most from training that is balanced in what it develops. The flexibility and balanced stress enabled by non-linear periodization supports its implementation when physical activities require different and sometimes antagonistic physiological capabilities.

Specificity

Resistance training in tennis should focus on developing maximal force, mechanical power, and stretch-shorten cycle ability [78]. Local muscular endurance and injury prevention are included as components of generic specificity training for the development of physiological systems important to recovery and fatigue. Training often encompasses competitive play components that use over-exaggerated exertion levels for shorter durations of time than typically experienced in competition [3]. Over-exaggerated exertion may serve useful purposes (such as psychological and “worst-case scenario” preparation), but must be carefully prescribed to avoid injuries and loss of specificity. For the highest level of specificity, play surface, environmental conditions, and implement types should correspond to the conditions of competition.

Players and coaches should tailor near-competition training to mimic implement type, playing surface, and opponent style of play so that physiological characteristics or developed in to accommodate demands similar to those experienced in competition. Using fatigue effects, heart rate, blood lactate, and rating of perceived exertion (on a Borg scale) from past competitions to design preparation strategies has been suggested [3, 14].

There is reason to suspect a prevalence of common training strategies that do not reflect the physical exertion characteristics of tennis; which is suggestive of adaptations that transfer poorly to competitions [3]. If athletes seek to transfer development from conditioning and preparatory activities to competitive scenarios, training strategies must incorporate acute program variables specific to those experienced in activity while simulating the play characteristics expected in upcoming competitions. However, the use of “tennis-specific training” alone will not replace the basic exercises that provide the foundation needed for development of all more specific tennis skills [39]. Continuous running is an example of a common training strategy that provides exceptionally low transferability to tennis while creating potentially counterproductive effects in important tissues and physiological systems [77]. Morante demonstrated the lack of physiological similarity between sub-maximal continuous running and competitive tennis in terms of internal body temperature and heart rate [44, 45] (see figure 8 for illustration). No tennis player experiences physiological demands similar to those experienced by distance runners. Therefore, using long, sub-maximal runs for tennis training is likely to create stress that does not strongly benefit play, but may interfere with the development of capabilities highly specific to tennis (e.g. speed, power, force production).

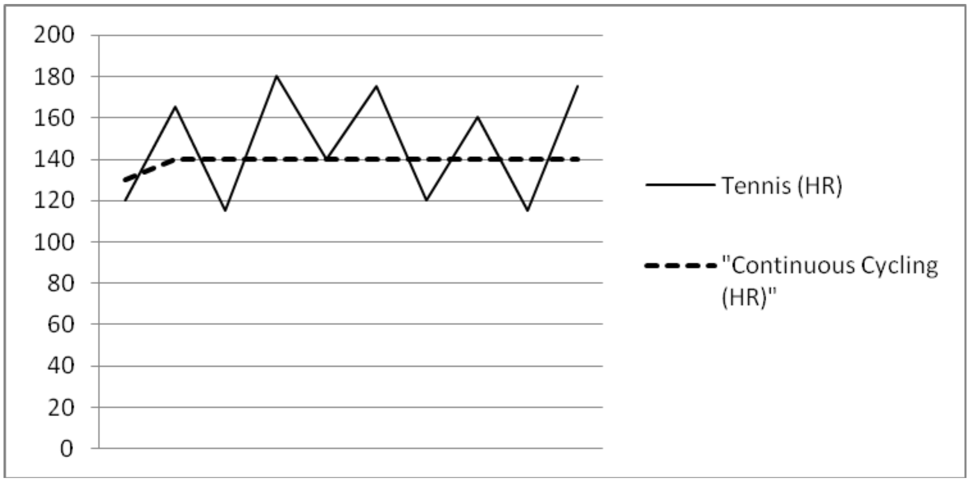

Figure 8. Heart rate and tennis vs. continuous cycling. Heart rates (HR) associated with tennis play (T) and continuous sub-maximal running (CR) are compared over the same arbitrary time points (TP). Adapted from data provided by [44]

Concurrent Training

Concurrent training is a method of exercise programming that seeks to develop different physiological systems during the same period of time. Tennis demands anaerobic and aerobic ability, which necessitates the simultaneous incorporation of training strategies designed to develop both systems. Unfortunately, the stress of aerobic training interferes with anaerobic adaptation at cellular signaling levels [77]. Many tennis players train with little or no emphasis on power development or in a manner secondary to aerobic development. Such practices are illogical, as indicated by the physiological demands of tennis [12]. Additionally, even if tennis were a predominantly aerobic activity, anaerobic training is far less effective when employed secondary to aerobic development, while aerobic systems do not seem to suffer interference from anaerobic development processes. Contrary to popular belief, varying resistance exercise programs have been shown to enhance performance in highly aerobic activities such as marathon running [79].

Sporer and Wenger studied the effects of aerobic training on anaerobic performance and made three primary conclusions: 1. Anaerobic and aerobic training should be separated by at least 8 hours, 2. Aerobic interference with anaerobic performance is localized to involved tissues, so athletes should separate the target muscles of aerobic and anaerobic training when concurrent training is necessary, and 3. All high intensity (whether continuous sub-maximal or high intensity interval) aerobic training types interfere with anaerobic development [80].

Individualization

Resistance training and other conditioning strategies should target the specific physiological needs of the player of interest. Women typically have a smaller bone structure and lower levels of muscle mass in the upper body compared to men of similar skill level. As such, women should prioritize upper-body force and power development in addition to emphasizing the lower body power and force essential to tennis. Older players struggle with the losses in power production, and if fatigue in the corresponding physiological systems is to be avoided, development of power production abilities must be prioritized.

Some players should place emphasis on developing force production abilities, while others need to better develop recovery abilities during rest periods between exertion bouts. Other players will benefit most from improved coordinative skills and finely-tuned tennis skills (like improved serving velocity and accuracy). Player-specific development strategies are the best way to address players with different characteristics. When such measures are taken, players develop the physiological systems that are most likely to suffer from fatigue and thus cause less than desirable competitive outcomes.

Intervention Strategies

Few studies have examined intervention strategies related to improving recovery in tennis [19, 47]. Therefore, recovery strategies commonly use "shot-gun" approaches in hopes of generating "something" that may help. For muscle soreness and protection against damage, the best approach appears to be different ranges of tennis-relevant motion with progressive exposure to heavy resistance exercise, especially carefully loaded maximal eccentric loads to protect the associated musculature from damage and increase connective tissue strength [28, 47]. With protection from non-functional overreaching or overtraining, one to two days of complete rest appear effective in eliminating residual fatigue from loading stress. Proper periodization of conditioning programs is important to creating varying stressors throughout exercise progressions [23, 39].

Nutritional intake to provide adequate calories appears to be an important aspect of successful recovery from the demands of competitions and conditioning activities [41, 42]. As little as 10 grams of essential amino acids before and after conditioning sessions or competitions may help jump to start protein synthesis and repair. Antioxidants may impact inflammatory-promoting free radical responses yet their roles remain a topic of great interest. Hydration appears to be paramount to limit performance decrements, and as such, sweat rates should be calculated, body mass monitored, and hydration protocols established for each competition or conditioning session [40, 43, 70]. Adequate sleep appears to be important in order to optimize a host of different repair and remodeling signals in tissue, but the sleep needs of athletes remains unclear [81].

Summary

Tennis players are likely to experience fatigue as widely ranging in nature as tennis itself. The demands of activity are dictated by the physiological systems involved, the characteristics of the match, and the physical characteristics of the players themselves. The characteristics of muscle activation, psychological demands of play, and environmental demands of play are the key determinants of the physical stress likely to result from competitive bouts. Incorporating fatigue and recovery enhancing strategies while developing skills specific to tennis minimize the performance decrement of fatigue and maximize the rate of recovery. Most successful strategies require little more than optimal hydration and nutritional practices, and periodized training that can address the specific needs of the individual while creating minimal interference with the development of other important physical skills. Optimized hydration and nutrition are paramount factors of recovery and can minimize perceptions the fatigue and the stress of activity. Training is used to enhance skill level, ensure optimal recovery from competition, and minimize the performance decrement and discomfort caused by fatigue. Of key importance, is the consideration that physical readiness means little if players are not ready to play because of psychological fatigue.

Prevention is the name of the game

- Optimizing conditioning, nutrition, hydration, and acclimatization to competitive demands will prevent fatigue to the furthest extent possible
- Don't wait until glycogen depletion or extreme hypo-hydration occur to address the issues – It is too late by then
- Expose players to forceful eccentric, SSC, and power-oriented resistance exercise to build resistance against DOMS and enable sustained play with smaller decrements in physical performance
- Look for and aggressively address signs of non-functional overtraining. Even when fatigue is psychological, don't underestimate the importance of rest and recovery

Work on recovery before recovery is needed

- Managing stress of competition and preparation – periodization is key to avoiding non-functional overtraining while promoting balanced development
- BCAA's, whey protein, water, carbs all consumed regularly but especially before, during and after physical exertion
- Don't be afraid of using compression over a good night of sleep after conditioning or play

A well-rounded conception of "fatigue"

- Use objective performance tests and perceptual tests to determine the presence and type of residual fatigue
- Listen to the body – If players feel weak, slow, imprecise, poorly coordinated – they are fatigued
- Characteristics of match-play and players will strongly affect the nature of fatigue, so don't treat every player of match as if they were the same

A well-rounded conception of "recovery"

- Motor unit recruitment determines the demands of play. When fatigue is present, train using activation patterns that develop relevant tissues while avoiding activation and mediating recovery of fatigued tissues
- Give time to regain normal performance measures. Use objectively measured performance to objectively prescribe rest and recovery
- Attack recovery like the demands of the game attack players – establish nutritional, hydration, psychological, and physiological recovery plans

Summary Table: Highlighting practical approaches to minimizing fatigue and optimizing recovery

Practical Applications

A better understanding of the various physiological mechanisms of fatigue allows players and coaches to identify and address such factors when they occur. Varying match characteristics change the nature of the fatigue experienced, as do the psychological and physiological training status of the player involved. Fatigue is best addressed by considering where fatigue is likely to be present, the possible sources of fatigue, the characteristics of physical exertion and participants that modulate the nature of fatigue. Fatigue may be minimized with development of recovery capabilities. Optimization of recovery occurs with proper hydration, nutrition, rest, environmental acclimatization, and conditioning programs that develop the physical attributed needed to effectively compete. To expedite recovery, conditioning should target stretch-shortening cycle, forceful eccentric, and power oriented contractions. Furthermore, psychological fatigue can be identified using simple perceptual surveys and the seriousness of such fatigue relative to its potential effect on performance should not be underestimated.

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Musculoskeletal Aspects of Recovery for Tennis

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Introduction

"Recovery" implies the return to optimal musculoskeletal function from a suboptimal condition. This suboptimal condition may be due to overload from play, lack of conditioning, and/or injury. Strategies for recovery should be based on knowledge of the musculoskeletal factors required for optimal function, how these factors may be altered in the tennis athlete, and how to construct a tennis specific program for recovery.

Musculoskeletal Factors Required for Function

Tennis involves high body segment velocities, motions, and loads[1]. Data from adult players shows that the elite player must generate 4,000 watts of energy (1.2 hp) in each serve[2]. The entire body is involved in generating the energy[2]. Through a kinetic chain of sequential activation of body segments from the ground to the hand, mathematical analysis of the contributions of different segments of the body to the energy and force has shown that 51% of the energy and 54% of the force is generated by the legs and trunk muscles. Only 14% of the energy and 20% of the force is produced by the shoulder muscles[3]. 70% of the force to generate elbow motion and wrist flexion is generated from the trunk[4].

To generate these forces, the different segments must rotate and go through large ranges of motion. Trunk rotation velocity is approximately 350º/s, shoulder rotation velocity approaches 1,700º/s, and elbow extension velocity approaches 1,100º/s[2]. These velocities are developed rapidly over 0.4-0.6 seconds, creating large accelerations in the shoulder. The total arc of shoulder internal – external rotation range of motion averages 146º. These velocities and accelerations can produce, in professional players, ball velocities of 95-110 miles per hour in females and 120-135 miles per hour in males. There is no comparable data for loads in younger athletes, but the forces are quite high as shown by serve velocities approaching 85 miles per hour in females and 105 miles per hour in males.

These loads are frequently applied and with high-energy demands. The elite young tennis player has been found to average 2.3 hours of practice or play per day, 6.1 days per week[5]. During tournaments, the player may play 1-3 matches per day. The average 2 set match requires approximately 100 serves. The average point requires 5.7 direction changes, and the total distance run may be 2-3 miles, in short bursts of 3-30 feet. This is why energy expenditure evaluations reveal that the metabolic demands in tennis are 70% alactic anaerobic, 20% lactic anaerobic, and 10% aerobic[2].

Multiple intrinsic and extrinsic factors can affect the musculoskeletal recovery of a tennis athlete. Extrinsic factors include intensity of the match, duration of the match, time between matches, and environmental temperature. Although extrinsic factors are difficult to control, they must be taken into consideration when either preparing to play a match or recovering from playing a match (Table 1). The intrinsic factors are the major factors to address in recovery. These include joint and muscle flexibility, local muscle strength, power, endurance, and balance, and kinetic chain activation. For optimum recovery, these factors must be addressed before, during, and between matches. Fluids, hydration, and fuels for muscle activity are also important, but will be only summarized, as they are treated in more detail in other chapters.

Table I. Extrinsic Factors Affecting Performance and Recovery

Tennis	Recommendations*
Match Intensity	
Different Surfaces	
Match Duration	
Number of Matches	
Per tournament	
Per season*	Age 11 – Max of 40 matches per year
	Age 14 – Max of 70 matches per year
	Age 16 – Max of 90 matches per year
Rest between matches	One hour of rest per hour in competition
Environmental and Heat Stress	See USTA Guidelines

*As recommended by the United States Tennis Association (USTA)

Flexibility and Joint Motion

The first intrinsic factor is muscle flexibility and joint range of motion. Joints must move through large ranges of motion when the tennis player is running, turning, or hitting, and the muscles must be of sufficient flexibility to stretch and shorten to accommodate to the motions required. Alterations are commonly seen in tennis players and are associated with increased injury risk and decreased ball velocity[3, 6-9] (Table II). De-conditioned muscles develop adaptive stiffness due to lack of repetitive use. Injured muscles or joints develop inflexibility due to lack of use, immobilization of the muscle or joint, or direct and repair by scar tissue.

Table II. Muscle Flexibility and Joint Range of Motion Alterations

Factor	Alteration
Lack of Conditioning	**Adaptive Stiffness**
Injury	**Lack of Use** **Immobilization** **Direct Injury**
Overload from Play	**Injury** **Thixotropy**

The most common type of muscle inflexibility or joint stiffness is due to overload secondary to continued play. It is well documented that tennis players develop loss of rotation in the hips[9], trunk[10], and shoulder[11-14]. These alterations may develop after acute[15] and chronic[14, 16] exposure to tennis activities and can be modified by directed stretching programs[13, 17]. The acute changes and relatively quick response to stretching suggest that a large component of the alteration is due to changes in muscle stiffness.

The high demands of tennis cause the muscle fibers to sustain micro-damage as a result of the continuous repetitive actions of running, serving, and hitting. The muscle fiber damage leads to a sensation of stiffness in the involved muscle group(s). One explanation of the changes in muscle flexibility may be an internal adaptation to repetitive tensile load known as thixotropy. Thixotropy is a biomechanical property of muscle and represents internal stiffness of the tissue. It is largely determined by the preceding history of movements and contractions[18]. Thixotropy is defined as the passive stiffness that occurs after a chronic exposure of muscle to tension[18-20]. When a muscle is contracted to a particular length, once the muscle has relaxed, stable cross-bridges form in the fibers at that length to give them their short-range elastic component (SREC)[20]. If the muscle is then shortened, the compressive forces on the sarcomeres, stiffened by the presence of the SREC, may lead to detachment of the some of the bridges[20]. This detachment or damage has been found to be a compounding issue that once it develops, will remain in the muscular region for an extended period of time creating muscle stiffness which will decrease the maximum strength generated. Preliminary baseball data from our lab shows that the acute changes in motion following a single game throwing exposure may measure as much as 11 degrees, and that these changes may take as long as 2-3 days to return to close to baseline. Therefore, both acute and chronic changes in muscle due to eccentric load can affect the amount of flexibility in both upper and lower extremity muscle groups.

Local and Kinetic Chain Muscle Function

The second intrinsic factor is muscle function. Optimum muscle function is required to generate the forces required in tennis and to protect against the loads applied to the body as a result of tennis play. Strength is the ability to generate a force or protect against a load, power is the ability to do that quickly, and endurance is the ability to do that over extended times. Muscle balance allows maximum joint protection and smooth motion of joints. Muscles may develop alterations due to lack of conditioning, wrong emphasis in training, fatigue, injury, or thixotropy (Table III). The areas that are often weak as a result of play or are overlooked during training are the peri-scapular musculature (lower trapezius, serratus anterior, and rhomboids)[21], hip abductors (gluteus minimus and medius)[22], and the local muscles of the core (multifidus, quadratus lumborum, and transverse abdominis)[23].

Table III. Muscle Function Alterations

Factor	**Alteration**
Lack of Conditioning	Weakness Lack of endurance
Wrong Emphasis in Training	Front muscles over back muscles “Football Type” conditioning Heavy in-season conditioning
Fatigue	Weakness Lack of tennis specific training
Injury	Direct injury
Thixotropy	A shortened muscle is a weak muscle

The scapular muscles are responsible for stabilizing the scapula as the arm goes through the hitting zone. Weakness of these muscles results in alteration of static position or dynamic motion known as scapular dyskinesis. The scapular dyskinesis is loss of dynamic control of scapular retraction, depression, and external rotation. Scapular retraction is regarded as a key element in closed chain coupled scapulohumeral rhythm[6, 24, 25]. The biomechanical result is a tendency towards scapular internal rotation and protraction around the rib cage. Excessive scapular protraction alters the scapular roles in shoulder function[7]. The normal timing and magnitude of acromial motion is changed, the subacromial space distance (acromio-humeral interval) is altered, glenohumeral arm angle may be increased, and maximal muscle activation may be decreased.

Alteration of the amount of knee flexion used during the serve has been associated with increased stresses in the arm. Tennis players who did not have adequate bend in the knees, breaking the kinetic chain and decreasing the contribution by the hip and trunk, had 23-27% increased loads in horizontal adduction and rotation at the shoulder and valgus load at the elbow[26]. A mathematical analysis of the tennis serve showed that a decrease in 20% of the kinetic energy developed by the trunk resulted in a requirement of 34% more arm velocity or 80% more shoulder mass to deliver the same energy to the ball[3].

Weakness or tightness at the hip can also affect the arm. Decreased hip flexibility in rotation or strength in abduction (positive Trendelenburg) was seen in 49% of athletes with arthroscopically-proven posterior-superior labral tears[27].

Core stability requires control of trunk motion in all 3 planes of motion. Synergistic activation patterns exist involving the transverse abdominus, abdominals, multifidi, and pelvic floor muscles that provide a base of support for all the trunk and spinal muscles[8]. Fatigue of these muscles can result in the proximal portion of the kinetic chain to be unstable resulting in altered muscle activation and increased stress being placed on the distal extremities. There is also difficulty in directly assessing these muscles, so they are also often neglected or ignored with respect to musculoskeletal training or rehabilitation[23].

Each of these local areas can be sources of alterations. They may have local effects, but because of the required kinetic chain activation and sequencing, they may have distant effects to performance and injury risk as well. In addition to recovery of local function, care must be taken to ensure all the segments are working in a coordinated sequenced activation.

Fluids/Hydration

The third intrinsic factor is fluid intake and hydration levels of athletes. Most tennis athletes take the court, whether it is the first match or subsequent match of a tournament, in a dehydrated state. It has been shown that prior to thirst being recognized by an athlete, 1.5L of water could have already been lost[28]. During an entire match, a player can lose fluid at a rate greater than 2.5L/hour[29]. Although these players consume fluids between sets, the maximum uptake of fluid is only 1.2L/hour[30, 31]. This creates a deficit in hydration status which can impede performance. It is known that a decrease of between 1.5-3% of body weight due to fluid loss results in decreased ability to generate maximum muscle strength, and decreases muscle endurance.

Fuels

The final factor is fuels – the quantity and quality of food being consumed. The foundation of an athlete's diet during play is carbohydrates such as glucose and fructose. The metabolic demands of tennis require large amounts of readily available carbohydrates in the muscles to be used as immediate sources of fuel. Depletion of glycogen stores and the resulting decrease in adenosine triphosphate (ATP) during competition places the athlete in a position where performance can be affected. The goal for tennis athletes should be to maximize glycogen stores by eating meals rich in carbohydrate prior to competing while appropriately replenishing what is expended during vigorous activity through pre and post exercise consumption of carbohydrate.

Strategies for Improved Recovery for Musculoskeletal Function

Musculoskeletal recovery must be a planned activity. Maximum flexibility, local and kinetic chain muscle function, fluids, and fuel should be in place before the match, and replacement and recovery should be done between matches. Quick on-site evaluation of key musculoskeletal parameters can direct the interventions.

Flexibility

Areas of particular risk include hip range of motion in rotation, lumbar flexion/extension, and shoulder rotation. All of these can be frequently assessed through easily implemented tests that are well described in the USTA High Performance Profile (HPP) (Table IV). They should be checked at least 3 times per year during active play and may be safely done between matches. Changes in hip or shoulder rotation of more than 5 degrees, or changes in sit and reach of more than 2 cm, suggest the need to improve flexibility before the next tennis match.

Table IV. Evaluation Tests

Test	**Parameter***
Hip Rotation	Seated & Prone Goniometric Measurement
Trunk Motion	Sit and Reach
Shoulder Rotation	Supine Goniometric Measurement, Scapula Stabilized
Hip/Trunk Strength	Single Leg Stability Series
Peri-Scapular Strength	Observation for Scapular Dyskinesis
Kinetic Chain Strength	Observable Change in Ball Strike Mechanics Change in Performance Parameters

*From USTA High Performance Profile (HPP)

Flexibility of both the upper and lower extremity can be increased via standard static and/or ballistic stretching. The hamstring, hip flexor, and hip rotator muscle groups should be targeted for the lower extremity while the pectoralis minor and posterior shoulder muscles should be the point of focus in the upper extremity. The “sleeper” stretch, and cross arm stretch[32] or towel stretch can be utilized to increase shoulder rotation flexibility whereas the “open book”[33] or corner stretch[34] can help elongate a shortened pectoralis minor.

Figure 1. Sleeper stretch for stretching of the posterior capsule and posterior rotator cuff.

Figure 2. Cross arm stretch for the posterior capsule of the shoulder and posterior rotator cuff.

Most literature that has examined the effects of stretching on the body and/or performance prior to activity has found mixed results[35, 36]. Following activity however, it has been shown that the response of muscle following exposure to eccentric load is to become stiff[19]. Following exposure to these loads, stretching has been shown to reduce the stiffness and increase range of motion of the affected joint(s)[37], therefore stretching following activity should be considered.

A post exercise cool down may be beneficial in reducing the sensations of stiffness and soreness which are often associated with lactic acid build up and thixotropy. It has been shown that a “cool down” or recovery activity can return lactic acid values to pre-exercise levels[38] and change the feeling of muscle stiffness. Studies have also shown light exercise and ice are more beneficial than ice alone in reducing lactic acid as well as increasing range of motion[39]. Ice should not be used unless inflammation or injury is present. It has been demonstrated that the application of ice on the dominant arm of overhead athletes decreases shoulder muscle strength, proprioception, and accuracy of throwing[40, 41]. Therefore, the application of ice in between same day matches is not recommended unless inflammation or injury is present.

Local and Kinetic Chain Muscle Function

Hip and trunk, peri-scapular, and shoulder muscles are most commonly altered in tennis players. On-site evaluation of hip/trunk strength, peri-scapular strength, and rotator cuff strength may be accomplished by HPP tests (Table IV). Kinetic chain strength may be evaluated by observed changes in ball striking mechanics (pulling through, opening up) or in performance (ball velocity).

Most of the preparation for recovery of muscle function should be done before the matches. Proper training should be periodized and specific for the demands of tennis[43].

Peri-scapular muscles such as the serratus anterior and lower trapezius should be a point of focus. Early training should incorporate the trunk and hip in order to facilitate the kinetic chain proximal to distal sequence of muscle activation. Little stress is placed on the shoulder during the movements of hip and trunk extension combined with scapular retraction. Specific exercises known as the low row and inferior glide have been shown to activate the serratus and lower trapezius at safe levels of muscle activation[44].

The scapula serves as the base or platform for the rotator cuff. A properly stabilized scapula allows for optimal rotator cuff activation. A recent study found that rotator cuff strength increased as much as 24% when the scapula was stabilized and retracted[45]. For this reason, recovery should focus on scapular strengthening rather than placing an early emphasis on rotator cuff strengthening. Once the scapula is properly stabilized, more advanced exercises can be incorporated to strengthen the larger global muscles around the shoulder as well as the rotator cuff.

In order to create a proximal stable base, training protocols should start with the primary stabilizing musculature of the core i.e. the transverse abdominus, multifidus, and the quadratus lumborum[23]. Due to their direct attachment to the spine and pelvis, they are responsible for the most central portion of the core stability. Exercises include the horizontal side support and isometric trunk rotation[23, 46]. These exercises can be performed by athletes at all levels. This stage of rehabilitation is not only to restore core function by itself, but also is the first stage of extremity rehabilitation.

Between match recovery for muscle function should emphasize low-load, low repetition (3-5x) “toning” exercises using tubing or light weights, preceded and followed by light stretching.

Fluids/Hydration

Pre-hydration and post-hydration are important components in maximizing performance and recovery. Estimating urine specific gravity by the use of dip sticks is an easy way to know hydration status. The recommended pre-hydration guidelines are to consume 17-20oz of fluid (ideally water or carbohydrate solution) approximately 2-3 hours prior to activity in order to allow the fluid to process through the digestive system and be absorbed by the tissues of the body[47]. Fluid will be needed for warm-up and pre-match activities so 7-10oz should be ingested 10-20 minutes prior to activity. In order to help combat fluid loss during tennis play, players should drink 7-10oz of fluid every 10-20 minutes during activity. Before and after match body weighing can estimate the amount of fluid loss and identify the need for replacement. Post-activity, a carbohydrate based fluid, such as a sports drink which also contains moderate levels of sodium, should be consumed within 1-hour following the cessation of activity. Sodium conserves fluid volume and increases the athlete's desire to drink[48]. The carbohydrate in the beverage replaces glycogen stores and improves the rate of sodium and water absorption in the intestinal tract[49].

Fuels

The day before competition, meals comprised primarily of carbohydrate should be consumed however, it is important to include a small amount of protein as well. The consumption of carbohydrate will help replenish any fuel stores which were depleted during practice and help "preload" the glycogen stores of the body for the next day, whereas the protein which will be broken down into amino acids, will aid in the repair of muscle tissue. On the day of competition, a meal rich in carbohydrate is recommended where 2 grams of carbohydrate per kilogram of body weight has been found to increase performance[50, 51]. This meal should be consumed no later than 2 hours prior to competition however this time recommendation can varying depending on the amount of carbohydrate being consumed. The 2 hour timeframe is suggested to allow the food to be properly digested and to limit the possibility of sustaining muscle injury or fatigue. Consumption of moderate to high amounts of fat and protein during pre-competition meals is not recommended because both are more difficult to digest in comparison to carbohydrate and athletes can experience gastric irritation (upset stomach) as a result of eating these types of macronutrients.

If glycogen stores are not replenished following a match or in between matches, performance can be negatively affected. Muscles are most receptive to glycogen storage within 30 minutes following activity[52]. Tennis athletes should focus on whole foods if possible however a beverage with high levels of carbohydrate is a suggested alternative for those players who are attempting to recover in between matches or who have a low appetite for solid food following activity. While carbohydrate consumption is critical following the final match of any day, post competition meals should include the 3 major macronutrients (carbohydrates, fats, and protein) in order to restore fuel stores, regulate tissue function, and rebuild muscle tissue. Nutrition strategies in training should be oriented towards more protein and less carbohydrate, to maximize muscle and tissue repair and restoration.

Special Topics for Recovery

Several topics are covered here with specific reference to the tennis player. These key topics contain information for the player and coach regarding muscle soreness, pain, and therapeutic modality use for recovery.

Muscle Soreness

Soreness may be a worrisome condition, with implications for continuing play and for determining when the recovery process has progressed enough to allow full return to training and playing.

In the event that muscle soreness occurs during tennis play, measures can be taken to alleviate the negative sensation. Static stretching can be utilized to combat the thixotropic effects of tensile load on muscles. If possible, muscles should be kept in lengthened positions during recovery periods in order to protect against developing stiffness. Light, dynamic exercise can be applied as well with emphasis being placed on regaining full ranges of motion whereas therapeutic massage can be an effective tool against lactic acid build up. If muscle flexibility and strength are normal, the player may continue play.

Pain

Low grade pain is a more worrisome condition as it usually indicates more injury to the tissues, and may mean that continued play will create or worsen the injury. Should the athlete complain of pain during play, it is important to assess whether the problem is localized or generalized, and is associated with other problems such as inflexibility or weakness. The utilization of a pain rating scale can help determine the severity of the injury as well as the participation capabilities of the athlete[53] (Table V). An athlete should not continue competing if swelling, range of motion limitations, or muscle weakness is present. The pain scale can also be used to assess the degree of recovery from any type of injury. Return to play may be allowed in pain levels 1 and 2.

Table V. Pain Rating Scale and Recommendations

Pain Rating	Complaint	Determination
1	Pain after match or next day	May play – athlete should warm-up well
2	Pain during match with normal stroke mechanics and no loss of performance	May play – place emphasis on stretching and watch mechanics
3	Pain during match with change in mechanics and performance loss	No Play

4	Pain during play with minimal playing ability	No Play

Therapeutic Modalities

The demands of tennis discussed in the early portion of this chapter clearly indicate the whole body or kinetic chain stresses that are imparted to the body during elite level tennis play. The stresses may lead to temporary or longer term impairment of human performance. This transitory impairment can last minutes or hours, or up to several days following matches or training. Recovery of glycogen stores, which is just one measure of human recovery typically occurs within 24 hours following exhaustive exercise and rehydration[54]. Longer lasting impairments in muscle function may be related to exercise induced muscle damage, DOMS, and thixotrophy[55]. Elite level athletes attempt to combat these stresses induced during competition and training with focused sessions of recovery. These sessions are designed to shift the stress-recovery balance towards recovery and away from stress[56]. These recovery sessions often include the use of therapeutic modalities. These modalities attempt to accelerate the body's recovery mechanisms, and allow for a more rapid and effective return to training and/or competition. Unfortunately, little high level evidence exists in the scientific literature regarding the effectiveness of the use of these recovery modalities and what studies do exist rarely use elite level athletes as subjects. This section will summarize some of the current evidence and discuss the use of therapeutic modalities for elite tennis players. The modalities discussed will include massage, active recovery, cryotherapy and ice water immersion, compression garments, and electric muscle stimulaton.

Massage

Massage is a particularly common recovery modality used by tennis players worldwide. It is popular as it is known to promote relaxation and is generally a pleasant or positive experience for the recovering athlete. Sports massage is typically defined as a collection of massage techniques for aiding recovery or treating pathology. Frequently used forms include effleurage, petrissage, and deep transverse friction massage. Effleurage techniques are performed along the length of the muscle, typically in a proximal to distal sequence[57]. Petrissage techniques include kneading, wringing, and scooping type strokes performed with deeper pressure to individual tolerance. Deep transverse friction massage is performed with the fingers moving transversely across the target tissue.

The effect of massage on recovery following competition and exercise training does not show any clear physiologic advantage when subjected to critical review and research paradigms (Table VI). Typical theories on why massage would be beneficial for recovery from exercise or competition for tennis players include positive effects on blood flow, clearance of blood lactate and other metabolites. Recent research however using Doppler ultrasound techniques have found that massage had no effect on arterial or venous blood flow [58-62]. Studies comparing the effects of a period of massage to a supine rest period following exercise or activity simulation, found that regardless of which condition was applied (massage vs. rest) no differences existed in subsequent performance or physiologic parameters such as blood lactate concentrations and fatigue[63,64]. One preliminary report[65] examined the effects of massage on creatine kinase levels. A thirty minute massage in this study did reduce the effects of DOMS and creatine kinase levels however the study had a very small subject population and no follow-up studies with larger populations have been performed to date regarding this parameter.

One final study may best help to understand the effects of massage given the paucity of literature on this subject supporting the use of massage from a physiologic standpoint. Several studies have tested the effect of massage on the mood, anxiety and relaxation levels of athletes [66,67]. These studies point to the positive psychological benefits from a period of massage and could highlight one aspect of therapeutic massage not measured in the physiological studies on massage effects. Given these positive psychological responses, and the importance of relaxation as one part of recovery, the use of massage may be indicated following heavy performance. Further research in this area is clearly needed before more exact recommendations can be made.

Table 6. Summary of Research Related to the Effects of Sports Massage on Recovery from Exercise and Competition.

Table 5. *Table Summarizing Research Related to the Effects of Sports Massage on Recovery from Exercise and Competition*

Study (Year)	Study Design	Level of Evidence	Participants	Professional(s) Conducting the Intervention	Techniques	Treatment Time	Results and Authors' Conclusions
Hemmings et al[20]	Within subjects experimental design with counterbalanced design	3	Eight amateur boxers (mean age 24.9 years, SD 3.8)	Sports massage therapist	Effleurage, petrissage	20-minute standardized protocol consisting of 8-minutes for the legs, 2-minutes for the back, and 10-minutes for the shoulders and arms	1) No significant difference. between groups for performance. 2) Massage program significantly increased perceptions of recovery 3) No statistical difference in blood lactate or glucose levels after either intervention. 4) Blood lactate concentration was significantly higher after the massage program.
Robertson et al[32]	Within subjects experimental design with counterbalanced design	3	Nine male games players, mean age not presented (range 20-22 years)	Physiotherapist	Effleurage, kneading, stroking, picking up, wringing, rolling	20-minute standardized protocol	1) Massage intervention did not affect blood lactate concentration or heart rate. 2) No difference in mean or maximum power after massage. 3) Subjects scored significantly lower on the fatigue index after massage.
Dolgener et al[33]	Randomized controlled trial: pre-test/post-test design	2	22 male recreational runners; passive recovery group (n=7, mean age 24.7±5.3), bicycle recovery (n=7, mean age 26.1±6.5), massage recovery (n=8, mean age 24.2±6.77)	Massage therapist	Effleurage, petrissage	20-minute standardized routine	Massage was no better than passive or active recovery methods in reducing blood lactate concentration.
Tiidus et al[36]	Quasi-experimental pre-test/post-test	3	Nine volunteers (4 male and 5 female), mean age not reported (age range 20 to 22 years)	Massage therapist	Effleurage	10-minute	1) Massage did not significantly increase either arterial or venous blood velocity above baseline resting levels. 2) Massage failed to improve isokinetic peak torque of the quadriceps versus the contralateral control leg.
Shoemaker et al[39]	Within subjects experimental design with counter-balanced design	3	10 healthy subjects (7 male, 3 female); mean age 35.8± 3.4 years)	Massage therapist	Effleurage, petrissage, tapotement	5-minute massage per location and technique	Massage did not increase muscle blood flow (pulsed Doppler echo Doppler) regardless of type of massage or the muscle group receiving the massage.
Hinds et al[40]	Within subjects experimental design with counter-balanced design	3	13 male volunteers, mean age 21±1.4 years	Physiotherapist	Effleurage and petrissage	Two 6-minute bouts separated by a 1-minute period	1. Massage did not significantly increase femoral artery blood flow, blood lactate, blood pressure, or heart rate as compared to a control condition. 2. Skin blood flow and skin temperature were significantly increased after massage as compared to controls.
Jonhagen et al[41]	Randomized controlled trial: pre-test/post-test group design	2	16 subjects (8 men and 8 women), mean age 28 years (range 20-38)	Sport physical therapist	Effleurage, petrissage	12-minute standardized protocol	1. No statistical difference between massage and control group for level or duration of pain. 2. No statistical difference for concentrations of CGRP and NPY between massage and control groups. 3. No statistical difference for maximal strength and functional measures between groups.
Lightfoot et al[42]	Randomized controlled trial	2	31 college-age subjects (12 men and 19 female)	Massage therapist	Petrissage	10-minute to the left calf	Massage intervention to the left calf demonstrated no difference for soreness levels or leg volumes as compared to the control group.
Weber et al[43]	Randomized controlled trial: pre-test/post-test design	2	40 untrained volunteer female subjects, group mean age 23.7 years, SD 4.0	Physical therapist	Effleurage, petrissage	8-minute standardized protocol	No statistical difference between massage, active recovery, microcurrent, and controls for soreness ratings and force generation.
Hart et al[44]	Within subjects experimental design with counter-balanced design	3	19 college aged volunteers (10 men, 9 women), mean age 20.6±1.2 years	Certified athletic trainer	Petrissage (kneading) and effleurage (broad stroking)	5-minute standardized "sports" massage	The sports massage protocol did not significantly reduce either leg girth or pain as compared to the control leg within 72 hours of exercise.
Monedero et al[45]	Within subjects experimental design with counterbalanced design	3	18 healthy trained male cyclists, mean age 25±0.9 years	Certified masseur	Effleurage, stroking, and taponement	Massage group: 15-minute massage Combined recovery group: 7.5 minutes of massage and 7.5 minutes of active recovery	1. Combined recovery significantly better at removing blood lactate at 12-mintues (as compared to all interventions). 2. Combined recovery was a superior approach to maintaining performance over passive recovery and active or massage interventions.
Dawson et al[46]	Quasi-experimental pre-test/post-test	3	12 runners (8 males, 4 females), mean age 35.2±8.3 years)	Massage therapists	Effleurage, petrissage	30-minute standardized protocol	The use of massage, when compared to the control leg, did not facilitate a faster return to baseline measures for strength, soreness, or leg circumference.
Hilbert et al[47]	Repeated measures pre-test/post-test RCT	2	18 volunteers (male and female), mean age 20.4±1.0 years	A senior physical therapy student	Classic Swedish techniques (effleurage, percussion, petrissage)	20 minute standardized protocol	1. The massage protocol did not impact any of the following variables: range of motion, peak torque, neutrophil count, mood, or unpleasantness of soreness. 2. The massage protocol led to a significant decrease in intensity of soreness (Differential Descriptor Scale) in the massage group as compared to the control group.
Smith et al[48]	Randomized controlled trial: pre-test/post-test design	2	14 untrained males; massage group (n=7, mean age 20.1±1.1) and control group (n=7, mean age 18.8±0.3)	Physical therapist	Effleurage (stroking), shaking, petrissage (kneading), wringing, cross-fiber massage	30-minute standardized "sports" massage performed 2 hours after exercise	A significant trend analysis for treatment by time interaction effect with 1) the massage group reporting lower levels of muscle soreness; 2) reduced CK levels in the massage group; 3) massage group demonstrating elevated neutrophil levels.

Table VI. From Brummitt J, NAJSPT 3(1):2008

Active Recovery

As was mentioned earlier in this chapter, a cool down or active recovery has been recommended for athletes following heavy periods of exercise. The theory is that the active movements when sub-maximal in nature would assist with the rate of post-exercise lactate removal. A recent study by Gill et al[68] examined post-match recovery in rugby players measuring creatine kinase. While the post-exercise recovery reduction in creatine kinase was better than athletes who did a passive recovery, the active recovery reductions were not superior and indeed were not significantly different than those occurring with the use of compression garments or contrast temperature water immersion. The authors did point out that the effects may be sport specific to the amount of contact injury occurring in rugby players making the generalizability to tennis players limited. In general, current recommendations for performing an active cool down, and submaximal exercise to promote recovery are supported, however the evidence is not universally superior to other modes of recovery in experimental studies.

Cryotherapy

The use of ice following an acute injury is well supported in the literature and a commonly used practice during rehabilitative exercise and physical therapy. The analgesic effects and initial vasoconstrictive action following ice application are well documented and protocols for the application of ice to an injured or recovering athlete following exercise and return to competition are common [69]. The use of cryotherapy for recovery however, is not well supported in the literature. Cheung et al, [55] in a review of treatment for DOMS concluded that current research does not support the efficacy of cryotherapy, apart from its analgesic effect used in the treatment of injury. One study [70] investigating recovery following a simulated game in baseball pitching found a combination of cryotherapy application to the shoulder and light recovery exercise to enhance 24 hour shoulder strength recovery. The present use of ice following baseball pitching in elite level baseball players may be indicated and might have application to tennis where repeated bouts of serving on consecutive days may necessitate recovery strategies for the shoulder to allow players to optimize recovery. Further research however is needed before a more definitive recommendation in this area can be made.

Water Immersion

The use of contrasting hot water immersion and ice water immersion has been advocated for recovery in athletes. Cold plunges and other types of whole body immersion pools are available in many spas and health clubs with the theory that the alternation of hot and cold water immersion would affect blood flow and enhance recovery. Coffey et al [71] measured performance following a 4 hour recovery period where both active and passive recovery and contrast water immersion were administered for a 15 minute period following exercise. The researchers found no difference or benefit from the cold water immersion in performance measures.

Given the lack of research in this area, these modalities cannot be recommended other than for the possible relaxation water immersion might provide to the athlete following intense physical exercise or competition.

Compression Garments

Compression garments have been recommended to aid in post-exercise recovery. Several types are worn including graduated compression stockings typically used medically to prevent deep vein thrombosis, compression sleeves to prevent swelling in the limbs or extremities, and elastic tights and exercise clothing worn after training. Support for these compression garments is currently lacking. One study by Chatard et al,[72] used graduated compression garments during an 80 minute recovery with elevated legs decreased blood lactate concentrations in older trained cyclists and led to a great post-exercise recovery compared to control subjects. Berry et al, [73] studied the effects of elastic tights on post-exercise blood lactate concentrations finding no difference in any variable from the compression garment.

Electrical Muscle Stimulation

Electrical muscle stimulation is used extensively by physical therapists and athletic trainers during the rehabilitation following injury. The electrical muscle stimulation can be used for many reasons and to address multiple goals such as the reduction of swelling, reduction of pain and for neural re-education of injured muscle. Electrical muscle stimulation or (EMS) has been advocated for recovery following vigorous exercise to promote additional muscular contractions which may aid recovery by increasing local blood flow via local vasodilatation as well as via the muscle pump effect from the induced contraction [56]. Unfortunately, several studies in uninjured athletes show no significant benefits with the use of EMS in downhill runners [74] or in the knee extensors when compared to active or passive recovery[75]. Despite these equivocal findings, the use of EMS for recovery following training or competition continues to be recommended over joints or injured tissues due to the anti-inflammatory effect. The use of ice coupled with EMS is used in rehabilitation and is often continued as the player makes the difficult transition to the return to play program and eventually the initial stages of competition. Further research is needed before more direct recommendations can be given. Numerous EMS units are available and used by tennis players for recovery, however, direct evidence is presently lacking when the desired outcome is solely recovery following exercise training or competition.

Summary

Recovery of optimal musculoskeletal function for tennis play is a complex issue. Many factors involving muscles, tendons, joints, strength, endurance, blood flow, fuels, fluids, and rest enter into consideration. While much more information needs to be uncovered, it does appear that strategies that try to maximize recovery only after a match or between closely scheduled matches are less effective than strategies that seek to maximize recovery by creating optimal musculoskeletal function before the match or tournament. Careful attention to kinetic chain aspects of flexibility, strength, and balance, tennis specific periodized conditioning programs, and adequate fuels and fluids will enable the athlete to play with more reserve, and will improve the results of post-match or inter-match recovery programs.

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Heat and Hydration Recovery in Tennis

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Introduction

Tournament tennis play often requires athletes to compete in multiple matches per day over many consecutive days, sometimes for as long as two weeks. Many tournaments are played in hot and sometimes humid conditions which increases thermal stress and can lead to heat and hydration concerns for tennis players - both from a performance standpoint and a health and safety perspective.

The negative effects of hypohydration (less than optimal hydration) and exercise induced hyperthermia (increased body temperature) on exercise performance are well known[1-4]; however, the factors that influence recovery and restoration of the tennis athlete's fluid and electrolyte balance after training and competition have received far less interest in scientific research and within the coaching communities. The difficulty with recovery hydration research and subsequent guidelines is the need to account for multiple variables including: muscle and liver glycogen changes, individual sweating rates and electrolyte losses, movement efficiency, environment, individual anthropometric characteristics, and level of physical training. In competitive tennis, whether at the junior, collegiate, adult, senior or professional level, it is commonly understood that the restoration of carbohydrate stores, along with fluid and electrolyte levels after practice or competition are vital to performance, health and safety. However, specific guidelines or recommendations have not yet been well established – especially for the tennis athlete.

The difficulty in providing specific guidelines for tennis athletes during recovery is that the replacement of sweat losses will obviously depend on the extent of the losses incurred during exercise and the time and nature of future exercise bouts[5]. As tennis has no standard length for matches, and match times can range from 30 minutes to four hours, providing general recommendations is more challenging than for sports that have set match times. This said, recovery hydration and electrolyte replacement immediately post-activity is vital to performance of the athlete in subsequent matches. This is especially important for athletes with multiple matches or practice sessions in one day. If the fluid deficit is ignored, performance during subsequent exercise might be negatively affected [6]. It is also important to consider that fluid replacement after exercise should also be considered hydration for the next exercise bout.

Heat Issues and Recovery in Tennis

Due to the intermittent nature and varied physical demands of tennis practice and competition, the maintenance of core body temperature within an optimal range is challenging – especially in hot and humid conditions. The large majority of points in tennis last less than 10 seconds with rest periods lasting no more than 25 seconds [7-24]. Such a work/rest ratio can cause large changes in body temperature, but allows ample time for fluid replacement and opportunities to help reduce the gradual rise in body temperature. During tennis play an athlete's metabolic rate increases substantially compared to resting values [25], which then takes time to return to normal levels after tennis play.

Very limited data are available on core temperature in tennis due to the difficulty of monitoring in a “live” tournament situation. Furthermore, traditional lab based experiments that have tried to simulate tennis may provide misleading data. In a tournament study of 14 and under national level boys, average core temperature earlier in the day before a singles match was 37.67 (0.38)°C and their average core temperature rose to 38.07 (0.38)°C before the second match of the day (doubles)[26]. This increase in pre-match core temperature may be partially explained by the increase in wet bulb globe temperature (WBGT) from 29.1 (0.5)°C before the singles matches to 31.3 (0.5)°C before the doubles matches. During matchplay, core temperature expectedly rose for all athletes and wide variability between athletes was found[26].

Acclimatization

When playing in hot and humid environments, it is important that the athlete becomes acclimatized to perform at optimum levels. The acclimatized athlete will begin to sweat earlier, will have a higher sweat rate for a given core temperature and can maintain a higher sweat rate for a longer time period [27-29]. An acclimatized player also loses fewer electrolytes in sweat than a player who is not acclimated [29, 30]. A common myth or misconception among many athletes is that when they become adjusted or acclimated to the heat, the need to replace fluids decreases. Heat acclimatization actually increases the requirement for fluid replacement because of the earlier onset of sweating [31]. Figure 1 demonstrates the typical time-frame that it takes for an athlete to appropriately acclimate to a hot and humid environment. In an ideal situation, athletes would prepare appropriately before competing in hot and humid environments by taking the necessary steps to acclimate effectively. The difficulty with most tennis competitions is that individuals do not have the luxury of acclimating fully to the new environment. Most players arrive one or two days before the tournament, which does not allow for sufficient acclimation in previously non-acclimatized individualized.

Range of Days Required For Different Adaptations to Occur During Heat Acclimatization

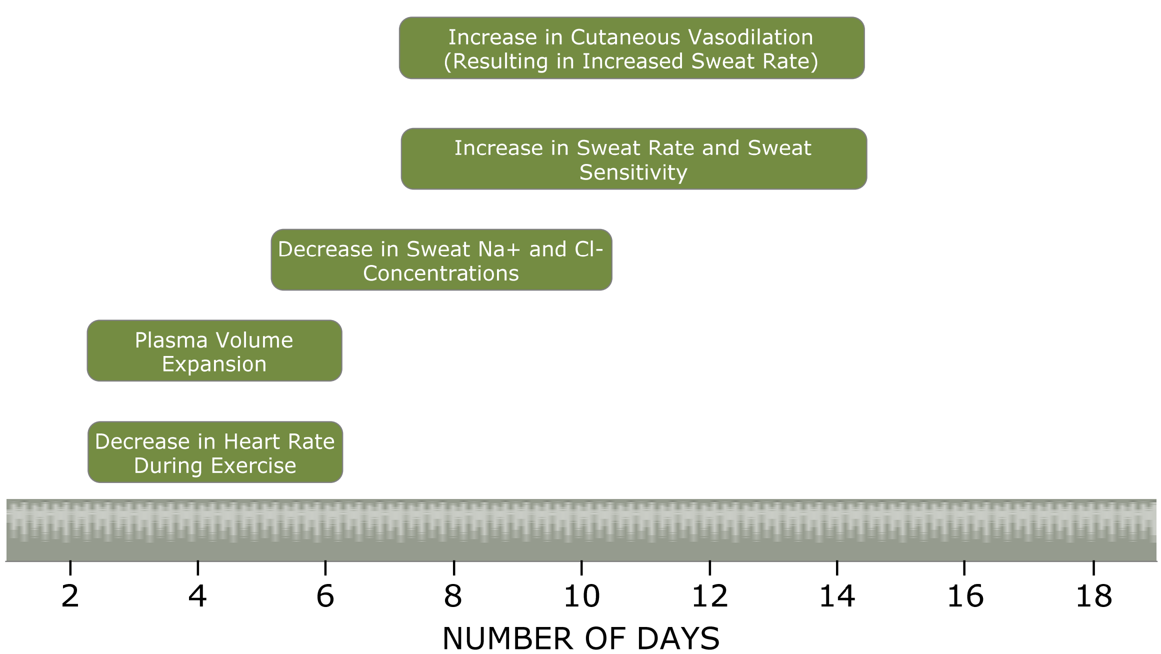

Figure 1: Timeframe required for different adaptations to occur during heat acclimatization (information adapted from Wendt et al [32])

Research studies demonstrate that subjects exercising in the heat reach the point of voluntary exhaustion at similar and consistent body core temperatures despite different starting core temperatures or rates of heat storage [33]. This is important for tennis athletes as certain core temperatures not only put them at greater risk of developing heat illness (safety concern), but also a reduction in on-court performance. The National Athletic Trainers' Association[34] and The American College of Sports Medicine[35] both consider an athlete's core body temperature of greater than 40°C (104°F) as a major indicator of heat illness, which is a concern for the health and safety of the athlete. Even core temperatures greater than 39°C correlate with performance reduction in tennis players[7].

In efforts to reduce performance-limiting and potentially harmful increases in core body temperature during tennis in the heat, the process of whole–body precooling has been experimentally analyzed to see if it can reduce thermal load during intense exercise[36]. This precooling can be achieved via different modalities, including cold air cooling, cold water immersion and the use of water-cooling garments [37]. The current body of evidence suggests that precooling is able to increase capacity for prolonged exercise at various ambient temperatures. However, regardless of the method used, the practical application at present is limited because of the time required to achieve sufficient body cooling to improve exercise performance [36].

Sweating and Dehydration

Evaporative cooling (sweating) is the most effective method that humans use to limit the rise in core temperature[4]. Sweating is maintained by intracellular water shifting to the extracellular space, which results in cell dehydration while adversely affecting skeletal muscle cell function [38]. The goal of adequate hydration is to limit fluid loss from sweat and respiration. The magnitude of sweat loss increases substantially in thermally challenging environmental conditions (e.g. WBGT > 23°C). The water lost in sweat is derived from all body compartments, but most originates from the extracellular space, especially during exercise in the heat [39].

Dehydration negatively influences muscle performance by impeding thermal regulation, altering water movement across cell membranes, and interfering with actin-myosin cross-bridge formation [40]. Hydration with muscle fatigue and/or increase in core temperature has a negative summation effect on performance, recovery and health[41, 42]. However, dehydration alone may not be the major problem. The production of sweat leads to an increase in plasma osmolality (an increase solute concentration) triggers an increase in plasma-anti-diuretic hormone (ADH), which leads to free water retention in the kidney and systematic vasoconstriction. With the consequent increase in osmotic gradient (fluid moves to equalize solute concentrations), which is supported by an exercise-induced increase in intravascular albumin [43], fluid is mobilized from the intracellular compartment to maintain the extracelluar fluid volume [43]. From a recovery standpoint this is very important as no significant correlations have been shown between postmatch perceived thirst and sweat rate or body weight percentage change [44]. This supports the notion that thirst is neither a rapid enough indicator of body water status nor a sufficient stimulus to prevent a substantial net body water loss during exercise in a hot environment [45].

Researchers have studied the influence of limiting fluid volumes and human body function. One area that has received interest over the last decade is how dehydration/hypohydration may alter neuromuscular function. Apart from the direct influence on core and skin temperature when the external environment is hot and humid, evidence is emerging that hyperthermia directly affects brain function by altering cerebral blood flow and metabolism, thereby decreasing the level of central cognitive or neuromuscular drive, which may in turn decrease muscle function, alter the perception of effort, or both [46]. There is currently scant literature on a sensitive marker of central drive and hydration status [47]. From a recovery standpoint we understand that neuromuscular, muscular, cardiovascular and metabolic recovery have different time-courses, and this needs to be optimized by the correct fluid and hydration program for tennis athletes (for a discussion of the effect of these biological systems and recovery, see chapter on physiological recovery).

As dehydration can manifest with clinical symptomatology similar to concussion, some experts have speculated that dehydration may negatively influence performance on tests commonly used for concussion assessment [48-50]. 24 recreational trained males (21.92 $\pm$ 2.95 yo) were analyzed using the Standardized Assessment of Concussion to Test Mental Status, The Automated Neuropsychological Assessment Metrics (ANAM) and a balance test. The results showed that individuals who were dehydrated (2.5 $\pm$ 0.63% of body mass and Urine Specific Gravity (USG) = 1.025 $\pm$ .004) showed significant deterioration in visual memory and fatigue measures as well as a significant increase in the number and severity of symptoms of concussion related symptoms [51]. The four most commonly reported symptoms were:

1. feeling slowed down (91.7%)
2. fatigue/drowsiness (91.7)
3. difficulty concentrating (87.5%)
4. balance problems (75%)

Headache and dizziness were reported in 50% and 54.2% respectively during the dehydration condition [51]. These data are very important for the tennis athlete because such symptoms are what coaches often refer to when they say a player was "flat" during training or competition. Removing dehydration as a barrier may help preclude the development of playing "flat," which could lead to a consistently higher level of performance.

In a national level 14 and under boys junior tournament, Bergeron et al.[26] found that the players monitored went into matches with USG levels of 1.019 (0.004) for singles and 1.025 (0.002) for doubles. As doubles were played later in the day, the data suggest a cumulative negative-effect on hydration status in a "real-world" tournament situation. The prevalence of junior tennis players walking onto the tennis court already in a state of mild/moderate dehydration has also been shown in a study evaluating hydration level in a practice scenario.[52] It is clear that more needs to be done to educate coaches, players and parents on the need for appropriate hydration throughout practice and tournaments to avoid players starting matches in a dehydrated state.

Apart from the consequences of reduced fluid volumes associated with dehydration, it also results in a shift in the utilization of glucose. Dehydration increases glucose utilization in parts of the forebrain by 30% to 73% in water deprived rats [53]. The forebrain integrates cognitive, sensory and motor function, and regulates temperature, reproduction, eating, sleeping and emotional display. Therefore, a reduced function in the forebrain can lead not only to performance decrements for the tennis player, but can also result in disruption to most functions needed for daily living. Gross et al. noted that dehydration led to increased glucose utilization in the forebrain, with concomitant decrease in other brain regions. The researchers concluded that many brain regions experienced depressed metabolism in water-deprived rats [53]. A reduced intracellular volume can reduce rates of glycogen and protein synthesis and a high cell volume can stimulate these processes [54]. Although this information has not been well-researched in competitive athletes, it does provide insight into the effect of dehydration on glucose uptake and utilization on brain function.

Effect of Hypohydration on Muscle Groups and Muscle Action

No specific muscle group or action appears more susceptible to hypohydration than others [47]. Muscular performance is reduced when athletes are dehydrated. A review by Judelson et al. found that 3-4% hypohydration reduces muscular strength by approximately 2% [47]. Muscular power, as defined by the power generated when a muscle engages in a maximal concentric action at the optimal shortening velocity [55], is reduced by 3% when the athlete is hypohydrated by 3-4% [47]. High intensity muscular endurance, as measured during 30-120 seconds of repeated activity is reduced by 10% when the athlete is hypohydrated by 3-4%[47]. Individual studies have ranged in reduction on performance depending on type of activity and level of dehydration. A study of athletes dehydrated by 3.1% found large reductions in mean upper body power (7.17%) and mean lower body power (19.20%) [56].

Rehydration

When discussing tennis recovery, specifically post-training or post-competition, one of the most important areas to consider is rehydration. Rehydrating after practice or matches is vital not only to replenish important nutrients, electrolytes and fluid levels to help the athlete recover from the physical exertion, but also to prepare the athlete for future training and match sessions. As mentioned previously in this chapter, many tennis players go into practice and/or competition already in varying states of dehydration[52]. This increases the rehydration needs of the athletes relative to a euhydrated state before practice or competition.

A study looking at rehydration rates after athletes were dehydrated by 2% body mass in hot and humid conditions (36.0 $\pm$ 1.0 °C and 65% $\pm$ 5 % relative humidity) found that during the one hour post-exercise rehydration period, athletes consumed 150% of fluid lost during exercise (divided into 4 equal volumes). The athletes consumed either a carbohydrate-electrolyte drink or water. Urine volume was monitored for 4 hours after the exercise session. In the carbohydrate-electrolyte rehydration protocol the total urine volume was 800 ± 277ml compared with 1155 ± 374 ml in the water protocol [57]. The sodium deficit was significantly less (more favorable) in the carbohydrate-electrolyte trial (-88 ± 15 mmol) than in the water trial (-156 ± 49 mmol) (see Figure 2)[57].

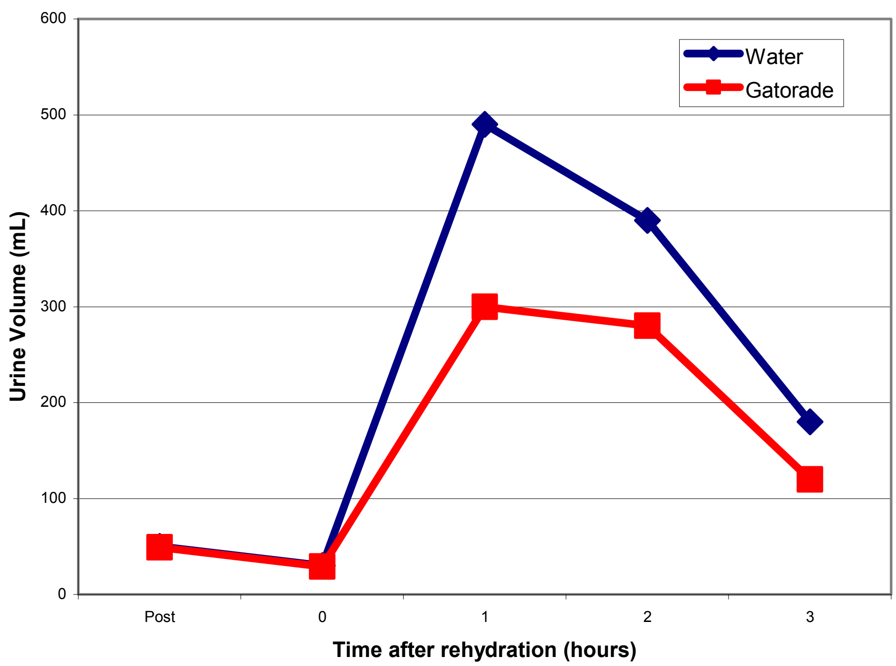

Figure 2: Urine output post exercise after rehydrating with the same total volume of fluid. The water trial resulted in approximately 30% more urine produced during recovery than the Gatorade group[57].

This study[57], along with previous studies[58], has shown that the ingestion of a carbohydrate-electrolyte beverage resulted in more effective rehydration than plain water [58]; others have also observed a lower urine output with carbohydrate-electrolyte solution than with water[59]. It normally takes 2h after drinking a bolus of fluid before any significant renal excretion of water occurs [60]. Drinking a large volume of fluid has the potential to induce a greater decline in plasma sodium concentration and osmolality, which, in turn, has the potential to induce greater diuresis. It is recommended to consume smaller volumes of fluid on a more regular basis during recovery to speed rehydration.

Table 1: Comparison of Popular Sports Drinks and Beverages

Comparison of Popular Sports Drinks and Beverages Consumed by Tennis Players

Name	Carbohydrate Content	Carbohydrate (grams)	Protein (grams)	Calories	Sodium (mg)	Potassium (mg)	Caffiene (mg)	High Fructose Corn Syrup	Type of Carbohydrate
Accelerade® RTD	6%	15	4	80	120	15	No	No	Sugar, Trehalose
Amino Vital®	3%	8	<1	35	10	35	No	No	Fructose
Bottled Water	0%	0	0	0	0	0	No	No	N/A
Cytomax®	5%	13	0	50	55	30	No	No	Fructose, Dextrose, Matlodextrin
Gatorade®	6%	14	0	50	110	30	No	Yes	Sucrose Syrup, HFCs
Gatorade® Endurance	6%	14	0	50	200	90	No	Yes	Sucrose Syrup
Gatorade G2®	3%	7	0	25	110	30	No	Yes	Sucrose Syrup, Sucralose, Acesulfame Potassium
Life Water®	5%	13	0	50	120	20	No	No	N/A
Powerade®	7%	17	0	64	53	32	No	Yes	N/A
Propel® Fitness Water	1%	3	0	10	35	0	No	No	
Soda, Cola	25%	25	0	100	30	?	Yes	Yes	N/A
Vitamin Water®	5%	13	0	50	0	70	0-75	Yes	N/A
Powerade ION4®	5%	14	0	50	100	25	No	Yes	HFCS
Powerade Zero®	0%	0	0	0	55	35	No	No	N/A
Clif Shot®	8%	19	0	80	200	50	Varies	No	Organic Brown Rice Syrup Solids
Clif Quench®	4%	11	0	45	130	35	No	No	Organic Evaporated Cane Juice
GU20®	5%	13	0	50	120	20	No	No	Maltodextrin and Fructose
Hammer HEED®	10%	25	0	100	62	16	No	No	Maltodextrin
Capri Sun Sport®	8%	19	0	72	66	36	No	Yes	HFCS and Sugar
Ultima Replenisher®	2%	6	0	50	75	150	No	No	Maltodextrin
CeraSport®	3%	10	0	38	100	38	No	No	Rice Syrup Solids
CeraSport EX-1®	2%	5	0	20	200	100	No	No	Rice Syrup Solids
GameOn MyoHydration®	3%	10	2	50	110	130	No	No	Maltodextrin and Fructose
Carbo-Pro®	19%	57	0	224	0	0	No	No	Glucose Polymers
Gatorade Endurance®	5%	14	0	50	200	90	No	Yes	Sucrose Syrup and HFCS
Perpetuem ®	23%	54	6	260	231	156	No	No	Maltodextin
Powerbar Endurance®	5%	13	0	60	165	8	No	No	Maltodextin, Fructose, and Dextrose
Hammer Sustained Energy®	30%	73	10.5	343	112	0	No	No	Glucose Polymers and Corn Solids
EnduroxR4®	15%	35	9	180	140	80	No	No	Dextrose, Fructose, and Sucrose

Information adapted from [61]

Flavor and Palatability of Fluid

Ensuring that tennis athletes consume appropriate fluid levels before, during and after practice and competition is a major priority. However, many athletes have trouble consuming adequate levels. Athletes typically drink more fluid if it is flavored[4, 62]. Research demonstrates that athletes drink approximately 30% more fluid when consuming a flavored sport drink than when consuming water [63]. This is important for the coach, parent or trainer to take into account. Plain water may not always be the most effective fluid for hydration, due to the lack of taste; many athletes will unintentionally consume less water than a flavored alternative.

Table 2: Sweat Rates and Fluid Loss During Tennis Play

Sweat Rates and Fluid Loss During Tennis Play

Typical Tennis Match

	Sweat Rate ($L \cdot h^{-1}$)	Time of Match (hours)	Fluid Loss During Match (Liters)	Replaced ($L \cdot h^{-1}$)	Net deficit at the end of the match (Liters)
Low Sweat Rate	1	1.5	1.5	1.0-.1.6	~ 0 - +0.9
↓	1.5	1.5	2.25	1.0-1.6	~0.15 - 0.75
Medium Sweat Rate	2	1.5	3	1.0-1.6	~0.6-1.5
↓	2.5	1.5	3.75	1.0-1.6	~1.35-2.25
High Sweat Rate	3	1.5	4.5	1.0-1.6	~2.1-3

Long Tennis Match

	Sweat Rate ($L \cdot h^{-1}$)	Time of Match (hours)	Fluid Loss During Match (Liters)	Replaced ($L \cdot h^{-1}$)	Net deficit at the end of the match (Liters)
Low Sweat Rate	1	3	3	1.0-.1.6	~0 - +1.8
↓	1.5	3	4.5	1.0-1.6	~0 - 1.5
Medium Sweat Rate	2	3	6	1.0-1.6	~1.2 - 3
↓	2.5	3	7.5	1.0-1.6	~2.7 - 4.5
High Sweat Rate	3	3	9	1.0-1.6	~4.2 - 6

Sodium's Role in Hydration and Rehydration for Tennis

The importance of the addition of sodium to fluid consumed during, and especially after training or competition has been shown to be vital for improved rehydration. The need for sodium replacement is due in part from sodium's role as the major ion in the extracellular fluid, and to replace the obligatory losses in sweat. If sufficient sodium and water are ingested, some of the sodium remains in the vascular space, which results in plasma osmolality and sodium concentrations that do not decline, as may occur if plain water alone is ingested. As a result, plasma levels of vasopressin (anti-diuretic hormone) and aldosterone are maintained, and an inappropriate diuresis (due to the body continuing to be in a net negative fluid balance) is prevented [5]. Many published reports emphasize the importance of adequate sodium replacement and rehydration in athletes, including tennis players. It is suggested that normal dietary intake may not be adequate for many competitive athletes, when daily sweat losses are high and there is an ongoing expansion of the extracellular volume, such as that which may occur during the early stages of training or during heat acclimatization [5].

Some coaches and parents are concerned about the addition of extra sodium to the diet of athletes. Common sports drinks typically contain sodium in the range of 10-25 $mmol \cdot l^{-1}$ [5], which is lower than most sweat sodium levels in athletes (20-80 $mmol \cdot l^{-1}$)[5]. Therefore, a need exists to continue to educate coaches and parents on the importance of increasing sodium content in an athlete's diet (both solid and liquid nutrition) when training or competing in hot and humid conditions.

Below et al., studied athletes who consumed different volumes of an electrolyte drink or an electrolyte-carbohydrate drink. Participants consumed drinks containing either electrolytes (619 mg Na+, 141 mg K+) or the same electrolytes plus carbohydrates (79g carbohydrates) during an initial 50 minute exercise bout, and then immediately undertook a cycle ergometer performance test. They received these drinks in either a large (1330 ml) or small (200 ml) volume. Fluid and carbohydrate each improved performance independently: performance times were 6.5% faster when the large beverage volume was consumed as opposed to the small volume, and were 6.3% faster when carbohydrate-containing beverages were consumed as opposed to the carbohydrate-free beverages [64]. Both fluid consumption and carbohydrate replenishment are important factors that delay fatigue during high exercise performance [5].

Sodium also stimulates glucose absorption in the small intestine via the active co-transport of glucose and sodium, which creates an osmotic gradient that acts to promote net water absorption. Sodium has been recognized as a vital component of a rehydration beverage by an inter-association task force [65] on exertional heat illnesses because sodium plays a role in the aetiology of exertional heat cramps, exertional heat exhaustion and exertional hyponatremia.

Shirreffs and Maughan[66] have reported that for athletes to remain in positive fluid balance, the amount of sodium they consume needs to be greater than sweat sodium loss. Yet research has been shown that athletes typically do not replace sufficient sodium to match that which is lost in sweat and during urinary sodium excretion. Subjects were shown to be in sodium deficit for four hours after exercise, even when replacing with a commonly used carbohydrate-electrolyte beverage at 150% of body-mass lost during exercise [57]. The recovery of plasma volume to levels greater than post-exercise was achieved 1 h after rehydration in the 6% carbohydrate-electrolyte drink whereas the water trial achieved the same level after 3h [57]. A similar finding has been supported by other research [59]. This body of research has shown that rehydration capabilities are improved for athletes who ingest sodium enriched fluids compared to plain water.

The Right Amount of Sodium?

When different sodium levels were examined in rehydration drinks some interesting findings were seen. Maughan and Leiper dehydrated participants by 2% of their body mass using an intermittent exercise protocol in the heat. After the exercise protocol the participants ingested a test drink with a volume equal to 150% of the fluid lost. These test drinks contained 0, 25, 50 or 100 mmol/L of sodium. It was clear that urine output in the hours after exercise was inversely proportional to the sodium content ingested. For the participants in this study to remain in a positive fluid balance, the amount of sodium in the test drink exceeded 50 mmol/L [67]. Similar results were found by Shirreffs et al,[68] who demonstrated that even when a volume equal to twice the amount lost in sweat is ingested, subjects could not remain in positive fluid balance when a low sodium drink (23 mmol/L) was consumed. A positive fluid balance was eventually maintained when drinks containing 61 mmol/L of sodium were consumed in amounts $\geq$ 1.5 times the loss of water.

Costill and Sparks[59] showed that ingestion of a glucose-electrolyte solution after dehydration resulted in a greater restoration of plasma volume than did plain water. Gonzalez-Alonso et al.[58] have also confirmed that a dilute carbohydrate-electrolyte solution ($60 g \cdot l^{-1}$ carbohydrate, $20\ mmol \cdot l^{-1}\ Na^+$, $3\ mmol \cdot l^{-1}\ K^+$) is more effective in promoting post-exercise rehydration than either plain water or a low-electrolyte diet cola.

Addition of sodium can increase volitional fluid intake, [69, 70] which results in individuals consuming more total volume; however, if excessive sodium is added to the fluid it can make the liquid unpalatable, thereby reducing the total volume consumed [70]. Therefore, the palatability of excess sodium is an important determining factor, as levels of consumption may be as important as sodium content of fluid. Studies looking at the mechanisms of post-exercise rehydration showed that the ingestion of large volumes of plain water after exercise-induced dehydration resulted in a rapid fall in plasma osmolality and sodium concentration [69], which leads to a prompt and marked diuresis caused by a rapid return to control levels of plasma renin activity and aldosterone [71]. This results in a much larger sodium deficit (a negative consequence) in purely water rehydration beverages than from traditional sports drinks [57].

Other Electrolytes – Are their benefits?

Potassium

Potassium is the major ion in the intracellular fluid, whereas sodium is the major ion in the extracellular fluid. Potassium is thought to be important in achieving rehydration by aiding the retention of water in the intracellular space. However, a study of rats that were dehydrated by 9% revealed that rats drank substantially more and achieved superior rehydration with a sodium-enhanced drink when compared to a potassium enhanced drink or free water. [72]. A similar result was found when a comparison of these drinks was performed in humans [73]. Although potassium may be important in enhancing rehydration by aiding intracellular rehydration, more data is needed before conclusive evidence is able to show the benefits of potassium supplementation for rehydration.

The banana effect

It has previously been speculated that potassium may be a beneficial electrolyte for athletes in general since it is a major cation in the intracellular space, and potassium supplementation could enhance the replacement of intracellular water after exercise and thus promote rehydration [74]. Experimental investigation has demonstrated that inclusion of potassium (25 $mmol \cdot l^{-1}$) may, in some situations, be as effective as sodium (60 $mmol \cdot l^{-1}$) in retaining water ingested after exercise-induced dehydration [73]. Addition of either ion will increase the fraction of the ingested fluid which is retained, but when the volume of fluid ingested is equal to that lost during the exercise period, there is no additive effect of including both ions (potassium and sodium) [5]. As sodium has important other benefits such as increasing drive to drink and replacing sodium losses that are large in sweat, it appears from the literature that no added benefit is gained by adding potassium to recovery drinks. Potassium rich foods or supplements have not typically been shown to provide additional benefit [75].

Magnesium

Magnesium is sometimes touted by coaches and physiologists as an electrolyte that could possibly benefit athletes during competition, and especially during rehydration after training/competition. Magnesium is lost in sweat and this results in a reduction in plasma magnesium concentration, which has been thought to contribute to muscle cramps [60]. However, this decline in plasma magnesium concentration during exercise is more likely to be due to compartmental fluid redistribution rather than to sweat loss [60]. The current research does not support the need for any supplemental magnesium in post-exercise rehydration and recovery drinks. Also, other non-sodium electrolytes have not been shown to be beneficial in recovery sports drinks if the athlete is consuming an appropriate well-balanced diet [60].

Hyponatremia

When discussing recovery hydration, the majority of recommendations are based on increasing a tennis player's fluid consumption. For the vast majority of players this is the major focus of hydration education. However, it is important to be aware of the health concern known as exercise associated hyponatremia (EAH). EAH is the occurrence of hyponatremia during or up to 24 hours after prolonged physical activity,[76] and is defined by the serum or plasma sodium concentration (Na+) below the normal reference range (typically Na+ less than 135 mmol/L)[77]. The lower the level of Na+, the more severe the symptoms; however, variability is large and Na+ alone is not always a reliable predictor of the clinical severity of hyponatremia[78]. EAH is typically caused by an increase in total body water relative to the amount of total body Na+. From a tennis player's perspective this may occur after competing for hours in a hot and humid environment, with subsequent sodium loss from sweating. If fluid replacement is accomplished only with water or low/no sodium fluids, this could result in a dilution of body fluid with hyponatremia to a potentially dangerous level. Unfortunately, no specific blanket recommendations can be made as there is a wide variability in human sweat rates in general,[79] and tennis players specifically[26, 52]. Although EAH is a severe and dangerous condition, compared to marathons, triathlons, and other ultra-endurance events, the reported incidence of EAH in tennis is very low [80]

Risk Factors (adapted from[76]):

- Athlete-related
  - Excessive drinking behavior
  - Weight gain during exercise
  - Low body weight

- Female sex
- Nonsteroidal anti-inflammatory agents

▪ Environment or Event-related

- High availability of drinking fluids
- >4 hours exercise duration
- Unusually hot environmental conditions

Cramping

Muscle cramping during and after tennis play is an unwarranted aspect of high-level competitive tennis. Cramps typically occur with slight muscle fasciculations[75] or "twitches" that the athlete only notices between points or at the changeover. These subtle signals alert the athlete (and coach) that s/he may only have 20-30 minutes before severe cramps may occur, which would severely hinder the athletes ability to perform at a competitive level. These cramps are often experienced post-play during recovery, between matches and between days during training and competition. With respect to exercise-related muscle cramping, there are typically two forms of cramping that tennis players are most often confronted with:

1) Overworked muscle fibers

2) Muscle cramps related to extensive sweat losses and a sodium deficit, known as exertional heat cramps [75].

Exertional heat cramps, as opposed to muscle fatigue cramps, typically spread from one area to another within large muscle groups, as adjacent and nearby muscle fibers and bundles alternatively relax and contract [81]. From a recovery standpoint during tournaments, a clinically relevant sodium deficit may develop over several days of repeated sweat electrolyte losses that exceed daily dietary salt intake[75]. When this subtle cumulative sodium deficit occurs, athletes may be surprised to suffer exertional heat cramps, given that they encountered no problems during the previous days in similar conditions. Priority management is to replace and retain salt and water that was lost during sweating, and to make sure that muscle glycogen stores are at adequate levels.

Initial signs of exertional heat cramps (muscle twitches) can often be treated effectively by consuming 16-20 ounces (~0.5 L) of a traditional sport drink with 0.5 teaspoon (3g) of salt added and mixed into the drink[75]. Salt tablets may be a suitable option (1g of NaCl per tablet) but such tablets should be taken with plenty of fluid (3 crushed and dissolved tablets in 42 ounces (~1L) of fluid).It is vital that cramp-prone athletes avoid a water and sodium deficit from previous training or tournament play so that they do not begin the next training or competition bout already at risk[82, 83]. Figure 3 provides strategies for exertional heat cramp-prone athletes.

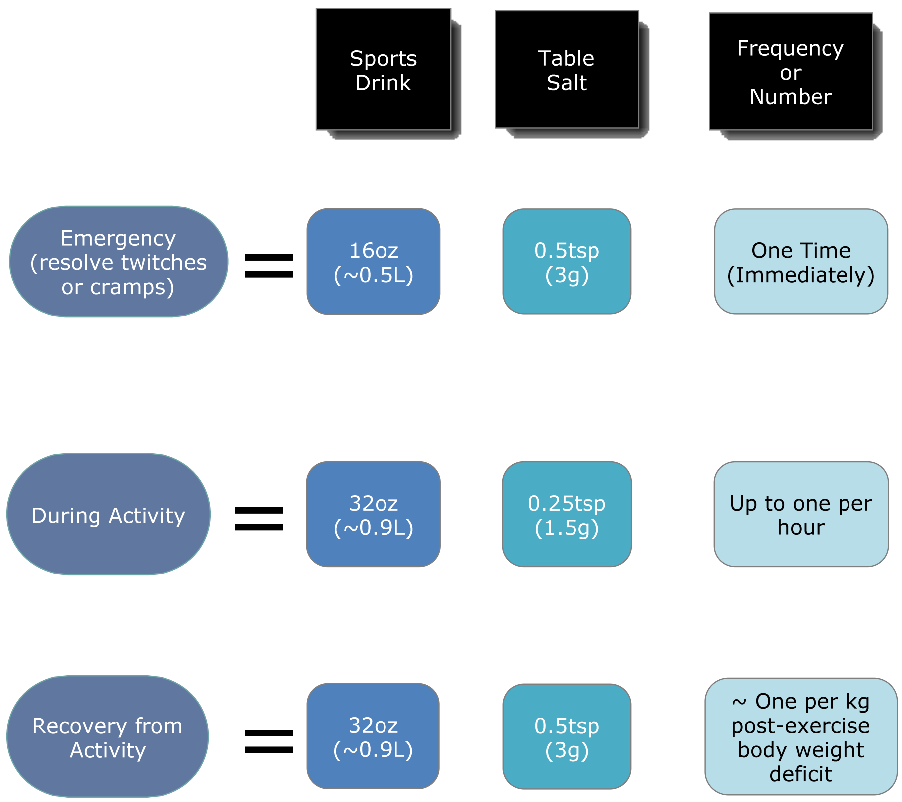

Figure 3: Suggested Fluid Mixtures for Exertional Heat Cramp-Prone Athletes Using Sports Drink and Table Salt (NaCl) (adapted from [75, 84])

Practical Application

Due to the fact that individual sweat rates are highly variable and the sweat sodium concentrations between athletes can range between 20-80 mmol/L [85], it would be an oversimplification to prescribe a universal drink formulation for all tennis players. This is why an individualized fluid program is suggested.

If a tennis player has to follow up with a practice session or match within one to two hours, it is recommended that a CHO-electrolyte beverage be consumed that contains sodium concentrations of 30 to 40 mmol $\cdot L^{-1}$ [86].

As ad libitum drinking often leads to involuntary dehydration [45], it has been recommended to have tennis athletes on a specific hydration schedule during match changeovers and practice sessions[4]. The trainer, coach and athlete can develop an individualized hydration schedule by measuring fluid loss. The easiest method is to weigh (kg) the athlete before a practice (match) session and then subtract the athlete's post-exercise weight (kg) and amount of fluid ingested (L) during play (Equation 1). This will determine the athlete's fluid volume loss for that particular session. This value can be divided by time intervals to determine the athlete's approximate fluid loss (sweat rate) per unit of time. From this value an individualized practical hydration routine can be established.

$$\text{Total Fluid Loss} = \text{BW (pre-exercise, kg)} - [\text{BW (post-exercise, kg)} - \text{Fluid ingested (L)}] \quad (1)$$

The following example demonstrates the practicality of equation 1. A tennis player who has a pre-exercise weight of 80kg and plays for 2 hours while ingesting 2 L of fluid with a measured post-exercise weight of 78kg, will have an approximate fluid loss of 4 L in two hours or 2.0 $L \cdot h^{-1}$. This equation does not account for fluid loss due to urination. If the athlete must urinate it needs to be accounted for in the equation.

Total Fluid Loss = 80kg – [78kg – 2L] = 4 liters of fluid

Hourly Sweat Rate = Total Fluid Loss / Time of practice = 4L / 2hours = 2.0 $L \cdot h^{-1}$

Another practical tool for coaches and trainers to help athletes with their hydration monitoring is to utilize a urine color chart[87]. Figure 4 is a simple chart that can help athletes' awareness of their hydration status in a simple, non-invasive manner.

AM I HYDRATED?

Urine Color Chart

1		**If your urine matches the colors 1, 2, or 3, you are likely properly hydrated.** **Continue to consume fluids at the recommended amounts.** **Nice job!**
2		
3		
4		**If your urine color is below the RED line, you may be <u>DEHYDRATED</u> and at greater risk for heat illness!!**
5		
6		**<u>YOU NEED TO DRINK MORE!</u>**
7		
8		Speak to a Health Care Provider if Your Urine is this Dark and is Not Clearing Despite Drinking Fluids

Figure 4: Am I Hydrated – Urine Color Chart

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Post-practice or match hydration is not only important for immediate recovery, but also for subsequent performance during play in a subsequent session on the same or the following day. Rehydration post exercise has three major purposes:

1) replace fluid volume to an equal or greater extent than the volume lost while sweating

2) ingest liquid and/or solid carbohydrates to aid in glycogen resynthesis[88]

3) replace electrolytes lost during sweating

Water cannot be the only fluid consumed after tennis play, as the athlete is typically in a hypohydrated state and an increase in plain water will dilute the lowered electrolyte concentration in the blood and plasma even further. This fall in plasma osmolality and Na^+ concentration reduces the athlete's drive to drink and stimulates urine output, which could lead to adverse consequences such as excessive hypohydration and hyponatraemia[69, 89]. The addition of Na^+ in post-exercise beverages has been supported by multiple position stands[1, 35]. Na^+ supplementation after tennis play should be consumed at a rate of ~1.5 $g \cdot L^{-1}$[82].

Practical Heat Acclimatization Guidelines (adapted from [32])

- Full adaptation takes 7-14d
- Heat acclimatization is best achieved by strenuous interval training (i.e. tennis) for at least 1 hour per day, at a minimum of every third day
- Exercise bouts of 1.5-2h seem most effective for the induction of heat acclimatization
- Acclimatization responses are maintained for at least 1wk, but probably less than 1mo.

Practical Rehydration Guidelines (adapted from [32])

- Consumption of fluids during rehydration after exercise should exceed fluid lost (130-150%)
- It takes 20-30 min for ingested fluids to be evenly distributed throughout the body
- The use of sports drinks with 6-8% carbohydrate solution and sodium improves intestinal water absorption
- Water retention can be optimized by the ingestion of solutions containing at least 50mmol/L of sodium (~3 grams/L of table salt) in a volume 1-1.5 times the amount of sweat lost
- Heart rate, core temperature and hydration do influence each other during and after exercise (Figure 5 and 6)

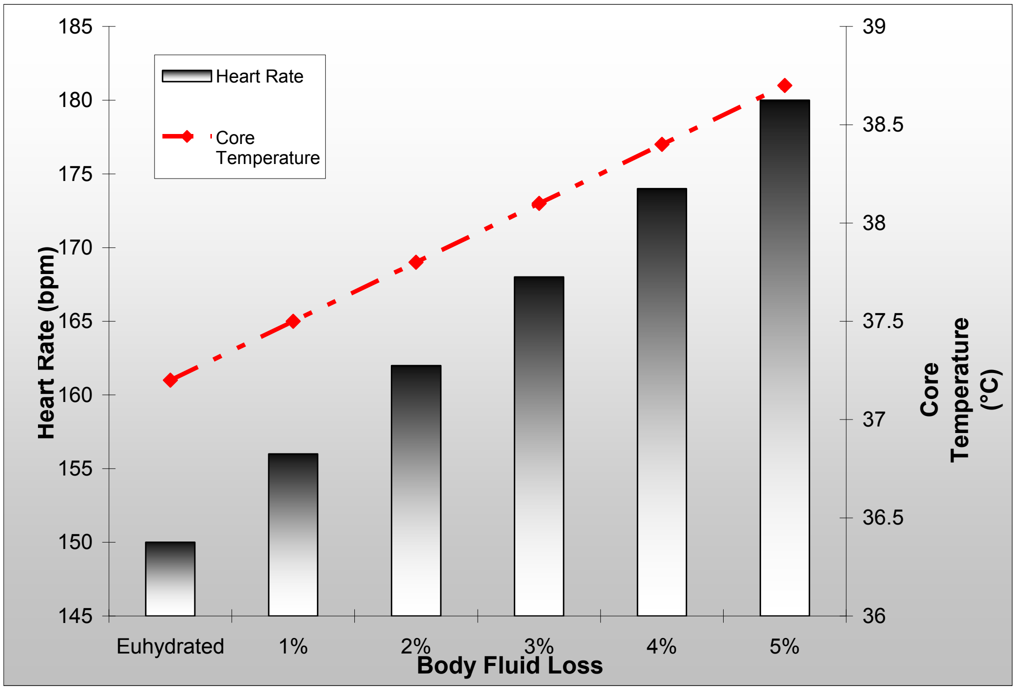

Figure 5: Effect of body fluid loss on heart rate and core temperature

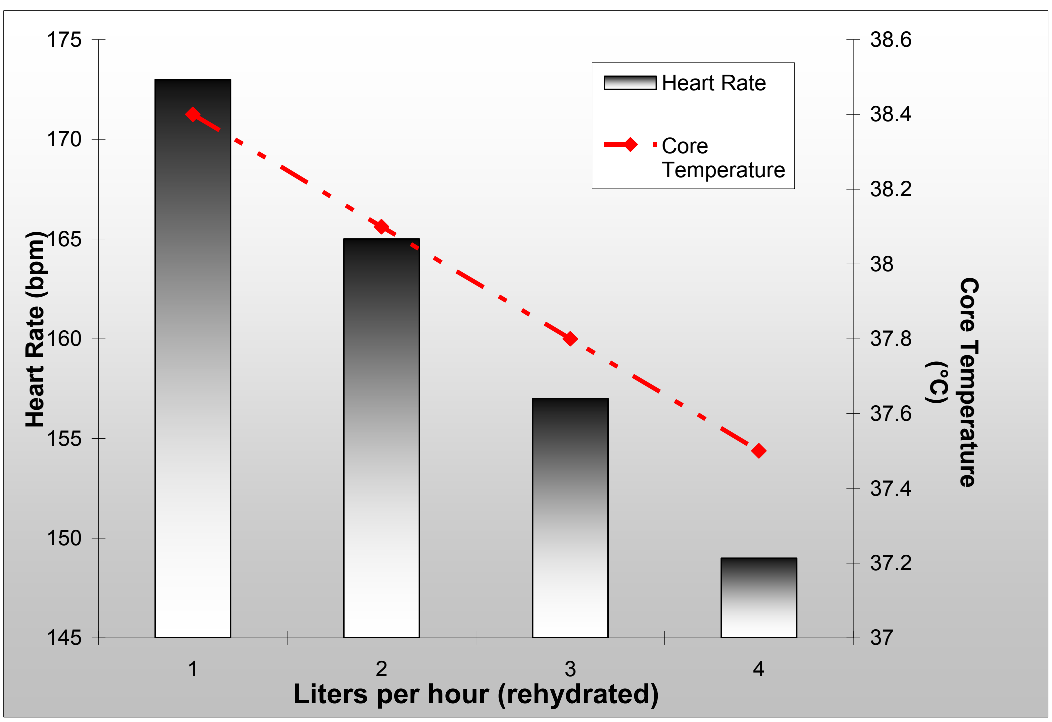

Figure 6: Effect of body fluid loss on heart rate and core temperature (information adapted from [38, 90])

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Psychological Aspects of Recovery in Tennis

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Introduction

Developing talent as a tennis player is both a science and an art. Countless hours are spent planning training, watching matches, and running through drills. As coaches strive to put together the best plan for conditioning, toning and honing athletic performance, athletes work hard to rise to the challenges on the court and in the gym. Unfortunately, the best laid plans can easily go awry, leading to frustration, decreased performance, reduced enjoyment, and even departure from tennis all together. Coaches and athletes may be caught by surprise when an athlete doesn't respond to training as expected. Often fears of overtraining and burnout lurk behind every perceived drop in performance or bad day. Yet despite these fears and the great attention to training detail, little to no attention is given to the concept of recovery, the impact that recovery has on performance, and the systematic planning of recovery with the same focus that is giving to planning training. Recovery is often overlooked or worse, taken for granted.

This chapter is designed to explore overtraining and recovery as they relate to the importance of training balance. It will also explore the psychological components of proper recovery that can help young athletes navigate the challenges and potential pitfalls of training to become a competitive athlete. These topics key in the pursuit of successful talent development and peak performance. Even more importantly, adults working with young athletes have a responsibility for the overall healthy development and personal well-being of the young men and women who play tennis under their care. Providing a balanced, healthy, sound experience for every young athlete, regardless of their potential, should be at the center of any sport experience.

Modern Training

Once upon a time, tennis was the gentile pursuit of the wealthy. ‘Gentlemen’ did not sweat or over exert themselves on the court and ‘ladies’ played in full length skirts while politely tapping the ball to their opponent. Overtime, the sport has evolved from merely a social past time to a high powered high stakes pursuit. It has grown into a game of speed, power, grunts, and passion. While many people still play tennis just for fun, for many others it is much more than a game. Understanding the modern training environment is the first step towards better understanding how best to prepare athletes to thrive in it.

Advances in equipment technology, sports nutrition, biomechanics and sports medicine have all played an important role in shaping and enriching modern tennis. Major racquet innovations have changed ball speeds and stroke dynamics. Improved nutrition helps athletes play longer and recover faster. And sports medicine has made great strides in the treatment and prevention of sport related injuries, allowing athletes to play harder and enjoy longer careers. For example, injuries that used to require major surgeries and months of rehab with no guarantee of recovery now create mean minor detours in training. In each of these areas, sport science advances have contributed to the advancement of the game.

Perhaps one of the most important and most fundamental changes in sport, including tennis, over the past few decades, has been how athletes train. Exercise scientists experiment to find new and better ways to push the body farther and get greater results. Research journals such as *Medicine and Science in Sport and Exercise* and the *International Journal of Sports Physiology and Performance* are focused on reporting key advances in the field. Coaches routinely turn to the sport scientists and their findings for information on how to enhance skill development, endurance, speed, and power. At the very foundation modern athletic training, tying together these key elements of training is the concept of periodization.

The science of periodization is used to design training that will help athletes' tax their bodies through increasing phases of progressive overload and rest (1). Simply put, periodization (figure 1) is the give and take or hard work then rest pattern that coaches use to elicit performance gains and set a new baseline of ability for the next cycle of training. Coaches design practices, specifically relying on the SAID principle – "specific adaptations to imposed demands" (2), to bring about the necessary changes in athlete skill and fitness. Although there are countless ways to implement periodization, the basic cyclical pattern of alternating progressive training stress loads (overreaching) with recovery to improve an athlete's level of performance, is the foundation of training programs across sports and is one of the major innovations in striving for peak performance.

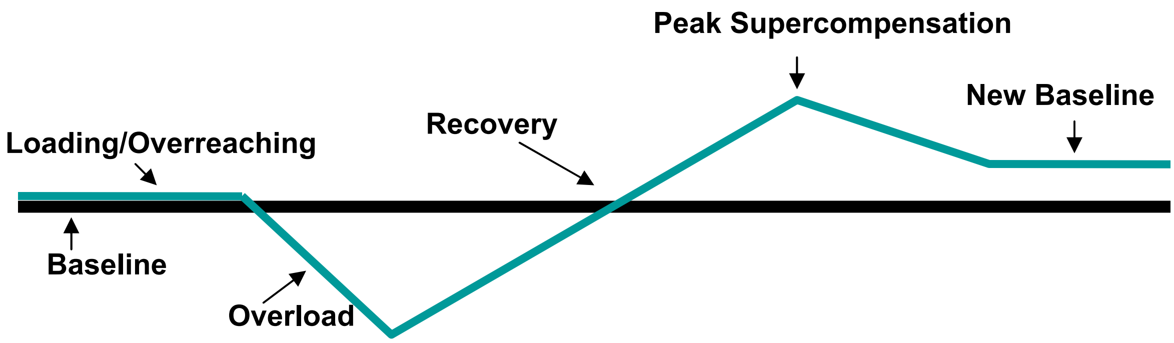


Figure 1: Training Periodization

Note that the training periodization formula includes both an overload or work phase and a recovery phase. Unfortunately, while many coaches and athletes do an excellent job with the training stress side or load of periodization, as mentioned they often underestimate or neglect the recovery element in the equation. While recovery will theoretically happen over the due course of time, researchers agree that it is an underutilized and under appreciated element in the question for peak performance (3). In order for proper recovery to occur, adequate resources and attention to the factors and activities that facilitate recovery need to be taken into account. Moreover, the importance of considering the multiple sources of stress that an athlete experiences, in addition to the purposeful physical loading and the need to consider multiple sources of related recovery also plays an important role in the quest for top athletic form. More on this later in the chapter.

Increasing stress loads for the modern athlete

Increased training, improved technology, and scientific enhancements have created increased performance expectations for athletes in all sports (4). According to Bompa (5), over a five year period from 1975 to 1980, the training loads of high level endurance athletes increased by up to 20%. With the continued increase in perceived rewards, media exposure and scientific training advances, it is not hard to envision how this has lead to continued increases in training expectations and demands. It is also easy to see the increased psychological pressure young athletes experience, especially as parents pin hopes on collegiate athletic scholarships and beyond. This increased stress load can do a number on training progress and potential accomplishments, in addition to the negative impact it can have on the enjoyment of the game.

Even recreational athletes are training at higher volumes and with more intensity than ever before. As a result, tennis is being played at a higher level and the game continues to become more challenging, even for those at the beginning levels of the sport. This creates a spiraling effect of ever increasing performance expectations coupled with a parallel increase in the need for more training. In other words, both the psychological and physical stress of playing tennis is increasing, while little is being done to help athletes manage or learn appropriate skills to diminish the stress or reduce the perceived negative impact. Unfortunately, for many athletes, the pressure to training harder often translates to train more rather than to train smarter and as such training and life balance become more elusive than ever.

The paradox of training

Canadian sport scientist, Goss (6) has called the potential for both positive and negative consequences that can result from modern periodized workouts the "paradox of training". It has been well documented that periodized or progressively increased training loads and recovery cycles can lead to performance gains (7-9). However, it has also been well documented that athletes can also experience very negative consequences when training, both personally and in terms of competitive abilities (10, 11). These negative training responses or maladaptations can be physical and as well as psychological. These consequences are costly for athletes at any level, but can be even more so for those that are in developmental stages of personal as well as sport growth, such as youth and adolescent athletes. Of further concern, in the long term, a negative training related experience can lead to the departure from sport all together due to injury, burnout, or a combination of both. This makes the need for positive recovery and sport life balance all the more important.

What's in a name?

In both the literature and in common language, negative training responses go by many names, including overtraining, overreaching, over use, maladaptive syndrome, overstress, overworked and staleness. The wide variety of labels is related to the lack of consensus or definitive understanding of the problem itself within the scientific literature (12, 13) and the often singular focus of the studies (e.g. considering just cellular muscular damage or only psychological fatigue).

In addition to the perplexity caused by the multiple definitions, the concept of overtraining is often a confusing because the line between intended consequences (e.g., faster, stronger, better skills) of training and unintended ones (e.g., injury, staleness, burnout) can be very fine. Certain temporary negative consequences are expected while the athlete recovers and responds but the gray line of when they go from normal and recovering to lingering too long/they don't seem to be recovering is hard to pinpoint. As such, to date, researchers haven't been able to come up with singular definition or model that fits all the variables associated with overtraining.

To help focus the discussion for the purpose of this chapter, the most common and familiar terms will be used. Overreaching will be used to describe the short term intentional training stress or load that an athlete experiences. This is the center of training, the workouts designed to enhance performance through overreaching, or pushing athletes just beyond their current level of performance through changes in volume and/or intensity. When done properly, overreaching works an athlete hard and will make her tired and perhaps a bit sore. This response is expected and typically lasts one to three days.

Overtraining is used to describe the longer term unintentional consequences of training that are of concern. Overtraining typically last longer than just a few days, occurs when negative consequences linger, and can be both 'short' and 'long' term in nature. Short term consequences last several days up to a few weeks depending on many factors such as the preparation of the athlete and the level of training intensity, while longer term overtraining may last a month, a full season or even multiple seasons if not identified and treated properly. Overtraining may be due to too great of a stress load, insufficient recovery or a combination of both (see Figure 2). This becomes especially important when you consider that stress and recovery include both factors in and outside of the training environment.

Both overreaching and overtraining will have a negative impact on performance, however, the short term drop in performance seen with overreaching, is anticipated and is followed by gains. In the case of the overtrained athlete, there will be little to no improvement followed by further stagnation or drops in performance. As we will see, it is often the assumption of the coach and the athlete that is negative response is due solely to poor training design, lack of sufficient work load/intensity or lack of effort on the part of the athlete. This two dimensional application of the concept over looks several key elements that shall be discussed in this chapter.

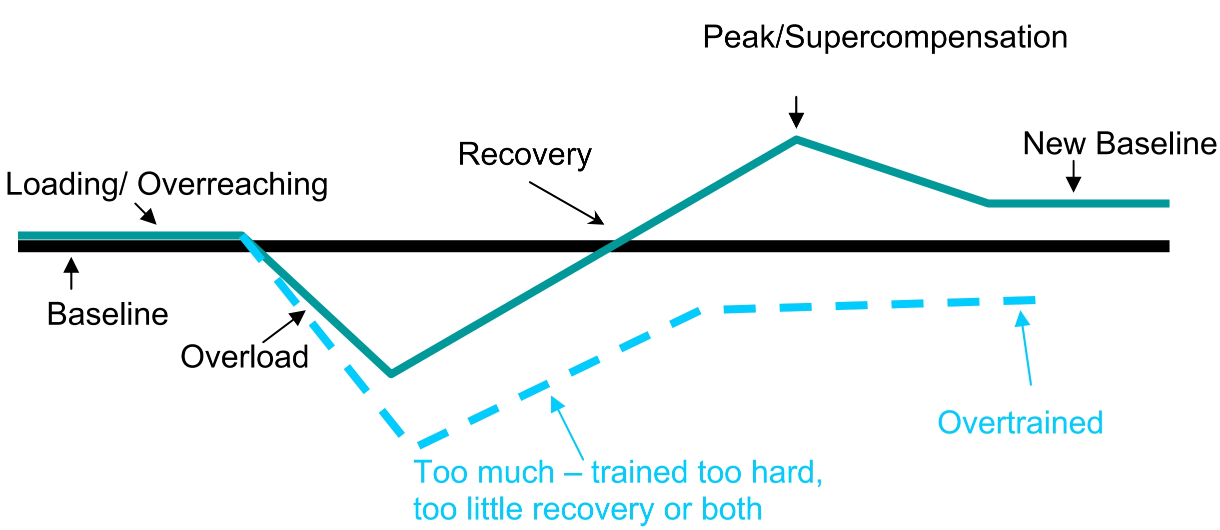


Figure 2: Poorly performed periodized overreaching resulting in overtraining

The impact of sport culture on training

Given the potential for overtraining among athletes and the potential for long term personal and performance damage, it is not surprising that it is an often discussed concern. Despite this, it is troubling how often the potential early warning signs are ignored or, worse, misinterpreted by coaches, athletes and parents as lack of effort or training. For many, drops in performance are automatically met with the response that more training and hard work is required. Pluim, the medical doctor for the Dutch Davis Cup Team wrote, in 1994, “unfortunately, a typical coaching response in such circumstances [reduced performance] is to work the player harder – which is usually the wrong thing to do”(14).

The idea that an athlete needs to back off is often a concept that is not well received, especially when a coach or athlete feels that training loads are not particularly great or intense. The athletic culture teaches a ‘go hard or go home’ mentality where only the quitters back off. In this environment, athletes fear being seen as not qualified or not talented enough, feeling inadequate, or not being ‘true athletes’. Additionally, both the athletes themselves and the culture of sport, separate the physical being from mind and expect high performance, regardless of any outside pressures or turmoil. As such, a solid understanding regarding physical overtraining, the influence of psychological and emotional stressors, the importance of recovery and the balance of stress to recovery necessary for peak performance is essential not only for the coach to understand but for parents and athletes as well. This will help dispel the myths and misunderstandings around peak performance and athletic training success. Let's begin by first gaining a better understanding of physical overtraining.

What science tells us about overtraining

As training knowledge expands, the sciences are helping the sports world gain a better understanding of how to enhance athlete performance through systematic training. In an effort to better understand why training sometimes leads to improved performance, while at other times it leads to overtraining, many researchers have attempted to quantify the experience using physical parameters (15, 16). Fry and colleagues have identified over 200 potential physical and psychological symptoms that have been connected to overtraining (10). While the list of potential side effects is quite long, this does not mean that overtrained athletes experience all of them or even a majority at one time. Most athletes report one to several of the more common symptoms (see table 1) of overtraining.

Table 1: Common Signs and Symptoms of Overtraining

Physical	Psychological
Decreased performance	Increased anger
Muscle weakness	Increase irritability
Muscle soreness	Increased depression
Chronic fatigue	Reduced motivation

Sleep disturbance	Mental exhaustion
Increased waking heart rate	Emotional exhaustion
Increased injury	Decreased self esteem
Increased upper respiratory infections	Sadness
Disturbed sleep	
Changes in appetite	

Although the signs and symptoms of overtraining have been well documented, early detection of physical overtraining is difficult due to the multitude of symptom combinations that can occur and the fact that many of the potential red flags are also associated with typical training responses one would expect to see with planned overreaching (3). For example, athletes often experience soreness or a bit of fatigue and irritability after a hard workout. These are common responses to any overreaching effort. By the time the soreness has lingered long enough to become a concern, the athlete is often already be in a state of being physically overtrained.

Overtraining Theories

Steinacker and colleagues (17) have called overtraining and the identification of the syndrome to be one of the most complex tasks in athletic medicine. As noted, in an effort to discover how to catch overtraining before it becomes a long term concern, researchers have sought to define and measure the symptoms experienced by athletes suffering from maladaptations to training (10, 12, 18). Multiple theories regarding physiological responses to training have been suggested in explanation of why athletes become overtrained (19, 20). While the majority of physiologically based theories have merit in explaining different physical aspects of athletic overtraining, no one theory has yet come up with a comprehensive overriding explanation. This has lead many researchers to conclude that multiple theories are probably at work within this complex problem. Basically, this is not a simple cause and effect problem with a singular solution. It is a multiple source, multiple outcome concern with many potential areas to address in the attempt at prevention.

Guided by the various physiological models of overtraining, doctors and researchers have found medical indicators that can be used to monitor and quantify physical overtraining. These include indicators such as heart rate, blood born and saliva born markers (21). Unfortunately, to date, none of these have proved to be useful for early detection or early diagnosis and none have proven to be practical for routine use (22). While the current medical markers can confirm an athlete’s overtrained status, particularly if compared against the athlete’s own established healthy baseline data, these markers are not useful until an athlete is already in trouble (23). Often, by the time medical detection is made, an athlete is overtrained to a point where recovery may take the better part of a season or perhaps beyond.

In addition to late detection, current methods of overtraining exploration are invasive and expensive. They require costly, time consuming and sometimes painful collections of blood, saliva and, on occasion, tissue sample. Thus, coaches and researchers have called for more practical and user friendly tools for the prediction of and ultimately the prevention of overtraining.

The understanding and exploration of the psychological side of overtraining and of the importance of recovery in the training model, have begun to play an important role in the study of physical overtraining and improved training management in an effort to reduce maladaptations and enhance performance (24). Before exploring the key connection between training and recovery, it is important to take a further look at overtraining as it applies specifically to athletes and the youth athletic population to understand the magnitude of concern.

The impact of overtraining on athletes

Research indicates that overtraining is a problem in elite athletics (25). High level training requires dedication, focus, and determination. Striving for performance improvements without going too far can be like walking a tightrope. And just like performing the daring circus act, misstepping or pushing too hard can spell disaster. Raglin and Wilson (26) reported that 7 to 21% of all endurance athletes experience staleness in a season and according to Kreider, Fry, and O'Toole (23) "overtraining is a major problem among competitive athletes" (p. vii). Over a quarter of the Olympians competing in 1996 reported that they felt that they had overtrained for the Games and that it had a negative impact on their performance (27).

While overtraining is often discussed in endurance based sports such as swimming, running, and cycling, this does not mean they are the only ones susceptible to experiencing negative training maladaptations. Difficulties among athletes across a wide variety of sports have been reported (28-30).

Traditionally, overtraining has been associated with high level college or elite level competitors. Kenttä, Hassmén, and Lunqvist, highlight the situation in elite sport “that many coaches promote athletes to become entirely devoted to sport and strive to optimize performance around the clock”, unfortunately they also underscore the fact that is the same athletes with intense levels of commitment that are the greatest risk for negative consequences(31). It is important to note, that overtraining and the myriad of negative consequences are a serious concern for younger athletes as well (32), The increasing pressure of youth related sport (33, 34) coupled with the increased volume of training for young athletes (35, 36) and the busy lifestyle that many Americans leads, sets up junior achievers as prime candidates for trouble.

Specific to the world of junior tennis, Gould and colleagues (37, 38) found high levels of youth sport burnout among this population. Burned out athletes lose their once high level of enjoyment of the sport and many never return. In addition to the tragic fact that poor youth sport experiences often have a lifelong impact on an individual, youth burnout also has a serious impact on the sport of tennis as well. When young people leave the sport of tennis with a bitter taste for the game, we lose potential future talent and/or lifelong fans and supporters of the game. By all accounts an outcome to be avoided as much as possible.

Beyond stagnant or decreased performance related to overtraining, research has found links to an increase susceptibility to upper respiratory infections (URI's) as well as chronic or overuse injuries(23, 24, 35). This increase in injuries could be due to any combination of overtraining factors such as repeated trauma to the injury site due to high training volume and/or intensity, poor form associated with fatigue, or poor attention related to the negative psychological impact of training. REWORK Specifically, the increased training loads in youth sport have been linked to a large increase in overuse injuries among junior players (39-41), which contributes to the overall overtraining problem. This provides another important reason to understand and take care to prevent this from occurring in youth elite sport.

Staleness

As noted so far, the discussion of overtraining often centers on the physical signs and symptoms of trouble. These concerns are significant, but they are not the only maladaptations experienced. Many athletes report feeling stale as a part of the overall negative experience they have in response to overreaching. Staleness is the relatively early sign that training may be going awry (42) and may signal the beginning of longer term problems. Staleness is associated with dropped performance, mood changes, psychological fatigue and increased perceptions of effort for tasks that didn't previously overwhelm an athlete. Some athletes may report feeling the psychological components of staleness before any of the physical concerns are apparent. Unfortunately, many athletes are reluctant to voice these feelings for fear of being perceived as unable to ‘hack it’ or handle the pressure of being an athlete.

Athletes who become stale or who are experiencing staleness may also lose focus easily, will have a lower sense of enjoyment, report higher frustration levels, and sleep disturbances (43, 44). All of which further contribute to the increasing sources of stress an athlete experiences. Creating a sport environment where athletes could safely acknowledge the potential early psychological concerns would provide coaches with a valuable opportunity to ensure athletes are able to handle and recovery properly before a negative impact on training is seen.

Burnout

Beyond staleness, the next level of psychological maladaptation is burnout. Often, burnout is associated as a consequence of overtraining. However, some studies suggest that burnout may not be a product of too much training or overtraining(38). As we shall see, social, psychological and emotional stress as well as inadequate resources or recovery, all play a potential role in better understanding, and ultimately preventing burnout.

Burnout occurs when psychological, emotional and potentially physical withdrawal from sport occurs (45). Athletes who experience burnout report feelings of detachment, lowered feelings of accomplishment, and emotional exhaustion (46). While some athletes leave sport when experiencing burnout, despite the reduced feelings of engagement and enjoyment, not all athletes experiencing burnout stop playing. Instead, they continue to participate with a less than optimal mindset, high levels of stress, and as a result often play less than effective tennis.

The Cognitive Affective Stress Model of Burnout (45), the most widely cited model, highlights four key areas that determine burnout. According to this model, (a) a demand is made of the athlete, physical or psychological, (b) the athlete assess the demand (typically as either challenging or threatening), (c) there is a physiological/psychological response of anxiety or fatigue if the assessment made at stage (b) is negative and finally, (d) there is a behavioral consequence such as decreased performance or reduced effort. How the athlete makes his or her assessment is based on personality and resource factors. These resource factors include both the things available in the environment, such as support from others, and personal resources, like the ability to problem solve.

Directly related to the world of elite youth sport, Coakley (47) has suggested that high level adolescent sport can create a structure that does not allow a young athlete to develop a well rounded self image, a key element to being able to cope with set-backs. Athletes can develop a very one-dimensional persona putting them at greater risk of burnout when faced with sport crisis such as injury or performance slumps. Additionally, the environment of competitive youth sport often provides the young elite athlete with few opportunities to develop and exercise a sense of personal control and practice decision making, both of which are theorized to contribute to burnout.

Another key model of burnout emphasizes the sport commitment held by the athlete (48, 49). According to this model, athlete's commitment is based on their satisfaction as related to the costs and benefits, attractiveness of alternative opportunities, and the resources invested. The sport commitment model has provided insight into the differences between athletes who experience burnout but remain involved and those who withdraw or leave when they experience burnout. These studies have found that the individuals who experience high investment and a low sense of alternatives are more likely to remain in sport, despite feeling burned out, a situation referred to as entrapment. These athletes feel an obligation to continue participation, often due to actual or perceived expectations or pressures from others such as parents or coaches. Young athletes who are very aware of the financial and time sacrifices of their parents and families and who feel the pressure of achieving a scholarship or similar outcome, may feel they have little choice but to continue playing. Further work is needed to better understand the potential for entrapment, burnout, and long term consequences for youth athletes.

Most recently, burnout research has linked athletes with an ego focused goal style to burnout experiences (50). In an ego focused climate, athletes focus on social comparison ('Am I better than her?'), outcome goals (the scholarship or tournament trophy), and preservation of their athlete identity. Further, an inverse relationship was noted between task orientation (process focused goals and personal accomplishment emphasis) and low reports of burnout. This study also found that female athletes reported significantly greater levels of burnout than did their male counterparts. Other studies (38, 51) have indicated that athletes with perfectionist tendencies are more likely to experience burnout. Coaches may want to pay particular attention to these athletes to watch for early signs of concern.

Specifically within the world of junior elite tennis, the International Tennis Foundation has acknowledged that burnout is an important concern (52). Gould and colleagues (37, 38, 53) conducted a series of studies to examine the experience of burnout among this population in the United States. As might be expected, key differences were found in situational and personal factors between young tennis players who reported experiencing burnout and those who didn't. The young athletes associated physical, logistical, social/interpersonal, and psychological concerns, although the combination for each athlete was unique. Of these factors, situational pressure, such as that from a perceived lack of a social life and parental pressure as well as psychological factors like a sense of decreased motivation and loss of fun were found to be among those most often noted by the interviewed athletes(37, 38, 53).

In a well done interview study of burnout in junior tennis players done by Goodger, Wolfenden and Lavallee (54) in England researchers found support for Raedeke's (55) conceptualization of athletic burnout. Athletes demonstrated physical and emotional exhaustion concerns, showed signs of sport devaluation and reported a reduced sense of accomplishment. An unfortunate finding was that even after eventual withdrawal from competitive tennis, the athletes indicated that their feelings of being burned out from tennis had not diminished. This is of concern because there is little research that explores the potential long term impact of experiencing burnout.

Harlick and McKenzie have also studied burnout in junior tennis (56). Using a population of young athletes in New Zealand, these researchers looked levels of burnout and potential contributing factors. Higher levels of reported burnout were associated with a sense of amotivation and high time demands and demanding or negative parental involvement were both found to be key issues in follow up interview work with athletes reporting the highest levels of burnout. The authors also cited the changing landscape of youth tennis from fun and development towards an adult professional model as a contributor to the pressures that these young athletes face.

The Youth Sport Experience

Nowhere have the changes in training been more dramatic than in the world of youth sport, including tennis. Prior to the 1980's, most children's sport programs focused on fun and basic skill development. Kids took summer lessons or participated leagues that lasted just a few weeks. It was rare for sport involvement in any one sport to go beyond that. Since then, across youth sports, there has been a drop in the age at which kids begin participating in organized adult run sport activities and a dramatic increase in the time, money, and emphasis invested in the training of young athletes (35, 36, 57, 58). Currently, it is not uncommon for youngsters as young as three and four to begin participating in lessons and organized adult model sport. Unlike the children before them, today's young athletes don't just practice once or twice a week, many train on a daily basis and compete in their sport year round. While the increased participation has raised the game, it has also increased the potential for pressure and problems for these young players (58, 59).

As global sports market continues to drive the value of talented athletes up well meaning, overeager and often under informed parents, hoping to give their children an edge buy in to the ‘sports as the way up’ idea. Stories like the one reported on the front page of a national new paper of a 5 year old player with full sized adult racket in hand (60) and an accompanying story about his ‘potential, the large tennis scholarship he had received and his families willingness to be uprooted thousands of miles to pursue training opportunities for this young player only fuel the often misdirected fire. The pressure to become what is expected of him is going to be tremendous on this young man and the odds that any youth player, no matter how talented, navigates the minefield of training, injury, and puberty and comes out on the adult side intact and playing at the top of the world are statistically minuscule at best. This does not mean that training and striving for greatness is not a worthwhile quest. But the system of talent development often overemphasizes the adult model outcome while failing to acknowledge the unique needs and influences on the junior developmental elite athlete. Coaches and parents of these young men and women should pay particular attention to the overtraining and underrecovery issues as they relate to the developmental athlete that are highlighted in this chapter.

In addition to the increased time spent in organized activities, youth sport has seen a concerning trend as more young people specialize in activities at increasingly younger ages. Even just 10 years ago the *'multi-sport letterman'* was the standard of athleticism in high schools and even many colleges around the country. The perceived potential payoff and adult model of play imposed on the developmental game have both parents and young athletes assuming that talent can only be fostered by a solo focus as soon as possible. This single minded focus can increase the young athlete's risk of experiencing overtraining, developing repetitive use injuries, and burnout complications due to poor life balance, inadequate recovery, and insufficiently developed coping skills.

In 1995, Hollander and colleagues (61) set out to examine what risk young athletes were at in the high stakes environment of sport. Their study compiled the current findings regarding adolescent athletes, maladaptation to training and burnout. According to their report, there was significant cause for concern regarding youth sport participation and burnout. Their recommendations were that coaches should receive training on detection and prevention.

While it is often visibly obvious that young athletes do not have the size, speed or strength of adult athletes, it is easy to overlook the fact that they are also not as psychologically as developed. Many do not yet process the ability to gauge their levels of stress and recovery, may not have the language to express their needs, and have not yet developed skills such as time management and resiliency necessary to copy with both the physical and psychological pressures of training and competition.

Generally speaking, growth and development from birth through the end of puberty, takes place in stages and these changes may occur at varying times. For example, physical growth of the long bones that make an adolescent shoot up and become the tallest in his class does not necessarily go hand in hand with changes in emotional maturity. This may occur earlier or later. Many people make the mistake of assuming that an adolescent-athlete's ability to handle situations or understand concepts will go hand in hand with his or her physical appearance or prowess on the court. However, research suggests that their coping resources are not as strong or as well developed as those of an adult (33). Further research (6, 34) exploring the ability of adolescent athletes to handle stress found older athletes were better equipped than younger athletes. Due to differences that can occur in maturation, parents and coaches need to be especially mindful of the multiple levels of development and the unique growth pattern for each individual child-athlete.

Further, Gould (37, 38, 53) also noted differences between the coping skills of individuals reporting feelings of burnout and those who didn't. Specifically, athletes who experienced burnout were more likely to feel they had less input into their own training plans, to perceive high expectations from key individuals (e.g. high perceived parental criticism), and were less likely to use planning strategies such as goal setting.

Beyond the physical: Brining together the mind body balance

Where physical medicine has not been able to help coaches and athletes predict or accurately monitor training and recovery for warning signs of trouble, sport psychology researches have been exploring the mental side of the training experience for clues (8, 62). Changes in mood as well a better understanding of how athletes perceive, experience, and cope with stress may help provide key information that will be able to help athlete properly plan recover and recover. This would improve their ability to stay healthy and avoid negative overtraining consequences.

Perhaps most significant shift in the sport science research has been the exploration of the training experience and the potential maladaptations by viewing the athlete from a multifaceted perspective that views the athlete as a whole person who trains rather than just from a myopic 'you are an athlete' perspective(11, 63). This new paradigm considers the stressors and resources outside the training bubble as well as the physical and psychological systems of the individual and how all these factors interact, as well as the potential negative and positive impacts on training outcomes. As Meyers and Whelan (64) state "performance is not simply dependent upon what happens in training or competition, but it is also contingent upon events in the larger world" (p.347).

A multisystem approach

Sport science has been striving to understand the experience of overtraining through a better understanding of the body's systems. While this approach is important, it is equally important to step back and look at the whole picture, what researchers Kenttä and Hassmén (11) refer to as the multidimensional athlete. Athletes bring both their mind and body to the court when they play and in addition to being tennis players they are siblings, children, students and many more things. As such, the stresses that they experience are a result of both the things they do in training, as well as from the elements in their everyday lives. Their ability to manage and recover from the multiple stressors will be based on personal as well as situational factors. Taking all of this into consideration is an important part of ensuring proper training balance.

Meyers and Whelen (64) have proposed a Multisystemic Model of Overtraining that considers the multiple sources stress an athlete may experience. They propose that overtraining and the related maladaptations are the result of an individual's ineffective response to prolonged stress experienced in one or more of the key areas: home, training, competition, and/or school. Similarly, the Conceptual Model of Overtraining and Underrecovery (11) encompasses the stress/stimuli, product/response or result and the final overall outcome. Both models help paint broad overview of the many important factors to be considered when striving to avoid maladaptations to training.

According to the Conceptual Model of Overtraining and Recovery, athletes experience multiple sources of stress, mediated by their recovery resources. In other words, the stress that an athlete experiences is filtered by the coping and recovery resources they have available. The amount of stress they experience impacts multiple potential areas of maladaptation: psychological, physiological, neuroendocrine, and immunological. The experienced impact can range from short to long term depending on the level of stress and the level of recovery resources available. Overall, the greater the long term effects, the greater the maladaptation and decrease in performance will be. This highlights the importance of being aware of multiple sources of stress, beyond the court, that an athlete might experience, as well as the importance of allowing for proper recovery and fostering and building coping resources.

Mood and overtraining

Some of the most interesting and promising research into the use of understanding the personal experience in an effort to better manage training and prevent overtraining, has been in the study of athlete mood. The most widely used measure of mood in athletics has been the POMS (65, 66) Researches have found that when healthy and well rested, athletes demonstrate a more positive mood profile while as they become physically and emotionally fatigued their mood profile shifts. Specifically, athletes who are experiencing negative consequences of training (short term overreaching or longer term overtraining) will have low vigor scores and will report high tension, depression, anger, fatigue and confusion scores. This is referred to as the iceberg profile (Figure 3).

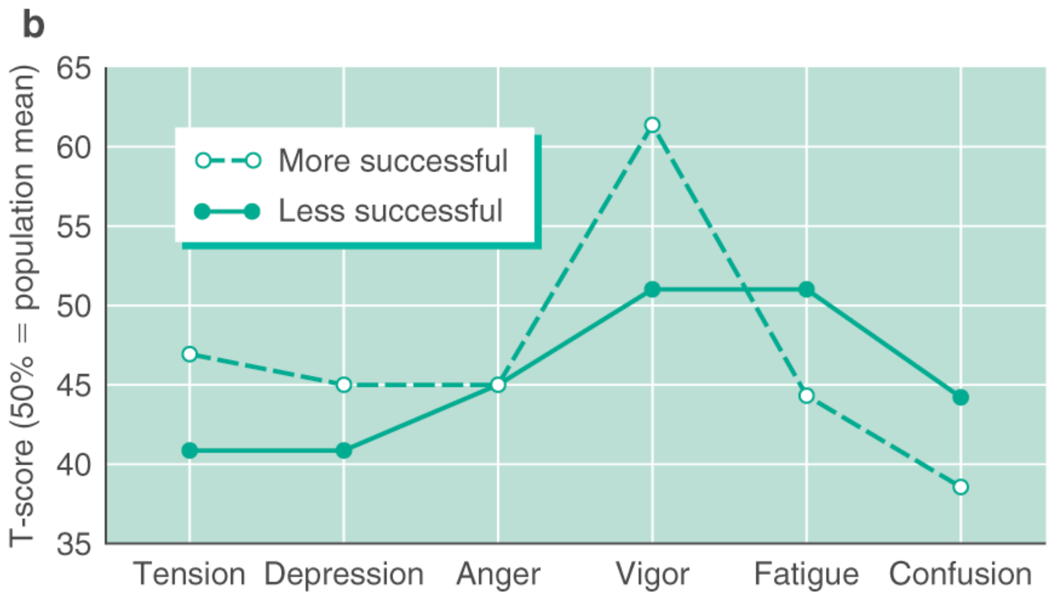


Figure 3. Profile of Mood States: Iceberg Profile (42)

Using mood state, researchers have been able to demonstrate a dose-response relationship between increased training loads and the more negative or iceberg profile of moods (8, 67). A great deal of individual variability exists in the exact profile that overtrained athletes produce indicating the need to consider each athlete and their personal mood profile on an individual basis. Recent work (68) has shown promise in using the measure of mood states in the exploration and adjustment of athlete training in an effort to reduce the potential for underrecovery and training maladaptation.

A closer look at stress and the athlete

As the Conceptual Model of Overtraining and Underrecovery and the Multisystemic Model of Training demonstrate, an athlete's performance is just one part of a much larger equation. Training stress combines with other sources of stress to impact an athlete. In order to successfully handle training and maintain a healthy life balance, the athlete needs to be able to successfully cope with or recover from the multiple types of stress. For example, a young tennis player who is struggling in math will often have trouble in other areas if the school stress (and possible related parental stress) begins to overwhelm him. As such, the interaction between an individual, his or her personality and coping resources, and the situation or environment, plays a crucial role in how well (or poorly) an athlete is able to manage stress (69). A coach working with this young athlete would need to be aware of and take these factors into account if training is to be successful both in helping this young man play tennis well and in an effort to help him develop into a well rounded, capable young man.

Stress and perceptions of stress are shaping up to be important parts of the overtraining and burnout prevention model. Increased stress has been found to be related to burnout in athletes (2, 37). However, stress shouldn't be viewed as inherently negative. Stress is simply strain that stretches resources. Stress is what makes life exciting. In fact, stress is in an integral part of sport, both training stress which elicits adaptations that make athletes stronger and faster, as well as competitive stress that keep matches exciting and unpredictable. Of course, there are also source of environmental (e.g., weather), social (e.g., friends and family), and psychological (e.g., self expectations) that routinely influence an athlete. Whether or not the stress they experience is negative or has negative consequences has a lot to do with an individual's perception of the event and his perceived ability to handle the stress (70, 71).

Traditionally in the sport model, the physical stress experienced by the athlete has always been considered central in the overtraining and burnout experiences. The expansion of the discussion to include the multifaceted life of the athlete and the multidimensional nature of their experiences has allowed researchers to step back and reconsider the influence of multiple sources of stress in the lives of athletes.

Resent findings indicate that although athletes experience training stress, it is often the additional experience of stress in other areas of life, the compounding impact of these stressors and the overall inability to recover properly that is related to the overtraining and burnout (63). This is in line with research that has highlighted connections between life stress, daily hassles and injury (72).

While it is outside the scope of the coach's job to handle or deal with the many sources of stress within an athlete's life, it is important for the coach to be aware of the multiple areas that may contribute to an athlete's overall load. The cumulative stress load is important because chronic stress has been related negative health and performance consequences (73). Regardless of the source, over time the build up of unresolved stress that an athlete perceives as being greater than what they can handle as well as lack of recovery from the sources of stress have been linked to emotional exhaustion, depression, lack of accomplishment and reduced performance (46). So the ongoing consequences of struggling in algebra, the feelings of not fitting in with ones peers, and/or too many days of intense practices without a day off all can potentially contribute to lower on court performance. Figure 4 provides an overview of the cumulative relationship between perceived stress, insufficient recovery, low or deficient coping skills as they result in burnout

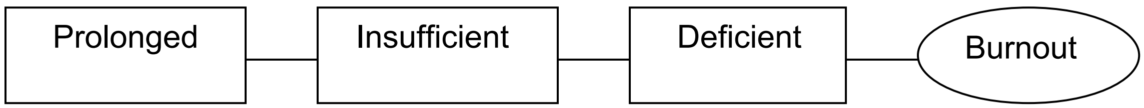


Figure 4: The relationship between perceived stress, insufficient recovery, deficient coping and burnout

Although stress has the potential to negatively impact performance, as well as on all well being, it is not an automatic sign of trouble ahead. As mentioned earlier, the impact of stress is filtered by whether or not an individual feels she has the resources to handle the stress. These resources can be internal (e.g., personality, hardiness, optimism) or external (e.g. social support). The key element is the perception that the situation is not beyond one's control.

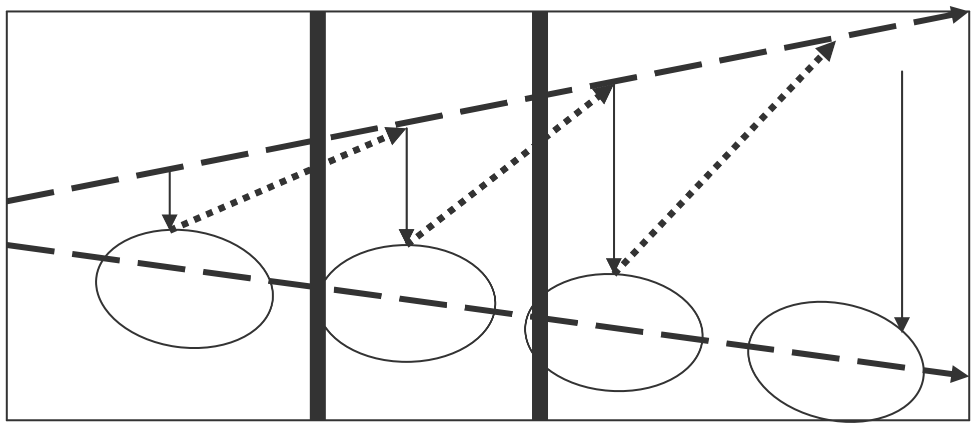
Recovery: The other half of the training equation

While coaches and athlete spend a lot of time and energy on the quality and intensity of training, the equally important element of recovery is often taken for granted. Meyers and Wehlen (64) suggested more maladaptive training problems are due to underrecovery than overtraining. The shift to exploring the problem from the context of underrecovery in sport (43) may provide coaches and athletes with better understand the importance of this concept as well as provide insight into proactive things that can be done to prevent problems before they start.

In this shifted paradigm of training, physical workload matters, as do additional sources of stress. Physical training intentionally tears the body down and other daily stressors wear on the athlete as well. It is important to note that even emotional and psychological stressful events have been shown to cause physical changes in the body, such as increased levels of the stress hormone cortisol. The physical research literature acknowledges the importance of recovery in the equation for training balance (10, 18). The under recovery model follows a similar focus but emphasizes the additional sources of stress from the multidimensional athlete concept as well as the personal and social resources an athlete has for coping and recovery. Ultimately the goal of recovery is the same as avoiding overtraining, to make athletes strong and quicker after they experience training. Properly planned and provided for recover allows for the physical adaptations and emotional rejuvenation if properly matched.

Recovery is not static. In the process of striving towards peak performance, not only does the nature of training change, so too does the need for recovery. As volumes and intensity of training increases, the need for recovery increases as well. Athletes may need more time between line sprint sets, more sleep, or more days off between high intensity workouts to maintain quality training. Unfortunately, when the changes in demands (physical or psychological) are not matched by changes in recovery, problems occur. Kellmann's (43) Scissor Model (figure 5) demonstrates that the greater the distance between the demands of training and the resources for recovery, the great risk there is for overtraining.

Figure 5. The Scissors Model of Training Stress and Recovery Needs (41)



Poorly recovered athletes are unable to meet new training demands (41). They may also experience boredom, frustration, decreased self esteem, and negative self talk (74). The end result of poor recovery is the same as that of overtraining, an athlete who will experience the physical and psychological maladaptive responses that result in performance loss, decreased enjoyment, potential illness or injury, and most likely burnout.

Even when the importance of recovery is acknowledged, many coaches and athletes are unclear on how to prevent underrecovery. Often recovery is viewed only in the passive form of time, the ‘if I train hard today and don’t tomorrow, I’ll be rested and therefore improve by the next day’ approach. Kellmann (41) suggests that recovery needs to be viewed in terms of both passive and active forms. For proper recovery it is crucial that athletes are proactive in their use of both forms of recover. Passive recovery activities include treatments that emphasize automatic processes such as ice baths to reduce inflammation and allowing adequate time to pass between workouts. Active recovery activities involves light, no load activity that helps facilitate the flushing of waste products from the system while not adding any new load like jogging or walking at the end of a training session or doing easy yoga.

No matter what sources of recovery are used, the balance between stress and recovery and the proactive use of recovery techniques remain at the center of a successful recovery strategy. Table 2 provides a list of both active and passive recovery options that athletes can employ to facilitate balance after experiencing physical, psychological, environmental or emotional stress loads. It is important to note that both active and passive recovery activities can be both sport and non-sport related

Table 2: Active and Passive Recovery Suggestions

Passive Recovery	Active Recovery
Massage	Light recovery activity
Hot baths	Muscle relaxation
Ice baths	Stretching
Quiet down time	Time with friends

Perhaps one of the most important elements of recovery is proper individualization (75). Just like training, a one size fits all approach is not appropriate for adequate recovery. Interviews with elite level athletes who have been both successful and unsuccessful at managing training balance found that recovery activities tailored specifically to the athlete were most successful at helping them maintain balance(24, 31). Athletes indicated that they often determined their personal recovery strategies through both trial and error and with help from others. From a physical perspective, coaches are often aware that while some athletes can train hard 3 or 4 days in a row without a break, others may need to take a break after every 2^{nd} intense session or they need to alternate hard and easy days. The same individual principles apply to the need for individualized psychological recovery. For some, personal recovery might be just playing a match for fun with no critique or objectives or playing a different sport like pick up basketball, while for others it might be completely unrelated to sport and may involve going to mall to hang out with friends or watching a favorite movie. The key is that the individual athlete is aware of his or her own personal recovery needs as they match up with the type of stress they are experiencing.

Importance of hardiness, optimism and support

As explored in the examination of stress and the athlete, the perception that an individual has regarding the situation (challenging vs. overwhelming) plays an important part in the way stress is experienced. In addition to assessments made regarding the situation, an individual's resources, both personal and environment, to handle the stress, is an important part of the whole equation and plays an important role in the level of recovery experienced.

Dispositional hardiness, a construct that includes the level of challenge, control and commitment that an individual has, has been theorized to have a buffering effect on the negative impact of stress (76, 77). Individuals with high or positive hardiness feel committed to a task and feel it is worthwhile, they feel they have a degree of personal control over the situation, and they see positive challenges associated with the activity that they can handle (78, 79). A related construct, optimism, has also been associated with lower perceptions of stress (80). Both hardiness (6, 81) and optimism (82) have been associated with lower perceptions of stress and better training balance. Further, both constructs appear to be things that individuals can learn or develop over time. Goss (6) found that older teenage athletes demonstrated higher hardiness scores than did younger athletes, indicating that it develops over time.

Positive coping skills (action and problem solving focused) have also been related to lower perceived stress and better perceived recovery from stress (74). In a study of high school students, researchers reported that individuals who felt they had stronger coping skills were less likely to perceive situations as being stressful (33). Overall, the better an individual’s perceived ability to handle situations is the more effective they will be at navigating through the rough spots.

In addition to personal factors that can reduce the impact of stress, social support from those in an athlete’s environment can also be connected to better coping and improved outcomes. Social support is provided in multiple forms and should be provided by multiple sources. Rosenfeld and Richman (83) created seven categories of support. These include listening, emotional support, emotional challenge support, reality confirmation, task appreciation, task challenge, and personal assistance. Not every athlete will need or benefit from each type of support but having the sources of support that one needs will have a positive impact on perceived stress and perceived coping ability. Keep in mind that is not the responsibility of any one individual to provide the athlete with all of these types of support. In fact, athletes will fair much better if they have multiple people providing different types of support. For example, parents should provide the listening and emotional support, while it is more a coach's role to provide the task challenge support an athlete needs. A coach may want to be aware of where an athlete gets the different types of support, to help enhance their overall ability for proper recovery. Table 3 provides an overview of each type of support.

Table 3. Categories of Social Support (76)

Listening Support - perception that one is listening without giving unrequested advice or being judgmental

Emotional Support - perceptions of unconditional care and comfort

Emotional Challenge Support - perceptions that one is being challenged to evaluate their own attitudes, values and feelings for the purpose of positive growth

Reality Confirmation Support – perception that someone else sees things in a similar manner or has had a similar experience

Task Appreciation Support - acknowledgement of efforts

Task Challenge Support – perceived motivational guidance and support to help the athlete improve a skill or effort

Personal Assistance Support – perceptions of financial or tangible support such as funds or transportation

Summary

On paper, shifting volume and intensity and building skill development progressions for athletic development is relatively straight forward. Train an athlete, provide a stress, allow for some time to pass, and reap the benefits of improved performance. In this framework, overtraining has been primarily viewed from the physical perspective, with psychological components being viewed only in the light of negative outcomes of a plan gone awry.

Newer schools of thought on optimal training have been developed to enhance training, reduce negative consequences, and provide athletes with improved life balance and well being. This shift in training theory emphasizes the role of active and aware recovery, the understanding of psychological stress influences in the training process, the power of perceived stress and recovery abilities, and the expansion of the training model to include a multidimensional view of the athlete and his or her resources. Figure 6 provides an overview of the holistic model of the athlete within the framework of the training and recovery environment.

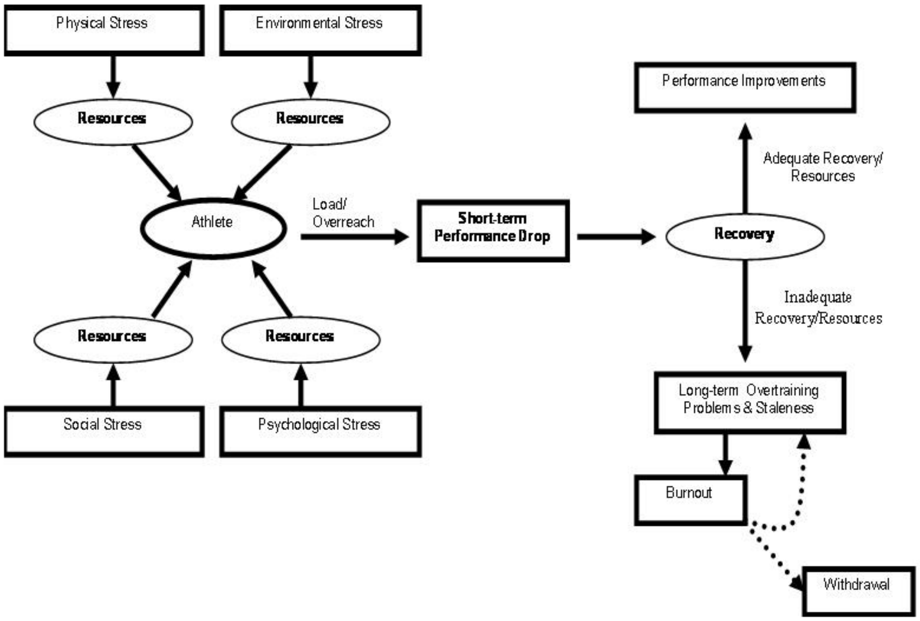


Figure 6. Multidimensional Model of Training and Recovery

Shifting the focus from purely the physical to a broader view will allow coaches to follow noted Welsh strength and conditioning coach and scientists, Jefferey's suggestion to "Train smart, train hard and recover well" (84) in their efforts to help young athletes become the best tennis players, as well as the best people, they can become.

What Can Be Done

Prediction: Who is at risk and when is trouble likely to occur

Currently, there are no measures that will, without fail predict overtraining. Due to the complex nature of training and of athletes, it seems unlikely that such a measure will be realistically available in the near future. The use of non invasive physical markers such as heart rate monitoring and tracking of sleep quality and amounts can provide some insight into the training response; however, they provide little information about what aspects of training or life are having the negative impact on an athlete.

The most promising way to handle overtraining is to better understand the athletes and their training experiences as well as to help build and provide strong skills and attitudes. Learning more about who your athletes are, what other sources of stress they experiences and how they handle stress (perceptions and available coping resources) will provide the most in-depth information for making accurate training and recovery needs adjustments and provide athletes with the strengths necessary for healthy balance.

Who is at risk?

Being aware of which athletes are more susceptible to overtraining can be an important first step to prevention. There are a few strong cautions when considering an athlete's susceptibility, however. First, given the very volatile nature of being an adolescent and the shifting hormones, developing skills, and experimentation with personal self identity, coaches should keep an open mind regarding an athlete's coping strengths as they relate to perceive likelihood to be under recovered. Additionally, assessing an athlete as high risk can create a 'self filling' prophesy situation, while assessing an athlete as low risk may give a false sense of security and cause the oversight of early signs of concern. Either of these situations creates a scenario where the individual has been lost to the stereotype of who they might be.

Precautions noted, athletes at higher risk for experiencing overtraining include those who:

- are younger,
- have less well developed coping skills,
- have experienced an injury or performance slump,
- have perfectionist tendencies,
- demonstrate a high need to please others (particularly parents and coaches),
- display a high athletic identity (only see themselves as being an athlete),
- are in situations where high demands or expectations are placed on them or they perceive the demands to be high,
- and are highly self critical.

Awareness of key psychological and behavioral cues that may signal poor recovery can provide warning for the prevention of overtraining. Early detection of changes in mood, self confidence, and sleep patterns (85) all have the potential to help prevent training maladaptations.

Clearly define recovery

True recovery goes beyond simple time off from an activity. For recovery to be complete and useful for achieving balance and optimal recovery, it is crucial that it be matched to the needs of the individual and, more specifically, to the type of demands being recovered from. This requires a clear understanding on both the part of the coach and the athlete, regarding the nature of the stress as well as the recovery needs of the athlete be well understood. This process will require trial and error, education, as well as open clear lines of communication. Athletes who fear rebuff, ridicule or reprisals such as loss of court time, will be hesitant to speak up about stress and recovery. Creating an on court culture that stresses the value of the process of training and performance gains over merely outcome will help create a situation where athletes are able to be open and honest..

Psychological measures

Multiple psychologically based measures of monitoring athlete response to training have been developed. As with any psychological measure, it is crucial to use the measure as it was intended and according to the given parameters for the information to be useful, reliable and valid. These measures were not intended to determine athlete selection or to explore long term overtraining. These measures were designed to be used across time to help both coaches and athletes better understand how an athlete typically responds to training so that changes can be explored. Ideally these measures allow the comparison of pre season or low stress data to other points in the season. When used consistently, these measures can help identify at risk times and potentially areas for intervention with individual athletes.

With the use of any paper and pencil personal assessment, it is important to acknowledge the potential for subjective athlete feedback. Athletes may be concerned with how their responses may be interpreted or how the results may impact his or her ability to train or compete; as such they may try to manipulate their scores. Repeated use of the measures as well as clear and consistent instructions and reassurance as to the purpose of the measure can help reduce this concern. As a coach, be sure to provide clear and useful feedback across time, to help athletes better understand both the value and purpose of these tools.

RPE – Rate of Perceived Exertion

The simple Borg's Scale of Perceive Exertion (86), using the 6 to 20 rating of low to high effort, or the simplified 1 to 10 scale, can be used to help athletes assess effort. Kenttä and Hassmén (68) have suggested that athletes can use the familiar Borg scale to assess workout stress and then recovery activities can be rated using the same scale format. Ideally, recovery activities will equal perceived exertion of training. Further, they suggest the use of the TQR, Total Quality Recovery concept where athletes account for both recovery actions and perceptions. Recovery actions are assigned point values with optimal hydration receiving eight points, nutrition two points, sleep and rest four recovery points, relaxation and emotional support three points and stretching and warm down earning up to three points. Totaled these activities have the potential to add up to 20 Total Quality Recovery action points. This approach can be useful to help athletes learn to take ownership for their recovery actions and to equate effort to recovery needs.

POMS

The POMS asks individuals to indicate how they have been feeling "this past week, including today" using 65 different adjectives in six mood areas: tension, depression, anger, vigor, fatigue, and confusion. Rating options range from 0 (not at all) to 4 (extremely). All but fatigue are negative mood states. While the POMS doesn't provide the whys or sources of the athlete moods, over time, the POMS allows for the monitoring of an athlete's mood for changes or disturbances. These can then be further explored. Additionally, mood tracking over time can help an athlete better understand the mood shifts that routine occur as a regular part of overreaching. A coach interested in exploring the use of the POMS for monitoring team or athlete recovery should contact one of the many researchers conducting current work in this field .

Recovery Cue

The Recover Cue is a seven item measure created by Kellmann, Botterill and Wilson at the Canadian National Sport Centre for use with their athletes (87). The items (table 4) cover an athlete's perceived recovery over the course of the previous week.

Table 4. The Recovery Cue (79)

1) How much effort was required to complete my workouts last week?

1	2	3	4	5
Excessive effort				Hardly any effort

2) How recovered did I feel prior to the workouts last week?

1	2	3	4	5

Still not recovered — Feel energized and recharged

3) How successful was I at rest and recovery activities last week?

1	2	3	4	5

Not successful — Successful

4) How well did I recover physically last week?

1	2	3	4	5

Never — Always

5) How satisfied and relaxed was I as I fell asleep in the last week?

1	2	3	4	5

Never — Always

6) How much fun did I have last week?

1	2	3	4	5

Never — Always

7) How convinced was I that I could achieve my goals during performance last week?

1	2	3	4	5

Never — Always

Like the POMS, the Recovery Cue does not provide specific details about what is causing changes in the athlete’s environment, but like the POMS it allows for the monitoring of the athlete’s state over time. The specific nature of the questions as they relate to training and sport also help guide questions and follow up interaction when changes are noted. The Recovery Cue format can be easily modified to suit specific sport needs or concerns and can provide a coach with key starting point questions regarding how an athlete is doing.

REST-Q-Sport

The REST-Q-Sport (88) is a longer more detailed measure than either the POMS or the Recover Cue and as such it provides a greater amount of detail. Two versions of the measure (a 72 or a 56 item form) are available to help a coach explore an athlete's perceived stress and perceived recovery across a variety of general and sport specific domains (Table 5). While the inventory can be done using paper and pencil, it is also available in electronic form that allows for responses to be easily charted over time. To date, the REST-Q-Sport has shown promising results in helping coaches work with elite level athletes and monitor for early signs of overtraining/ underrecovery related concerns (89, 90). The full measure, instruction manual and a program disk for administering the Rest-Q Sport has been compiled into a book The Recovery Stress Questionnaire for Athletes by Kellmann and Kallus published in 2001 and available from Human Kinetics Publishers.

Table 5. Areas of measurement on the REST-Q-Sport (80)

General Psychological Stress	General Psychological Recovery
General stress	General well being
Social stress	Success
Conflicts/pressure	Social relaxation
Emotional stress	Self regulation
Lack of energy	Self efficacy
Emotional exhaustion	
Fatigue	
Sport Specific Physical Stress	**Sport Specific Physical Recovery**
Somatic complaints	Sleep
Injury	Somatic relaxation
Disturbed breaks	Fitness/being in shape
	Personal accomplishment

Prevention: Practical advice for preventing overtraining and underrecovery

Education

Perhaps one of the most basic and easiest to implement guideline for the prevention of overtraining and underrecovery among athletes, is though athlete (and potentially parent) education. Athletes who understand the focus and intent of training are better prepared to handle the stress that will accompany increasing volume and/or intensity. Further, awareness of the symptoms they may experience during intended overreaching as well as early warning signs of staleness will empower athletes to monitor their own responses more effectively

Athletes typically understand that they have to work hard in order to improve and in order to succeed. What many athletes do not understand is that training is not the actual cause of improvement. Only when training is matched up with proper recovery can positive adaptations happen. Conclude training sessions with a clear discussion of the recovery activities necessary to facilitate adaptations. Provide athletes with an understanding of the active and passive recovery they need to make the most of training and to handle the stress they experience in life that may potentially impact training.

Be proactive

Don't wait until problems occur before beginning overtraining and underrecovery prevention. Training balance should be a part of season and practice planning. Brainstorm recovery strategies and consider potential contingencies plans for injuries, staleness, unexpected life stress, and other potential training barriers or recovery concerns. The better prepared a training plan is, the less likely that unexpected events will cause derailment. Whenever possible, include the athlete, at an age appropriate level and empower them to take care of their own recovery needs.

Bring the parents into the discussion of recovery and balance

Parents may not realize the potential that they have to be either a tremendously positive force or a negative one with regard to their child's participation (or lack of continued participation) in tennis(91). Educate parents, particularly those new to tennis or those who appear to be overemphasizing winning or who are overly involved, about the potential negative impact of over scheduling, high stress expectations, and over emphasis on just one aspect of life. Provide clear guidelines for parents regarding what to expect when training loads are high, warning signs of trouble to be on the look out for, and be very clear about how they can best facilitate their child's growth and recovery. Overall, do more than just make your own stand on these issues known, make sure the parents have clear suggestions and guidelines about the positive and helpful behaviors they can contribute to their young athlete's developmental environment.

Individualize

The one thing that has been well established through multitude of overtraining and underrecovery models and elements, is that every individual's experience is highly unique. Just as training plans are optimal when individualized, so too are recovery/balance plans. Understanding the unique stress sources, the recovery skills and resources, and the perceptions of optimal balance of each athlete, will provide the key information needed to create the best suited plan for his or her growth and development.

Know and utilize the basic recovery modalities suited to tennis

Perhaps the most obvious recovery resource is one that is as over looked and taken for granted as recovery itself, sleep. You lay down, you get up – there you slept. This ensures neither restful nor quality sleep and this does not guarantee that the sleep has provided recovery. Reid, Crespo and Calder (92, 93) in a series of articles on recovery modalities for tennis suggest that a minimum of 7-9 hours of shuteye a night is key. Of course, developing teens have been found to need 10 or more hours. Unfortunately, across all ages, most Americans have been found to get inadequate sleep most nights.

Proper sleep is crucial because in addition to the mental down time, many physiological systems such as cellular repair and growth only occur at optimum levels during the sleep cycle. Sleep cycles that are too short or that are disturbed by TV, electronics (e.g. ringing cell phones) or other distractions can reduce the effectiveness of this recovery activity. Reid and colleagues point out the importance of setting up a sleep routine, using relaxation techniques and avoiding stimulants such as caffeine or a high protein meal in the hours before bedtime.

Other useful passive recovery techniques might include curling up with a good book or listening to music. You may have to help your athletes brainstorm ways to find private quiet time, especially those who live in busy multi-children households or who are living in a dorm style setting.

The concept of active rest is often very popular with athletes because it is proactive, it is all about specific things they can do to become better at their sport. Teach and provide reminders to stretch, cool down properly, and cross train effectively. Make sure they understand what it means to rest on a rest day and why it matters. Provide athletes and their parents resource contacts for professionals who specialize in facilitating healing and recovery such as massage therapists, physical therapists and acupuncturists.

Respect the other stress sources and facilitate positive stress management

On the courts, it can be easy to forget that training isn't the most important or only element of the players life, especially when the athlete is enthusiastic. As much as we would like training to be independent from the other stressors and activities, the reality is that they often overlap. Understanding and acknowledging the multiple levels of stress that an individual may be experiencing will help when determining what levels of recovery are necessary. For example, ideally when an athlete steps onto the court, all focus is on practice and the stress of school is forgotten, unfortunately this is not always automatic. This transition can be difficult for any athlete, especially younger ones. Creating a warm up activity that allows for recovery from the tension of school will provide a smooth transition into practice and will help the athlete be better prepared for the stress of training.

Cultivate the team

One of the important factors cited by young athletes, is the importance of peers, particularly as they move from childhood to adolescents. Unfortunately, the nature of competitive athletics with heavy practice and competition schedules, often sets the player apart from his or her peers, even among those who play tennis. This removed the opportunity to build and cultivate key peer relationships that would provide fun as well as peer social support. Strive to create a team culture that allows for opportunities to socialize. Warm up, cool down and competition travel all allow great opportunities for kids to be kids with their friends. Encourage friends and peers outside the sport as well to help athletes maintain a well rounded sense of self and to provide a great network of support when things go well or poorly.

Facilitate post workout recovery

As a part of the job, coaches get out baskets of balls, check the nets, and fill water coolers. In your preparation for training, don't forget to coordinate necessary resources for post training recovery. Are water and healthy snacks available? Have you made parents aware of what post practice food should be available and when to optimize recovery? Do you provide time to stretch and cool down appropriately? If possible are passive recovery resources such as ice cups or bags available and stretching maps out to encourage stretching. Maybe the club will even set aside a designated recovery area to encourage post workout care. The more the coach does to facilitate and emphasize the importance of recovery activities, the more seriously the athletes will take it and the better their follow through will be.

Shared ownership of training

Traditionally, particularly for junior athletes, coaches design and implement training. Age and level appropriate shared ownership of training will allow athletes to increase their decision making skills as well as perceptions of control. Involvement in the activities that matter most to them will help foster positive engagement and reduces the risk of burnout or withdrawal. Further, it helps draw then into and promotes ownership of their own efforts when training is done ‘with them’ rather than ‘to them’.

Supporting athletes

Research has clearly shown that support plays a key role in stress coping. However, it is not necessary, nor is it realistic for the coach or any singular person to provide an athlete with all the needed support. Instead, a coach should work together with an athlete, assistant coaches, parents and teammates to identified needed sources of support and resources that an athlete might have. Then occasional follow ups or reminders can be used to encourage athletes to use their support resources when stress loads increase or when resources feel as though they are dwindling. Keep in mind that the majority of support resources that an athlete may need to maintain a healthy training balance may be outside of sport. Encourage the involvement of parents in the creation of an unconditionally supportive environment that includes opportunities for both parental as well as positive peer support (friendships) both in and out of tennis.

Goal setting

Goal setting is a versatile skill, that if done properly, will not only help an athlete achieve something, but can also boost confidence and empower an athlete to feel they can be successful. Much has been written about the power of goal setting for achievement both in and out of athletics. Strive to create a task centered goal setting environment where the emphasis is on personal growth and development, stepping stone improvement, and self challenge. Avoid singular use of outcome goals that emphasize only comparison with others or rigid demanding goals that only support perfection.

Keep the fun

At first glance, keeping the fun may seem overly simplistic and counter to the demands of elite sport. However, all fun is not created equal. Carefully consider the motivations of your young athletes. At the heart of it, many young athletes compete to feel competent and worthy and to enjoy the activity (94). Be aware of your athlete's readiness to treat training like work (or not) and provide practices that tap into their level of motivation. Even older, elite athletes report that they no long wish to play when it is no longer fun. The definition of fun may change, but fun remains a central theme even for professional athletes. Athletes who enjoy an activity and gain a sense of self worth are more likely to remain resilient in the face of frustrations, fatigue and other challenges.

Foster control, challenge and commitment

Hardiness and the accompanying elements of perceived control, assessment of a positive challenge and commitment or feeling an activity is worthwhile is an important component for successfully managing stress. Further hardiness can be developed and strengthened over time in an environment that teaches and models positive hardiness. Help athletes better understand the factors within their control (effort and learning) and place less emphasis on those that are beyond their control). Help athletes, through formal goal setting and day to day practices, set realistic but personally satisfying goals. And make sure that participation in tennis continues to provide an athlete with the sense of accomplishment and the supportive environment necessary for maintained commitment.

Use breaks

Water and rest breaks are a common part of any practice plan. But what about breaks from training itself? The use of breaks, both planned and spontaneous, can be an important part of helping your athlete maintain positive balance. Planned breaks can be something to look forward to, particularly when planned overreaching is at its peak. Unplanned breaks can provide a pleasant and well deserved reward for hard work or can be an intuitive coach's way to help athletes cope with end of semester finals or anxiety over an upcoming match. Monitoring athletes moods, affect or other element (see Prediction) will provide insight into when these might be most effective.

Understand and craft your sport culture

Even the most well equipped athlete may struggle in a sport culture that doesn't recognize the importance of balance and recovery. Careful consideration of the environment and prevalent culture should include the language used and the goal emphasis. It is easy for the competitive nature of an upper level, where it appropriate and the participants have the skills to cope with it, to become the environment for all levels. This creates a situation of pressure and outcome focus that may be inappropriate for developing younger athletes. This can be further compounded by the media culture which places an overemphasis on outcome as well. Strive to intentionally create an age and developmentally appropriate culture for the different levels of athletes that allows for both age and situation appropriate recovery. This will provide a safe, realistic and appropriate model of balance for these young players.

Encourage athletes to be multidimensional by acknowledging other activities they do and by taking an interest in them beyond their athletic ability. Simple questions about sibling, hobbies, or vacation plans can help de-emphasize the dangers of the development of a one-dimensional identity. Allow a creative athlete to make locker decorations or encourage an outgoing athlete to help a younger player with a drill. Acknowledging these 'off the court' skills help athletes see themselves as having more value than just as a tennis player. Ironically, this greater sense of self will actually strengthen their tennis by reducing the stress of only being good at one thing and helps them better manage frustration.

Seeking additional resources

Despite their best efforts, athletes may not be equipped to handle the multiple sport and life sources of stress they will experience as elite junior athletes. Meehan and colleagues (63) found that even competitive adult athletes struggled with balance and overtraining issues. Dr. Robert Heller, in an article advising coaches on how to work with anxiety in young tennis players advocates that “the serious player should have a ‘team’ to work with’ or to at least have an advisory board that can be utilized when trouble occurs(95).

In the effort to enhance recover, provide better balance and reduce the potential for maladaptations such as burnout a sport psychology consultant who specializes in skill development and sport performance can be a useful tool for a team and/or for an individual athlete. Be sure to find a professional will a strong knowledge and understanding of both competitive sport as well as the needs of the youth sport athlete. The Association for Applied Sport Psychology provides a state by state data base of consultants certified in the practice of applied sport psychology at http://appliedsportpsych.org/consultants .

The language of balance: Preparing an athlete for healthy training

Being an athlete is a very non-traditional lifestyle. The young tennis player is often following a very different path than many of his or her classmates. While friends are going to the mall on weekends, chatting on the computer, or hanging out after the movies, the young athlete is practicing and traveling to tournaments. Encourage the young athlete to decide what they want balance to be for them. Often it is the unrealistic expectations of being able to do it all or having the same 'balance' that someone else has that places undo pressure and stress on an athlete. Remind them of the importance of personal and individual balance and the need to know and respect their own needs.

What about your balance?

Recovery and balance become mere words without meaning if, as a coach, you are not providing a healthy role model for both. Consider your own sources of stress, how you perceive and handle them, and your recovery resources. Strive for a personal sense of balance. It may be a busy life and schedule but it shouldn't be a stressed out one. Do you keep an optimistic mindset with a focus on problem solving and an emphasis on taking care of the factors you can control while letting go of those out of your control? If your actions and behaviors don't demonstrate balance and respect for recovery. the message to your athletes get will work against all the positive balance and proper recovery mindset you try to instill. Our actions always speak louder than our words, especially under watchful teenage eyes. Taking it a step further, be aware of your own recovery habits regarding hydration, nutrition, stretching, and caring for injuries. Again, a do as I say not as I do model will only undermine the effectiveness of your teaching.

Rehabilitation: Return from edge

Recovering from overtraining and underrecovery depends on many factors. Athletes and coaches often don't realize that an athlete is in trouble until several weeks may have passed. And as noted, the common initial reaction to dropped performance is to push harder. As a result, athletes typically need two or more weeks of physical rest. Some athletes may even need several months of little to no training stress to allow the body to recover if overtraining has taken a great toll.

While recovery from overtraining is possible, it is not without disruption to an athlete's training and competitive plans. More importantly, experiencing overtraining can shake an athlete's confidence in her ability to perform. Overtraining and underrecovery can often be a more difficult journey because unlike an injury there may be no visible problem other than poor performance and the emotional concerns.

Prepare an athlete regarding what to expect and help him or her create a realistic timeline, much as you would for the recovery from an injury. Work together to understand the mis-match of stress and recovery resources that set the athlete up for maladaptation to training and brainstorm together ways to improve future training designs. Also, encourage the athlete to seek out support from peers, family and others as a means of building additional recovery resources. The use of task focused goal setting and encouraging personal investment in the process will also enhance recovery and facilitate the building of strong skills once the athlete is back on track.

Frequently Asked Questions

How many matches it is appropriate to schedule in a given day for a junior (18 years old or younger) player?

There is no hard and fast answer such as a match up between age and number of recommended matches. Instead, it will be important for the coach and parents, together with input from the athlete, to determine and set limits on number of matches an athlete plays in a single day or over the course of a weekend. When determining then number of appropriate matches, important factors to consider include the age of the athlete, the depth of experience the athlete has had, and the level of coping skills and recovery resources the athlete has. A useful rule of thumb is to start slow or with a minimum number of matches initially. Let the athlete's interest and an assessment of how well he or she handles a variety of stressful situations be the guide.

How much time should be allowed between individual matches to allow for adequate recovery – to allow for high level performance while also reducing the risk of injury?

Adequate recovery depends on the demands of the situation. Coaches and parents need to know the athlete well enough to be able to determine an individual's recovery needs on a situation by situation basis. Recovery should not become the topic of discussion only at match time. The needs and implementation of balance stress to recovery should be a part of every day training conversation. This will empower both the athlete and the coach to be better equipped to make decisions at crunch time.

One of the best tools available for monitoring training stress and recovery is a detailed log that tracks both objective (e.g., hours on the court) and subjective (e.g., perceived fatigue) over time. Occasional mood assessments, journaling or other markers can be used to track an athlete's progress as well as her psychological and emotional levels of distress. Being aware of the common signs of staleness, knowing how a particularly athlete typically responds to over reaching, and careful monitoring of training will provide the clues needed to determine how to adjust training to avoid more serious overtraining and related maladaptations.

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Nutritional Recovery for Tennis

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Abstract

The game of tennis has evolved to a fast paced explosive sport based on power, strength and speed. As the game of tennis has advanced and transformed the application of science to the sport has also advanced. Nutrition is one aspect of science that assists athletes optimize health, performance and growth. The demands of the tournament circuit create the greatest nutritional challenges to tennis players. The aim of this manuscript is to summarize the recent research in the application of nutrition to recovery of tennis. The goals of nutrition recovery for tennis players include: replenishment of glycogen stores; restoration of fluid and electrolyte balance; manufacturing of new muscle proteins and other cellular components; and restoration of the immune system.

Introduction

Persistent fatigue accompanied by impaired sporting performance is often experienced by tennis players during their professional career. Fatigue is defined as the sensation of tiredness with associated decrements in muscular performance and function (1). The fatigue may present itself as a decrease in stroke accuracy, serve velocity, and court movement, and an increase in percentage of errors and mental mistakes. Success at a competitive level in tennis is in part determined by a player's ability to resist fatigue.

There are many possible causes of fatigue and these include: a medical illness, overtraining syndrome, insufficient sleep, rapid growth, allergies, psychological stress, nutritional factors and poor recovery practices. Mendez-Villanueva et al. suggest that the causes of intermittent exercise fatigue in tennis were from three main categories: metabolic, neuromechanical and thermal (1). The associated nutritional causes of fatigue and performance decrements include: carbohydrate depletion, dehydration, energy depletion and micronutrient deficiencies.

The demands of the tournament circuit create the greatest nutritional challenge to tennis players. Due to the variable nature of the matches, and the unpredictable competition timetable players often find it difficult to anticipate and consume their nutritional requirements. Fatigue can develop as the duration and intensity of physical exertion increase, and the length of rest periods decrease. It can also be magnified by the environmental temperature, degree of acclimatization, travel demands and hydration status.

This manuscript summarizes the recent research and progress in the application of nutrition to recovery in tennis. Since tennis specific data is limited, scientific information from other sports and laboratory studies will be interpreted and translated to the conditions of competitive tennis.

The goals of nutrition recovery for tennis players include:

1. Replenishment of glycogen stores;
2. Restoration of fluid and electrolyte balance;
3. Manufacturing of new muscle protein, red blood cells and other cellular components;
4. Restoration of the immune system.

Physiology of tennis

The physiological demands of tennis vary according to the duration of the rally, the work to rest ratio during the match and the number of points a player must win to decide the match. These factors can also vary depending on the surface of the court and the player's gender, skill level, and style of play. In general tennis rallies are brief, 2 - 10 seconds and involve short maximal sprints of 8 - 12 meters per point. The rally-to-game ratio is generally low, 20-30% of the game time, with relatively inactivity between points and between games. Mean maximum oxygen uptake is about 50-60% and heart rates are elevated to 60-80% of maximal rate for the duration of the match (1,2,3).

The fuel requirements of tennis are provided by both the aerobic and anaerobic pathways. Depending on the length of the rally, the ATP/CP and anaerobic glycolosis provide substantial contributions to the fuel needs. For matches where the rallies are short, blood lactate concentrations will generally remain low (<3-4 mmol/L). However, for matches with long rallies the lactate concentrates may be elevated up to or exceeding 10 mmol/L. The metabolic cost of doubles play is less than for a singles match (2,3).

The conversion of muscle glycogen stores to lactate during intense exercise results in an increase in muscle and blood acidity. This is associated with reduced muscle power. Phosphocreatine levels return to about 50% within 60 seconds of intense exercise. Complete depletion of the stores may take approximately 3-5 minutes for full recovery to occur (1). International Tennis Federation rules allow 20 seconds recovery between rallies and 90 seconds between changes of ends. In general, lactate levels in tennis are seen to remain low during tennis and contribute little to fatigue. However for certain players an increase in circulating lactate levels in tennis can occur and could induce fatigue (1,4). As phospocreatine stores are progressively depleted with subsequent rallies separated by incomplete recovery periods, there will be a greater reliance on aerobic metabolism (1).

Carbohydrates from the foods we eat are broken down and converted to glucose. Glucose is the main source of fuel for our cells. When the body doesn't need to use the glucose for energy, it is stored in the liver and muscles as glycogen. The close association between fatigue and low muscle glycogen and blood glucose levels in prolonged exercise is well established (2,3,4). When glycogen stores are low the supply of ATP from glycogen is reduced. Prolonged matches in tennis have shown a decline in blood glucose levels after several hours of play. Carbohydrate intake during such play is associated with better maintenance of optimal concentration of glucose in the blood (2).

Carbohydrate is a substrate that is used by contracting skeletal muscle and central nervous system function. The study of carbohydrate metabolism for tennis has been limited. Lees (2003) summarized the small number of studies on tennis in which the effect of carbohydrate supplementation during play improved alertness, concentration and coordination and reduced errors through play (5).

The American College of Sport Medicine's position statement recommends that athletes should consume 30-60 g/h of carbohydrates during exercise. The carbohydrate can be in the form of glucose, sucrose, maltodextrins and fructose. Fructose should be limited because of the possibility of gastric discomfort. This rate of carbohydrate ingestion can be accomplished by drinking 600-1200ml/h of a sport drink. Ingesting higher levels of carbohydrates or concentrations too large (>8%) do not increase oxidation rates and can lead to gastric distress. The timing of carbohydrate ingestion during practices and matches should be in small amounts but with a regular supply, therefore at each change over during a tennis match (6).

The game of tennis has evolved to a fast paced, explosive sport based on power, strength and speed. Players need to be able to perform repeated dynamic movements involving acceleration, deceleration, multi-directional agility and explosive jumps, all in a reactive environment. As the game of tennis continues to advance and transform the application of science to recovery in tennis changes. A scientific approach has helped and will continue to help guide many players in their training and nutritional preparation and recovery.

Environmental impact on tennis

The environment adds to the physiological demands of tennis. Environmental temperature, degree of acclimatization, and international travel often exaggerate the demands of the sport and can cause a significant delay in the recovery process.

Major tournaments are played in countries where the summer temperatures regularly exceed 30C/86F, with the court temperature being even higher because of the enclosure of the space, reflection of radiant energy, and retention of heat in the playing surface (2). Therefore, tennis is a sport that has a high risk of activating heat stress llness. The acclimatized player will however, begin to sweat earlier, lose fewer electrolytes in their sweat and have a higher sweat rate for a given core temperature (7).

Exercising at altitude presents other environmental challenges. Altitude exposure results in increased ventilation, diuresis and an initial reduction in total body water and plasma volume (8). Due to the fact that the air at altitude is also dry, greater water loss occurs through breathing. Hence, maintaining hydration status and effective thermoregulation when exercising in these environments represents a major challenge to the trained athlete. This is further complicated by a marked decrease in appetite when ascending to a high altitude environment, which leads to energy imbalance and weight loss (8).

Studies on mountaineers have demonstrated that fuel selection shifts to a greater use of blood glucose in men both at rest and during exercise compared to sea level. The predominant use of blood glucose, without sparing muscle glycogen, represents a challenge for male athletes training for long hours in these environments. Women when exposed to altitude appear to rely to a greater extent on fat as a fuel (8).

International travel creates challenges to players in optimizing their nutrition and recovery. A sudden change in the environment can alter the nutritional needs and the recovery practices required. Different foods, cultures, hygiene standards, and languages can be overwhelming to players. These challenges can be compounded if a player is on a tight budget.

Youth and elite sport

Busy competitive schedules commence at a young age for elite tennis players. Many young tennis players train 4 - 6 hours a day while still attending school. It is not unusual for gifted players to re-locate and spend time away from family and friends. In addition, the travel commitments initially occur on a shoestring budget, and can often produce an isolating lifestyle. Gifted players are known to dominate the professional ranks while in their teenage years. This is particularly common in the women's circuit.

Growth and maturation refer to two distinct biological processes. Growth refers to an increase in the total body size, and/or the size of specific body parts. Maturation refers to the timing of progress towards the mature biological state (9). Tennis players generally follow a predictable pattern of physical growth and maturation but the rate at which they go through this varies by individual. Athletes' peak growth and maturation phase occurs during adolescence but this can be delayed for certain athletes due to the demands of training. Therefore, athletes of the same chronological age can vary by as much as 5 biological years, especially during adolescence (9).

Performance is often influenced by maturity, which the athlete can not control. Initially, early maturers have a physical size advantage and often perform better than the late maturers. These athletes experience more success earlier due to a physical growth advantage and not necessarily due to enhanced skills or abilities. Conversely, late maturers can experience failure and frustration because of the lack of early success (9).

Heat stress can diminish performance, and readily threaten a young player's health and performance. Children are known to have a reduced sweating response compared to adults. They sweat less and maintain a higher core temperature during exercise in the heat. Children and adolescents are also known to consume much less fluids than adults. Bergeron et al. investigated adolescent players and the differences in fluid intake and core temperature between consuming sport drink and water. The results showed that the players came into training dehydrated, and most did not match sweat losses with equivalent fluid volume during training. The study also reports that sport drinks may be more effective than water in minimizing fluid deficits and in controlling mean core temperature of adolescent tennis players (10).

The impact of a heavy training, international travel and a large competition schedule during the growth years as well as unrealistic societal expectations can have an impact on the elite tennis players both physically, emotionally and mentally.

Macronutrient requirements for refueling and muscle repair

In recent years, the advancement of the field of macronutrient requirements for recovery has occurred. Macronutrients are nutrients required by the body in relatively large amounts to produce energy, such as protein, fat and carbohydrate.A nutritional priority for athletes after training and competition is restoration of muscle and liver glycogen stores. The effects of muscle and liver carbohydrate depletion have been shown to reduce body stability and control; strength and power; precision of strokes and mental functioning (2).

Ferrauti et al. researched the changes in blood glucose concentrations during the course of repeated tournament and practice matches, and quantified the incidence of hypoglycemia in elite tennis players. The results indicated that glycogen stores were sufficient for the energy needs of a single match played for 100 minutes. However if energy intake was insufficient between matches, there was a high risk of glycogen depletion and hypoglycemia at the re-start of play (11).

Kovacs 2005, reported that Burke et al. demonstrated that the ingestion of carbohydrates with a high glycemic index can result in a 48% greater rate of muscle glycogen resynthesis than the ingestion of low glycemic index carbohydrates 24 hours after exercise (6).

Due to results from non-tennis specific endurance exercise lasting more than 90 minutes the recovery of muscle and liver glycogen stores with dietary carbohydrates is thought to be important in supporting the glycolytic requirements of tennis (6). However recent evidence has also highlighted that carbohydrate is one of the most promising nutritional immune protectors. Carbohydrates reduce the stress hormone response to exercise thus minimizing its effect on the immune system. It also supplies glucose to fuel the activity of the immune system white cells (12).

Muscle and body protein metabolism is a constant balance between protein breakdown and protein rebuilding. During exercise the balance shifts towards protein breakdown, while during recovery the balance tips in the opposite direction. The recent interest in the role of protein in recovery is due to the increased protein turnover, and the structural components of the muscle that can be damaged in response to the strenuous exercise (13). A substantial breakdown of muscle protein occurs with prolonged and high intensity exercise. Recent research has shown that an early intake of essential amino acids and quality protein foods promotes protein rebuilding (14).

It has also been proposed that there is a synergistic physiological effect of carbohydrate, and protein administered in combination. The physiological response is a further elevation of insulin levels which increases glucose uptake into the cell and enhances glycogen resynthesis rates and net skeletal-muscle protein synthesis. Carbohydrate intake also stimulates an immune response, which increases protein uptake and rebuilding (15).

The results from the importance of protein in recovery are promising but are inconclusive. Further research is needed to clarify the type, frequency and timing of protein intake. Relatively little is known about the potential contribution of dietary fatty acids to recovery. More research is needed on the effects of altering essential fatty acids intake on immune function and recovery (12).

Further research on the macronutrients requirements for recovery still needs to occur, including studies on sport specific needs. In tennis, problems especially occur with recovery when tournament matches finish late at night, the players have post match commitments (press, doping) or travel occurs to distant accommodation sites. Also the international nature and the sponsorship requirements of the sport cause worldwide travel and no uniformity in recovery products provided.

Fluid and electrolyte requirements for rehydration

Exercise induced dehydration and hyperthermia is known to impair tennis performance and increase the risk of heat-related injury and illness (2,16,17). Dehydration is defined as the deficit of total body water content and it adversely affects movement patterns, mental functioning, physical work capacity and motor skills (4). Hyperthermia is defined as an increase in body temperature (7). In tennis thermoregulation is largely accomplished through evaporative heat loss through sweating with convective heat exchange being an additional factor on windy days (7).

There are limited scientific studies recording the actual sweat ranges and fluid intakes in tennis players. Bergeron et al. reports the sweat losses incurred in tennis to be approximately 1.5-2 L/hr for males and 1.0 L/hr for females in a hot environment. Higher sweat losses have been reported during matches involving prolonged rallies, high ambient temperature and restricted airflow in the playing venue *(*17). Sweat rates up to and greater than 2.5 L/hr during singles match play have been reported (2,3,16,18).

With gastric emptying rate for beverages rarely exceeding 1.2 L/hr, maintaining hydration can be a major challenge for some tennis players. Player's innate drinking behavior and ability to perceive thirst can also limit preservation of hydration status during the match (2,3,7,19). Thirst is not a rapid enough indicator of body water status. For certain players a deficit of 1.5 L of body water can occur before thirst is perceived and by this time impaired exercise thermoregulation has already started (3,7).

Exercise performance has been shown to be impaired when an individual is dehydrated by as little as 2% of body mass and a loss of 5% can decrease work capacity by about 30%. As the magnitude of dehydration increases, there is an accompanying increase in body temperature (7).

Although the exact mechanism is unknown, skeletal muscle cramps are associated with numerous congenital and acquired conditions, including hereditary disorders of carbohydrate and lipid metabolism, diseases of neuromuscular and endocrine origins, fluid and electrolyte deficits and pharmacological agents (20). Heat cramps occur most often in active muscles that have been challenged by a single prolonged event (>2-4 hours) or during consecutive days of exertion (20).

In tennis, skeletal muscle cramps are common and many players experiment with different types of fluid sources to try to prevent muscle cramps during and post matches. Consumption of hypotonic fluid or pure water leads to a whole-body sodium and water imbalance. High urine output occurs following drinking large volumes of electrolyte-free drinks which do not allow athletes to remain in a positive fluid balance for more than a very short time. Plasma volume will not be restored until after 60 minutes with plain water compared to complete restoration of plasma volume in 20 minutes with an electrolyte drink (19). Over consumption of hypotonic fluids and/or high sweat rates or sodium-concentrated sweat may lead to large losses of sodium and put one at risk of hyponatremia (low plasma sodium levels <130mE/L) (20). A final negative consequence of the ingestion of plain water is the removal of the drive to drink (19). Water is only adequate for rehydration purposes when solid food is consumed, as this replaces the electrolytes lost in sweat.

The post match urine output is reported to be inversely proportional to the sodium content of the ingested fluid. Maughan and Leiper, 1995 report that subjects only remain in positive fluid balance throughout the recovery period when the sodium content exceeded 52 mmol/L. However there was no difference in change in plasma volume between trials five and a half hours after the end of the rehydration period (19). It has been proposed that players who have high sweat losses and large electrolyte losses should increase their dietary salt intake after matches (2). Loss of sweat during exercise needs to be replaced after exercise and individual knowledge of sweat rate is necessary to develop a hydration plan (20).

Rapid and complete restoration of fluid balance after exercise is an important part of the recovery process. Rehydration after exercise can only be achieved if the electrolytes lost in sweat, as well as the lost water, are replaced. The composition of sweat varies considerably not only between individuals, but also with time during exercise and it is further influenced by the state of acclimatization (19). The need to replace electrolytes after dehydration is linked to the loss of electrolytes in sweat. Sodium and chloride are the main electrolytes in sweat; losses of potassium and other ions are rather small (7,19).

No single formulation of sport drink will meet all players requirements as the sodium content of sweat varies from individual to individual. The upper end of normal range for sweat sodium concentration is 80 mmol/L, which is similar to the sodium concentration of many commercially produced oral rehydration solutions that are used in the treatment of diarrhea-induced dehydration. The sodium concentration of most sport drinks are in the range of 10-25 mmol/L while sodas contain virtually no sodium. Meals have greater electrolyte content than all sport drinks. The addition of substrate is not necessary for rehydration, although a small amount of carbohydrate (2%) may improve the rate of intestinal uptake of sodium and water (19).

Bergeron et al. investigated the impact of a single and multiple match fluid-electrolyte responses in male and female tennis players on successive, multiple day competitive matches played in a hot environment. The results highlighted that daily hydration and plasma sodium levels were generally maintained without specific intervention (e.g. intravenous fluids or special rehydrating agents). There was early evidence of a sodium depletion trend after 3 days of competing (18). The accumulative effect of repeated high sodium losses over several days can lead to low extracellular sodium especially if daily sodium ingestion is low. Therefore many tennis players are required to supplement their sport drink and/or daily diet with sodium (7).

The palatability of the beverage is important. Rehydration is more likely to be achieved if the taste is perceived as being pleasant. Carbonation is not known to have an effect on the restoration of plasma volume (19).

Even though tennis has a standardized rest period of 90 seconds after every 2 games, and specific guidelines about exercising in the heat, there are practical challenges of matching fluid intake to sweat losses in tennis. Importantly, only a small degree of dehydration (2% body weight) may be needed to affect physical and mental performance (7). Consumption of carbohydrate-electrolyte drinks during and upon completion of competition will contribute to delaying fatigue due to dehydration but may also improve performance (4). Players need to develop a fluid plan and continue to monitor their actual fluid losses during matches and practice.

Timing of nutritional recovery

Players may enter more than one competition within a tournament (singles, doubles and mixed) and junior tournaments often have multiple matches played per day. Players often finish matches with depleted muscle and liver carbohydrate stores, a substantial fluid deficit, decreased immune system function, and muscle damage (2). Playing more than one match per day can cause insufficient time for recovery and therefore the player will start the next match with suboptimal hydration and fuel status. Insufficient recovery time is defined when the interval between matches and training is less than 8 hours (2).

The timing, dose and the form of carbohydrate to be ingested are important. Ivy et al. studied the effects of delaying post exercise recovery on restoration of muscle glycogen. An immediate intake of carbohydrates vs a 2 hour delay in eating, increased recovery time and permitted greater glycogen storage when the recovery period available was less than 8 hours (21). Rates of glycogen synthesis are highest immediately after exercise. A two-hour delay in administering carbohydrates results in a 47% reduction in glycogen synthesis than if the carbohydrate is provided immediately post-exercise (6,22). Therefore thirty to sixty minutes immediately after exercise is seen to be the critical time to ingest nutrients with the aim of facilitating recovery (13). The rate of glycogen storage is more rapid initially post- exercise. For some hours immediately after exercise there is an increase in blood flow to the muscle and enhanced insulin sensitivity, amino acid uptake and protein synthesis, which makes the tissue most responsive to nutrient supplementation during that time. Carbohydrate restoration declines with time returning to normal resting values eight hours after exercise (13). The muscle can restore its fuel (glycogen) levels by about 5% per hour, provided that enough carbohydrate is eaten. Inadequate carbohydrate intake over repeated days of exercise would result in gradual loss of glycogen stores and reduced tennis performance (13). Therefore continuous carbohydrate intake (during and post matches) is important for matches lasting three or more sets and during days where multiple matches are played.

Information is limited on the interaction of an immediate intake of protein and carbohydrate on recovery and it is based on data from studies on resistance exercise. A maximal net muscle protein ingestion of between 6 - 20g is recommended for recovery (13).

Fluid losses can be very large in tennis and continual loss of fluid through sweating and urination generally occurs after exercise. Rehydrating immediately after matches and/or training are of prime importance during tournaments (22). The volume of fluid to consume to aid rehydration must be 1.5 - 2 fold than the volume lost in exercise (2). The fluid consumed needs to be rich in electrolytes as fluids low in sodium will not sustain fluid balance in recovery. Plain water can lead to hemodilution and enhanced urine production, followed by a reduced drive to drink; with the net result is maintenance of dehydration (22). Continual replacements of fluids need to occur over the subsequent hours of rest.

If the time between prolonged training sessions and matches are less than 8 hrs then refueling and rehydrating should commence immediately post competition and training. Carbohydrate, protein and fluid intake should commence as soon as practical following a match to maximize available recovery time for glycogen storage, muscle repair and rehydration. Since appetite is often lower in the period immediately post-exercise, carbohydrate-protein intake in the form of fluids may be useful at this time (4).

The demand for energy to sustain work levels, imposed in a hot environment, provokes considerable physiological strain for players during tournaments and long training sessions. Adequate nutrition and hydration help players prepare and compete in extended matches and to recover during multiple tournament play (4).

Ergogenic aids and their role in recovery

Ergogenic aids are perceived to provide the magic solution to success. Ergogenic aid literally means 'work enhancing'. Nutritional ergogenic aids are products that contain nutrients in amounts greater than the dietary reference intakes and food. There are a multitude of ergogenic aids on the market, both legal and illegal, that advertise that they aid recovery.

Poor regulation of the supplement industry allows athletes to be bombarded with advertising that exaggerates or completely invents unproven benefits arising from the use of supplements. Many of the ergogenic aid products do not have sound scientific research that is specific to the needs of a sport. Athletes can be motivated by fear that their competitors might be taking supplements and that they can't afford to miss out on any ‘performance edge’.

The author does not promote the use of these supplements as there are risks associated with ergogenic aids as they are often produced on an unregulated basis. These products may contain or be contaminated with prohibited or dangerous substances; even if such substances are not listed on the ingredient list. Players are 100% responsible for any products they put in or on their bodies. Of the thousands of ergogenic aids on the market only five have an adequate amount of supportive scientific research. These include: caffeine, creatine, bicarbonate, glycerol and antioxidants.

Caffeine:

Caffeine is a naturally occurring stimulant found in the leaves, nuts and seeds of a number of plants (23). Major dietary sources of caffeine, such as tea, coffee, chocolate and cola drinks typically provide 30-100 mg of caffeine per serve, while some non-prescriptive medications contain 100 -200 mg of caffeine per tablet.

Controversy has existed for many years on the potential ergogenic benefits of caffeine. It is proposed to increase endurance work capacity via increased lipolysis and lipid oxidation and decreased glycogen depletion; and an enhancement of neuromuscular and central nervous system function and psychomotor coordination (24).

On 1 January 2004, caffeine was removed from the 2004 World Anti-Doping Agency Prohibited List, allowing athletes who compete in sports that are compliant with the WADA code to consume caffeine, within their usual diets or for specific purposes of performance, without fear of sanctions (23).

Not many studies have been conducted on caffeine supplementation in tennis players. Caffeine has been suggested to be a hyperglycemic agent but stimulating glycogenolysis. Ferrauti et al *(*1997*)* investigated the effects of carbohydrate and caffeine on metabolic responses and tennis performance. The study demonstrated that caffeine caused a faster adaptation of metabolism to the work load after rest for women tennis players. The male tennis players did not show any benefit from caffeine ingestion (24). This study also reported that supplementation of carbohydrates stabilized blood glucose during continuous competitive tennis and improved carbohydrate substrate availability. Recent research on caffeine and dehydration show there is no evidence to support caffeine restriction on the basis of impaired thermoregulation or changes of hydration status at levels less then 300-400 mg/d (20).

Studies now show that the effect of caffeine on 'glycogen sparing' during sub-maximal exercise is short-lived and inconsistent, not all athletes respond in this way. Therefore, it is unlikely to explain the enhancement of exercise capacity and performance seen in prolonged continuous events and exercise protocols. In addition, caffeine-containing drinks such as tea, coffee and cola drinks provide a significant source of fluid in the everyday diets of many people and any effect of caffeine on urine losses is minor, particularly in people who are habitual caffeine users. The neuromuscular effects are likely to involve alterations to the perception of effort or fatigue, as well as direct effects on the muscle (23).

Beneficial effects from caffeine intake are seen to occur at small-moderate levels of intake (1-3 mg/kg BM or 70-150 mg caffeine), when caffeine is taken before and/or throughout exercise, or towards the end of exercise when the athlete is becoming fatigued. At higher levels of intake, caffeine has the potential to cause increases in heart rate, impairments or alterations of fine motor control and technique, and over-arousal (interfering with recovery and sleep patterns). Impairment of technique may affect the performance of a number of sports, and over-arousal may interfere with the ability to recover between training sessions, or multi-day competitions. These concerns add to the importance of finding the lowest effective dose of caffeine that can be used to achieve a performance enhancement. There may be interactions between caffeine and other supplements/nutrients used by athletes (e.g. bicarbonate, creatine, carbohydrate) that need to be explored in terms of performance outcomes and potential side-effects. Long-term intake of large amounts of caffeine (>500 mg per day) are generally discouraged (23).

Creatine:

Creatine is a naturally occurring compound found in skeletal muscle and is found in dietary sources of meat and fish. It is also synthesized in the liver from three amino acids: arginine, glycine and methionine (23). There is an estimated 2 g daily turnover of creatine in the body (25).

Creatine supplementation has been shown to enhance the performance of exercise involving repeated sprints or bouts of high intensity exercise, separated by short recovery intervals. Therefore, competition or training programs involving intermittent high-intensity work patterns with brief recovery periods (<1 min), or resistance training programs may be enhanced by creatine loading (23).

Phosphocreatine is the primary fuel to buffer changes in muscle ATP during short maximal exercise and during transitions between rest and exercise. The potential benefits of oral creatine supplementation on improved capacity to perform both single and intermittent short maximal exercise bouts have been investigated since the 1990’s. As tennis corresponds to the exercise modes to which creatine supplementation might have a beneficial impact, Op’t Eijnde et al investigated the impact of oral creatine loading on stroke power and precision in elite tennis players. The findings indicated that short-term creatine intake (20-25 g/day for a period of 4 - 7 days) did not have a beneficial impact on stroke quality in elite tennis players (26).

Beneficial effects from creatine intake are seen to occur with the following protocols. The rapid loading protocol involves taking 20 g of creatine daily, divided into 4 doses, and for 5 days. These doses should be taken with a meal or snack supplying a substantial amount of carbohydrate (50-100 g). The slow loading protocol involves taking 3 g/day which is consumed with a substantial carbohydrate meal or snack. Once the muscle creatine content has been saturated it will take about 4 weeks to return to resting levels. A daily maintenance dose of 3 g will allow elevated levels to be maintained (23). Extended or excessive loading protocols are not recommended and creatine ingestion should occur in a cyclic process.

Although creatine supplementation is widely used across many sports, it is only proven to be beneficial in a small number of sports where athletes repeat short maximal efforts with brief recovery periods. The long-term consequences of creatine use are unknown. There are anecdotal reports of an increased risk of muscle cramps, strains and tears and weight gain (23). Players older than 18 years should individually test whether creatine supplementation provides benefits to their tennis performance.

Bicarbonate and Citrate:

Bicarbonate and citrate loading are popular ergogenic aids used by athletes performing short duration, high intensity sporting events and competitions. They are extracellular buffers which maintain a stable electrolyte gradient between intracellular and extracellular environments. The aim of bicarbonate and citrate loading is to increase the muscle buffering capacity to dispose of excess hydrogen ions generated through anaerobic glycolysis (27).

The most extensively researched and practiced form of increasing the muscle buffering capacity is the acute loading of bicarbonate. The traditional method is 0.3g sodium bicarbonate per kg of body weight taken 60-90 minutes before training and competition. This practice elevates both pH and bicarbonate concentrations in the blood before and during exercise. Burke and Pyne (2007) analyzed the relevant studies on bicarbonate loading and concluded there is a benefit to events or sports in which high lactate and hydrogen-ion production and fatigue occurs (27). Serial loading protocols are being examined to help prevent the gastrointestinal problems encountered by some athletes during the acute loading protocol. A number of research questions need to be addressed to enhance the potential application of bicarbonate and citrate loading in elite tennis.

The beneficial effects from bicarbonate and citrate intakes are seen to occur with the following acute and chronic loading protocol. Acute loading includes consuming 0.3 g sodium bicarbonate or 0.3-0.5 g citrate per kg body mass (~20 g), 60-90 min pre-event. They must be consumed with 1-2 litres water to reduce gastrointestinal problems due to osmotic diarrhoea. Chronic loading includes consuming 0.5 g sodium bicarbonate per kg body mass, split into four doses spread over the day. Loading is carried out for 5-6 days to achieve a chronic increase in blood buffering capacity that is maintained for at least 24 hours after the last dose (23).

No studies of citrate or bicarbonate loading have been undertaken with tennis and the effects may vary in individuals. Players over 18 years of age should practice bicarbonate and citrate loading in appropriate training sessions to assess the benefits and side-effects. The main side effect reported is gastrointestinal distress.

Glycerol:

Proper hydration is important for optimal tennis performance and is seen to play a role in the prevention of heat illnesses. Glycerol is naturally occurring and it is the backbone of triglyceride (fat) molecules. When ingested it exerts an osmotic effect that allows the body to temporarily retain extra fluid that is consumed at the same time as the glycerol (23).

Glycerol before exercise has been investigated intensively but never in tennis. It is reported to improve hydration status and expand plasma volume to a greater extent than does water alone. Post exercise rehydration with glycerol has also been reported to enhance plasma volume restoration. However, glycerol itself does not provide any tennis-related skill or agility performance advantage (16). Some side-effects noted in individuals including headaches and gastrointestinal problems, particularly when consumed after a meal.

The recommended loading protocol is: 1-1.5 g glycerol per kg body mass consumed 2 hours pre-event in conjunction with 25-35 ml fluid per kg (23).

Antioxidants:

Sudden increase in training stress leads to temporary increase in production of free oxygen radicals. Supplementation with antioxidant vitamins may help to reduce oxidative damage until the body's own antioxidant system can adapt to the new challenge (23).

Antioxidants have been most extensively researched since the 1990's and studies in humans have not conclusively demonstrated enhanced exercise performance after antioxidant supplementation (12, 23). Athletes have been encouraged to consume vitamins with antioxidant properties such as vitamin A, C, E and B-carotene. Furthermore, exercise has a pronounced effect on both zinc and iron metabolism and requirements of these minerals are certainly higher in athletes than the sedentary population (12). Further research on these vitamins needs to occur to determine the application of antioxidants in elite tennis.

The recommended protocol includes: a daily dose of 500 mg vitamin C and 500 IU vitamin E. In addition, a 2 week dose to be provided to athletes undertaking a sudden increase in training stress or a shift to a stressful environment (23).

For athletes and coaches it is almost impossible to keep up-to-date on the prolific growth of the supplement industry. Athletes and coaches are recommended to use sport scientists, physicians and sport dietitians to assist assess the ergogenic aids of interest.

Summary

This manuscript reviewed the recent developments of the application of nutrition to recovery in tennis. A scientific approach has helped and will continue to help guide many players in their nutritional preparation and recovery.

One of the major problems in researching tennis is the variation in the nature of the game itself and the different playing styles of the players (3). As tennis continues to change, the physiological demands for optimal performance must be continually investigated to help provide athletes, coaches and Certified Athletic Trainers with information that will aid in the development of efficient and productive tennis performance and injury prevention (3).

There is a growing understanding of the role of nutrition in the recovery processes and only a few studies have been aimed at quantifying the interaction of protein and carbohydrate on the recovery of performance ability. The current belief is that the use of carbohydrate-protein beverages immediately after exercise allows for provision of needed nutrients and a favorable hormonal milieu. High protein-carbohydrate feedings during recovery are presently being practiced and tolerated but further investigations are warranted.

Dehydration and heat stress are a common occurrence in tennis. Tennis players need to perform their own studies to gain individual knowledge of their sweat rates during different environmental conditions. They also need to trial different sport drinks so an individual specific hydration plan can be developed (20).

The needs for sodium replacement stems from its role as the major ion in the extracellular fluid. It is speculated that the inclusion of potassium, the major cation in the intracellular space, has a limited role in promoting rehydration. There is no suggested additive effect of including both ions. More research is also needed in this area (19).

Restoration of nutrition recovery should occur when the other sport science and medicine recovery strategies occur. Interestingly, there is relatively little scientific data to show the effectiveness of all of these recovery techniques together on the recovery of athletes (4).

Practical Applications

Success in a tennis tournament involves winning several consecutive matches frequently separated by less than 24 hours. Tennis players must develop effective strategies for post exercise recovery so that high level performance can be repeated. Below is a list of practical nutritional applications that can be used by tennis players.

1. Optimize Nutritional status:

Nutritional status is important for success in tennis. It affects the player's health and their ability to train, and recover from exercise. Nutritional status is ideally checked 1-4 times per year via blood, body composition and urine testing.

Recommended blood testing measures include: iron status (hemoglobin, hematocrit, ferritin, serum iron, transferrin saturation, total iron binding capacity); blood glucose and electrolytes (basic metabolic profile), zinc, vitamin D, and lipids (total cholesterol, HDL, LDL, VLDL, triglycerides).

Body composition testing measures body composition changes as growth, training and dietary intervention progress. Reliable techniques include a DXA (dual-energy x-ray absorptiometry) scan and ISAK (International Standard for the Advancement of Kinanthropometry) anthropometry restricted profile. Specific gravity testing of a player's urine is an effective field test to determine if a player is hydrated or dehydrated.

2. Focus on Carbohydrates:

Glucose homeostasis is disrupted several times during the course of a tennis tournament. Continuous carbohydrate intake is therefore important for matches lasting three or more sets and during days where multiple matches are played.

• Consume 30-60 g of carbohydrates per hour of play.

• Consume sport drinks and carbohydrate rich foods (i.e. fruits, gels, sport bars) during matches and training, and in between matches to promote optimal fueling and rehydration.

• Monitor carbohydrate intake due to individual metabolic responses.

• Players need to carry an emergency fuel supply incase matches are delayed and/or very long in length.

• Sport products rich in carbohydrates include:

Food Source	Grams of Carbohydrates
Sport Drink - 16 oz	30 grams
Sport Gel – 1 pack	20-38 grams
Sport Bar - 1	25 – 55g
Sport beans / shots – 1 oz	25 grams
Banana – 1 medium	28 grams

3. Add a dash of Protein to recovery foods:

• Consume 6-20g of protein immediately post-exercise so to promote adaptation to training and recovery from matches.

• Your recovery food should consist of 30+ grams of carbohydrates and 6-20g protein:

Examples of nutritious carbohydrate-protein recovery snacks include:

10 oz of liquid meal supplements

10 oz smoothie

1 sport bars

2 cups of cereal with 1 cup of milk

1 bowl of fruit salad and 8 oz of yogurt

1 meat or peanut butter sandwich.

• The most current recovery bar vs snack bar guidelines include:

	Snack Bar	Recovery Bar
Carbohydrate	15-60 grams	30+ grams
Protein	3-20 grams	6-20 grams
Saturated fat	1-1.5 grams per 100 calories	1 gram per 100 calories

Examples include:

Powerbar Harvest, any flavor
Clif Bar – some flavors
Erin Baker’s Breakfast Cookie
Odwalla Bars – some flavors
GeniSoy – soy protein bar

4. Start your recovery immediately:

Thirty to sixty minutes immediately after exercise is seen to be the critical time to ingest nutrients with the aim of facilitating recovery. Then repeat two hours later or refuel again at your next meal.

5. Drink up:

- Player needs to drink at least 1.2 L of fluid per hour of practice and during matches.
- Drink a volume of fluid in excess of the existing fluid deficit to allow for ongoing sweat and urine losses. Players may need to replace 150 per cent of the fluid deficit to obtain baseline values.
- Replace electrolytes (sodium) to maximize the retention of fluid via sport drinks or foods.
- Players need to be acclimatized to the weather prior to playing in tournaments.
- Players need specific hydration schedule during match changeovers and practice sessions. See field tests below to help determine the individual hydration plan.
- Test urine specific gravity. The results are: 1.005 – 1.010 = very hydrated; 1.010 – 1.015 = hydrated; 1.015 – 1.030 = dehydrated.
- A fluid balance test assists players to develop strategies which can be implemented to achieve and maintain proper hydration levels based on the information gathered.

NAME:							**WEEK COMMMENCING:**		
Date	**Practice/ Match**	**Duration (mins)**	**Weather (indicate type and °C or °F)**	**Wt Before training (kg)**	**Wt after training (kg)**	**Solid Food consumed (g) during activity**	**Fluid Type (water or sport drink)**	**Fluid Volume (ml) consume d during activity**	**Urine excreted (ml)**

Instructions for completing the fluid balance chart include:

Instruct player to record:

- their weight before & after training and match play, wearing the same clothes;
- the type & length of the session;
- the weather temperature and type (cloudy, humid, etc. and °C or °F);
- the type and amount of fluid consumed in ml;
- the type and amount of solid food consumed in grams; and
- amount of urine excreted.

The two key factors to analyze on the “Fluid Balance Chart” are:

1. Percent Body Weight Change: % Dehydration = 100 x [pre-exercise wt (kg) – post-exercise wt (kg)]/pre-exercise wt (kg). Players should be able to keep their % body weight around 1% or less for a 2-hour session.

2. Total Sweat Loss: total sweat loss (ml) = 1000 x [pre-exercise wt (kg) – post-exercise wt (kg)] + ml fluid consumed + solid food consumed – ml urine excreted.

This provides information on sweat loss and in turn aids the athlete in determining her individual fluid requirements based on her sweat loss.

Athletes should be encouraged to perform this test in different environmental conditions.

6. Practical considerations:

• To prevent gastrointestinal discomfort then recovery foods should be low in fiber, liquid and easily digestible.

• Have foods that are portable and have minimal storage or preparation so players have rapid access to nutrition after the match.

• Always carry an emergency food kit.

• Always travel overseas with foods that are part of your recovery regime.

• Have foods that are sealed for the benefit of drug testing.

• Consume recovery foods that are labeled with nutritional information.

7. Be proactive with international travel:

In preparation for tournaments overseas, it is important to be proactive with travel and competition nutrition plans. Often when traveling foods available are unfamiliar and inaccessible which can lead to suboptimal fueling, decreased performance and other complications. A player should take a travel nutrition kit which will provide cooking supplies necessary to prepare meals from anywhere in the world. The kit should include a hot pot travel cooker, travel power converter, measuring cups and spoons and a selection of the following foods:

Carbohydrates:	Protein: (all shelf stable)
-Ready rice, pasta, noodles, couscous	-Tuna, salmon, chicken (canned or pouch)
-Instant mashed potatoes	-Tofu
-Instant oatmeal/grits	-Soy or whey protein powder
-Crackers, granola, cereal	-Omega-3 rich or natural peanut butter
-Instant Breakfast powder	-Nonfat dry milk powder
-Canned fruits	

Seasonings/Other:

-Spice blends

-Low-sodium bouillon cubes

-Salad dressing individual packets

Upon arrival visit the local supermarket to obtain supplemental foods.

8. Be wise when selecting ergogenic aids:

Players need to be educated on the ergogenic aids they desire to take. Athlete physicians, certified athletic trainers and sport dietitians should be sought for meaningful and safe advice.

9*. Seek Professional Help:*

Players need to be organized and have a proactive plan for food and fluid consumption during tournaments. Some players would benefit from seeking professional help from a certified sport dietitian who will provide individual specific advice and a nutrition plan. The organization that certifies sport dietitians in America is Sport Dietitian – USA. Go to http://www.scandpg.org/ and look for a Sport Dietitian nearest to your tennis club.

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Tennis Recovery and Medical Issues

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Abstract

Recovery is an essential aspect of the overall health, well-being, and performance of the competitive athlete. Recovery literature as it relates to medical issues in the athlete, and sport-specific recovery literature in tennis are lacking. With the expansion of opportunities for tennis athletes to participate in multiple matches and multiple events throughout the year, understanding the medical issues related to recovery is important. This chapter will review recovery strategies for tennis athletes as they relate to medical issues, specifically immune function, fatigue, and overtraining / chronic fatigue syndromes. Recommendations based on the sport specific demands of tennis will be discussed.

Introduction

Tennis is an extremely popular sport in the United States and worldwide, with more than 75 million participants (Pluim '07). Tennis can be played by athletes of all ages and body types, and requires minimal equipment and clothing needs. Unlike many team sports where participation after college can be difficult to arrange, tennis can be played throughout the athlete's lifespan and is accompanied by significant health benefits, especially in the aging population. A recent literature review demonstrated that tennis participation was associated with enhanced aerobic fitness, lower percentage body fat, more favorable lipid profile, a lower risk for developing cardiovascular disease, and improved bone health. (Pluim et al BJSM '07). In addition, the demands in tennis are such that both aerobic and anaerobic energy systems are taxed, and the basic skill acquisition is not complex, making it a sport that can be enjoyed by most everyone.

The physiological demands of singles men's tennis have been evaluated. Duration of a tennis match can be anywhere from one to more than 5 hours (Fernandez 2006, Kovacs 07) Activity consists primarily of short bursts of high intensity exercise interspersed with long duration lower intensity exercise (Kovacs '07, Mendez-Villanueva '07). In a typical point, a tennis player will average 3 meters of movement per shot, and 8-12 meters during the course of a point (Parsons 1998). In a best out of three sets match, a tennis player will average 300-500 high intensity efforts (Deutsch '98), and the intensity of exercise for matches is 50-60% of maximal oxygen uptake 60-80% of maximum heart rate (Fernandez BJSM 06). The physical demands of tennis depend on the strength, endurance, agility and skill of the individual athlete. Recovery from tennis play depends on the pre-exercise status of the individual, plus the duration, intensity and frequency of activity. The undertrained/overtrained continuum of the athlete effect his or her ability to withstand repetitive practice and competition events. The frequency, duration and intensity of match play and training will also play an essential role in determining the individual recovery needs.

Opportunities for participation in the sport of tennis have increased, and athletes are now playing year round and in multiple settings. The United States Tennis Association (USTA) hosts official tournaments for athletes age 10-18 at a variety of competitive settings: from local to state, to regional to national and finally super national competitions. With these expanded opportunities for participation, there are health related concerns regarding the ability of athletes, -- especially younger athletes – to recover. These concerns include recovery between matches, between tournaments, and between individual practice sessions.

Recovery is multifactorial and encompasses nutritional, physiological, physical (both musculoskeletal and medical), and psychological components. Appropriate recovery for the younger athlete differs from the older, more experienced athlete. There are limited data regarding medical illnesses which occur in tennis and only sparse prospective data evaluating the effect of exercise on medical illness. Sparse data are regarding appropriate recovery in sport to maintain optimal health and performance. Many of the available recommendations regarding recovery from sports with similar physiologic demands and/or level and frequency of participation.can be transferred to tennis.

For elite players, there are a variable number of tournaments and matches that are played per year. Typically, players compete in 15-30 tournaments per year which results in 50-150 competitive singles matches, and possible an additional 50 matches if doubles competition is include (personal communication Mark Kovacs). Top junior players may play both United States Tennis Association events and International Tennis Federation junior tournaments, and some may also participate in adult professional events. Elite level competitive junior players train from 2 to 8 hours daily, 5-6 days per week. Training variability depends on schooling (traditional school versus home schooling), coaching (private coach versus tennis academy) and location (training culture differences)

The purpose of this chapter is to discuss recovery as it relates to medical issues, specifically immune function, fatigue, and overtraining / chronic fatigue syndromes. Sports organizations have published concerns regarding sport specialization, overtraining, and possible secondary deleterious medical consequences, (TPCC 08, AAP 06, AAP 00, Mountjoy IOC 08) especially in the adolescent athlete. The nutritional aspects of recovery will be discussed in detail in other chapters, and will be discussed here briefly as it relates to understanding recovery from fatigue and overtraining. In addition, recovery as it relates to musculoskeletal injuries and psychological issues are also discussed in detail separately, and are thus only briefly discussed as they also have a bearing on overtraining and chronic fatigue.

Injuries and Illness in Tennis

Although injury rates in tennis are difficult to discern (Alyas ’07, Girard ’07, Pluim ‘06), tennis enjoys a low overall incidence of injuries, especially in the younger athlete (Emery ’03). The upper extremity is a common sites of injury, with shoulder and elbow injuries predominating (Sciascia ’06, van der Hoeven ’06). In elite tennis players, lower extremity stress fractures and lumbar spine injuries are common. Over a two year period, professional tennis player showed an absolute risk of 12.9% of having a stress fracture, with junior players at highest risk (Maquirriain ’06). Lumbar spine injuries are unknot only common, but may be underdiagnosed. Alyas et al studied asymptomatic elite adolescent tennis athletes, and found that only 15.2% had a normal lumbar spine MRI (Alyas ’07). There was a high rate of pars interarticularis injuries and facet arthroses in this asymptomatic population. Despite these data, tennis players have fewer and less severe musculoskeletal injuries than athletes who participate in contact sports.

The participation of adolescents athletic activity has increased over the past twenty years, and has been estimated at 30-45 million for ages 22 through 18. Overuse injuries account for 50% of all injuries in pediatric sports medicine (Dalton ’92).This figure may be an underestimation for tennis where collision/contact injuries are rare. Overuse injuries are more common during peak growth velocity (AAP ’06), especially if underlying biomechanical problems are present (AAP ’06). Overuse injuries result from overtraining. Kibler described the vicious overload cycle (Kibler 1990 MSSE), where tissue injury leads to clinical symptoms, functional biomechanical deficits, suboptimal functional adaptations and ultimately tissue overload. Several factors are present in overuse injuries, some intrinsic and others extrinsic. Intrinsic factors include age, gender, body weight and height, muscle imbalances, flexibility, weakness and fatigue. Extrinsic factors include training errors, equipment, technique, environment, facilities and overtraining. A Cochrane database review of runners demonstrated that overuse injuries in the lower extremites can be prevented through modifications of training schedules, specifically by decreasing training duration, frequency or distance.

In an effort to limit overuse injuries, the American Academy of Pediatrics Council of Sports Medicine and Fitness recommend the following: sporting activity should be limited to a maximum of five days a week with at least one day off from organized physical activity; athletes should be advised that the weekly training time, number of repetitions, or total distance should not increase by more than 10% each week; and athletes should have 2-3 months off per year from their particular sport. Additional recommendations include an emphasis on fun, multiple activities, and education regarding burnout plus caution regarding multi-game tournaments in a short period of time. These recommendations may be difficult to follow for the elite athlete who aspires to compete at a national or international level. However, it is noteworthy that only 0.2 – 0.5% of high school athletes make it to the professional level, depending on the sport (NCAA fact sheet).

At the collegiate level, participation in tennis is year round, and athletes are often struggling to balance academic with athletic demands. The National

Collegiate Athletics Association (NCAA) has developed rules to protect the health and welfare of the student athlete, yet many sports medicine professionals believe these rules are inadequate. In one study of collegiate tennis players, despite having a structured protocol that they were encouraged to follow during their academic break, after five weeks off they were significantly detrained (Kovacs ’07). This study raises concern that athletes may not want to participate at the level requested by their institution and want instead to recover and rest.

Immune Function

The association between exercise and immune function remains somewhat controversial. Nieman suggests a “J shaped” curve relationship between exercise and immune function: with moderate levels of exertion, the risk of infection is decreased compared to a sedentary lifestyle, but at significant levels of exertion, there is an increased risk for infection. (Nieman 2000). Most immune function research in sport has been in endurance athletes, particularly marathon runners Matthews studied runners during various phases of marathon training, an evaluated the incidence of upper respiratory infections. He found that the risk of upper respiratory tract infection is increased 2-6 times more than in non-runners (Matthews 02), and there was a positive correlation with both training distance and speed. However, Fricker followed distance runners prospectively during training, and found no such correlation (Fricker ’05).

In a study of elite rowers, there was no correlation between upper respiratory infections, immune function, and training (Nieman ’00). In this prospective study, elite female rowers were compared with non-athletes. Rowers had higher natural killer cell activity and phytohaemoagglutinin induced proliferative response, while other measures of immune function were similar compared with non-athletes. The number of upper respiratory tract infection (URTI) symptoms did not differ between groups. Furthermore, none of the immune system function parameters correlated with URTI symptoms over two months (Nieman BJSM ’00).

Some authors have demonstrated an association between exercise and a decrease in the number and effectiveness of white blood cell function, plus an increase in free radical, adverse changes in levels of adrenaline, cortisol, growth hormone and prolactin, and low glutamine levels, -- all of which have been associated with immune dysfunction and infection risk (Callahan in press, Woods ‘99, Beck 00, Gleeson ’99, Nieman BJSM 00, Nieman MSSE 00). Glutamine has been associated with T and B lymphocyte proliferation and antibody synthesis; low levels of glutamine have been correlated with athletes performing heavy, frequent, repetitive exercise, with subsequent increased risk of upper respiratory tract infections (Callahan & Gugliano, TPH in press, Castell ’96, Walsh ‘98). Laboratory markers of immune function, including secretory antibody in saliva, natural killer cell activity, and the ability of white blood cells to respond to infection, show diminished function in athletes during stressful phases of (Nieman D, BJSM ’00, Gleeson ’99) Salivary IgA levels, which inhibit pathogen colonization, bind antigen for transport across the epithelium and neutralize viruses while increasing immune function, show a J-curve response to exercise. Salivary IgA levels increase with moderate levels of training, but decrease when exercise is intense and extended for greater than 6 months. The depressive effect of intense exercise on immune function is only temporary, assuming there is adequate recovery time. With ongoing, repetitive high-intensity exercise and inadequate recovery time, the immunodepressive become more significant, thereby placing the athlete at risk for immune dysfunction and secondary infection. (Callahan & Giugliano, in press)

Nieman evaluated the acute immune response following two hours of intensive tennis drills in the adolescent athlete and demonstrated a mild perturbation in blood hormone levels, immune cell counts and immune function (Nieman et al '00). Neutrophil and monocyte counts increased *by 77%* and 26%, respectively, while lymphocyte count (predominantly natural killer cells) decreased. The neutrophil/lymphocyte ratio increased 96%; eosiniphils fell 33-41%; salivary IgA excretion rate decreased 30%, but returned to normal within one hour. These changes are less pronounced than those seen in endurance athletes (Nieman '97, Steerenberg '97). Novas evaluated the incidence of upper respiratory symptomatology in female tennis athletes, and demonstrated a J-curve response with regard to upper respiratory infections. Girls with either low or extremelyhigh levels of daily energy expenditure developed more upper respiratory infections than those with moderate levels of total daily energy expenditure (Novas '02). Although more prospective studies are needed, current data support the J-curve hypothesis. Immune function appears to be compromised with overtraining, incomplete recovery, or both.

Fatigue

Fatigue is defined in relation to metabolic, neuromechanical and thermal factors. (Mendez-Villanueva '07). Neuromechanical fatigue is covered in more detail in other chapters. Thermal fatigue is also covered in detail elsewhere, but will be discussed in this chapter because of some similar manifestations with metabolic fatigue. Metabolic factors related to fatigue include energy availability and accumulation of lactate and other byproducts (hydrogen ion and inorganic phosphate) in the muscles. The adenosine triphosphate (ATP) / phosphocreatine system fuels high intensity /high power anaerobic activity that lasts 5-6 seconds. Carbohydrate (CHO) is the only substrate that can produce ATP anaerobically, and is thus an important fuel source for tennis. ATP resynthesis and phosphocreatine availability is important for delaying fatigue.

Aerobic energy metabolism utilizes CHO plus fats and protein for ATP production. In skeletal muscle, glucose and fatty acids are the primary sources of aerobicenergy, and muscle and liver glycogen are the most important storage reservoirs for dietary CHO (Clark, Netters TPH in press). Muscle glycogen stores are an important determination of metabolic fatigue. Soccer players have higher muscle glycogen levels when they ingest a glucose polymer prior to and during half time when compared to players receiving placebo. (Leatt). Carbohydrate supplementation is associated with greater muscle glycogen availability and a delay in fatigue in intermittent sprint exercise (Balsom 99, Davis 00, Welsh ’02, Winnick ’05, Sedlock ‘08). Tennis specific studies are limited, and current recommendations regarding CHO supplementation in tennis are based on recommendations from other (Coyle ‘04, Casa ’00, Williams ’06, Sedlock 08, Montain ‘08).

The recommended ingestion of CHO during sport is 30-60 g of CHO during exercise, 1.0 – 1.5g/kg immediately after exercise, and an additional 1.0-1.5 g/kg every two hours thereafter in order to restore muscle glycogen. [Add a few sentences here regarding the need/importance of protein], (Berardi, ACSM ’07). CHO can be in solid or liquid form, and should be tailored to athlete preference(Clark TPH in press). Fluid replacement is also important as it relates to dehydration and thermoregulation (Montain ’08, Sedlock ’08). This is particularly important for the tennis player participating in tournaments with multiple matches in a short period of time. Lactate accumulation from intermittent intense exercise has been described, and contributes to the development of muscle fatigue (Fernandez ’06, Smekal ’03). Blood lactate levels and ratings of perceived exertion (RPE) were measured in professional singles tennis (Mendez-Villanueva ’07). Both correlated with the number of shots per rally and the duration of rallies, and were also higher when players were serving compared to receiving serve. Additional tennis specific studies will be helpful in further elucidating the role of lactate accumulation and fatigue.

Thermal stress plays a role in the development of fatigue in the tennis player. Tennis is often played in warm environment, and not only is there the potential for thermal stress related to a combination of high temperature, high humidity, direct sunlight and minimal wind: but also from the court surface itself. Such environmental stress causes an increase in sweat rate and sodium loss, especially in non-acclimatized athletes. If sweat loss and sodium loss are not replaced adequately, dehydration and sodium deficits occur, which produce fatigue and have a negative effect on performance (ACSM 07, Binkley '02, Carter '06).

Bergeron et al. performed on site studies of elite adolescent tennis players participating in the national boys' 14s junior tennis championships. Based on elevated urine specific gravity measurements, he demonstrated that many players began match play in a dehydrated state (USG) (Bergeron BJSM '07). Players with elevated urine specific gravity and dehydration developed an elevated final core body temperature relative to non-dehydrated players. This study demonstrated that elite junior boy tennis athletes often begin competition in a dehydrated state, and consequently place themselves at greater risk for developing complications from thermal stress.

In a separate study of similarly aged young tennis players, Bergeron evaluated core temperature recordings and voluntary intake of either water or a sports beverage (Bergeron 'BJSM 06). There were no significant differences between water or sports beverage intake with respect to fluid intake, urine volume, fluid retention, perceived exertion, thirst or gastrointestinal discomfort. Players who ingested a sports beverage did nave less body weight loss, which may be an indicator of a protective effect against dehydration.

In summary, metabolic fatigue is influenced by a player's acclimatized state, food intake and fluid intake. When proper attention is not paid to these factors, the result is a deleterious effect on performance and health.

Overtraining Syndrome and Chronic Fatigue Syndrome

Fatigue can also be divided into either physiologic or pathologic, with examples of physiologic fatigue including insufficient sleep, nutritional deficiency, jet lag, pregnancy induced fatigue, and training induced fatigue. Pathologic causes of fatigue include medical problems (infectious, hematologic, endocrine, toxic, iatrogenic, psychiatric), chronic fatigue syndrome and overtraining syndrome.

Well designed training programs incorporate and secondary physiologic fatigue, followed by adequate rest. When athletes train intensely, fatigue and a subsequent decrease in performance is a normal response. With appropriate rest and recovery (periodization), the athlete can then achieve over-reaching and supercompensation, and ultimately improved performance. See Figure 1 (Budgett). Recovery from training incorporates hydration and nutrition, sleep and rest, relaxation and emotional support, and stretching. If sub-optimal recovery occurs, then overtraining syndrome can develop. Overtraining syndrome is the pathologic endpoint in overtraining, and has also been termed “burnout” or “staleness”.

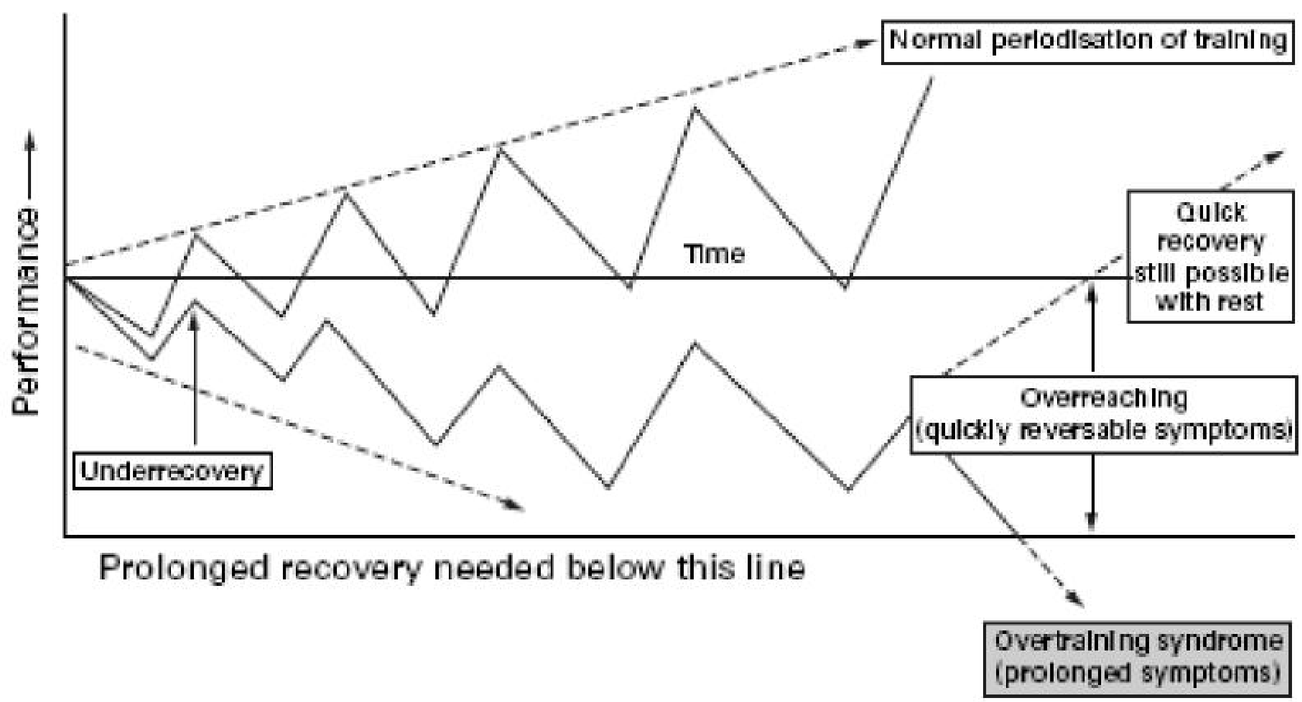

Figure 1 Overtraining or underrecovery, leading to the overtraining syndrome.

Figure 1: Normal Periodization of training, Overreaching, and Overtraining

Syndrome from Budgett BJSM '98

Overtraining syndrome has been defined as "a condition of fatigue and underperformance, often associated with frequent infections and depression which occurs following hard training and competition. The symptoms do not resolve despite two weeks of adequate rest, and there is no other identifiable cause" (Budgett '99). Overtraining in the young athlete has been defined as "a series of psychological, physiologic, and hormonal changes that result in decreased sports performance" (Small'02). Overtraining syndrome differs from chronic fatigue syndrome in that in the latter, symptoms must be present for more than 6 months. Overtraining syndrome has been described as a maladaptive response to training when the training is too severe or prolonged. At any one time, it has been estimated that 7-20% of elite athletes will be affected by overtraining syndrome (Lewis et al in press).

Training induced fatigue is characterized by transient symptoms of decreased mood, increased tension, depression and fatigue coupled with muscle glycogen depletion and increased creatine kinase levels. Resolution should occur within two weeks. If exercise is excessively prolonged or intense, or associated with additional stressors such as injury, illness or disturbances in mood, then overtraining syndrome can occur. The psychological response to injury should always be considered (TPCC '06). Athletes will complain of excessive fatigue, poor performance, sleep or emotional difficulties, and may develop frequent minor infections.

Table 1: Clinical Picture of Overtraining (modified from Sachtleben, '04)

Increased resting HR	
Weight loss	Decreased Performance
Poor healing	
Sleep disturbance	
Loss of appetite	Irritability
Depression	
Sore throat, lymphadenopathy	Restlessness
Legs feel heavy	
Excessive sweating	
Decreased drive for competition	Myalgias and Arthralgias

Overtraining syndrome was evaluated in a prospective study of trained cyclists over a 6 week period. (Halson et al J Appl Physiol '02). Athletes developed a significant decline in maximal power output and a significant increase in time to complete a simulated time trial after intensified training. A 29% increase in global mood disturbance, 9.3% reduction in maximal heart rate, 5% reduction in maximal oxygen uptake and 8.6% increase in perception of effort occurred, yet there were no changes in substrate utilization, cycling efficiency, lactate, plasma urea, ammonia and catecholamine concentrations. This study demonstrates that overtraining syndrome can occur despite minimal changes in laboratory measures, with only a short period of overtraining.

Overtraining syndrome is a diagnosis of exclusion, and other medical causes should be considered. The differential diagnosis of overtraining syndrome includes viral illness, notably infectious mononucleosis, anemia, depression, and thyroid disease. Other issues to consider are listed in table 2.

Table 2: Differential Diagnosis of Overtraining Syndrome

Illness
- Infection; Viral infections, (e.g. infectious mononucleosis, hepatitis)
- Malignancy
- Fibromyalgia
- Chronic fatigue syndrome
- Collagen vascular disease

Metabolic problem / endocrine
- Glycogen storage disease
- Thyroid disease
- Hypoglycemia

Psychiatric
- Substance Use
- Depression

Chronic fatigue syndrome is defined as severe fatigue which is present for

Chronic fatigue syndrome is defined as severe fatigue which is present for greater than 6 months. It includes fatigue that is not alleviated by rest, leading to severe decrease in work, education or personal activities plus at least 4 of the following symptoms: impaired memory or concentration; multijoint pain; sore throat; new headaches; tender cervical or axillary lymph nodes; un-refreshing sleep; muscle pain; post exertional malaise. The medical evaluation for overtraining syndrome or chronic fatigue syndrome includes a complete review of systems and physical examination, review of training and nutrition programs, laboratory studies including a complete blood count, sedimentation rate, chemistry profile, testing for mononucleosis, thyroid function studies, urinalysis, and ferritin.

Other tests include drug toxicology screen, profile of mood states (POMS), and nutritional and psychological evaluation. It is important to address the training regimen as well as other potential stressors (Herring, TPCC ’06). The treatment of overtraining syndrome is rest. If overtraining syndrome is long standing, an absolute rest period of up to 3-5 weeks may be needed. Ensuring appropriate recovery and nutrition after training is the best prevention of overtraining syndrome. How this translates into injury prevention is less clear. In rugby players, a decrease in pre-season training was associated with a decrease in injuries during training. [need ref] Data in other sports are lacking. General recommendations to prevent overtraining syndrome include the following: 1) education of athletes and coaches regarding periodization and training techniques; 2) adequate rest and recovery; 3) assessment of stress and coping mechanisms/support network; 4) avoiding monotony of workouts and training; 5) increasing resistance in training < 5% per week; 5) monitoring training to include objective measurements of heart rate, weight, performance, sleep and mood.

Summary

Immune function, fatigue, overtraining syndrome and chronic fatigue syndrome are medical issues that directly impact tennis athletes. More research is needed to evaluate the effect of tennis play on immune function, especially as it relates to the younger athlete participating in an expanding number of events. Fatigue is a common symptom and can be related either to a decrease in energy availability, depletion of muscle glycogen Overtraining syndrome develops in the setting of prolonged, intense training without adequate recovery. Recovery as it relates to these medical issues centers around appropriate physical and mental rest, appropriate hydration and nutrition, and avoiding prolonged and intense training without proper periodization. More tennis specific research is needed to better evaluate the effects of tennis on these important medical issues.

Practical Applications

Athletes participating in tennis activity should be monitored for recovery as it relates to medical issues by paying attention to their overall sense of wellbeing, energy level, and allowing for appropriate hydration and energy intake between practices and competitions. Early intervention when there are symptoms and/or signs of overtraining should be provided and education of athletes, coaches, and parents are essential. Care must be taken in the young athlete who may be at particular risk for overuse injuries and overtraining.

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Recovery and the Young Tennis Athlete

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Abstract

The game of tennis has now evolved to an art form, with science wedded with performance mechanics to allow for best equipment, improvements in training and conditioning, optimal nutritional enhancement, gamesmanship and the sports psychology of success. The days of arduous points earned with wooden racquets have been replaced by high technology equipment, with enhanced power, increased speed, and explosive athleticism on the court; serves of 210 km/h are now common (Kovacs 2007).

Competitive tennis by its nature is a true interval type sport, challenging both aerobic and anaerobic abilities of the player. Skill, consistency and tactical mastery are critical factors for success but adequate agility, power, aerobic and anaerobic conditioning are also required to optimize on court performance.

Recovery can be defined as the body's ability to return to a state of readiness following a physical and/or mental challenge. In tennis this applies to the player's ability to be ready to play the next shot, the next point, the next set or the next match. For optimal performance the player must be ready to execute each shot at top ability and then recover from a physiological, psychological, tactical and skill standpoint for the next shot. In this chapter we will focus on issues of physiological recovery as related to tennis conditioning for the youth player.

The capacity to perform work or activity requires energy. In the human body energy for muscular activity comes from the breakdown of ATP (adenosine

triphosphate). ATP is essential for cells to function. ATP is stored in muscle cells and is available for rapid use in the muscle to generate powerful, ballistic activities. However, the stores of ATP are very limited and can be exhausted in mere seconds of high intensity activity. ATP is also generated from two metabolic pathways in the body, the aerobic or anaerobic pathway. Without these ATP generating pathways the boy's ability to participate in tennis would be limited to one or at best three points, versus the typical one to three plus hour matches, let alone the ability to play several matches in one day.

The anaerobic pathway produces relatively few ATP from a breakdown of carbohydrate fuels to CO2 and lactate without the need for oxygen. ATP production is relatively fast bur short lived as the body cannot function as lactic acid accumulates and levels reach critical levels.

The aerobic pathway is capable of producing large amounts of ATP from carbohydrates, fat and even protein (although the latter is not typical, nor desired for athletic performance) and the fuels are broken down into CO2 and H2O. The ability of the aerobic pathway to produce ATP is limited by the body's fuel supply and its ability to provide oxygen to the active cell. In tennis all three systems function to provide ATP to allow the player to compete. Stored high energy phosphate compounds (ATP) are used during the powerful serve, anaerobic pathways augment ATP availability during sprints and rapid pace play throughout the point and aerobic metabolism allows the player to produce ATP to perform game after game, metabolizes lactic acid between points to prevent excessive accumulation and assist with replenishing stored ATP levels. Optimal conditioning, appropriately structured training and attention to nutritional and fluid requirements (both pre and during match play) optimize each energy system and enhance the player's ability to return as quickly as possible to a pre-exercise condition, or as close as possible within the time constraints of the game.

Factors That Impact Performance

Anaerobic and Aerobic Aspects of Play

Tennis players have physiological and anthropometric measures similar to those found in endurance athletes, even if the players have very different playing styles (Kovacs 2007). Their aerobic demands may be high, but not as high as would be expected in marathon runners. Pragmatically, adult elite tennis players require VO2max levels above 50 mL/kg/min to perform well on the court, but increasing their aerobic capacity to extremely high levels (e.g., >65 mL/kg/min) has not been shown to enhance performance significantly from those functioning at a VO2max of 55 mL/kg/min (Kovacs 2007). Exact numbers for appropriate VO2 max for the junior player have not been studied; as the teen becomes postpubertal, adult VO2max ranges should suffice. To ensure this base aerobic fitness requirement is satisfied, some form of aerobic conditioning should be incorporated into the base training of all competitive tennis players.

Changes in Court Style and Equipment

Different styles of play interact with different types of courts and equipment to change demands on an individual player. Fast courts (indoor surfaces, grass, and carpet) can result in point times of 3 seconds, while on slower courts (clay) average times may be 15 seconds (need refs?). The length of a point varies by style of play; the average duration of rallies for an attacking player in control of the rally was found to be 4.8 + 0.4 seconds, whereas the duration was 8.2 + 1.2 seconds for an all-court player (range 6-11 seconds). The duration of the point was 15.7 +3.5 seconds for a baseline player in control of the rally. All these differences were found to be statistically significant ($p<0.05$) (Bernardi et al 1998). On a clay court, attacking players engage in 21 + 5.5% playing time with respect to total match time, all-court players for 28.6 + 4.2%, and baseliners play for 38.5 + 4.9%, with all these results statistically significant ($p<0.05$)(Bernardi et al 1998). On hard courts, the percentage of playing time was similar at around 20% for all types of players (Doherty 1982).

Variations in Lactate Metabolism

Lactate production has been found to be variable in tennis research; those players who play longer points with shorter recovery times tend to produce higher lactate levels than those with short points with longer rest periods (Kovacs 2007). Elevations of serum lactate above 7-8 mmol/L correlate with declines in technical and tactical tennis performance (McCarthy-Davey PR, 2000).

While aerobic conditioning is essential to meet the physical demands of the long duration and the moderate mean heart rates seen during play, where a match may last over 5 hours (Bergeron 1991) stored and anaerobic energy production are essential for each point. Anaerobic demands include the burst movement necessary for rapid changes of direction, for explosive serves and ground stokes, and the need for a high percentage of type 2 muscle fibers necessary for tennis performance (Kovacs 2007). Thus, the player/coach/trainer must focus on other aspects of game improvement in addition to an adequate aerobic conditioning base (eg VO2max at 55 mL/kg/min). To put this in simpler terms, traditional aerobic training at moderate intensity for long duration will not optimize the performance during competition, where points often last less than ten seconds, and burst energy requiring anaerobic ATP production is required.

To enhance performance, coaches using heart rate monitors on their players should encourage brief periods of higher heart rates (75-95% of maximal heart rate) interspersed with longer periods of lower heart rates (40-70% of maximal heart rate) to replicate the actual demands of the game, rather than aiming for a constantly elevated heart rate. Attention to both aerobic and anaerobic training, then, can help optimize play during matches, with interval training at high intensity combined with adequate rest designed to achieve optimal aerobic training benefits. Interval training with short duration bouts (lasting 10 to 60 seconds) with a 1:3 to 1:5 work-to-rest ratio should be incorporated into the training and conditioning schedule to simulate game play. Such a format provides both aerobic and anaerobic conditioning, enhances recovery and familiarizes the player with the body's responses to game-like play.

Nutritional Recovery in the Young Athlete

Daily caloric intakes have been shown to be 4500 calories/day in male tennis players and 2800 calories per day in female tennis players (Bergeron et al 1995). In the young athlete, these numbers can vary tremendously based on the intensity of the training program and duration and frequency of tournament play, especially for those feeling compelled to engage in fad dieting or who succumb to urban myths on what is best to eat, or not eat. Junior tennis players are certainly not immune to disordered eating, and insufficient food or fluid intake can impact recovery and performance significantly. Parents, coaches, and trainers may be unaware of how little- or how out of balance- a particular teen's intake may be. Increased fluid consumption is required on hotter days where sweat losses increase, and increased caloric needs occur as the training schedule escalates. Many children and adolescents do not realize that if they increase their energy expenditure, their typical same feeding schedule with regular quantities of food may not allow for adequate glycogen storage, the coinage for endurance for athletes working out more than 90 minutes per day (Rome and Blazar 2008).

With prolonged high intensity play, muscle glycogen stores are depleted and resynthesis of muscle glycogen requires a relatively high dietary intake of carbohydrates. Full restoration of glycogen stores following a high intensity, extended match may take several days. Players should be encouraged to consume small, regular, palatable sources of carbohydrates following and even during long matches (although absorption during active play is limited) to optimize glycogen stores. Good sources of carbohydrates include selections from breads, grains and fruits. For more rapid uptake of carbohydrates, simple sugars (juice, candy) can be used, but the benefits can be short lived.

Differences in Fluid Balance and Temperature Regulation in Children versus Adults

The ability of children to regulate their body temperature utilizes different mechanisms than is found in adults, but with similar results under normal conditions (Falk 1998). However, under extreme conditions as would occur during most days of the US summer tennis calendar, children's ability to maintain a "normal" temperature is challenged, especially during prolonged, high intensity activity. Water is lost from the body via the urinary system, the skin, the respiratory surfaces, and the gastrointestinal tract (Danci, Constant et al 2006). Restoration of water balance occurs through fluid and food intake. Mechanistically, increases in plasma osmolality and activation of osmoreceptors intracellularly and baroreceptors extracellularly stimulate hypothalamic release of arginine vasopressin. Vasopressin acts in the kidney to decrease urine volume and promote water retention to preserve fluid balance. Increasing levels of vasopressin are associated with greater thirst and greater fluid intake. An increase of 1% to 2% plasma osmolality sufficiently provokes the thirst reflex (Maresh, Gabaree-Boulant et al 2004).

Thirst is generated at a higher plasma osmolality than vasopressin release, resulting in first, a concentration of urine and conservation of body water and second, a subsequent drive to increase fluid intake. This lag time is a major reason why thirst is not a good indicator for fluid replacement.

Sweat losses in tennis playing adults have been on average greater than 2.5 L/hour (Bergeron 1995). Unfortunately, the gastric emptying rate for beverages tends to be under 1.2 L/hour, so even under ideal rehydration practices, fluid replacement can be a losing effort (Armstrong et al 1985; Coyle and Montain 1992; Coyle and Montain 1992a). Younger players tend to avoid things that produce gastric discomfort; and if they learn that drinking more than 1.5 L/hr gives them gastronintestinal rumblings, they will limit set fluid intake, at the expense of needed rehydration, and without knowledge of their physiologic needs for energy that would impact their performances. Even college players manage only 1.0 L/hour of water consumption (28), perhaps due to learned behavior avoidant of GI distress. As said by Kovacs and others, “ad libitum drinking typically leads to involuntary dehydration.” (Kovacs 2007; Greenleaf 1992). They may not even perceive thirst until over 1.5 L of body water has been lost (Greenleaf 1992); by the time they have lost 5% of their total body fluids, their work capacity can be diminished by 30% (Sakin and Costill 1988). It is essential that players begin match play in a well hydrated state and continue to address scheduled rehydration practices during and between match play to minimize the effects of dehydration. Body weight is an easy way to assess dehydration. Once the body weight drops by 3-4% during a match, performance is significantly impaired.

Heat and Hydration Concerns in the Prepubertal Child

At birth, total body water is about 75% of total body composition (D'Anci, Constant et al 2006). By puberty, total body water (TBW) drops to approximately 60% in boys and 50% in girls (D'Anci, Constant et al 2006). Longitudinal TBW data from Caucasian boys and girls ages 8 to 20 years of age collected using deuterium nuclear magnetic resonance spectroscopy reflects the differences in puberty between boys and girls (Chumlea, Schubert et al 2005). Girls' %TBW increased until age 14 years and then leveled off, while in boys this increase and subsequent plateau occurred at 16 years. Table 1 shows the actual number data of %TBW at these ages by gender.

Table 1: Percent Total Body Water by Age and Gender (adapted from Chumlea, Schubert et al 2005)

Age	Girls	Boys
8 years	14.8 ± 1.9L	16.2 ± 2.0L
14 years	27.5 ± 3.7L	32.6 ± 6.8L
16 years	28.4 ± 4.1L	40.6 ± 7.7L
20 years	29.0 ± 3.4L	42.0 ± 5.0L

As children maintain a smaller absolute blood volume than do adults, there is a greater reliance on blood flow to the skin away from the core to aid in heat dissipation (Bar-Or Shephard et al 1971). Thus, in extreme temperatures, children are more prone to heat related consequences than adults, with their smaller surface areas. During exercise and/or hot and human conditions, the human body may not adequately dissipate heat, resulting in progressive increases in both core temperature and skin temperature (Moran 2001). Clear increases in core and skin temperature in prepubertal children exercising in high ambient temperatures reflect the reduced evaporative cooling and/or higher peripheral blood flow in children versus adults (Falk 1998). As compared to adults, the prepubertal child's athletic performance is limited by a lower absolute blood volume and increased competition in the child for blood flow between the skin and the active muscles (Maughan and Shirreffs 2004). The cardiac output of prepubertal children ages 10 to 13 years has been found to be 1-2 L/m lower than that of adults at any given metabolic level (Bar-Or, Shephard et al 1971; Drinkwater, Kupprat et al 1977).

Table 2 outlines differences between prepubertal children and adults. The combination of these factors put the prepubertal child at a disadvantage athletically as compared to the postpubertal child, with recovery impacted by suboptimal rehydration, core cooling, and other factors. In some tournaments, depending of timing of puberty, prepubertal and postpubertal teens of the same age may compete, with competitive advantage especially for those postpubertal youth meeting hydration needs easily, with adequate recovery time for core cooling, and adequate energy intake. Attention to these factors may or may not be enough to compensate for changes in strength, endurance, recovery, and other factors in the prepubertal child competing in the same arena.

Table 2: Differences in Physiology between Prepubertal Children and Adults, as adapted from Sinclair, Crowe et al 2007).

	Children	Adults
Surface area to mass ratio	greater	lower
%Total Body Water	greater (80%)	lower (60%)
Absolute blood volume	lower	greater
Cardiac output	lower	greater
Metabolic heat production per pound of body mass during exercise	greater	lower
Sweating mechanism	less efficient	more efficient

Sweating is an effective heat loss mechanism for prepubertal children during mild heat exposure, but is less effective during periods of combined heat and exercise stress when compared with adults (Drinkwater, Kupprat et al 1977). Development of the secretory function of apoeccrine (axillary) and apocrine (axillary and pubic area) sweat glands during puberty partially explain the differences in sweat rates between prepubertal and postpubertal children. Apoeccrine sweat glands, which only develop during puberty, produce sweat rates seven times that of eccrine sweat glands found elsewhere in the body, despite the fact that the latter being the most abundant and active since birth (Falk 1998). Although these glands remain unchanged after 2.5 years of age, children with their lower density and lover volume of total sweat make smaller sweat droplets per surface area (Falk 1998).

The relative magnitude of water loss and potential for dehydration are similar between prepubertal children ages 10-12 years and adults, with both groups often failing to ingest sufficient fluids during exercise (Meyer, Bar-Or et al 1995). The recommended adequate water intake for both children and adults under average conditions is 1 mL/Kcal. Excess energy expenditure with water loss can result in significantly greater fluid requirements. “Voluntary dehydration”, or the lack of adequate fluid intake, can be found commonly in child athletes following climatic heat stress. Children may not recognize the need to replace lost fluids, or be “too busy” to take the time to meet their needs. Thus, children and coaches need specific guidelines for fluid intake, with surrounding adults helping ensure that adequate rehydration occurs (American Academy of Pediatrics 2000). When environmental temperatures change, children may also require longer acclimation periods than adults. Child athletes in hot climates should begin athletic activities in a well-hydrated state and drink fluids over and above their thirst threshold, especially since thirst occurs relatively late in progression of dehydration, as noted above. To accomplish these ends, structured rehydration schedules may be beneficial for child athletes.

Fluid intake during athletic events can be enhanced by presenting palatable carbohydrate-electrolyte fluids in lieu of plain water (Rivera-Brown, Guteirrez et al 1999). What is particularly troubling is that after periods of physical exertion, voluntary fluid intake may be inadequate to offset fluid deficits (Bergeron, McKeag et al 2005). Mild to moderate dehydration can persist for hours after the conclusion of physical activity and can be cumulative during the course of a tournament

Heat Stress in the Peripubertal and Postpubertal Athlete

Heat stress negatively impacts performance and can threaten a young athlete's health and safety (American Academy of Pediatrics 2000, Hoffman 2001). In endurance sports such as cycling, carbohydrate/electrolyte drinks have been found to add more benefit than simple rehydration with water. To assess the effects in elite young tennis players, Bergeron et al looked at ad libitum fluid intake of water versus a 6% carbohydrate/electrolyte drink in 14 elite tennis players at IMG's tennis academy in Bradenton, Florida, during April of the study year. Of the nine boys and five girls, with average age 15.1 years, no differences were found in fluid intake, urine volume, fluid retention, sweat loss, perceived exertion, thirst, or gastrointestinal distress. However, a significant difference ($p<0.05$) between the groups was found in body weight percent change after training (carbohydrate/electrolyte group lost 0.5%, water group lost 0.9% body weight). Core body temperature was lower in the carbohydrate/electrolyte group than in the water group. Of note, both groups were relatively dehydrated before they even started, with initial urine specific gravities of 1.024 and 1.025, respectively. This study found that ad libitum consumption of a carbohydrate/electrolyte drink may be more effective than water in minimizing fluid deficits and mean core temperature responses during tennis and other similar training in teen athletes (Bergeron et al 2006). Moreover, all participants needed to be drinking more throughout the day, especially in conditions of heat or intense training. Regular reminders may not be enough; most of these players did not match sweat losses with an equivalent fluid intake volume during training sessions, as reflected in their percentage change in body weight. With a total sweat loss for each group for the entire two hour training session of only 2 liters per person, with a little more effort, appropriate fluid/calorie intake could have occurred.

When playing long matches and/or several matches in a day, a player needs to be cognizant of restoring not just hydration levels but also energy stores. Negative disturbances of glucose levels have been found particularly after the rest period between a first and second match during live tournament play (Ferranti et al 2003). While the players warmed up for the subsequent match, a sudden drop in glucose levels was noted, which in highly competitive situations could affect a player's attitude and readiness to compete at the highest level. A commercially available 6% carbohydrate-electrolyte sports drink has been shown to help delay the onset of exercise induced muscle cramps in activities of long duration; however, it did not prevent cramps entirely (Jung et al 2005)

When looking at urine specific gravity during a four day tournament, fewer than half the tennis players had achieved optimal hydration status as measured by urine specific gravity readings above 1.025 (Bergeron 1995). Tennis players should aim for urine specific gravities of under 1.010 to indicate adequate and appropriate hydration (Bergeron 1995).

Acclimitization in Prepubertal versus Postpubertal Youth

The acclimatization rate to hot, humid environments is somewhat slower in prepubertal children than in adults (Wagner, Robinson et al 1972; Inbar, Morris et al 2004). As per the American Academy of Pediatrics' guidelines, 8 to 10 exposures of 30 to 45 minutes is recommended on a daily basis for optimal acclimatization of the prepubertal child (American Academy of Pediatrics 2000). Adaptations in prepubertal children have been seen following acclimation for 8 to 14 days (Wagner, Robinson et al 1972; Inbar, Morris et al 2004). In extremely hot conditions, when air temperature exceeds skin temperature, children's greater surface area to mass ratio becomes a liability, resulting in greater heat absorption from the environment (Falk and Dotan 2008). In this kind of extreme heat, sweating is the only means of cooling the body (Bass and Inge 2001).

As noted above, children have a 2.5 times lower sweat rate than adults due to less sweat production by a similar number of sweat glands in the child versus the adult (Bass and Inge 2001). Also, the sweating threshold, or the core temperature when sweat begins to be exuded, appears to be higher in children than adults (Falk 1998). In milder conditions, when ambient temperature is substantially lower than skin temperature, children have been found to tolerate exercise similar to adults (Drinkwater, Kupprat et al 1977). When the ambient air temperature is similar to the athletes' skin temperature, children can tolerate at least one hour of moderate exercise (Drinkwater, Kupprat et al 1977). However, their core temperatures will be relatively higher than adults under similar conditions, with impact on recovery.

Despite these noted differences in heat tolerance and abundant anecdotal evidence, no epidemiologic data is currently available on negative outcomes of children's inferior heat tolerance as compared to adults. In a ten year study in North Queensland, Australia, where hot weather and heat intolerance are both potential threats to performance, child athletes were found to have no differences in incidence of heat illness as compared to adult athletes (Brun and Mitchell 2006).

Hydration and Cognitive Function

Cognitive function can be clustered into several main domains: memory functions, attention functions, perceptual functions, executive functions, psychomotor functions, and language skills (Schmidt, Benton et al 2005). Each of the cognitive domains can be further divided in a number of more specified functions. For example, memory functions include encoding of short-term and long-term memory, storage and retrieval functions, and working memory. Mild dehydration produces alterations in a number of important aspects of cognitive function such as concentration, alertness, and short-term memory (D'Anci, Constant et al 2006). Even a 2% loss of fluid body weight can impair performance on such tasks as short-term memory, perceptual discrimination, arithmetic ability, visuomotor tracking, and psychomotor skills (Clan, Koulmann et al 2000; Clan, Barraud et al 2001). A recent examination of voluntary dehydration in 10 to 12 year old children found that dehydration throughout the day may negatively impact cognitive function (Bar-David, Urkin et al 2005). In most sports in which child athletes compete, the need to have the necessary cognitive function throughout training and competition is vital to perform at the highest level.

The Adolescent Mindset: Help or Hindrance?

"It can't happen to me." "That would never happen." "Long term consequences? You mean what happens tomorrow?" And then there's the old adage from Mrs. Piggle Wiggle's book of childhood cures, "I'll do it because I want to, not because you tell me to". Success for the adolescent elite athlete requires support from family, coaches, trainers, pediatrician and/or other medical caregivers to enhance physical performance while keeping the teen's "head in the game". Overinvolved parents have not been associated with improved tennis performance, but parental approval of the youth's athletic choices and success does correlate with better attitudes about play and competition (Ommundsen et al 2006).

In a study of soccer players, pressure from parents and coaches in combination was found to be associated with maladaptive achievement, with young players displaying an overconcern for mistakes, doubt about their soccer actions, and lowered perceptions of competence. Supportive, mastery-oriented coaching positively impacted teen soccer players. In a study of young tennis players, athletes with parental support displayed a higher enjoyment of tennis and felt that tennis was a key part of their lives. However, these views also correlated with lower state rankings than players who reported a lower level of parental support (Hoyle and Leff

1997). Does this mean that the players with less parental support were “hungrier” for a win? Further research is needed to tease out supportive parental factors.

In a study in Britain of 282 elites athletes ages 8 to 17 years playing soccer, tennis, swimming or gymnastics, self motivation (27%) and parental influence (57%) brought children into tennis (Baxter-Jones et al 2003). Among the tennis players, 25% decided autonomously to start intensive training, with children from lower socioeconomic classes underrepresented, as were total number of one-parent families as compared to British national norms. This study notes that talented youngsters without a supportive parent will have limited opportunities to succeed in this sport, particularly if they come from an economically challenged background.

When teen athletes identify a perceived parental belief that effort directly causes sport success, they tend to live what they learn; in other words, they connect their own success to their own effort (White et al 2004). This reflects an internal locus of control, an ability to have an impact on their own destiny. In contrast, teen athletes’ perception that parents believe in superior ability, external factors, and use of deceptive tactics as precursors or necessary components to sport success, leads them to hold these same beliefs. Thus, if a parent has an external locus of control, and blames lack of success solely on external factors, so shall his or her teen. Conversely, success is due to external factors for this parent/athlete duo, allowing for less internal pride in the accomplishment.

When addressing questions of importance to a young athlete’s career, the adolescent mindset and normal developmental tasks of adolescence need to be taken into account. Little data exists on optimal weeks in a row of competition for junior elite athletes, whether a 12 year old should be allowed to play 3 matches in a day, or how much time should be allowed between individual matches to allow for adequate recovery. Physiologic aspects, where data is known, are covered elsewhere. Nutritionally, the young athlete already has been shown to underestimate their thirst and body's fluid and energy needs. Young athletes may also underestimate time needed for physiologic recovery, asking for that third match to go on even when performance will likely be impacted. "Burnout" and overtraining can be self-induced by the overly conscientious or competitive teen, or by "achievement by proxy" from a parent or coach.

Effects of Fatigue on Performance

Fatigue reduces tennis-hitting accuracy by up to 81% (Davey et al 2002; Davey et al 2003). Best training should include strategies to avoid fatigue during competition in order to remain injury free and improve chances of winning (Kovacs, Sports Med 2007), For the non-elite tennis player, improving fitness and having fun without extreme exhaustion or injury constitute worthwhile goals.

During a 5 week, unsupervised break from collegiate tennis, 8 male players demonstrated a significant increase in fatigue plus clinically significant reductions in speed, power and aerobic capacity (Kovacs et al 2007). Thus, prolonged breaks between matches without adequate supervised training may not be in competitive players' best interests. On the flip side, the problems of overtraining, which can also happen in the very competitive young athlete, can emerge; many teens feel that "more is better" and will far exceed recommendations of trainers, coaches, doctors, and parents in order to gain themselves a perceived competitive advantage. These results tend to backfire, as injuries occur, effects of overtraining on performance become evident, or they show the effects on the psyche ranging from maladaptive coping strategies such as disordered eating and burnout.

Musculoskeletal Injuries in the Young Tennis Player

Intensely active young tennis players are more at risk for severe injury than their recreational tennis-playing peers (Kibler and Safran 2000). Where the young elite player subjects his or her body to repetitive tensile overload, deletrious maladaptations in strength and flexibility can occur, compromising play and recovery. The higher the number of years of tournament play, the higher the risk of maladaptations; in today's world of junior players starting younger and younger, proper training and recovery become paramount.

Injury patterns in tennis as in other sports tend to be more sport-specific than gender-specific, although girls tend to have more patellofemoral problems than boys due to anatomical differences in hip width and Q angle (Kibler and Safran 2000). Young female athletes have also been postulated to have less upper extremity strength and to begin competition at a lower level of physical conditioning than boys. If this hypothesis is correct, we should see more overuse and stress-induced injuries in girls from poor physical conditioning, and more shoulder and elbow injuries from comparatively less upper body strength, in addition to the increase in patellofemoral injuries. One study looked at injury patterns in elite junior athletes of both genders from 1996 to 1998 at the United States Tennis Association (USTA) Tennis Championships (Safran et al 1999). More new injuries occurred in 16 and 18 year old boys than in girls, but the overall prevalence of injuries remained similar among boys and girls. The number of girls with lower-extremity injuries was disproportionately greater than found in boys, while boys had more injuries to the abdomen, back and groin than was found in the girls. Boys and girls both displayed high rates of injuries to the back and shoulder; girls had more injuries in the feet, leg, calf and wrist. Boys had more injuries in the ankle, groin and hand. Another 6 year-study of USTA Boys' Championships found that the incidence and prevalence of lower extremity injuries was twice as high as injuries in the upper extremities, with high statistical significance ($p < 0.007$) (Hutchinson et al 1995). Overuse injuries were common, as were back injuries; tennis toe, tennis shoulder, and tennis leg were rare in the elite young male player.

Mechanisms of injuries for the young players depend on whether macrotrauma (a likely one-time event) or microtrauma (from repetitive stress) has occurred. Injuries from macrotrauma include acute sprains, acute joint injuries, fractures, dislocations, and contusions. These injuries occur usually in players' lower extremities, with the injury patterns in boys and girls' noted above. Microtrauma results in tendonitis, chronic muscle strains, and joint instability; these injuries can be found in the upper and lower extremity.

During tennis, explosive bursts of energy are required for hitting, serving, starting, and stopping. The average tennis point requires 8.7 changes of direction, with each change generating a load of 1.5 to 2.7 times body weight on the planted leg, knee and ankle, giving an increased likelihood of injury if improper training techniques are employed (Safran et al 2000).

Adaptive and maladaptive body responses to biomechanical stresses can occur. Positive adaptations include increased bone density from mechanical load applied against gravity; increased tendon collagen content; increased VO2max as training progresses, and increased anaerobic threshold. Negative adaptations include decreased back flexibility, as measured by decreased sit-and-reach measurements, as compared with age-matched controls (Kibler and Chandler 1993). Young tennis players also display trunk extensor weakness in absolute magnitude and in strength balance (Ellenbecker 1995). Many trainers and coaches have adapted core strength training to compensate for these injury patterns and ideally prevent them from occuring.

Another maladaptive response includes internal rotation and horizontal adduction inflexibility in the dominant shoulder of tennis players, with progressive inflexibility found with increasing years of play (Kibler et al 1996; Kibler and Chandler 1993; Kibler 1998). In contrast to baseball, where decreased internal rotation is coupled with increased external rotation, in tennis this progressive inflexibility appears to be a true limitation of total shoulder rotation (Safran 2000).

Increased bone density as a protective response will occur in the properly nourished young athlete; but in those athletes with inappropriate eating habits during times of peak bone deposition, osteopenia can occur, as well as stress fractures. In those young athletes with the female athlete triad (amenorrhea, osteopenia, and disordered eating), osteopenia at the spine can result in low back pain with recurrent stress, or in stress fractures in their lower extremities. In tennis players with overuse, pathologic reactions include stress fractures of the metacarpals, ulna, and humerus (Bollen et al 1993; Murakami 1988; Young et al 1995; Rettig and Beltz 1985)

Proper training techniques in the young athlete are imperative; new sports skills are learned easiest earlier in life, typically between the ages of 8 and 12 years. Proper coordination of motor firing patterns can lead to efficiency of muscle activation that will allow efficient biomechanics to enhance performance over a lifetime and decrease injury risk. In contrast, improper learning can lead to injury. In tennis, the two most common mechanisms come from training with oversized equipment for a young athlere, or trying to learn skills that require more muscular force than the athlete can generate (Saffran 2000). If the racquet is too heavy, too long, or with a grip too large, the young player will try to move the racquet repetitively through the hitting zone with a maladaptive strategy- excessive dropping of the racquet head during cocking, or more motion and muscle activity in the trunk, to muscle the ball over despite the oversized racquet. Maintaining balance becomes very difficult. Power development to hit the ball hard or with heavy topspin requires a coordinated, sequential linkage of body segments, called the kinetic chain (Safran 2000). The prepubertal athlete may not have the muscle strength, mature motor pattern or mechanical advantage to generate the power; young players may lack the lower leg strength found in older players. To compensate, they may use excessive trunk lean while serving, dropping or leading with the elbow in the serve and forehand, excessive wrist snap or slap in the forehand, or pulling up and away from the ball with the backhand. Attention to the mechanics of the swing should start early, even at the expense of power, to instill lifelong biomechanical habits that will prevent injury later when the young person achieves puberty and, therefore, increasing strength.

Epiphyseal and apophyseal injuries of long bones can occur in young tennis players (Saffran 2000). Traumatic inversion injury of the ankle, or falls on an outstretched arm, can produce epiphyseal bone injuries rather than ligament sprains. The physician or trainer will feel tenderness during palpation over the epiphysis rather than over the ligament with these injuries. Traction apophysitis, as occurs with the Achilles tendon at the heel, quadriceps tendon at the tibial tubercle, and the wrist flexors at the humeral medial epicondyle, can occur with repetitive load on the tendon insertion on a growing bone.

Other common specific injuries in young tennis players include rotator cuff inflammation in the shoulder, a common injury at all ages. This injury occurs from chronic repetitive hitting and overhead serving. In young people, instability of the glenohumeral joint serves as the mechanism of injury, in contrast to rotator cuff impingement or degenerative changes that might be found in the older player. “Tennis shoulder”, or a drooping, internally rotated shoulder due to long term overhead arm use leading to generalized laxity of the shoulder capsule and musculature remains relatively uncommon in adolescent tennis players. “Tennis elbow”, or lateral epicondylitis, as well as medial epicondylitis (injury to the medial epicondylar apophyseal growth plate) can occur in young tennis players (Gregg and Torg 1988), from chronic repetitive overload. Small avulsion fractures remain more common than ulnar collateral ligament injuries in the young tennis player (Safran 2000). Wrist tendonitis can happen in players using lots of topspin and in novices with a mechanically improper technique (Kibler and Chandler 1993).

Since lower extremity injuries are more common in young people due to the rapid starting and stopping combined with sharp, lateral movements, preparticipation warm-up and dynamic stretching becomes essential. Acute injuries later in the match occur with increasing fatigue; chronic injuries occur due to inadequate rest or rehabilitation following an injury.

Limitations of the current available research on sports injuries in tennis include the prevalence of adult tennis research and the lack of sufficient data on girls and young women tennis players. The latter is in contrast to the marked increase in girls’ participation in sports since the advent of Title IX in the 1970’s.

Prevention: Prehabilitation and the Preparticipation Exam

During the preparticipation exam, the pediatrician, sports medicine doc or clinician should pay attention specifically to the flexibility of the back, shoulder, and elbow; strength estimation through situps, pushups; power through the vertical jump and medicine ball; and anaerobic power through a brief sprint or shuttle run.

Assessment of posture while standing can identify lumbar lordosis, which is common in young people and can decrease core trunk stability (Sciascia and Kibler 2006). Inablity to achieve balance of the trunk over one leg during one leg stance and one leg squat can identify areas for focused conditioning. Hip range of motion and trunk flexibility should be assessed. With shoulders and other body areas, injury can occur when the kinetic chain sequencing is inadequate or the demands are too high (Sciascia and Kibler 2006). If room for improvement in flexibility, strength, or specific areas are found, prehabilitation can include tennis-specific conditioning exercises.

In elite female junior tennis players ages 12-16 years, the dominant arm displays greater wrist extension/flexion and forearm pronation strength than the nondominant arm. After dominant arm injury, isokinetic testing can help guide rehabilitation, with a goal of regaining strength in the dominant arm to again exceed strength of the nondominant arm. Achieving only equal strength to the nondominant arm could lead to progressive injury (Ellenbecker et al 2006).

Overtraining may be initiated by the teen or junior player themselves, or by an uninformed parent, coach or trainer. Many children initiate year-round training at exceptionally young ages, and by their teens may be training over 20 hours a week, in or out of specialized centers (Magra et al 2007). This trend is aided and abetted by a “catch them young” philosophy, and the media has added to the allure with stories of Tiger Woods in golf, and Maria Sharapova in tennis. ”Achievement by proxy” refers to the parents garnering vicarious success through the achievements of their offspring; these are the parents who live and die depending on how their child performs. This disturbing trend can result in overtraining, overuse injuries, burnout, and maladaptive coping strategies such as disordered eating in the young athlete. Conversely, when a parent or coach's drive is athlete centered, the success in a child is balanced and the best interests of the child are kept in mind. Young athletes often are highly motivated, and despite pain may choose to participate in sports for reasons that include the sheer love of the game, fear that they may lose their competitive edge or position in a coach's favor, to prevent being teased, or to impress their peers, parents, or coaches with their "toughness" despite injury.

Overtraining injuries and competitive staleness can be addressed by variations in the training focus and intensity of workouts. Although youth sports have developed into sport specific, year round endeavors, there are still key competitive periods and off-seasons for each sport. For training it can be efficient to break the season into one (or two) series of training phases: off-season; pre-season, and competitive-season.

During the off-season, immediately following the competitive-season, training can be less intense and less sport specific. The player should focus on general fitness concepts; participate in fun, modified tennis games with an increased emphasis on pleasure versus winning. The off-season is also an excellent time to focus on basic skill development/refinement.

In the pre-season training phase the intensity of the training increases and the training becomes more sport specific. Interval training simulates game play both in intensity and duration. Drills include tactical components and are executed under game-like conditions. The training emphasis shifts to skill perfection during the competitive-season. Drills focus on skill and scrimmage match play becomes more frequent, along with regular competitive play.

Summary

In order to generate the next cadre of elite young tennis players who compete at the national and international level and to enhance fitness for those players who move away from competition but maintain interest in tennis as a lifetime sport, careful attention to issues of overtraining, inadequate conditioning at the aerobic and anaerobic level, improper equipment, and allowing for adequate recovery nutritionally, physiologically, and psychologically between matches, tournaments, and training sessions. A paucity of tennis-specific research exists in the area of competition levels. Other key factors include adequate recovery time, fluid and nutritional rehabilitation together with supportive parenting/coaching environment. However, the structurally, physiologically and psychologically immature male or female elite athlete may be at more risk from environmental stressors, suboptimal nutrition, nutritional depletion, insufficient recovery time and orthopedic stress if too little time is allotted between matches or if too many matches are played in a given day, especially without regard to match duration . Prehabilitation, stretching, and creative ways to ensure adequate fluid and energy intake to avoid pre- and post-event dehydration and nutritional depletion are essential components for elite tennis success in young people. The younger the athlete, the more attention needs to be placed on fluid and energy replacement to ensure adequate recovery despite the physiology of youth.

Practical Application:

- Skill development and technical aspects of training are best addressed when athletes are fresh and rested. Fatigue limits hitting accuracy by up to 81% and alters the motor-pattern sequencing.

- To optimize performance and recovery for tennis, conditioning drills should simulate game like conditions: the work-to-rest ratios for training should fall between 1:3 and 1:5, to best simulate match conditions.

- To optimize performance and recovery for speed, agility and power, the work-to-rest ratios for training should be from 1:25 to 1:40, with these far longer times allowing for appropriate recovery.

- Players whose game style is to be on the attack and play shorter points require more short, anaerobic-focused training with a focus on speed, strength, and power.

- Players with a more defensive game style require training to enhance muscular endurance.

- Extrapolating from adult elite players to postpubertal teens, a VO2max of over 50 mL/kg/min for males and over 42 mL/kg/min for females is a minimum standard for elite performance; over 65 mL/kg/min for males and over 55 ml/kg/min for females does not add aerobic value for tennis play.

- Young athletes- and old- need to be trained NOT to rely on thirst to cue them to drink; thirst will not appear until 1.5 L of body water loss, already setting in motion risk for elevated core body temperature and dehydration, negatively impacting performance.

- Athletes should start matches well hydrated and consume approximately 200 mL (6.6 ounces) of fluids per each change of ends in mild temperatures, with more recommended during warm weather play (200-400 mL). Young players are more likely to drink flavored sports drinks than water, with one study pointing to preference for grape and orange. In addition, a carbohydrate/electrolyte sports beverage may be more effective than water in minimizing fluid deficits and thermal strain in highly skilled, acclimatized adolescent elite tennis players during tennis play in conditions of heat.

- Carbohydrate replacement during tournament play is also critical to help minimize the effects of glycogen depletion.

- Monitoring of urine (aim for clear color) and weight can help young players ensure adequate hydration.

- Further data is needed to better address questions on the number of matches in junior tennis, the time between matches to ensure adequate recovery in the young athlete, and number of sequential weeks of competition without a break. These efforts help to avoid injury and burnout in the young athlete.

- To avoid overuse injuries, variety in intensity and duration is encouraged throughout the year and within each training session.

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