Coaching Tennis
A biomechanical problem?

Required Mechanics

- Torque
- Angular Impulse
- Fluid Mechanics
  - Magnus Force
- Friction
- Elastic Energy (Recoil)
  - Coefficient of Restitution (Impact)

\[ F = ma \]
\[ Ft = m\Delta v \]
\[ \tau = I\alpha \]
\[ \tau t = \Delta I\omega \]

Functional Anatomy
and Tennis Grips
Wrist Flexors
1. Flexor Digitorum Superficialis
2. Flexor Digitorum Profundus
   • 4 Heads
3. Flexor Carpi Radialis
4. Flexor Carpi Ulnaris
5. Palmaris Longus
6. Flexor Pollicis Longus

Wrist Extensors
1. Extensor Digitorum
2. Extensor Carpi Radialis Longus
3. Extensor Carpi Radialis Brevis
4. Extensor Carpi Ulnaris
5. Extensor Indicus
6. Extensor Digiti Minimi
7. Entensor Pollicis Longus
8. Extensor Pollicis Brevis

Grip Size
- A too-small grip requires more muscle strength to keep the racquet from twisting in your hand. Prolonged use of a grip that's too small can contribute to tennis elbow problems.
- A grip that's too large inhibits wrist snap on serves, makes changing grips more difficult and also requires more muscle strength. Prolonged use of a grip that's too big can also contribute to tennis elbow problems.

One Hand versus Two-Hands?
Rebound Velocity and Grip Strength

The Kinetic Chain

Stretch Shortening Cycle

The Kinetic Chain
Training versus Performance

- Imbalance of internal versus external arm rotators.

Stroke Mechanics

- Basically the ball must be propelled from the racquet face over the net and into the court.
- Control is the number one so most strokes do not evoke a major stretch-shortening cycle (serve excepted).
- Gravity must be taken into account so for most strokes you are hitting the ball upwards.
- Additionally the more advanced player must deal with the spin of the ball and choose what type of spin (if any) to put on his/her return.

Rationale for the Tennis Topspin Forehand Stroke

Why is topspin so important and prevalent?
Nadal's Average topspin rate is 3,300 rpm (max ≈ 4,900 rpm). Approximately 20% greater than other top tour players.

Torque is needed to provide spin

\[ \tau = Fd_{\perp} \]

\[ \tau = I\alpha \]

\[ \tau_t = I\Delta \omega \]

Moment of inertia of ball is fixed, contact time is affected by racquet stiffness and string tension, but it is torque you can control the most via the path the racquet moves during contact.

Topspin  No Spin  Backspin

Figure 4-18(a), (b) These pictures illustrate the racquet movement necessary to hit slight underspin (a) and heavy underspin (b).
The modern tennis forehand is a brushing action behind the ball. The full swing path is like a windshield wiper brush. But the ball is on the strings for approximately 4 milliseconds so the ball does not leave with much sidespin.

- [http://www.youtube.com/watch?v=y8AJYfkJ4hc&feature=related](http://www.youtube.com/watch?v=y8AJYfkJ4hc&feature=related)
- [http://www.youtube.com/watch?v=2gdxJQrDYE](http://www.youtube.com/watch?v=2gdxJQrDYE)

Bernoulli’s Principle

Pressure $\frac{1}{\alpha}$ velocity

Air has to travel further over the top of the airfoil, hence greater velocity and less pressure.

Magnus Effect

A ball travelling with spin will experience different amounts of friction on its side causing it to deviate from its expected path.
Magnus Force

- The Magnus force is due to the imbalance of resistive forces on the ball that follows from the imbalance of velocity of the air flow spinning past the ball, is proportional to spin frequency, air velocity and the value of the drag coefficient at the ball velocity.
- “…is not quite the same as the Bernoulli effect; it is more than the Bernoulli effect, which is why it is called the Magnus effect and not the Bernoulli effect.” R.K. Adair, The Physics of Baseball, 2nd edition, HarperPerennial, 1994.

Figure 6-1 As the tennis ball encounters the oncoming air notice how a small boundary layer of air travels around the tennis ball as it spins.

Figure 6-2 In this diagram you can see how the boundary layer of air being carried around the ball in a topspin direction interacts with the oncoming air to create a high pressure zone above the ball.
The more topspin, the higher the ball can be hit over the net and still land in the court.

**Margin of Error**

The more topspin, the higher the ball can be hit over the net and still land in the court.

**Ball Impact with the Ground**

- Given balls are relatively standardized this is affected by the court surface, angle of impact and spin.
Elastic Force

When a falling ball hits the ground the reaction force compresses it until its C of g stops its downward motion. The elastic recoil of the ball back to its round shape causes it to push against the ground, generating a ground reaction force that moves ball upwards.

\[ F = k \Delta s \]

Coefficient of Restitution

- "When two bodies undergo a direct collision, the difference between their velocities after impact is proportional to the difference between their velocities before impact."

\[ v_1 - v_2 = -e(u_1 - u_2) \]

or

\[ -e = \frac{v_1 - v_2}{u_1 - u_2} \]

If one of the bodies is stationary (i.e. impact with the floor).

Then \(-e = \frac{v_f}{u_1}\)

As \(v_f^2 = v_i^2 + 2ad\)

\[ v_f = \sqrt{2ad} \]

\[ -e = \frac{\sqrt{2ah_r}}{\sqrt{2ah_d}} = \frac{h_r}{h_d} \]

Coefficient of Restitution

Depends on:
- the nature of both contacting surfaces.
- the temperature of the surfaces.

Also in non-uniform materials (e.g. baseball, golf ball) \(e\) may change with the speed of contact.
Friction (in negative direction) is less in the topspin case (can even be positive). Hence, the horizontal velocity is greater after impact. Vertical velocity is determined by coefficient of restitution not the spin.

**Figure 6-7** Compare the angle of rebound when a ball has topspin to the situation when the ball has no spin. There is a slight backward push by the spinning ball which causes its rebound angle to be slightly less than the rebound of a ball with no spin.

- As discussed previously the spin imparted to the ball will affect the trajectory and hence the angle the ball strikes the ground.

A ball with backspin can slide if it impacts the ground at a very shallow angle (it overcomes limiting friction).
Different spins, same strike angle

Different spins, different strike angle

Can you determine the relative bounce of the ball for ball with backspin?

However, do not think a ball with backspin will bounce higher. Because it comes in flatter with less vertical velocity, the vertical velocity after impact will also be lower.

In addition, a ball with backspin may “slide” rather than grip the court surface as shown before.

If the grass court is not too worn (early in Wimbledon?) then a heavily sliced ball has more change of skidding. The grass courts at Wimbledon are playing slower than in previous years.
Racquet Mechanics

Two primary focuses
- Performance
- Vibration damping (injury prevention)

Racquet Facts
- A heavier frame generates more power.
- A heavier frame vibrates less.
- A heavier frame has a larger sweet-spot.
- A stiffer frame generates more power.
- A stiffer frame has a larger sweet-spot.
- A stiffer frame transmits more of the shock load to the arm than a more flexible frame.
- A stiffer frame provides a more uniform ball response across the entire string plane.
- A larger frame generates more power.
- A larger frame is more resistant to twisting.
- A larger frame has a larger sweet-spot.
- A longer frame generates more velocity \( (v_t = \omega r) \) and therefore more power.
- The string bed in a longer frame generates more spin due to increased velocity.

String Facts
- Lower string tensions generate more power (providing string movement does not occur).
- Higher string tensions generate more ball control (for experienced players).
- Longer string (or string plane area) produces more power.
- Decreased string density (fewer strings) generates more power.
- Thinner strings generate more power. (Disputed by Wilson)
- More elastic strings generate more power. (Generally, what will produce more power will also absorb more shock load at impact.)
- Softer strings, or strings with a softer coating, tend to vibrate less.
- Thinner strings tend to produce more spin (control).
- Decreased string density generates more spin.
- The more elastic the string, the more tension loss in the racquet after the string job.
Rebound power is really coefficient of restitution. Centre of string impacts only simulated.

Swingweight is effectively the moment of inertia of the racquet. Notice how this is the key factor rather than simply the mass of the racquet.

Figure 1: Calculated values of RP at a point 16 cm from the tip of the racquet, vs. racquet weight, for 268 different racquets.

Figure 2: Calculated values of RP at a point 16 cm from the tip of the racquet; vs. swing-

Figure 6–10(a), (b) From this diagram one can see how a torque is created from off-center impacts below the central axis of the racquet (a) and above the central axis of the racquet (b).

Moment of Inertia = A racquet’s resistance to rotation = mass (m) x radius (r)²

Figure 2-4 This diagram shows how the moment of inertia of a racquet head can be increased to reduce rotation during and following impact.
Physics and Finance

- Basically the laws of physics suggest you should use the **heaviest** racquet you can manage (increased control and power) and the **thinnest** natural gut strings your budget can handle!

Perimeter Weighting Systems

The goal is to increase the moment of inertia, and hence reduce rotation, on off centre impacts.

- Functional Anatomy/Kinesiology
- Muscle Mechanics (stretch shortening)
- Fluid dynamics (Magnus force)
- Angular Kinematics ($v = \omega r$)
- Linear Kinetics (friction, impulse [impact], coefficient of restitution)
- Angular Kinetics (impacting spin, moment of inertia [serve and racquet])
- Motor coordination issues (movement and reaction times)
- Tennis (dimensions of court and net, rules, tactics, etc.)

So to analyse the sport of Tennis we have had to use knowledge about the topics on the next page.

Clearly other sports also require detailed analysis to understand fully.