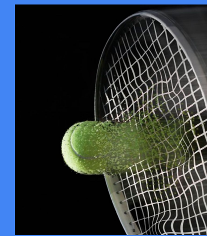
String Tension vs Final Potential



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Purpose:

To examine the relationship between the tension of tennis racquet strings and the force exerted on a tennis ball during baseline conditions (absent a player).

The Physics:

Physics concepts explored in this project include:

- Elastic potential energy
- Elastic collisions
- Spring force
- Kinematics are also involved, in that an elastic object was dropped from a certain height, collided with another elastic object/surface, then traveled upward a certain height.

➔ A tennis ball and the surface of a tennis racquet are both elastic objects. When a tennis ball strikes the strings on a tennis racquet, both the ball and the racquet deform.

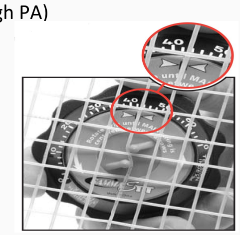
➔ The strings on the racquet are highly elastic compared to the ball and will provide a restoring force to the ball upon impact.

➔ The deformation of these elastic objects will allow for some of the energy of the collision to dissipate as heat. The classic "poc" sound of a tennis ball being hit by a racquet is another example of energy dissipating during the collision.

➔ Due to this dissipation of thermal energy it is expected that the tennis ball will not return to its original height.

Materials (Building Process):

- Two tennis racquets with different string tension
- One tape measure- 6 feet long
- One tennis ball
- Camera to record data
- One assistant to secure each tennis racquet to the ground
- String Tension Tester (Gamma Sports, Pittsburgh PA) *(Instrument seen in image below)*



A tape measure was attached to a wall, then extended to the ground to provide measurement in the backdrop of each test. A tennis racquet was placed flat on the ground, the head of the racquet adjacent to the end of the tape measure (i.e.: 0 inches). An assistant stood on the tennis racquet handle to ensure that there would be minimal dissipation of energy from the tennis ball bouncing off the racquet. A camera was set up on a tripod to record the height that the tennis ball reached after bouncing off the racquet strings. The relative String Tension Index (STI) of each racquet was measured with the String Tension Tester (Gamma Sports, Pittsburgh PA).

Data:

Trial	1	2	3	4	5	6	7	8	9	10	Avg
T1	58	56	55	40	54	52	44	51	48	60	51.8
T2	66	60	63	63	68	65	62	66	69	53	63.5

Table 1: STI measurements with average,T1 and T2 are two different tennis racquets

Trial	1	5	3	4	5	6	7	8	9	10	Avg
T1	111.76	107.95	107.95	106.68	107.95	110.49	109.22	111.76	110.49	113.03	109.73
T2	104.14	110.49	104.14	107.95	109.22	106.68	106.68	110.49	105.41	109.22	107.44

Table 2: Final height of bounce trails with average (in cm), T1 and T2 same racquets as seen in Table 1

The Testing Process:

➔ The test performed was designed to determine if the string tension of a tennis racquet has an effect on the distance a tennis ball travels after a collision.

Measuring tension:

The relative string tension, or String Tension Index (STI) of each racquet was measured with a spring-loaded String Tension Tester (Gamma Sports, Pittsburgh PA). Although this device does not provide the exact tension of the string, it does provide a basis for comparing both racquets. The device is inserted between the "mains" and "crosses" (vertical and horizontal strings), then twisted until the main is centered on a mark on the surface of the device. This was done in 10 different locations on each tennis racquet, and the results were averaged. *(Table 1)*

Measuring collision results:

A tennis ball was dropped from height of 5 feet (152.4 cm) onto the center of a tennis racquet. The height of the tennis ball after colliding with the tennis racquet was recorded with a video camera. The still frame images from each trial were isolated when the tennis ball reached the maximum height of its trajectory after the collision (*See images below*). The test was repeated ten times per tennis racquet. *(Table 2)*

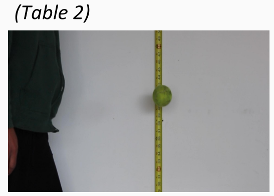
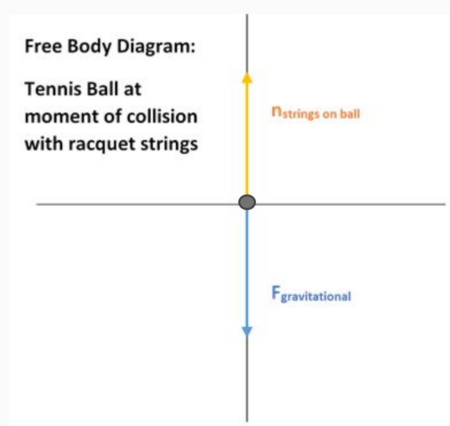


Image 1

Image 2

➔ *Accuracy:*

In performing each trial, the primary obstacles to consistency were ensuring that the tennis ball was accurately dropped from the same height and ensuring that the ball accurately collided with the same location on the surface of the tennis racquet with each trial. Because the string tension on a tennis racquet is unevenly distributed across the surface area of the racquet face, it was likely that results would be highly variable. Trials in which the ball seemed to strike outside the "sweet spot" at the center of the racquet head were discarded.



Analysis/ Calculations:

➔ We anticipated the tennis ball would not return to its original height in either case- due to a loss of energy (thermal) from the system

➔ We anticipated that the racquet with a higher String Tension Index would transfer less elastic potential energy to the tennis ball, resulting in a lower final height after the collision

➔ We expected this result because upon impact the strings of a tennis racquet stretch and deform storing potential energy. As they return to their original shape/position the energy stored in them is then transformed to kinetic energy as the ball leaves the racquet and the contact is lost.

➔ The looser the strings are the farther they can stretch, and the more potential energy they will contain

➔ This can be compared to springs: a rigid spring with a larger spring constant will have less displacement compared to that of a flexible spring with a lower spring constant

$$E_{initial} = E_{final}$$
$$U_{initial} = U_{final} + \Delta E_{thermal}$$
$$U_{gravitational,\ initial} = U_{gravitational,\ final} + \Delta E_{thermal}$$
$$(m_{tennis\ ball})(g)(h_{initial}) = (m_{tennis\ ball})(g)(h_{final}) + \Delta E_{thermal}$$

The experiment assumes drag/air resistance is negligible. In the case of this experiment, energy is lost from the system (tennis ball) when it collides with the racquet. As the tennis ball deforms the strings stretch and retract during the collision, energy is lost as heat.

$$E_{collision} = K_{tennis\ ball} + U_{spring,\ tennis\ strings} + U_{spring,\ tennis\ ball} + U_{gravitational,\ tennis\ ball}$$

The racquet with loose strings has a lower spring constant, but a higher compression distance, whereas the tighter strings have a higher spring constant, but a lower compression distance. The tennis ball and the racquet strings also form an action reaction pair, thus the force the ball applies on the strings at the moment of full compression of the racquet strings is equal to the force the strings apply on the ball.

T1 and T2 represent the different tennis racquets used, T2 has a larger Spring Tension Index ("larger k value"), these racquets differ by 11.7 units on the STI. The average resulting height of the tennis balls after collision differs by 2.29 cm in favor of our hypothesis. The resulting gravitational potential energy of each tennis ball also correlated with our predictions, in that the ball colliding with the more rigid racquet would travel less distance after the collision and therefore have less gravitational potential energy after the collision.

T1/ T2: $U_{gravitational,\ initial}$ =(approximately) 0.8513 J

T1: $U_{gravitational,\ final}$ = 0.6130 J ΔE= 0.2383 J

T2: $U_{gravitational,\ final}$ = 0.6002 J ΔE= 0.2511 J

Sources of Error:

- The experiment assumes drag/air resistance is negligible
- The time was not recorded during the collision so an accurate velocity could not be calculated
- The initial height (152.4 cm) was diligently controlled, but could have varied slightly with each trial
- The initial velocity of the tennis ball could have been slightly larger than zero with each trial
- Height measurements were carefully taken although some random error is unavoidable when measuring heights in this fashion
- The tennis ball made contact with different locations on the racquet face

Conclusion:

This experiment explored the relationship of string tension and potential energy of a tennis racquet and its effect on the distance a tennis ball travels after a collision. It was difficult to see a large difference in the final heights of the tennis balls relative to the different string tensions. If this experiment were repeated the initial height would vary to see how initial gravitational potential energy changes the final. This experiment could also be repeated testing an additional two racquets, one strung very tightly and one very loosely, to test the different extremes of the potential energy of a tennis racquet on a basic level.

Sources:

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Image of String Tension Tester (Gamma Sports, Pittsburgh PA)

https://gammasports.com/wp-content/uploads/2017/01/GAMMA-String-Tension-Tester-Instructions-1.pdf