Efficient Deceleration: The Forgotten Factor in Tennis-Specific Training

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SUMMARY

EFFICIENT DECELERATION IS PARAMOUNT TO ALLOW FOR FAST AND EXPLOSIVE CHANGES OF DIRECTION. BECAUSE MOST TENNIS POINTS HAVE BETWEEN 3 AND 7 CHANGES OF DIRECTIONS, THE DEVELOPMENT OF THE COMPONENTS IN CHANGE OF DIRECTION MOVEMENTS IS A MAJOR COMPONENT OF COMPETITIVE PLAY. TRAINING FOR TENNIS REQUIRES A STRONG UNDERSTANDING NOT ONLY OF THE ACCELERATION ASPECTS OF MOVEMENT BUT ALSO THE NEED FOR TENNIS-SPECIFIC DECELERATION. IN THIS ARTICLE, WE REVIEW TENNIS MOVEMENTS FROM BOTH AN UPPER- AND LOWER-BODY PERSPECTIVE AND DESCRIBE THE IMPORTANT COMPONENTS OF TENNIS-SPECIFIC DECELERATION WITH PRACTICAL EXAMPLES OF DECELERATION TRAINING IDEAS.

INTRODUCTION

For competitive tennis players, exceptional movement is a requirement to achieve success in junior tournaments as well as at the collegiate or professional level. Acceleration focused training is common in strength and conditioning programs for tennis players; however, less emphasis is sometimes given to the importance that effective deceleration training plays in both upper- and lower-body movements of the tennis athlete. The lower body needs to perform large decelerations to prepare for and recover after groundstrokes and volleys, as well as during the follow-through and landing phase of the serve (29). The upper body, particularly the muscles of the upper back and posterior aspects of the shoulder, feature the major muscles that help decelerate the upper limbs after ball contact in serves, groundstrokes, and volleys (30). As such, deceleration needs to be considered a vital component of a competitive tennis player's training routine to achieve peak tennis performance. To explore the complex nature of deceleration, a deterministic model has been used to showcase the multifaceted nature of deceleration and the many components that need to be trained to successfully execute the correct movements. A deterministic model is a systematic model that is used to analyze and evaluate an important component of a skill, which provides an approach that is based on a hierarchy of factors that are dependent on the result or outcome of the performance (22). Figure 1 describes a deterministic model for deceleration that can help the strength and conditioning specialist highlight areas that need to be trained during the phases of a periodized training program. At the simplest level of analysis, deceleration is the fine interplay between musculoskeletal, neural, and technical components. To develop effective deceleration capabilities in tennis athletes, it is important that the strength and conditioning program includes ample time on all 3 of these broad areas of training.

PLYOMETRIC MOVEMENTS

Plyometric exercises typically are incorporated into an athlete's program by the strength and conditioning specialist to improve explosive movements by improving power outputs (21). Plyometric movements involve an eccentric loading immediately followed by a concentric contraction (14). Plyometric training enhances athletic performance, typically by improving power outputs as measured by concentric contractions. However, the benefit of plyometric training also aids in the training of adaptations in the sensorimotor system that enhances the athlete's ability to brake, sometimes referred to as the "restrain mechanism" (35,36). In addition, plyometric training aids in the correction of mechanically disadvantageous jumping and change of direction movements. Another added benefit with respect to deceleration training is the landing components after a plyometric type movement. Because plyometric movements produce greater power outputs, as the result of the greater use of stored potential energy, than nonplyometric

KEY WORDS:
acceleration; deceleration; movement; quickness; speed; tennis

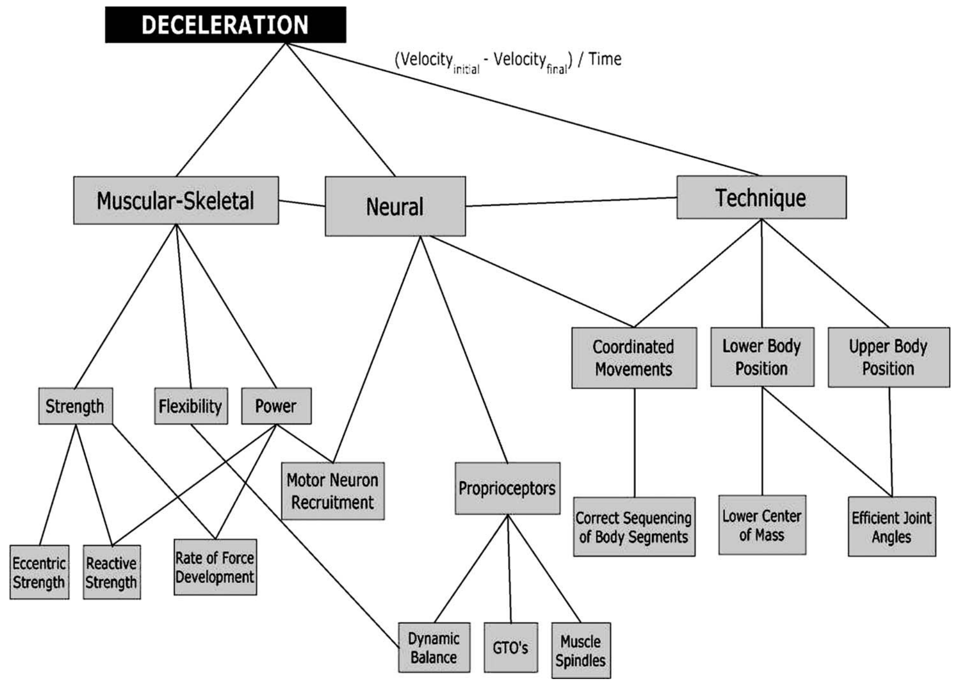

Figure 1. Deterministic model of deceleration.

Figure 2. Lower body deceleration after a tennis stroke.

movements (33), these greater forces require greater deceleration abilities. Therefore, training with the use of plyometric movements not only improves power and explosive movements but also results in training adaptations during the landing or deceleration phase of these movements. The need to develop this improved ability to "brake" and improve the restrain mechanism will be the major focus of the remainder of this article.

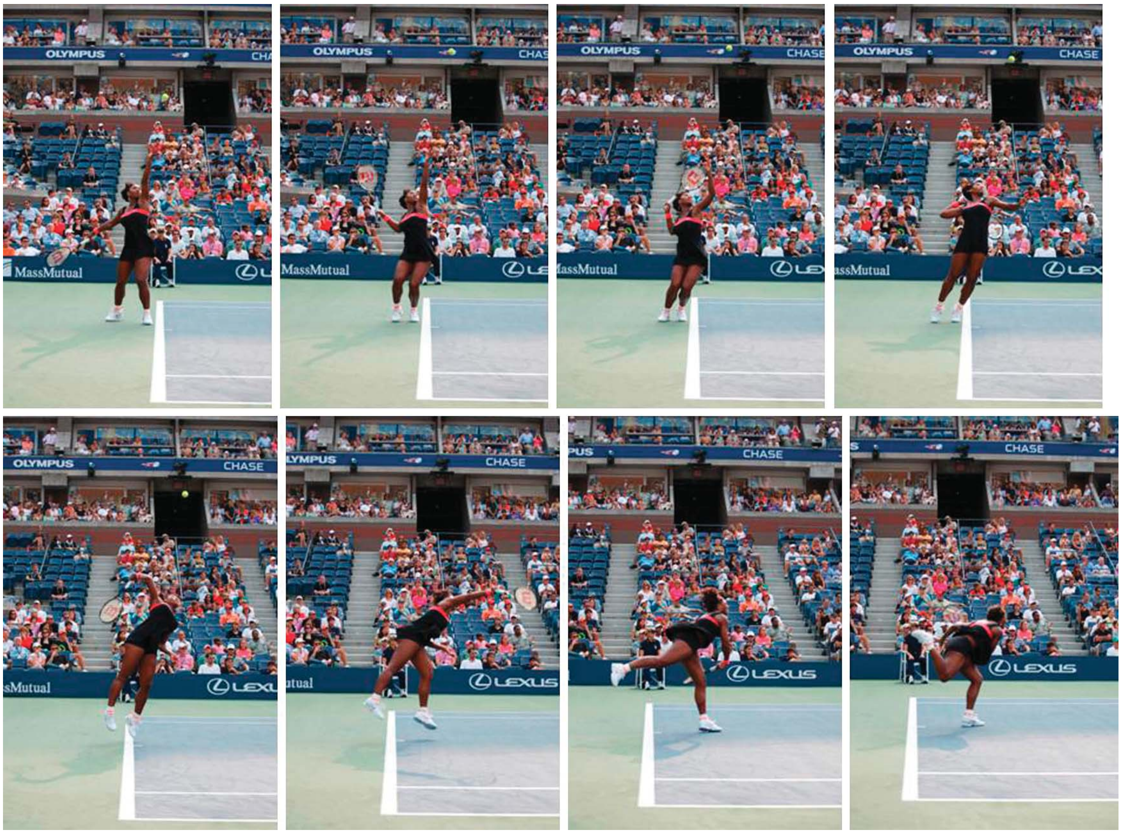

Figure 3. Upper and lower body deceleration after a tennis serve.

LOWER-BODY DECELERATION

Although training acceleration is vital to help an athlete become faster, this improved acceleration ability may not transfer into improved tennis performance if the athlete does not have the ability to decelerate the faster velocities in the appropriate time frame and under the needed control to make optimum contact with the tennis ball. The ability to effectively decelerate is also important while transitioning into a recovery movement that will allow the athlete to be in position for the next stroke in the rally. Figure 2 demonstrates the body position and importance of appropriate strength, balance, and coordination, first to accelerate into the forehand, and second to decelerate rapidly after contact with the ball has been made.

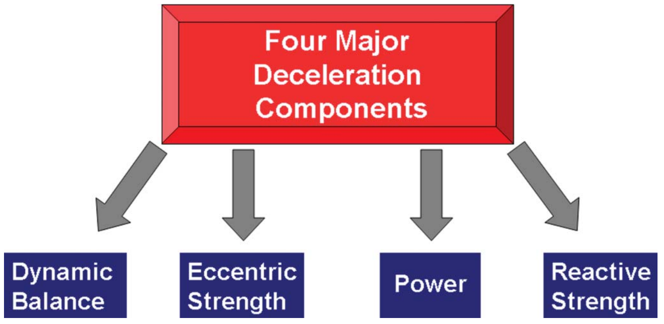

Figure 4. Four major deceleration components.

An athlete's ability to decelerate is a trainable biomotor skill and, as such, needs to be included in a well-rounded, tennis-specific training program. An athlete who can decelerate faster and in a shorter distance is an athlete who will not only be faster but will also have great body control during the tennis stroke. This greater control during the stroke will result in a greater level of dynamic balance (Figures 1 and 4), which translates into greater power of the strokes, and more solid racket and ball contact, which results in more effective execution. A major influence on a tennis player's ability to decelerate is momentum. Momentum is the product of the mass of a moving athlete and his/her velocity. As an athlete's velocity increases, momentum is amplified, requiring greater forces to decelerate the fast moving tennis player. A larger tennis player (i.e., greater mass) has a more difficult time decelerating and, if the coach focuses the

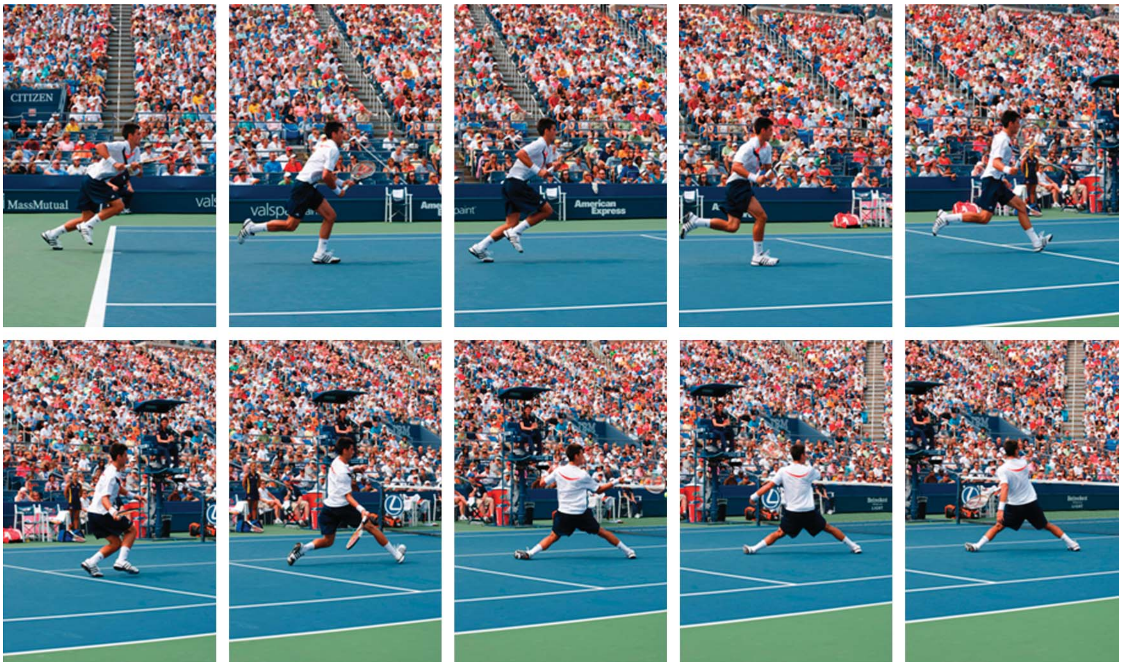

Figure 5. Deceleration and requirement of eccentric strength during a forehand stroke.

majority of movement training on acceleration without focusing ample time on deceleration, it will result in an athlete who has a faster initial velocity but who may not be able to control the body to slow down fast enough before and/or after making contact with the ball. This will result in reduced on-court performance and may result in the increased likelihood of injury. It has been proposed in the literature that the causes of the majority of athletic injuries are the result of inappropriate deceleration abilities of athletes and an overemphasis of acceleration-focused (concentric specific movement) exercises both on and off-court (11,26).

UPPER-BODY DECELERATION

In the upper extremity, the body uses eccentric contractions after ball impact in virtually all strokes to decelerate the upper-extremity kinetic chain. These contractions are of vital importance around the shoulder and scapular area because they help to maintain the critically important stability that is needed to both prevent injury and enhance performance. For example, during the serve (Figure 3), the upper arm is elevated approximately 90–100 degrees relative to the body (abduction). In this position, large forces are generated by the internal rotator muscles such as the latissimus dorsi and pectoralis major to accelerate the arm and racquet head forward toward an explosive ball impact.

Immediately after ball impact, the muscles in the back of the shoulder, including the scapular stabilizers (infraspinatus, teres minor, serratus anterior, trapezius and rhomboids [27]), have to work eccentrically to decelerate the arm as it continues to internally rotate. Fleisig et al. (9) reported anterior translational forces during the acceleration and follow-through phases of the overhead throwing motion to approximately 1× body weight in the glenohumeral joint. The posterior rotator cuff muscle–tendon units are responsible for maintaining joint stability by resisting this anterior translation/distractional force to prevent injury to the

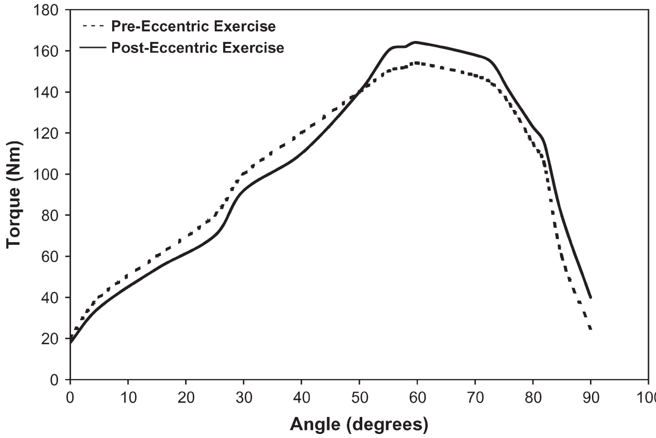

Figure 6. Length–tension curve before and after eccentric exercise. Adapted from Brughelli and Cronin (3).

glenoid labrum and other structures in the shoulder (9). This deceleration is critical for injury prevention because the inability to dissipate these large forces by the muscles in the back of the shoulder and scapular area can lead to injury (Figure 3). Similar results are seen in tennis movements and require appropriate training (7).

In addition to the high levels of activity identified during the serve, the same rotator cuff and scapular muscles work to decelerate the arm on the forehand during the follow-through phase. Training these important muscles provides important muscle balance to the tennis player. Players are deficient in these important decelerator muscles (5,16,31) and do not understand the importance of training these muscles by incorporating deceleration type training programs into their normal training regimens.

TRAINING SPECIFICITY

It has been shown in the scientific literature that linear acceleration and linear maximum velocity are separate qualities from multidirectional movements that require a change of direction and/or a deceleration of movement (43). Young et al. (43) found that straight-ahead sprinting, such as a 100-m sprint in track and field, does not transfer directly to the movements typically seen on a tennis court. This result is caused by the differences in movement mechanics, muscle firing patterns, and motor learning skills required to perform straight line sprinting versus tennis play that require start and stop movements and numerous changes of direction in every point. As a result, training for tennis-specific acceleration, deceleration, and recovery movements (change of direction) requires movement patterns, distances, and energy system focus that resembles competitive tennis play. Because tennis is an untimed competition, it may last anywhere from 30 minutes to 5 hours (17). However, from a practical standpoint, we know that high-level competitive tennis has some typical patterns that occur during matches

Figure 7. 90/90 prone plyometric exercise.

Figure 8. Prone horizontal abduction plyometric exercise.

Figure 9. Reverse catch deceleration training exercise.

that can help the strength and conditioning professional when designing programs. Athletes typically encounter between 3 and 7 directional changes per point, rarely move more than 30 yards in one direction (16,38). In addition, point length averages are around 6 seconds, with the majority of points lasting less than 10 seconds, and a typical work-to-rest ratio during individual points and matches is between 1:2 and 1:5 (15,16,18,19,30). All these factors can be used to help develop tennis-specific deceleration training programs.

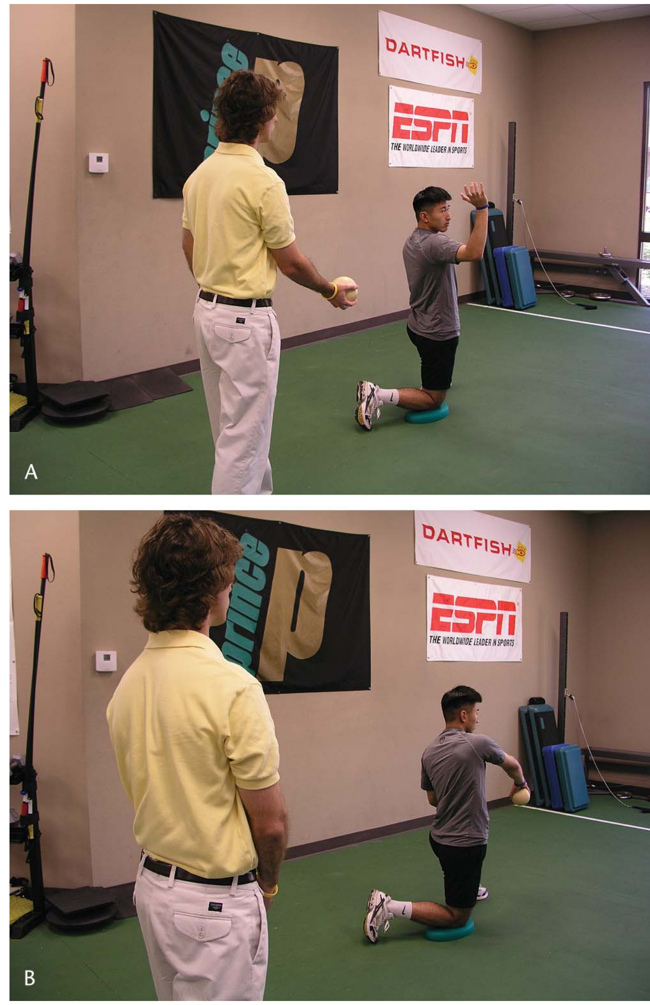

Figure 10. Tennis-specific reverse catch. A) Start. B) Deceleration phase.

WHAT FACTORS IMPROVE A TENNIS PLAYER'S DECELERATION ABILITY?

Dynamic balance, eccentric strength, power, and reactive strength are 4 major qualities that have a significant influence on an athlete's ability to decelerate, while maintaining appropriate body position to execute the necessary tennis stroke and then recover for the next stroke (Figure 4) (41). Although other components do contribute to an athlete's ability to effectively decelerate, these 4 factors will be investigated to aid the strength and conditioning coach in designing effective programs.

DYNAMIC BALANCE

Dynamic balance is paramount in tennis, specifically during the deceleration movement phase before or after the player makes contact with the ball. Dynamic balance is the ability of the athlete to maintain a stable center of gravity while the athlete is moving (1). This ability to maintain balance in a dynamic environment allows the athlete to successfully use the segmental summation of muscular forces and movements through the kinetic chain (13). This efficient energy transfer from the ground and up through the entire kinetic chain will result in a more efficient and powerful tennis stroke, in addition to faster racket head speeds and ball velocities. Additionally, dynamic balance can refer to the ability during movements of opposing muscles to work optimally together to produce uncompensated movement patterns (1). This is particularly important in the upper extremity when proper muscle balance must be maintained to improve shoulder joint stability. Although experts may not agree on the mechanisms involved in athlete-specific balance, the research suggests that changes in both sensory and motor systems influence balance performance (1). The feedback obtained from plyometric movements encompasses a number of reflexive pathways that aid muscle and neural adaptations to accommodate unanticipated movements (34). These adaptations are vital for the prevention of injuries during practice and competition.

ECCENTRIC STRENGTH

Eccentric strength requires training of the muscles during the lengthening phase of the muscle action. An example would be during the step before and the loading phase of a forehand (Figure 5). Eccentric strengthening exercises need to be performed both bilaterally and unilaterally. Nearly all tennis movements require the athlete to load one side of the body more than the other, and it is paramount that these uneven loading patterns are trained eccentrically as well as concentrically. It is known that physically trained humans can support approximately 30% more weight eccentrically

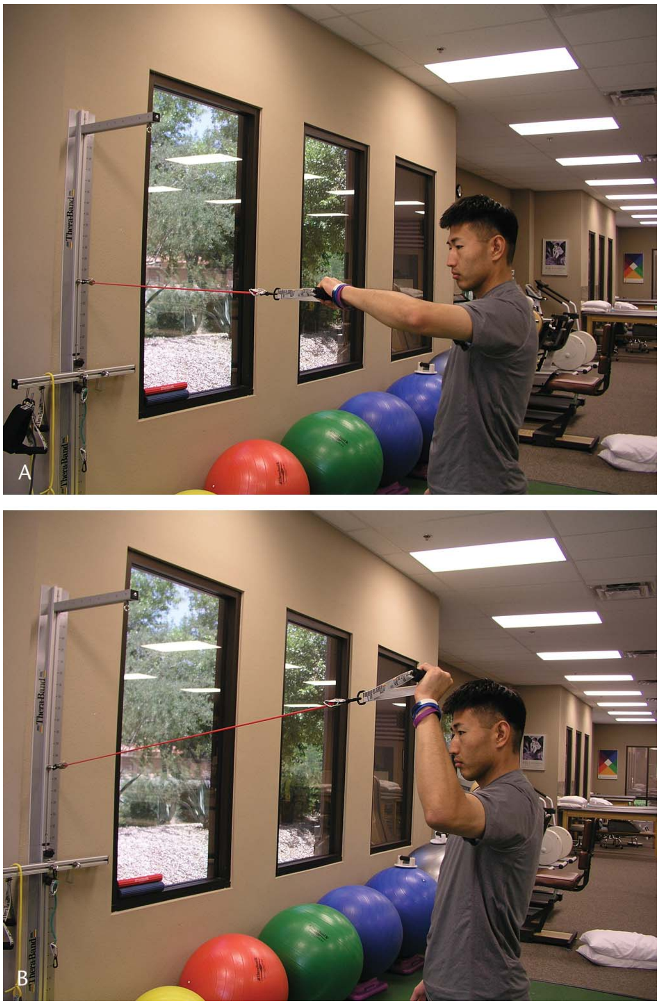

Figure 11. External rotation at 90 degrees with elastic tubing. A) Start. B) Finish.

than concentrically (6,23,40). Therefore, eccentric focused strength training needs to be incorporated into an athlete's periodized program to successfully maximize his or her athletic improvement. A second major benefit of training eccentric strength is to aid in the prevention of injuries (2,26). A large portion of injuries to tennis players is attributable to insufficient eccentric strength both in the upper body during the deceleration of the racket after serves, groundstrokes, and volleys, as well as in the lower body during the deceleration of the body before planting the feet to establish a stable base for effective stroke production.

Eccentric strengthening exercises have a positive effect on altering the length–tension relationship of muscle (3). The optimum length of peak tension occurs at longer lengths, therefore, shifting the curve to the right (Figure 6).

Length–tension curves for single fibers (sarcomeres), whole muscle, and single joints all have different shapes (3). As the result of these different shapes, it is vital for the athlete to be trained at a variety of angles and torques to stimulate adaptations in as many muscle fibers as possible to capture the greatest effect on altering the length–tension relationship, specifically during eccentric dominant movements. A great review of the eccentric exercise literature by Brughelli and Cronin (3) devised some tentative conclusions that should be helpful when designing programs focused on eccentric strengthening to optimize the length tension relationship.

- High-intensity and higher volume eccentric exercise result in greater shifts in optimum length
- Eccentric muscle actions at longer lengths result in greater shifts in optimum length
- It may be possible to produce a sustained shift in optimum length after 4 weeks of eccentric exercise
- Excessive muscle damage may not need to be induced for this shift in optimum length to occur with eccentric exercise

From the muscle physiology literature, we know that after eccentric exercise, the athlete's cytoskeletal proteins, such as desmin and titin, are disrupted and degradation occurs (10), possibly as high as 30% after a single bout of eccentric exercise (37). This process then results in a protective adaptation that strengthens the cytoskeletal proteins and prevents them from being damaged in the future. This is one of the major theorized mechanisms as to why eccentric strengthening is important for injury prevention, especially during movements that require rapid deceleration. Most muscle-related injuries occur when they are actively lengthened (11). From the literature, it appears that neural control of eccentric actions is unique from control of concentric actions (25). The central nervous system adjusts motor unit recruitment, activation level, distribution of that activation, and afferent feedback during eccentric muscle actions (8). Therefore, specificity of muscle contraction mode (i.e., eccentric, isometric or concentric) during training is important.

POWER

Power for the tennis player is what directly translates into greater racket head speed and ball velocity. Most forms of plyometric exercise movements are geared toward improving muscular power. Plyometric exercises are vital for the development of great deceleration abilities through a number of separate, yet interrelated

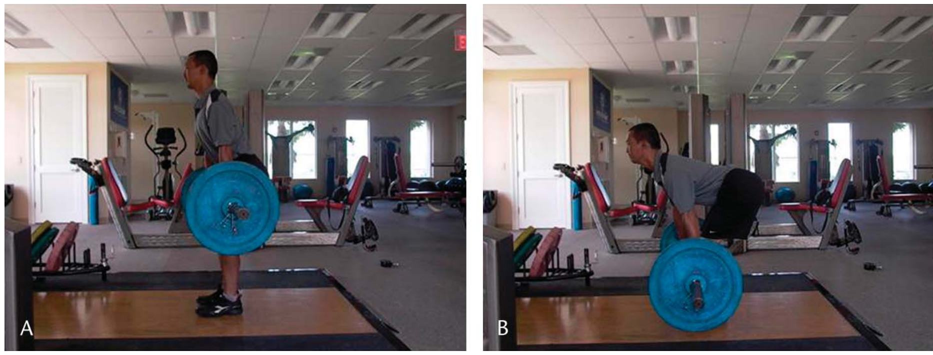

Figure 12. Romanian deadlift (RDL). A) Start. B) Finish.

mechanisms. Plyometric movements induce neuromuscular adaptations to the stretch reflex, as well as the elasticity of muscle and Golgi tendon organs (GTOs) (39). The stretch reflex is initiated during the eccentric loading and results in greater motor unit recruitment during the ensuing concentric contraction. GTOs have a protective function against excessive tensile loads in the muscle; however, plyometric training results in a degree of desensitization of the stretch reflex, which allows the elastic component of muscle to undergo a greater stretch (12). The combined adaptations results in a more powerful concentric contraction which, in tennis, would result in greater power and speed in recovering from hitting one stroke to the next. It is thought that a large portion of muscular performance gains after plyometric movements are attributed to neural changes rather than morphological (39). This improved neuromuscular function directly influences the major components needed for effective deceleration ability (Figure 1).

REACTIVE STRENGTH

Reactive strength has been defined as the ability to quickly change during the muscle contraction sequence from the eccentric to the concentric phase in the stretch–shortening cycle and is a specific form of muscle power (42). A plyometric training program that uses lateral and multidirectional movements while limiting time on the ground will develop reactive strength and

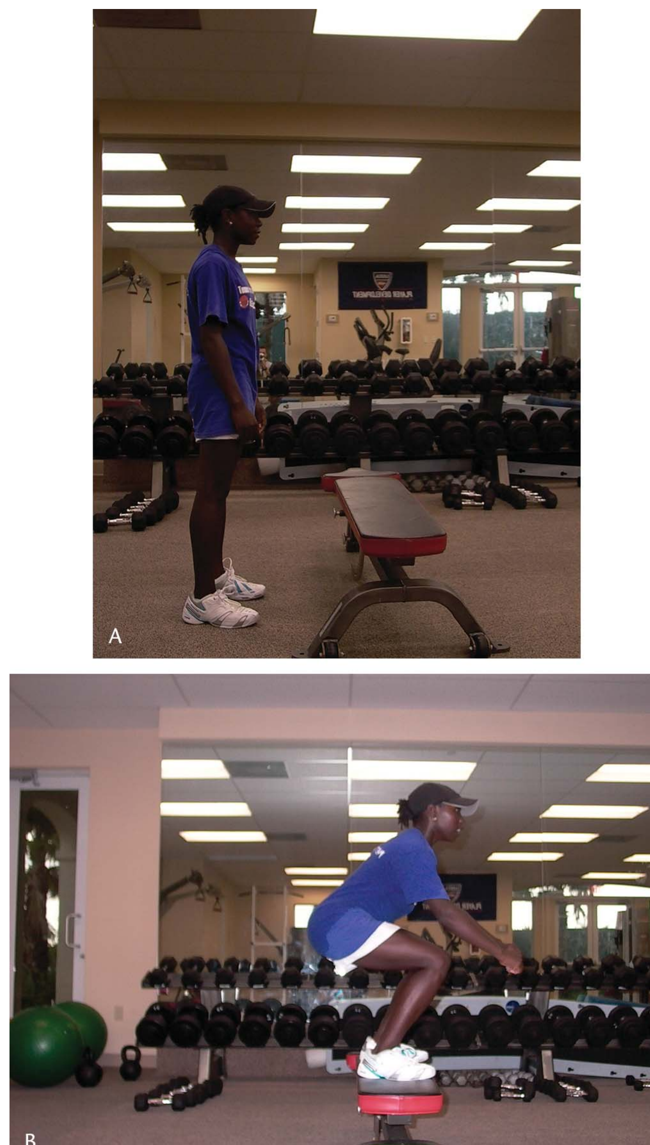

Figure 13. Box jump. A) Start. B) Finish.

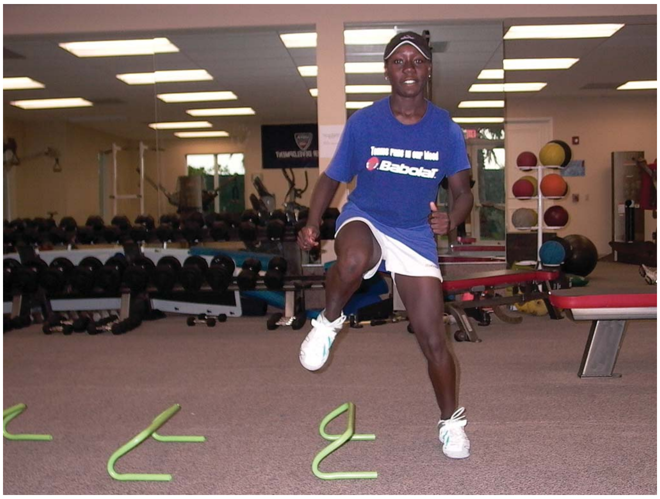

Figure 14. Lateral hurdle runs with hold.

subsequent power outputs in the muscles and movements that are seen during tennis play. This type of training directly relates to a tennis athlete in his or her recovery sequences between shots and also during the times in a point when he or she is "wrong-footed" and is in need of rapid change of direction. Increased muscle activity, specifically in the form of eccentric loading, will enhance muscle stiffness. This increase in muscle stiffness leads to more force absorption in the muscular–tendon unit rather than transmitted through the articular structures (32). It has been suggested that muscle activation is a dynamic restraint mechanism that results in protecting the joints such as the shoulder, hip, knee, and ankle (32).

PRACTICAL APPLICATIONS FOR THE TENNIS ATHLETE

Deceleration is a biomotor skill that is closely linked to agility and multidirectional movement training. As such, it needs to be trained in a multifocused training program with appropriate rest periods and loads that are progressed based on the tennis player's growth, maturation, and training stages. From a training perspective, the posterior muscles of the tennis athlete need to be a focus if the athlete is to become a successful player who has great deceleration ability. In the lower body, the hip extensors, including the glutes and hamstring muscles, need to be trained specifically in an eccentric manner with progressive increases in resistance. In the upper body, a major focus needs to be on the posterior aspect of the shoulder region, which will assist in the deceleration of the arm during the tennis serve, groundstrokes, and volleys. Because limited data are currently available on deceleration training guidelines, it is important to monitor training closely because eccentric loading can cause more delayed onset of muscle soreness than similar concentric exercise (23). Because multiple sets of exercises have shown greater results than single sets (20), deceleration training should be performed using multiple sets with varied repetition ranges based on the age, maturation and training status of the athletes.

UPPER-BODY EXERCISES

This section contains 5 upper-extremity plyometric exercises. Each exercise can be started with a small hand-sized plyometric ball weighing approximately 0.5 kg to start with progression to a 1-kg ball as training progresses and competency and tolerance to the exercise is demonstrated by the player. Exercise 5 (Figure 11) does not use a weight but rather a piece of elastic tubing to provide the overload for this exercise. The plyo dropping exercises typically use 30-second sets of exercise, whereas the reverse catching exercises use multiple sets of 15 to 20 repetitions to improve local muscular strength and endurance.

Exercise 1. Exercise 1 shows the 90/90 prone plyometric exercise that places the shoulder and upper arm in a functional position inherent in the serving motion. In this exercise, the player rapidly drops and catches the ball as quickly as possible, with the ball moving only a few centimeters as it leaves the grasp of the player temporarily before being recaught and dropped from the reference position as pictured. Typically, multiple sets of 30 seconds are used in training to foster local muscular endurance (Figure 7).

Exercise 2. Exercise 2 is a prone horizontal abduction plyometric exercise in which the athlete lies prone on a supportive surface with the shoulder abducted 90 degrees with the elbow extended. A small medicine ball is used to repeatedly drop and catch the ball as rapidly as possible as described for exercise 1 previously. By rotating the hand such that the thumb is pointing upward during the dropping and catching activity (i.e., external shoulder rotation) this exercise has been found to increase activation of the rotator cuff muscles (Figure 8) (24,28).

Exercise 3. Exercise 3 shows a reverse catch deceleration training exercise. In this exercise, the arm is again positioned in 90 degrees of elevation (abduction) and 90 degrees of elbow flexion as pictured. A partner stands just behind the player and throws a small 0.5- to 1-kg medicine ball toward the player's hand (30). Upon catching the ball, the arm moves into internal rotation until the forearm is nearly parallel to the ground, just as it is decelerated during the serving motion functionally. The player, after decelerating the ball, rapidly fires the ball backwards toward the partner, performing a concentric contraction of the

Figure 15. A) MB deceleration catch lunge (linear). B) MB deceleration catch lunge (Lateral). C) MB deceleration catch lunge (45 degrees). D) MB deceleration catch lunge (cross-over).

rotator cuff and scapular muscles. Recent research has demonstrated significant increases in eccentric strength in the shoulder of subjects when using these types of exercises in a performance enhancement training program (Figure 9) (4).

Exercise 4. Exercise 4 shows a variation of the reverse catch exercise where the athlete keeps the elbow straight during the catching and subsequent release of the plyo ball to simulate the serving motion and a PNF D2 diagonal pattern. The PNF D2 pattern is a functional diagonal pattern that closely simulates the movement pattern the upper extremity goes through during the throwing or serving motion. D2 extension, which is performed concentrically in this exercise, includes the patterns of shoulder flexion, abduction, and external rotation, whereas the eccentric action incurred in this exercise after the "catch" of the medicine ball (D2 flexion) includes shoulder extension, internal rotation, and slight cross arm adduction. This pattern is chosen for its activation pattern, which closely simulates the functional throwing or serving action, as well as its activation of the rotator cuff and scapular muscles. Emphasis is initially on the deceleration of the ball as the arm continues forward after catching the ball then rapidly reversing direction to perform an explosive concentric backward throwing movement (Figure 10).

Exercise 5. Exercise 5 shows the external rotation at 90 degrees exercise with elastic tubing. The traditional way of doing this exercise involves slow controlled internal and external rotation at 90 degrees of abduction. However, to increase the eccentric or deceleration emphasis of this exercise, a plyometric type format can be incorporated to add variety. Start with tension on the tubing with the shoulder elevated 90 degrees in the scapular plane (30 degrees forward from the coronal plane) (Figure 11). The shoulder should be externally rotated 90 degrees, which places the forearm in a vertical position. The athlete then rapidly decelerates forward into internal rotation until the forearm reaches a horizontal position.

Upon reaching this position, the athlete then explosively returns the hand and forearm back to the starting position with as little pause between the initial lengthening phase of the exercise and the concentric explosive phase as possible. This is repeated for multiple sets of 15 to 20 repetitions (Figure 11).

LOWER-BODY EXERCISES

Exercise 6. Exercise 6 shows a Romanian deadlift strength exercise that works on the muscular development of the hamstrings, glutes, and lower back muscles as force is applied during eccentric muscle actions. Repetition ranges and time under load for this exercise should focus on both muscular strength and endurance during the training program (Figure 12).

Exercise 7. Exercise 7 shows a traditional box jump with specific emphasis on the landing phase. It is important to have the athlete land in a strong squat position, which develops eccentric strength and rapid deceleration abilities. A more advanced athlete who has developed appropriate lower body strength can advance to performing a depth box jump. However, for younger athletes, or athletes with limited strength in the lower body, a depth jump should only be performed after appropriate training and lower-body strengthening exercises (Figure 13).

Exercise 8. Lateral Hurdle Runs with Hold. This is a traditional lateral-focused plyometric movement that works on the muscles of the lower body, from a stretch shortening perspective, but also at the end of each set of 4 hurdles the athlete needs to decelerate and come to a complete stop and hold the lowered center of mass position for 2 complete seconds before reaccelerating back into the exercise (Figure 14).

Exercise 9. Medicine Ball Deceleration Catch and Lunge (Linear, Lateral, 45 Degrees, and Cross-Over). This exercise focuses on the athlete catching a relatively heavy medicine ball during the eccentric portion of the lunge and then releasing it during the concentric portion of the lunge. The catching aspect of the movement loads the eccentric portion (Figure 15).

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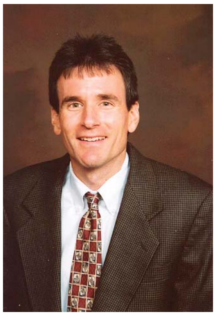

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