Investigating The Effect of Gauge, String Tension, Collision Spot On Velocity Of Tennis Ball After First Collision; and Determining The Combination That Obtains The Maximum Velocity After First Collision

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1. INTRODUCTION

Tennis is a sports game that consists of two players who aim to score a point. The main mechanic of the game is to throw the tennis ball to the opponent's court via a tennis racket by making the tennis ball bounce only one into your court. The main purpose is to reach a specific score. The player whose opponent is unsuccessful to throw the tennis ball to the opposite court is awarded the point.

Tennis is directly related to mechanical physics and some topics of it such as momentum and energy. Everything is related to physics at tennis such as the position of the player while hitting a tennis ball, the speed of a tennis ball, the angle between a tennis ball and a tennis racket. The investigation aims to investigate factors that are related to the speed of the tennis ball after the first collision. These factors are determined as a gauge, string tension, and an area where the ball collides with.

Tennis is a sports game that could be played by people of any age. Even five-year-old kids are able to play it. However, these little kids struggle with some difficulties due to their uncompleted and continuing muscular development. They are weaker than their opponents due to age differences, even their peers may be stronger from them due to early muscular development. Most of these kids do not know how to equalize their strength with their opponents, so the investigation aims to find out the best combination to obtain the maximum power, maximum velocity.

2. AIM

The aim of the investigation is to determine which gauge, string tension, and the area that a tennis ball collides with affect the velocity of a tennis ball after it collides with a tennis racket; and to find the most efficient gauge, string tension, and area combination to obtain the most velocity. Investigation of the effect of the gauge and the string tension is not based on the experiment. Rather than experiments, secondary data will be used. However, the area onto the tennis racket that preserves the most energy will be determined via experiment. The experiment will be based on laws of energy, and momentum.

A tennis ball that is steady will be dropped from a certain height, and its first rebound height will be observed. Its potential energy will be calculated after the first collision and E_p will be converted into E_k to obtain velocity.

3. RESEARCH QUESTION

To what extent do gauge, string tension, and an area that a tennis ball collides with onto the tennis racket affect the velocity of the ball after the collision of tennis racket and tennis ball; and what is the best gauge, string tension, collision area combination to obtain the maximum velocity after the collision?

4. BACKGROUND INFORMATION

4.1. Gauge: Gauge indicates the thickness of the string. There is the reverse proportion between the gauge and the velocity of a tennis ball after the first collision because as the gauge is more elastic, it provides more power. Thus, the thinnest gauge that could resist enough tension is going to be used in the experiment.

4.2. String Tension: It is one of the most determinant factors at the velocity of a tennis ball after collision with a tennis racket. Tighter string mention less velocity due to less power because it deflects less, and the ball deforms more. As the string deflects less, it stores less energy. Additionally, the ball disputes more energy if the ball deforms more. Also as the string is tighter, the ball will reside on string less, and that will cause less dwell time. As the tension increases, dwell time decreases directly proportionally with the velocity of the ball. Thus, the string tension will be chosen as looser as it can be to obtain the biggest velocity.

The relation between dwell time and tension is indicated as;

$$t_{dwell} \propto \frac{1}{\sqrt[2]{T}}$$

$t_{dwell} = dwell\ time$

$T = string\ tension$

4.3. Full Bed - Hybrid: There are two types of wiring the tennis racket are;

1) Full Bed: It indicates that wiring a tennis racket with same wire at both vertical and horizontal axis.
2) Hybrid: This type of wiring is wiring a tennis racket with different types of wire at vertical and horizontal axis

NOTE! Full bed is going to be used at the investigation to obtain reliable data

4.4. Work and Energy

The work done by a force is the product of the force in the direction of the displacement times the distance travelled.[4]

Energy is the capability of doing something, and the most important principle of it is the conservation of energy. This indicates that energy is not created or destroyed but is only transformed one into another.

$$\Delta E_{system} + \Delta E_{surroundings} = 0$$

Kinetic and potential energy are the forms of energy that can be converted into each other.

i) **Kinetic Energy;**
It is a form of energy that the particle has due to its motion. If a particle speeds up due to a force on a particle, the particle gains energy. It depends on the mass of a particle. Kinetic energy is directly proportional to mass. It is defined mathematically as;

$$E_k = \frac{1}{2} \times m \times v^2$$

$E_k = kinetic\ energy$

$m = mass\ of\ the\ particle$

$v = velocity\ of\ the\ particle$

ii) **Potential Energy:**
It is stored energy that depends upon the relative position of various parts of a system. There is more than one type of potential energy. However, gravitational potential energy is the one that is going to be mentioned in the investigation.

Gravitational Potential Energy: It is considered at the earth-mass system. Gravitational potential energy is directly proportional to the mass of a particle, acceleration of gravity, and height of the particle from a plane.

$$E_p = m \times g \times h$$

$E_p = potential\ energy$

$m = mass\ of\ the\ particle$

$g = gravitational\ acceleration$

$h = height\ of\ the\ particle\ from\ the\ plane.$

When work is done on an object, the energy transforms. When the ball is released from its initial height, gravitational force does work. Thus, the gravitational potential energy is transferred into kinetic energy, and a negligible amount of the energy is transferred into thermal energy. When the tennis ball hits the tennis racket, there is energy loss to the surroundings. The percentage of energy loss will be calculated in the investigation. After the ball rebounds with new velocity, kinetic energy will be transferred into the gravitational potential energy due to the work done by gravity. Energy loss due to the collision of the racket and ball will be taken into account. While the tennis ball is moving vertically, it loses energy due to drag force, and the drag force is proportional to the speed of the object. The tennis ball moves at small speeds, therefore the energy loss due to drag force will be neglected.

$$\Delta E = 0$$

4.5. Newton's Second Law: Average net force on a system is equal to the rate of change of the momentum in the system.

$$F_{net} = \frac{\Delta p}{\Delta t}$$

$F_{net} = net\ force\ that\ acts\ onto\ the\ system$

$\Delta p = momentum\ change$

$\Delta t = time\ change$

NOTE! If the mass is constant, Newton's Second Law could be indicated as;

$$F_{net} = m \times a$$

$F_{net} = net\ force\ on\ the\ particle$

$m = mass\ of\ the\ particle$

$a = acceleration$

4.6. Linear Momentum(p): It is the product of the mass and velocity, and its unit is $kg \times m \times s^{-1}$. Formula of it is;

$$p = m \times v$$

$p = linear\ momentum$

$m = mass\ of\ the\ particle$

$v = velocity\ of\ the\ particle$

4.7. Collision: Momentum is conserved at every type of collision. There are two main types of collisions. These are;

1. Elastic Collision
2. Inelastic Collision

2.i. Totally Inelastic Collision

At the elastic and inelastic collisions, particles that collide do not stick together after the collision. However, if totally inelastic collision happens, particles stick together after the collision. There is kinetic energy loss at inelastic and totally inelastic loss. Thus, the energy of a system does not conserved at them. During an elastic collision, there is a conservation of kinetic energy during the collision.

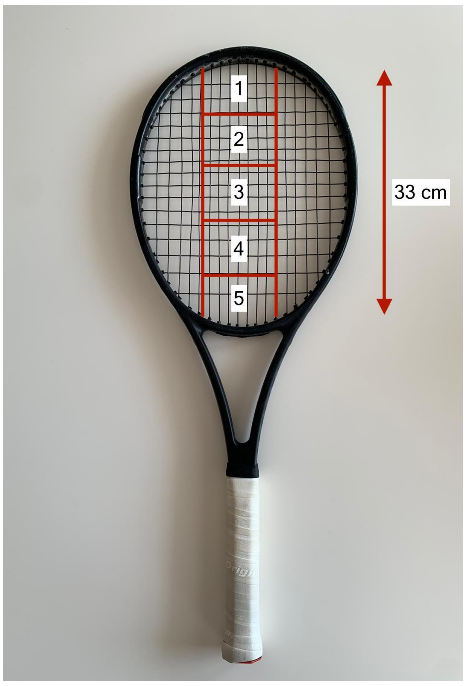
5. HYPOTHESIS

There are three significant determinants on the velocity of a tennis ball after it collides with string, these are: gauge, string tension, and area that the ball collides with on the string. There is an inverse proportion between the gauge and velocity of the tennis ball. As the gauge is thinner, the ball has more velocity after the collision. The reason for it is, more elastic gauge causes fewer energy losses to surroundings. Additionally, the string tension is also inversely proportional to the velocity as the gauge. It happens because as the string tension decreases, the ball will deflect more, and it will deform less. The more the ball deflects, the more energy does the ball preserve.

Investigation of an area that preserves the energy most is crucial as others. As it is claimed in the previous investigations, the softest area on the string would preserve the energy most, and the ball will have the most velocity after it collided with there. Spots on the string are named ‘Dead Spot’, ‘Node’, ‘Center of Percussion(COP)’, ‘Coefficient of Restitution(COR)’ and ‘Center of Mass(CM)’ respectively according to the top to bottom, as it can be seen at ‘Photo 1’. I assume the velocity of the ball will increase by ‘Dead Spot’ to ‘Coefficient of Restitution’ and decrease from ‘Coefficient of Restitution’ to ‘Center of Mass’.

After all the knowledge and assumptions are evaluated, the best combination to obtain the most velocity after the ball collides with the string is the thinnest gauge, lowest tension and when the tennis ball collides at the Coefficient of Restitution.

Photo 1: Collision Areas Onto the Tennis Racket



Names of the collision areas onto the tennis racket

1) *Dead Spot*
2) *Node*
3) *Center of Percussion(COP)*
4) *Coefficient of Restitution(COR)*
5) *The Area Between COR and Center of Mass(CM)*

6. METHODOLOGY

PART 1 - Marking the Areas Onto the Tennis Racket

1. Measure and write down the length of the tennis racket via ruler
2. Divide five equal parts to the length of the tennis racket
3. Measure and write down the length of the neck of the tennis racket
4. Mark five rectangular areas whose width is the same as the neck of the tennis racket($12.5cm$), and length is ⅕ of the tennis racket's length($6.6cm$)
5. Find the middle point of each rectangular area by using a ruler and mark the point via spray paint
6. Name the rectangles as one to five respectively head to the neck of the tennis racket

Sample Calculation of Part 1

- Length of the tennis racket is → $33.0cm$
- To obtain the length of each area → $\frac{(Length\ of\ the\ Tennis\ Racket)}{(Number\ of\ Rectangle)} = \frac{(33cm)}{(5)} = 6.6cm$
- Length of the neck of the tennis racket is → $12.5cm$

PART 2 - Scaling the Tennis Ball

1. Scale the tennis ball five times and write them down
2. Calculate the mean of the five values and obtain the average weight of the tennis ball

PART 3 - Wiring the String Onto the Tennis Racket and Arranging Its Tension

NOTE! This process could be done by professional tennis players or coaches, the tennis racket that is used at the experiment is wired at a tennis warehouse.

PART 4 - Setting Up the Experimental Setup

1. Place the tennis racket parallel to the plane, control whether it is parallel to the plane via water gage
2. Immobilize the tennis racket to the ground via strong tapes
3. Place the ruler that is $0.5m$ near the tennis racket

NOTE! Be sure that zero on the ruler is at the same height as the string of the tennis racket

NOTE! Check whether the ruler is at a right angle to the ground via t-ruler

4. Place the video camera in front of the ruler that is at the right angle to the ground

PART 5 - Obtaining the data

1. Turn on the camera and start recording
2. Drop the tennis ball into the middle of the first rectangle(drop point has already been marked via spray paint)
3. Note down the first rebound height
4. Repeat the latest two previous steps for each marked area five times each
5. Stop the record and turn off the camera
6. Check the video carefully and control whether the data that is taken is written correctly

7. VARIABLES

Table 1: Independent and dependent variable of the investigation

Independent Variable	The area that the tennis ball collides with onto the tennis racket - There are five different areas that are named as ‘dead spot’, ‘node’, ‘center of percussion’, ‘coefficient of restitution, and ‘center of mass’. These areas are named respectively head of the tennis racket to the neck of it. The tennis ball will be dropped into the middle of each area five times to obtain reliable data. The tennis racket’s string area’s length that is used at the investigation is $33cm$ and the neck of the racket is $12.5cm$. Thus, measurements of each area is $12.5 \times 6.6 = 82.5cm^2 = 0.00825m^2$.
Dependent Variable	Height of the tennis ball after it collides with the tennis racket (first rebound height $\rightarrow h_2$) - Dropping and make the tennis ball collides with different areas that are onto the tennis racket would change the first rebound height(h_2) due to the energy loss of the ball varies as the area that the ball collides with changes.

Table 2: Controlled variables of the investigation and methods of how the variables are controlled and the possible effects, if they are not controlled

Controlled Variables	Method of Control and Possible Effect on the Result
The height that the tennis ball will be dropped at each trial is $50cm \rightarrow h_1$	At the beginning of each trial, h_1 is going to be controlled by the ruler whether it is $0.5m$ or not. h_1 has to be $0.5m$, because all the potential and kinetic energy calculations will be based on h_1. If it varies at each trial, then the data that will be obtained is going to be random number. It will lead the investigation down the wrong path. **NOTE!** At the formula of gravitational potential energy, 'h' is the displacement of center of mass. In the investigation, displacement of the undersurface of the tennis ball is measured. It does not a variable that will cause any error margin because the displacement of the center of mass of the tennis ball and displacement of the undersurface of the tennis ball would be equal.

The temperature of the room is constant → $25^{\circ}C$	Temperature change may affect the tension of the string that is wired onto the tennis racket. Change in the string tension at each trial will lead to random data that does not reflect the truth.
String tension has to be the same at each trial → $23kg$	**NOTE!** Tennis jargon kg is used as a unit of tension. In this experiment, the string tension will be equal to the force corresponding to the weight of 23kg of an object. However, Newton(N) is the correct SI unit of it. Thus 'kg' will be converted into 'N' and 'N' will be used at the investigation. Formula of Conversion → $m \times g = W$ Sample Calculation → $23.00 \times 9.81 = 225.63N$ String tension is one of the parameters that change the energy loss onto the ball. Thus, it should be $23kg$ at each trial. If tension is different than $23kg$, then the hypothesis can not be verified. (The reason why specifically $23kg$is chosen is mentioned in the background section.)
Spot on the tennis ball that collides at each trial with string should be the same spot	Tennis balls have a hairy surface, so colliding the same spot with the string at each trial would decrease the error margin of the experiment.
The same gauge is used at each trial → $1.15mm\ and\ made\ of\ nylon\ gut$	Gauge has a direct impact on the energy conservation during the collision of all and string. Thus, the same gauge has to be used. The brand of the gauge does not matter. However, its thickness and material do matter. If different gauges are used at each trial, the investigation would reflect something except the main purpose of the investigation.
The same tennis racket should be used → preferably professional tennis racket should be used to reflect the reality	Each tennis racket has different specialities, but as long as the professional tennis racket is used, it would not affect the data. Avoid using different tennis rackets during the experiment, stick one of them. Unless you do not change, obtained data will be random.
The same tennis ball should be used at each trial	Except for some exceptions, every professional tennis ball is made to observe 50% of the energy after the first collision. Thus, as long as the tennis ball is chosen as professional, any brand's tennis ball may be used. However, do not forget to use the same ball during the whole experiment. Avoid using different balls during the experiment, stick one of them. It may result in some wrong conclusions.
The string should be wired as 'Full Bed'	The material and the thickness of the string has to be the same at both axes(vertical and horizontal). Unless it is wired as 'hybrid', obtained data from each trial would lead the investigation to the wrong path.
Wind should not exist in the laboratory	Angle of collision of the tennis ball with string should be the same at each trial. At the experiment, $90^{\circ}$is the angle between the string and the spot of the ball that collides. If there is wind inside the laboratory, then the angle may change and the existence of wind may cause an increase in the error margin.
The angle between the ground and ruler should be the same → 90°	To measure the correct first rebound height(h_1), the ruler should be perpendicular to the plane. If it does not perpendicular, then $h_1$would not reflect reality.

8. APPARATUS

Table 3: Materials that are going to be used at the experiment

Material Name	Material Size	Quantity of Material
Respirator Face Mask		1
Ruler	$50.00 \pm 0.05cm$	1
Spray Paint	Red	1
String	Thickness: $1.15mm$	1 Roll
Stringing Machine		1
Tennis Ball		1
Tennis Racket	Head Size: $625.81cm^2$ Length: $68.58cm$	1
Tape		1
T-Ruler	$30.00 \pm 0.05cm$	1
Video Camera	120fps, 1080p	1
Water Gage		1

9. SAFETY AND ETHICAL OR ENVIRONMENTAL CONCERNS

1. Wear a face mask in the laboratory due to the COVID-19
2. While marking via spray paint during the experiment, the face mask that is worn due to COVID-19 is switched with a respirator face mask to not to be harmed from spray paint
3. Safety goggles are used due to the stretched wire being used at experiment
4. The windows of the laboratory are wide-opened during the time spray paint is being used
5. The painting did not spread through the whole labrotary due to taken precautions

10. RAW DATA

Table 4: First rebound height of the tennis ball after colliding with different areas on the tennis racket

Number of the Area	**First Rebound Height**$(cm \pm 0.1)$				
	Trial 1	**Trial 2**	**Trial 3**	**Trial 4**	**Trial 5**
1	4.0	6.0	8.0	8.0	10.0
2	18.0	21.0	21.0	24.0	21.0
3	23.0	22.0	21.0	24.0	26.0
4	38.0	35.0	37.0	36.0	39.0
5	24.0	28.0	29.0	29.0	26.0

Table 5: Five measurements of weight of the tennis ball

Mass of the Tennis Ball($g \pm 0.10$)				
Trial 1	**Trial 2**	**Trial 3**	**Trial 4**	**Trial 5**
57.97	57.97	58.01	57.97	57.96

11. PROCESSED DATA

11.1. Sample Calculations

- Mean of the mass of the tennis ball → $m_{mean} = \left[\frac{m_{trial\,1}+m_{trial\,2}+m_{trial\,3}+m_{trial\,4}+m_{trial\,5}}{5}\right]$

Sample Calculation → $\left[\frac{57.97+57.97+58.01+57.97+57.96}{5.00}\right] = 57.98g = 5.80 \times 10^{-2}kg$

- Mean of the First Rebound Height → $h_{2_{mean}} = \frac{h_{trial\,1}+h_{trial\,2}+h_{trial\,3}+h_{trial\,4}+h_{trial\,5}}{5}$

Sample Calculation → $\left[\frac{4.0+6.0+8.0+8.0+10.0}{5.0}\right] = 7.2cm = 7.2 \times 10^{-2}m$

- Potential Energy Calculation→ $E_P = m \times g \times h$

Sample Calculation → $\left[57.97 \times 10^{-3} \times 9.81 \times 0.50\right] = 0.28J$

- Calculation of Difference at Energy → $\Delta E = \left|E_2 - E_1\right|$

Sample Calculation → $|0.0230 - 0.2843| = 0.2613J$

- Calculation of Velocity → $v = \sqrt{2 \times g \times h_2}$

Sample Calculation → $\sqrt{2.00 \times 9.81 \times 0.21} = 2.03ms^{-1}$

- Kinetic Energy Calculation → $E_K = \left[0.50 \times m \times v^2\right]$

Sample Calculation → $\left[0.50 \times 57.97 \times 10^{-3} \times (2.03)^2\right] = 0.35J$

- Percentage Calculation of Energy Loss → $x\% = \frac{(100\% \times E_1)}{E_2}$

Sample Calculation→ $\frac{(100\% \times 0.0230)}{(0.2843)} = 8.0\%$

Table 7: Mean value of the first rebound height (h_2)

Collision Area Onto the Tennis Racket	**Mean of the First Rebound Height**(m)
1	7.2×10^{-2}
2	2.1×10^{-1}
3	2.3×10^{-1}
4	3.7×10^{-1}
5	2.7×10^{-1}

11.2. Determining the Area that Preserves the Energy Most

- Total energy when the tennis ball is steady and $0.5m$ away from the tennis racket:

$$E_P + E_k = E_1 = (5.797 \times 10^{-2} \times 9.81 \times 0.5) + (0.5 \times 57.97 \times 10^{-3} \times 0^2) = 0.2843J$$

- Total energy of the tennis ball after the first collision with the string:

$$E_P + E_k = E_2 = (5.797 \times 10^{-2} \times 9.81 \times 7.2 \times 10^{-2}) + (0.5 \times 57.97 \times 10^{-3} \times 0^2) = 0.0409J$$

NOTE! The velocity of the ball is zero at the maximum height that it can reach

- Loss of energy of the tennis ball after the first collision:

$$\Delta E = \left|E_2 - E_1\right| = |0.0409 - 0.2843| = 0.2434J$$

- Percentage Calculation of Energy Loss:

$$\frac{(100\% \times 0.2434)}{0.2843} = 85.61\%$$

- Determining the velocity via kinetic energy formula:

$$v = \sqrt{\frac{2 \times E_2}{m}} = \sqrt{\frac{2 \times 0.0409}{5.797 \times 10^{-2}}} = 1.188m \times s^{-1}$$

NOTE! At the previous step, we converted the total energy into kinetic energy to determine the velocity

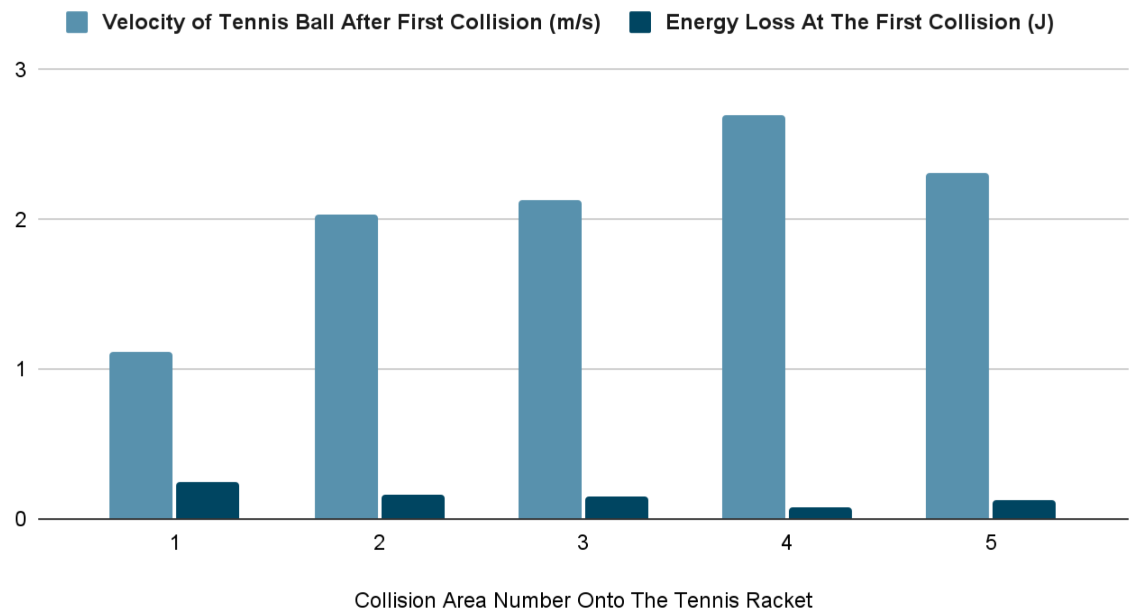
Table 8: Velocity of the tennis ball after the first collision

Collision Area Number Onto The Tennis Racket	**Velocity of the Tennis Ball** (ms^{-1})
1	1.118
2	2.029
3	2.134
4	2.694
5	2.310

Table 9: Energy loss at the first collision, and its percentage

Collision Area Number Onto The Tennis Racket	**Energy Loss At The First Collision (J)**	**Percentage of Energy Loss**
1	2.434×10^{-1}	85.61%
2	1.649×10^{-1}	58.00%
3	1.535×10^{-1}	53.99%
4	7.390×10^{-2}	25.99%
5	1.308×10^{-1}	46.01%

Graph 1: Bar graph of energy loss at the first collision, and the velocity of the tennis ball after the first collision



11.3. Secondary Data (String Tension - Gauge)

A computer-based experiment is done by the department of mechanical engineering of Kyungpook National University and aim of it is to investigate the effect of string tension and impact location on the power after the collision of racket with the ball and to have a reliable data and conclusion injuries due to playing tennis. The investigation is published in 'Journal of Mechanical Science and Technology, and the data that is shown in 'Table 10' belongs to the investigation that is mentioned. At the investigation, the tennis ball collides with the sweet spot of the tennis racket with $10.05 m/s$ and angle of incidence is 15° while string tension varies as 177, 222, 266, 311, 355N.[1]

'Table 10' indicates how does the coefficient of restitution(COR), which is the ratio of rebound speed to incident speed, changes when the string tension changes. As the COR is larger, more power could be obtained. (It would be told in detail at the conclusion)

Table 10: Effects of string tension on power and impact characteristics.

	String tension				
	177N	222N	266N	311N	355N
Duration of ball-string Contact	4.655 E-03s	4.575 E-03s	4.655 E-03s	4.125 E-03s	4.055 E-03s
Post-impact speed as a % of pre-impact speed	76.4%	76.2%	75.8%	74.6%	74.3%
COR	0.773	0.769	0.763	0.751	0.749
Ratio of speed angle change	0.217	0.147	0.109	0.108	0.101

'Materials in Sports Equipment' is a book that is about tennis and physics, and it compounds the investigations about the scientific background of tennis. One of the sub-topic of the book is about the effect of gauge on tension and power. It mentions that tennis players prefer a thinner gauge to reduce shock and vibration due to the collision of a tennis racket with ball.[9] Moreover, as the gauge is thinner it is more elastic, and it let the ball obtain more velocity.[8]

12. CONCLUSION

The experiment is done successfully after changing the methodology once. The hypothesis is verified by both the experiment and secondary data. It is declared that the velocity of a tennis ball after collision with a tennis racket is inversely proportional to gauge and string tension. In 'Table 10', it could be observed that as the string tension increases, the coefficient of restitution(COR) increases. COR is the ratio of vertical ball speed out to vertical ball speed in. Thus, a larger COR ratio states more power. The final conclusion is, as the string tension decreases, more power could be obtained. Additionally, as the gauge is less, more power could be obtained due to past investigations.[9]

One of the main purposes of the investigation is to determine the gauge, string tension, collision area combination that obtains the maximum velocity. The combination is determined as;

$$\begin{aligned} &gauge &&: 1.15mm \\ &string\ tension &&: 225.63N \\ &collision\ spot &&: 4 \end{aligned}$$

The hypothesis declares that velocity will be the maximum if it collides with the softest spot onto a tennis racket. Thus, the investigation aims to find the softest area onto a tennis racket. According to the data that is obtained by the experiment, 'Spot 4' is the softest place on the tennis racket because velocity is the biggest there. Energy loss is smallest at there by 25.99%, as it can be seen in 'Table 7'. The velocity of the ball increases by the head of the racket to the neck of it. However, 'Spot 5' is not the area that obtains the maximum velocity; 'Spot 4' is. While velocity at 'Spot 5' is $2.310ms^{-1}$, $2.694ms^{-1}$ is the velocity at the 'Spot 4'. The most energy inefficient area is found as 'Spot 1', energy loss is 85.61% there.

$$v_{Spot\ 4} > v_{Spot\ 5} > v_{Spot\ 3} > v_{Spot\ 2} > v_{Spot\ 1}$$

It could be deduced that velocity(v) and the rebound height(h_2) is directly proportional while they are inversely proportional by energy loss(E_{loss}).

$$v \propto h_2 \propto \frac{1}{E_{loss}}$$

There is no outlier data at 'Raw Data' section. However, during experimenting, there were some failure trials that the ball did not collide with the tennis racket. These trials were not considered while obtaining data in the 'Raw Data' section.

There are two types of errors that make the data less reliable:

1) Systematic Error

2) Random Error

Systematic error could be assumed as zero at the experiment because there is no measurement device that should be calibrated is used at the experiment.

The data is affected by a lot of random errors. Due to the fact that the experiment is about mechanical physics, the error margin increases because there are lots of external factors that increase it. The random errors are going to be evaluated as more detailed in the 'Evaluation' section.

13. EVALUATION

During the investigation the methodology has changed once due to the enormousness of the error margin. The investigation could be experimented via a motion sensor of the vernier. The probe is able to graph the velocity-time and displacement-time graphs of an object. Thus, both the velocity and height of the tennis ball after the first collision could be determined via a motion sensor. Although motion sensors and other required equipment are provided at the laboratory, the investigation experiments with another methodology. The reason is motion sensor caused a lot of error margin when the experiment is tried to be done via it. There was an anomaly between the data that is obtained by the motion sensor with secondary data. The reason for the anomaly is the motion sensor senses another object except a tennis ball during the experiment, and these objects increased the error margin of the data, and make them less reliable. Thus, the methodology that is used in the experiment is chosen. The methodology that is used already is more coherent because the motion sensor obtains data at smaller periods. However, by using the method that is used, the data could be obtained directly without any irrelevant data.

Photo 2: Motion sensor and LabQuest 1

The anomaly is not detected in the raw data(if it is detected then it would be outlied). The obtained data is coherent as other investigations, and computer-based programmes. However, there is an error margin due to the fact that the experiment can not be done at ideal conditions. Although there is no systematic error, there is random error due to external factors.

If the effect of the error varies at each data, then it is called random error. This type of error does not affect the data equally. It mostly occurs due to external conditions such as temperature and pressure. The experiment is repeated 5 times for each collision spot. The aim of repeating the experiment is to reduce the random error. However, in the experiment, uncontrolled variables that affect the error margin are:

Random error may occur due to:

1. room temperature of the laboratory
2. angle between the plane and ruler
3. rolling significant figures may have an impact on the error margin
4. human-based errors while obtaining the data

The reason of the investigation is to find out the best gauge, string tension and collision spot combination that obtains the biggest velocity to a tennis ball after the first collision with a tennis racket. The reason for finding the best combination is to equalize the tennis game for tennis players whose muscles are not developed due to their age. The investigation provided the information of best combination at conclusion section completely. The investigation has completed its purpose and verified the hypothesis.

14. <u>BIBLIOGRAPHY</u>

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