Biomechanics of a backhand drop shot

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What is a drop shot?

- Groundstrokes:
  - Most common shot where the racquet head hits the ball in a "flat" collision.
    - Surface of racquet head is perpendicular to the direction ball will go.
  - After it is hit, it continues to travel in a straight direction after it bounces.
  - Mainly hit from the baseline during rallys.

“Flat” Groundstroke

What is a drop shot? (Cont.)

- Drop Shots:
  - Racquet head grazes the ball in an angled or slashing motion (not flat).
  - This gives the ball backspin/underspin so that it tends to travel in another direction after it bounces.
    - Usually backwards or sideways.
  - Shot is designed to bounce near the net and quickly bounce a second time
    - Effective when opponent is on the baseline or not quick or agile.
  - Can be hit from anywhere on the court.

Slashing/Angled Drop Shot stroke

Motion Breakdown

- Like many other swinging movements, the kinetic chain also applies to the drop shot:
  - Leg Drive
  - Hip Rotation
  - Trunk Rotation
  - Shoulder and Upper Arm Rotation
  - Forearm Extension and Pronation
- Before the kinetic chain starts, regardless of stroke, players prepare for their swing by cocking their shoulders and arms.
  - Stores elastic energy that will later be used for the shot.

Motions of the dropshot

Objectives

- Calculate the amount of kinetic energy that the associated muscles generate to execute the drop shot.
- Calculate how much of this kinetic energy is transferred to the ball.
- Determine how much energy is lost following the collision and how does this compare with the backhand groundstroke.
- Determine the components of kinetic energy
  - How much is translational KE?
  - How much is rotational KE?

Translational KE Calculations

- For all calculations, ball hit at 1.8m behind the service box.
- Translational KE Immediately Before Impact:
  - X-velocity = 1.575m/s
  - Y-velocity = 1.125m/s
  - Overall velocity = 1.935m/s
  - **KE = 0.5(0.057kg)(1.935m/s)^2 = 0.1067J**

- Translational KE Immediately After Impact:
  - X-velocity = 10.350m/s
  - Y-velocity = 3.950m/s
  - Overall velocity = 11.078m/s
  - **KE = 0.5(0.057kg)(11.078m/s)^2 = 3.4976J**

Rotational KE Calculations

- Rotational KE Immediately Before Impact:
  - **Assumed to be zero**

- Rotational KE Immediately After Impact:
  - Time for 1 full revolution (T) = 6 frames * (1sec/250 frames) = 0.024 sec
  - Angular Speed (ω) = 2π/T = 261.799 rad/sec

  - **KE = 0.5I ω^2 = (0.5)(3.21*10^{-5})(261.799) = 0.0042J**
    - N.B. Moment of Inertia provided by H. Brody
- Does it make sense?
  - Yes, consider its mass and moment of inertia (hollow).

Tennis Ball KE Summary

- Total KE After Hit = 3.5018J
  - % Translational KE = **99.88%**
  - % Rotational KE = **0.12%**

- Total KE Transferred from Racquet = 3.3909J

How Much Energy was Lost During the Collision?

- Racquet Before Impact:
  - $KE = 0.5(0.337kg)(15.6221m/s)^2 =$ **41.122J**
- Racquet After Impact:
  - $KE = 0.5(0.337kg)(13.6956m/s)^2 =$ **31.605J**
- Ball Before Impact:
  - KE = **0.1067J**
- Ball After Impact:
  - KE = **3.5018J**

- Energy Lost = $Ke_{before} - Ke_{after}$ = **6.1215J**
  - Mostly elastic energy stored in strings but also some thermal (sound).

How Does the Loss Compare?

- Backhand Ground Stroke:
  - Before Collision: 100% KE in Racquet
  - After Collision:

KE in Ball	77.4%
KE in Racquet	14.30%
Energy Lost	8.30%

* Numbers adapted from Brody et al.

- Drop Shot Stroke:
  - Before Collision: 100% KE in Racquet
  - After Collision:

KE in Ball	8.25%
KE in Racquet	76.86%
Energy Lost	14.89%

Kinetic Energy Discussion

- Why the higher proportion of KE remaining in the racquet?
  - Angled slashing swing grazes the ball for less time thereby preserving more KE and imparting less to ball.
  - Groundstrokes hit the ball head on and have a longer collision time.

- After hitting the ball, the muscles in the shoulder and the intercostals as well as tendons/ligaments must work to bring the arm and racquet to a halt.
  - This work is equivalent to 76.86% of the original KE input.

Conservation of Momentum Calculation

- Mechanical energy may not always be conserved in collisions, but momentum always is.
- $\mathbf{M}_{1i}\mathbf{V}_{1i} + m_{2i}v_{2i} = \mathbf{M}_{1f}\mathbf{V}_{1f} + m_{2f}v_{2f}$
- Initial:
  - (0.337kg)(15.6221m/s) + (0.057kg)(1.935m/s) = 5.375 N*s
- Final:
  - (0.337kg)(13.6956m/s) + (0.057kg)(11.078m/s) = 5.2468 N*s

Conclusions

- Very little amount of rotational KE is needed compared to translational KE for execution of a drop shot.
- In drop shot much of the KE applied to hit the ball remains in the racquet immediately following the collision.
- Following the collision, muscles/ligaments must work/absorb 76.86% of the original KE from racquet.
- Momentum is conserved during this motion.

Future directions

- Determine the kinetic energy distribution of the ball when it is hit from different parts of the court.
- Utilize motion capture technology to isolate the individual steps of the kinetic chain and ascertain their energetic contributions to the swing.
- Explore how the moment of collision between the ball and racquet head affects the efficiency of KE transfer
  - Specifically, look at the deformation of the ball and the elastic energy stored there.

References

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