Lateral Acceleration: Djokovic, Nadal and On-Court Training

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Tennis movement can be characterized by primarily short lateral bursts over typically 3-4 m initiated by a reactive split-step. Movement can be improved by: 1) strength-speed training, 2) technical training, 3) and anticipation training. Kovacs (2009) summarized the importance of lateral movement training. This article will address on-court lateral acceleration with regards to strength-speed and technical training. Lateral acceleration depends on unilateral movement, or specifically, the outside leg to enhance ground reaction force (GRF).

Over and O'donoghue (2008) suggested movement training is often conducted without exact knowledge of physiological, technical and biomechanical demands. Instead, coaches and trainers should consider research and data implications. About 70% of tennis movement is lateral and 20% of tennis movement is forward (Weber et al., 2007). It has been estimated that the average professional on clay courts runs to only 5% of shots where distance > 4.5 m (Ferrauti, & Weber, 2001). Richers (1995) found the average number of continuous steps to the ball was 5.4 on hard courts and 5.7 on clay or grass courts. Steps may vary in stride length depending on rally speed, distance and time. Over the past 25 years, rally speeds have increased which might affect stride lengths and number of steps. SI.com staff (2015) tracked movement of 4 ATP players and found their movement per point was 8 – 14 m which depended on court position, playing style, and length of rally. At the 2017 Australian Open, the average rally lasted 4.47 and 4.85 shots and 5.44 and 5.93 s for the women and men, respectively (Carboch et al., 2018). In addition, selected ATP (N=34) and WTA (N=44) players from September 2019 to September 2020 had mean rally lengths of 4.21 and 4.06 shots with a player average range from 3.2 – 5.4 (Sackmann, n.d.a; Sackmann, n.d.b). Inter-serve and inter-point times were reported at 29-30 s (O'Donoghue, & Liddle, 1998) but more recently it has been reported that actual time from point to point varies about 25-45 s depending on the individual athlete (Bialik, 2014; Sackmann, 2020). From the data, it can be estimated a run over 4.5 m occurs once every 3-3.5 min.

Although runs > 4.5 m occur infrequently, high acceleration and deceleration are more common. Hoppe et al. (2014) found peak running speeds for adolescent players (12-14 y.o) was 4.4 ± 0.8 m/s (9.8 mph). Players exceeded 3 m/s (6.71 mph) once every 5 min or only 18.5 times per match. High acceleration and deceleration was defined as 2.0 m/s^2 (or 6.56 ft/s^2). High acceleration and deceleration was 51.7 and 47.0 times per match, respectively or 0.6/min each. High acceleration was 51.7 per match at 0.6/min or once per 1.7 min, twice as frequent as running distances > 4.5 m as reported for professional players. The typical top speeds for ATP pros is 15-16 kmh and for WTA pros is 13-14 kmh (Game Inside Group, Tennis Australia, 2016). Novak Djokovic reached 36.02 kmh (22.38 mph) in sprinting > 3 m.

Clearly, initial acceleration is more important than top end or maximal speed. In addition, anticipatory cues can optimize movement and reduce acceleration requirements by responding earlier. Nonetheless, technical footwork training should involve training unilateral explosiveness to improve rate of force development (RFD). In the 5 - 10 m interval, an athlete can reach an estimated 70% of top end speed (Duthie, Pyne, Marsh, & Hooper, 2006). Therefore, in tennis, most athletes reach approximately 70% of top end speed. Djokovic's 36.02 kmh was likely 80-85% of his top end speed, but the distance might have exceeded 10 m.

In short sprints, a combination of vertical and horizontal components of force are applied (Dintiman, G, 2020; Jeffries, 2017). In the initial acceleration 0 - 5 m phase, the horizontal component of speed is of greater importance than vertical component. For maximal top running speed, ground force is the most important determinant (Weyand et al., 2000). The first 3 steps from a standing or still position involves mostly horizontal force (Dintiman, 2020). At maximal linear velocity, a world-class sprinter achieves stride lengths and stride frequencies of 2.6 m and 5 steps/s, respectively (Dintiman, 2020; Mann & Murphy, 2018). Lateral acceleration has lower stride lengths and frequencies. Of interest is the acceleration of top professional tennis players.

LATERAL ACCELERATION OF DJOKOVIC AND NADAL

Novak Djokovic is arguably the best mover on the ATP Tour today. Rafael Nadal is considered one of the best movers of all time. In this case study, 40 groundstrokes were examined (Nadal = 18, Djokovic = 22). High speed 120 and 240 fps HD videography was filmed using a Sony 4K RX10 camera. Velocities and accelerations were estimated over 0.05 s increments from t = 0.00 s to 0.35 s. Measurements were done with displacement of head/shoulders. T=0.00 s starts at the end of the split-step when the head/shoulders begins to move laterally. It was noted that acceleration over each 0.05s interval was not constantly increasing or decreasing, but dependent on the rate of force production (RFD) from either leg.

Table 1. Lateral Movement Peak Acceleration

Case, Name, Movement Side	Peak Acceleration
Case 1: Novak Djokovic – right to FH	4.81 m/s^2
Case 2: Rafael Nadal – left to FH	4.70 m/s^2
Case 3: Rafael Nadal – right to BH	4.30 m/s^2

Table 1 shows 3 maximal accelerations calculated from the selected 40 shots. All maximal accelerations occurred on return games where defensive skills include greater movement. Service games which are initially offensive often do not require the same acceleration early in the point. It is assumed these peak accelerations probably represent the top 10% accelerations of both players (given the 3 measurements shown in Table 1 were the highest from 40 groundstrokes). It should be noted that the top 1 or 2% of peak accelerations may exceed these values. Figures 1 show Rafael Nadal shortly after initial acceleration. Comparatively, Usain Bolt in a starting still 4-point stance (i.e., hands and feet on the ground) has been calculated to reach an initial acceleration of 9.5 m/s^2 in the 100 m sprint. (Gómez et al., 2013). However, Djokovic and Nadal are sprinting repeatedly and Bolt is sprinting once. In addition, the short distances in tennis and the 100 m sprint do not have the same demands. Curiously, if the acceleration forces were only in the vertical direction, depending on the actual RFD and impulse, the vertical jumps for Djokovic and Nadal would be around 0.20 – 0.25 m whereas by comparison, Bolt would be ca 0.9 m (Gómez et al., 2013).

On wide balls, Djokovic can typically achieve stride lengths of 2 m and stride frequencies of 4 steps/sec. As noted earlier, acceleration over each 0.05 sec increment was not uniform but dependent on unilateral RFD. An athlete may initially push off from either leg unevenly as unilateral (i.e., single sideways) leg force may not be equal strength. In addition, leg drives are in different phases such as the takeoff or touchdown positions. Hence, acceleration measured for Djokovic and Nadal did not involve a steady RFD.

Figure 1A (left). Rafael Nadal 0.217s and 0.379s after initial acceleration in Case 2 moving to the forehand. 1B (right). Rafael Nadal 0.288s and 0.413s after initial acceleration in Case 3 moving to the backhand.

Few studies have been conducted with lateral speed or the development of lateral speed. Court surface such as clay or hard courts can affect concentric and eccentric forces in both the initial acceleration to the ball and deceleration in recovery. Weber et al. (2007) pointed out players will run 0.25 to 0.50 m more to the forehand side than the backhand side. Although cases were limited, we see that for Table 1, the measured acceleration to the forehand was higher than to the backhand (e.g., Nadal was recorded as 4.70 m/s^2 and 4.30 m/s^2 for the forehand and backhand, respectively). Therefore, acceleration to the forehand may be slightly more important for training. In novice athletes, t-test shows significant differences (p=0.001) between either lateral movement as measured over 4 m (Salonikidis, & Zafeiridis, 2008). For elite athletes, movements to either side were similar. Hewit et al. (2012) discussed unilateral leg movement in linear and lateral jumping and running. Largest leg strength differences were found in lateral movement (single leg countermovement lateral jumps or SLCM-L) but it was suggested that up to 15% difference was normal and acceptable. That is, an athlete might be 15% weaker in one leg than the other and normal athletic movement is not affected. Tennis, however, differs from most sports in requiring greater lateral movement and 180° change of directions (COD). Most field sports require cutting at 20-60° where asymmetric leg strength may not seriously affect movement.

It is reasonable to assume the same concepts in rate of force production and ground force reaction apply in a lateral direction as with linear speed. In lateral movement, most force is generated by the outside leg which is farther from the intended direction. After the stroke, deceleration for recovery to a favorable court position requires the legs to switch roles where in movement to the right, the left leg is the outside leg in explosive movement towards the ball. When the athlete moves back to the center or to the right, the left leg is the outside leg in change of direction (COD) or recovery phase.

Tennis players could be tested on the outside leg moving either to the forehand or backhand side. Using unilateral strength and plyometric training to train unilateral leg force production may improve athletes with weaker movement to one side. Nevertheless, it is important to train both legs for acceleration since they both assume the force-generating reactive power.

TESTING UNILATERAL POWER

Measurement of initial leg power can be correlated to leg strength. Hewit et al. (2012) tested single leg countermovement (SLCM) jumps vertically (SLCM-V), horizontally (SLCM-H), laterally (SLCM-L) with either legs. The largest leg discrepancies were SLCM-L. Lockie et al. (2014) found some correlation between lateral power and COD but lateral jumps were not the strongest predictors of the COD test. Young et al. (2002) found that COD was related to the outside reactive leg strength. For example, athletes averaging 24% stronger in the right leg were 4% faster moving to the left; moving to the right was not correlated with leg strength. Lateral movement due to unilateral leg strength was not considered a factor unless there was a significant strength difference between legs. In addition, Young et al. suggested reactive leg strength was a greater factor than concentric leg strength. It was suggested that technique and perceptual factors also affect lateral speed. Both studies (Lockie et al., 2014; Young et al., 2002) look at linear speed with 20-60° as the range of COD which represents more traditional cutting in team sports. A test for 3 m COD and acceleration (CODAT) was devised using 45˚ and 90˚ COD (Lockie et al., 2013).

As opposed to many field sports, tennis involves significant movement back to the origin which implicates many 180° CODs. Therefore, unilateral leg reactive strength might be a greater factor in tennis. Hoppe et al. (2014) indicated high acceleration and deceleration with 180˚ COD was a major characteristic of tennis movement. Habibi et al. (2010) found single leg hop power was correlated with 10 m sprints. It was found that a triple single leg hop was even a better predictor for 10 m sprint times. That suggests reactive strength in landing with rapid muscle contraction and stored elastic energy is critical. In addition, the explosiveness movement from a previous jump, hop or bound is more critical for acceleration than from a standing position.

In tennis, lateral speed is initially generated after an athlete makes a modest vertical jump or split-step with a resultant lateral bound. Although Lockie et al. (2014) suggested lateral jumps were not the strongest predictors of 20-60˚ COD ability, 180˚ COD were not investigated. Therefore, lateral jumps may still remain a predictive test for tennis. By definition, a hop is when the take-off and touchdown is done off the same leg and the distance covered is relatively small. A jump is either one- or two-legged but the distance is relatively greater. A bound is when the take-off leg and touchdown leg are opposite legs. With that in mind, single leg lateral bounds for both legs can show promise for improving contralateral force production.

The well-known Pro Agility Test and 3 Cone Drill has been shown to be correlated to 10 m sprinting (Mann et al., 2016). Both can be useful for tennis testing since they utilize 180˚ COD and acceleration/deceleration. In addition, as Young et al. (2002) and Habibi et al. (2010) suggested, reactive unilateral leg strength can be important. Figure 1 shows a simple single leg lateral jump (SLLJ) in which a countermovement is allowed and the takeoff and touchdown leg are the same. Measurements should be on the outside edge of the foot or shoe (green line). Lateral bounds in both directions should be executed and measure from a best of three bounds.

Figure 2. Single leg lateral jump (SLLJ) test with countermovement. Note the same leg (right leg in this example) is both the takeoff and touchdown leg.

EXERCISES

Wall Drives and Runs

Wall drives and runs are shown in Figures 3 and 4. In the crossover wall drive (Figure 3), the athlete crouches and leans with the inside shin angled towards the wall. A cross-over step is taken with the outside leg. The athlete can repeat in sets of 10 and then switch direction and legs. The lateral wall run is shown in Figure 4 has the athlete more upright. This exercise can be done with different number of steps: a) 1 step - lifting only the inside leg, b) 2 step, c) multiple step. A coach or another athlete can call the number of steps, e.g., "three," or "four."

Lateral Wall Drills

The single leg lateral jump test is often used as a repeated bounding exercise alternating legs (aka "alley hops"). Another set of simple movement exercises are wall drives and runs. Many athletes have trained with forward wall drives where the athlete faces a wall and leans forward at 45° with hands outstretched supporting the body against the wall. For tennis, lateral wall drives and runs are specifically applicable. Lateral wall drills allow the athlete to shift the center of gravity applying horizontal lateral force, while maintaining balance using a wall or fence.

The simplest drill is the lateral wall hold using either leg (Figure 3) which is also good for core and hips strength. The athlete leans sideways into a wall (fence is more difficult). The athlete lifts either leg with the knee up to the hips and maintains the leaning position for a few seconds and then may switch the legs and hold that position with the knee up for a few seconds. The athlete repeats leaning the other side. Once the athlete is comfortable with the positions, the athlete can do a second drill: lateral wall runs with sets of 2-6 rapid alternating steps. Repeat for a set of 6-8. Then the athlete does another set on the other side.

Figure 3. Lateral wall hold and alternating strides. Athlete holds positions for a few seconds. Athlete can also do quickly as a lateral run.

The second wall drill (Figure 4) is the load and crossover hold which brings the outside leg across and up. Athlete should start low with the outside leg at an angle and ready to push off. Both arms can be placed on the wall or fence and movement is more powerful and angled.

Figure 4. Load and crossover hold.

In Figure 5, the crossover load and lift applies greater force. Figure 5 shows loading off the outside leg. Balance is maintained only using one leg and the wall. Either inside or outside leg may be used in loading. Drive upwards and bring the knee above the hips.

Figure 5. Load and crossover hold.

Hops + Bounds + Sprints

Most split-steps in tennis involve a vertical component with landing first on the leg farther away from the intended direction and the other leg taking a lateral step with the toe pointing toward the intended direction. For training, the following exercises are useful:

Figure 6. Vertical single leg hop + lateral bound

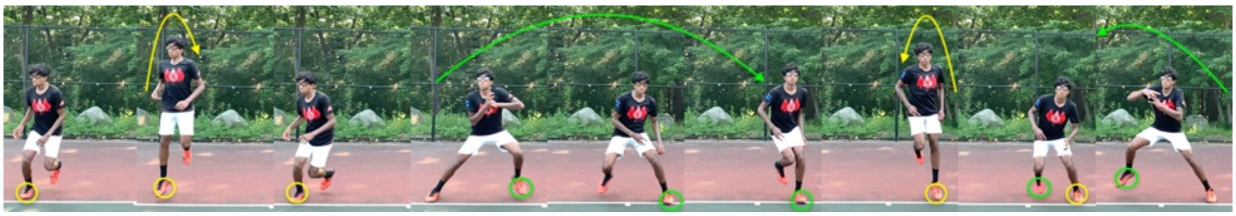
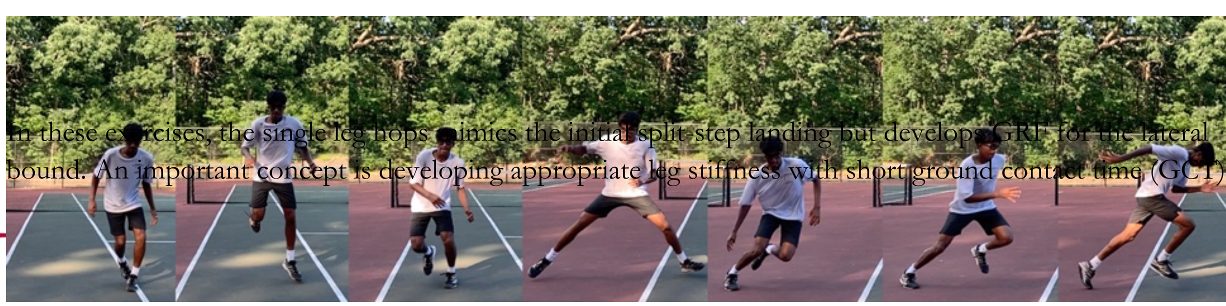


Figure 7. Lateral single leg hop + lateral bound

Figure 8. Vertical single leg hop + lateral bound + short sprint opposite direction

Figure 9. Lateral single leg hop + lateral bound + short sprint opposite direction



In these exercises, the single leg hops mimics the initial split-step landing but develops GRF for the lateral bound. An important concept is developing appropriate leg stiffness with short ground contact time (GCT)

(Ferris et al., 1999; Morin et al., 2007). It is important to note both leg stiffness and GCT affecting split-steps and the initial takeoff and touchdown steps may change on clay courts (Ferris et al., 1999). In the drill, the athlete shifts weight inside after the lateral bound to sprint in the opposite direction of the bound. Exercises shown in Figures 6 and 7 can be done in sets of 12-20 reps. Exercises in Figures 8 and 9 can be done in sets of 6-10 reps resting between reps. Exercises in Figures 8 and 9 could be combined with additional COD agility movement for tennis-specific repeated sprint ability (RSA).

Contrast Resisted and Assisted Training

Contrast training refers to varying loads with similar movement or exercises. For speed training, often contrast training involves only slight changes in force (Dintiman, 2020; Mann & Murphy, 2018) since larger forces can alter mechanics to alter movement. A classic contrast training is performing the same resistance exercise (e.g, leg press) with different loads. A classic contrast training for speed involves running uphill and downhill but at modest angles so not to alter running mechanics (Dintiman, 2020). Bungees and resistance bands can provide assistance or resistance forces without dramatically altering lateral movement. Shown in Figure 9 shows the bungee-assisted lateral explosion. Attached a bungee high so it pulls the athlete laterally but also upwards. Use a split-step into a crossover step and sprint 2-3 m. Figure 9 shows the bungee-assisted exercise. For bungee-resisted lateral explosion, attach the bungee low on the fence (see Figure 10). The athlete can split-step into a crossover step, focusing on a more upwards pull upwards and away and from the fence.

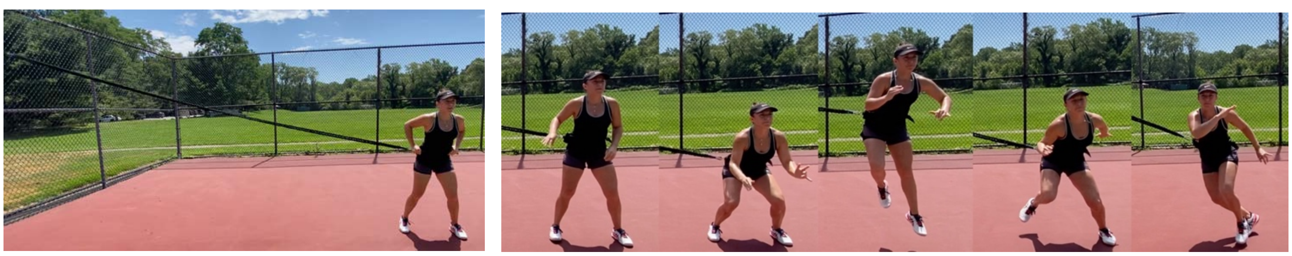


Figure 9. Bungee-assisted lateral explosion. split-step, touchdown and crossover towards band attachment.

Figure 10. Bungee-resisted lateral explosion. split-step, touchdown and crossover away from band attachment.

CONCLUSIONS

Tennis movement is mostly lateral but athletes may have differences in movement to either side which should be trained. Movement in tennis is mostly short accelerations and decelerations rather than top end speed. In this article, specifically lateral acceleration was tackled from a physical off-court training with regards to technical training. Tennis players who use the forehand weapon to cover most of the court often run farther for the forehand than backhand, which requires higher acceleration to the forehand. Focus in this article was on physical training with some technical training. Physical training should require elastic unilateral reactive leg strength training and COD movement. Little research exists on unilateral reactive leg strength training which has implications in tennis. A series of tests were recommended but need to be correlated to actual lateral speed and acceleration in future studies.

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