SASTA OLIPHANT SCIENCE AWARDS

Prize Winner

Scientific Inquiry

Year 11-12

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Investigating How an Increase in Velocity Affects the Range of a Topspin Ball Due to Magnus Force in Table Tennis

Introduction

In preparation for major table tennis tournaments, I considered a number of strategies to increase the effectiveness of my gameplay. One of the main strategies I used was to increase the speed of my shots to apply pressure on the opponent and make it difficult for them to play a good return shot. However, during my training sessions I noticed that increasing the ball speed increased the likelihood of it flying out without touching the opponent's side of the table.

The world's top players are able to hit the ball at very high speeds and still land it on the table because they are applying top spin onto the ball. Applying topspin causes a pressure differential between the top and bottom of the ball which makes it curve towards the table. This downwards curving which shortens the range of the ball and prevents it from flying out of the table is due to 'Magnus Effect'.

With the knowledge that Magnus Effect exists, I was interested in finding out whether it operated more significantly on faster topspin balls. More specifically, I wanted to explore the relationship between velocity and the horizontal range of topspin balls. By comparing the range of topspin balls to the range of no spin balls at the same velocities, I will be able to quantify the range difference due to Magnus Effect, which will display how significantly Magnus Effect operates on high-velocity balls.

Therefore, the research question for this experiment is:

How does an increase in velocity affect the range of a topspin ball due to Magnus Force in table tennis?

To investigate the research question, an experiment will be set up to vary the velocity of topspin balls and measure the range. This will then be repeated with no spin balls at the same velocities for comparison. This allows for the range difference between topspin and no-spin balls to be calculated, to the effect of quantifying the impact of Magnus Effect on the range of topspin balls at higher velocities.

To vary the velocity of the ball as accurately as possible and select a constant angle of projection, a training ball robot will be used. In this experiment, the Newgy Robo-Pong 1040+ robot will be used. This robot allows the velocity of the ball to be changed using pre-configured speed settings (1 to 25). Moreover, the robot has the capability to produce balls with no spin or with topspin by changing a setting. To measure the range of the ball accurately, the ball movement will be recorded using a camera. In this experiment, a Samsung Galaxy S7 phone camera will be used. The recorded video will then be analysed by the Vernier Logger Pro 3 software to calculate the range.

The choice to use a training robot as opposed to striking the balls myself helps to keep the velocity, spin, and angle of projection of the balls as consistent as possible. Moreover, the use of Logger Pro software with video recordings as opposed to manual measurements using a ruler also helps to obtain more accurate measurements of the range. These choices will contribute to isolating velocity as the only independent variable and allow for more trials to be conducted within the allocated experimenting time.

Background

Depending on how a racket contacts a ball, a table tennis player can impart different types of spin. These include a flat hit (no spin), topspin, backspin, side spin, or a combination of these spins such as side-top spin and side-back spin.

As any ball travels through air, it experiences a frictional force which slows it down. When a ball with no spin travels through air in a forward direction, the frictional force at the top and bottom of the ball is the same. However, when a spinning ball travels through the air, it experiences the frictional force differently.

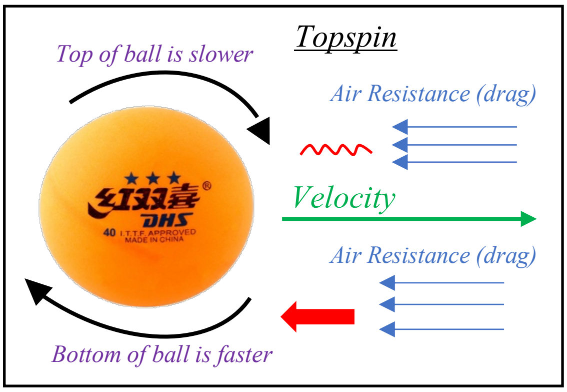


Figure 1 – The mechanics of Magnus Effect

In the case of topspin, the ball spins downward while travelling in the forward direction because spin is imparted on the top of the ball. As the top of the ball spins in the downward direction, it is resisted by the frictional force of air. As the bottom of the ball spins in the upward direction, it is further pushed by the frictional force of air. This results in a speed differential: the speed of the air on the bottom of the ball is increased (faster), while the speed of the air on the top of the ball is decreased (slower) (Du, A. 2021). This is illustrated in *Figure 1*.

The lower force at the bottom of the ball and higher force at the top of the ball results in a net downward force on the ball, causing it to curve down onto the table. This curving of a top spinning ball through air is called Magnus Effect. This causes a topspin ball to have a shorter horizontal range compared to the horizontal range of a no spin ball, as the no spin ball does not experience the Magnus Force that causes it to curve downwards (see *Figure 2*).

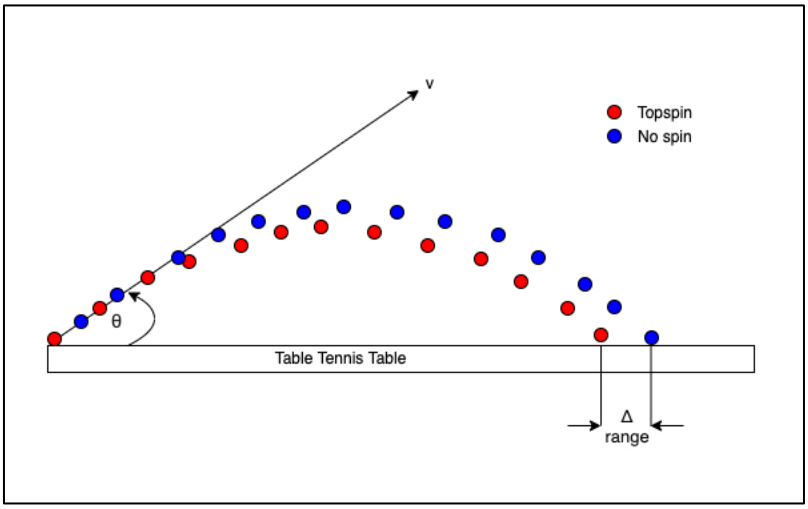


Figure 2 – Range difference due to Magnus Effect

Hypothesis

Based on the background information in paragraph 4:

As the velocity of a topspin ball is increased, the range difference between the topspin ball and no-spin ball is also increased, showing how Magnus Effect operates more significantly on topspin balls of higher velocities.

Variables

The <u>independent variable</u> in this experiment is the velocity of the topspin ball, which is varied by changing the speed setting of the training robot (7-25).

The speed settings on the robot range from 1 to 25, however, the really low speed settings (1 to 6) were not used in the experiment, as they produced very short trajectories that could not be accurately analysed. Therefore, the range for the independent variable was selected to be between 7 and 25. The robot allows the speed settings to be changed in increments of 1.

NB: The robot does not provide the ball velocity in ms^{-1}, however, increasing the speed setting increases the velocity by a specific increment.

The <u>dependent variable</u> is the range difference between the topspin ball and the no-spin ball travelling at the same speed, in metres. This is measured by Logger Pro.

<u>Controlled variables</u>

Table 1: Controlled variables and how they were controlled

Variable	How it will be controlled
The angle of the robot head as it projects the ball	Prior to the experiment, the robot (Newgy Robo-Pong 1040+) was set to a fixed angle. This was done by loosening the screw that enables the angle of the machine-head to be changed, and setting an appropriate angle that would make the ball land just within the full length of the table at the highest speed setting. This angle was not changed for any of the trials to eliminate the release angle affecting the range calculations.
The position of the robot	The robot was placed behind the table in a fixed position so that the height of the robot head did not affect the production of the range. If the robot was positioned higher in any of the trials, the range could have been extended. If the robot was positioned lower in any of the trials, the range could have been reduced.
The type of table tennis ball used (same mass, material and diameter)	To minimise the effect of ball size and type affecting the range, a single orange DHS-branded D40+ International Table Tennis Federation prescribed standard plastic ball was used for every trial.
The air in the room/ same room	Whenever the experiment was being conducted, all fans were turned off and the doors and windows were shut. The experiment was also always conducted in the same room. If it was conducted outside for any trials, the wind may have pushed the ball further, affecting the range.

The main <u>uncontrolled variable</u> in this experiment is the robot itself, as it is meant for training purposes and therefore the ball speed is not expected to be very accurate to the level desired by this experiment. This was seen during the experiment when the robot occasionally projected a ball with a significantly different range. To maximise the accuracy, outlier projections were redone to make sure five reasonable range measurements were taken for each speed setting, and the results were averaged to arrive at a single range measurement for each speed setting.

Materials

Table 2: Materials used in experiment with quantity and precision

Name	Quantity	Precision
Newgy Robo-Pong 1040+ Ball Machine	1	Speed settings: ± 1
Logger Pro Data Analyser Demo	1	Distances: ± 0.0001 m

Table tennis table (Joola)	1	
Table tennis ball (D40+)	1	
Phone Camera	1	

Method

1. Set up table tennis robot head to a fixed angle
2. Select 'topspin' option on table tennis robot
3. Select 'speed setting 7' on table tennis robot
4. Set up camera in a position that captures the entire table length
5. Press the start button on the table tennis robot and record the trajectory on camera
6. Record four more trajectories to get five trials for 'speed setting 7'
7. Repeat steps 3-6 for the speed settings '10', '13', '16', '19', '22' and '25'
8. Select 'no spin' option on table tennis robot
9. Repeat steps 3-7
10. For each trial, import the video recording into Logger Pro and play the video frame by frame and mark the ball position to highlight the ball trajectory.
11. Measure the length of the table and use the 'set scale' and origin settings on Logger Pro to scale range values to metres based on the actual length of the table tennis table (see *Figure 3*)
12. Collect provided data from Logger Pro of the x-ranges for no-spin and topspin balls
13. Compare the values of the topspin x-ranges to the no-spin x-ranges
14. Find the change in range

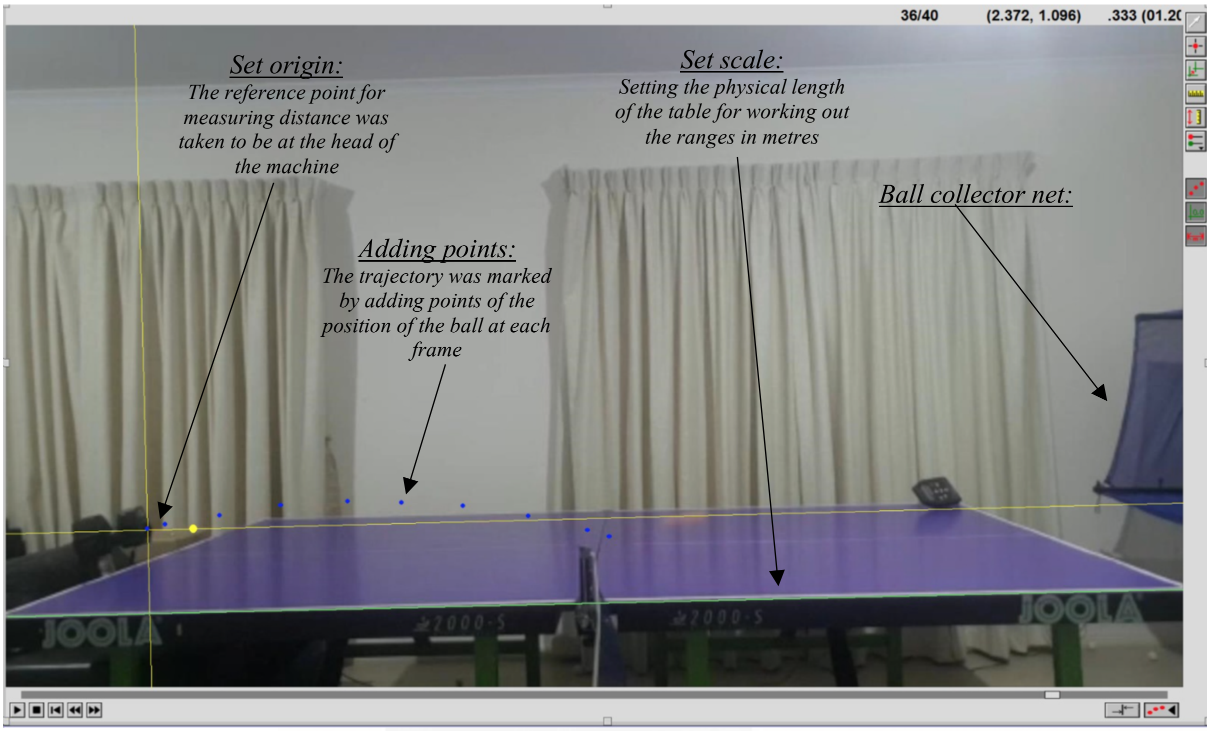


Figure 3 – Data analysis from Logger Pro

Risk Assessment

There were no major risks involved when preparing this experiment, as there were not many materials involved other than the table tennis robot, the table, and the table tennis ball itself. However, precautions were taken by placing a ball-collector net (see *Figure 3*) to stop the ball from travelling in unwanted directions, to minimise potential injuries where high-velocity balls might hit sensitive areas such as the eye.

Qualitative Data

- During some trials, particularly when the robot was operating at higher speed settings, the head would shake when the ball was being shot out, possibly altering the trajectory of the ball. To minimise this from happening, the robot was clamped tightly to the side of the table

- The projected balls would not always land in the same spot, revealing inaccuracy in the ball machine to produce balls of the same 'speed setting'

- Pressing the camera on and off between the trials sometimes caused it to change its position, which could affect how the data is perceived (perspective) when analysing the video in Logger Pro

Results

Justification of uncertainties:

- Ball machine: The uncertainty of the speed settings was taken to be $\pm$ 1 unit, as the speed settings are whole numbers, and the ball machine is a digital instrument for which the uncertainty is the smallest decimal value

- The ranges for the no-spin and topspin balls were taken to be $\pm$ 0.0001m because the resolution of Logger Pro was expressed to 4 decimal places, and is a digital instrument for which the uncertainty is the smallest decimal place

Table 1: Raw data of topspin ball x-range and no-spin ball x-range taken directly from Logger Pro analysis:

Speed setting ±1	**Trials**	**Topspin ball range (m)** ± 0.0001m	**No spin Range (m)** ± 0.0001m
7	1	0.8606	0.9293
	2	0.8312	0.9410
	3	0.9192	1.015
	4	0.8685	0.8992
	5	0.8286	0.8707
10	1	1.087	1.230
	2	1.119	1.301
	3	1.185	1.330
	4	1.105	1.272
	5	1.113	1.210
13	1	1.345	1.427
	2	1.390	1.504
	3	1.425	1.525
	4	1.417	1.483
	5	1.492	1.601
16	1	1.553	1.724
	2	1.446	1.483
	3	1.731	1.990
	4	1.489	1.656
	5	1.534	1.718
19	1	1.673	1.995
	2	1.659	1.737

	3	1.686	1.746
	4	1.801	1.878
	5	1.859	2.015
22	1	1.827	2.234
	2	1.686	2.006
	3	2.048	2.270
	4	1.790	1.883
	5	1.915	2.228
25	1	2.040	2.362
	2	1.827	2.192
	3	1.966	2.127
	4	1.950	2.112
	5	1.862	2.120

Sample calculations for uncertainties using the speed setting of 7:

- The average topspin range uncertainty was calculated by taking the maximum number minus the minimum number and dividing by two:

$$\text{Uncertainty} = \frac{(\max - \min)}{2}$$

$$\text{Uncertainty} = \frac{(0.9192 - 0.8286)}{2}$$

$$\text{Uncertainty} = \pm 0.05\text{m}$$

- The average no-spin range uncertainty was calculated by taking the maximum number minus the minimum number and dividing by two:

$$\text{Uncertainty} = \frac{(\max - \min)}{2}$$

$$\text{Uncertainty} = \frac{(1.0151 - 0.8707)}{2}$$

$$\text{Uncertainty} = \pm 0.07\text{m}$$

- The delta range uncertainty was calculated by adding the average topspin uncertainty to the average no-spin uncertainty

$$\text{Uncertainty} = 0.05 + 0.07$$

$$\text{Uncertainty} = \pm 0.1\text{m}$$

Table 2: Processed data of topspin average x-range, no-spin average x-range and delta range, with respective uncertainties

Speed setting (±1)	**Topspin Average Range (m)**	**Uncertainty (m)**	**No spin Average Range (m)**	**Uncertainty (m)**	**Delta Range[1] (m)**	**Uncertainty (m)**

[1] $delta\ range = no\ spin\ average\ range - topspin\ average\ range$

7	0.862	±0.05	0.931	±0.07	0.0690	±0.1
10	1.12	±0.05	1.27	±0.06	0.147	±0.1
13	1.41	±0.07	1.51	±0.09	0.0941	±0.2
16	1.55	±0.1	1.71	±0.3	0.164	±0.4
19	1.74	±0.1	1.87	±0.1	0.139	±0.2
22	1.85	±0.2	2.12	±0.2	0.271	±0.4
25	1.93	±0.1	2.18	±0.1	0.254	±0.2

<u>Sample calculations for values using the speed setting of 7:</u>

- The average topspin range was calculated by adding the ranges of individual trials for each speed, and then dividing the answer by the number of trials:

$$\text{Average topspin range} = \frac{(0.8606 + 0.8312 + 0.9192 + 0.8685 + 0.8286)}{5}$$

$$\text{Average topspin range} = 0.862\text{m}$$

- The no spin x-axis range was calculated by adding the ranges of individual trials for each speed, and then dividing the answer by the number of trials:

$$\text{Average no spin range} = \frac{(0.9293 + 0.9410 + 1.0151 + 0.8992 + 0.8707)}{5}$$

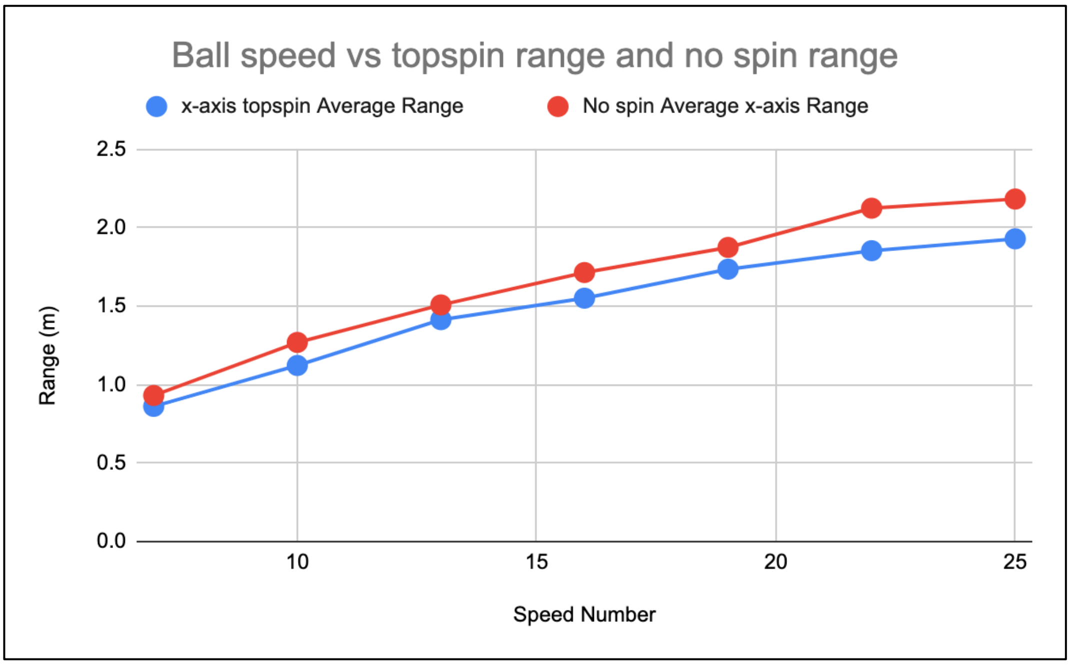
$$\text{Average no spin range} = 0.931\text{m}$$

- The delta range was calculated by subtracting the average no-spin range from the average top-spin range:

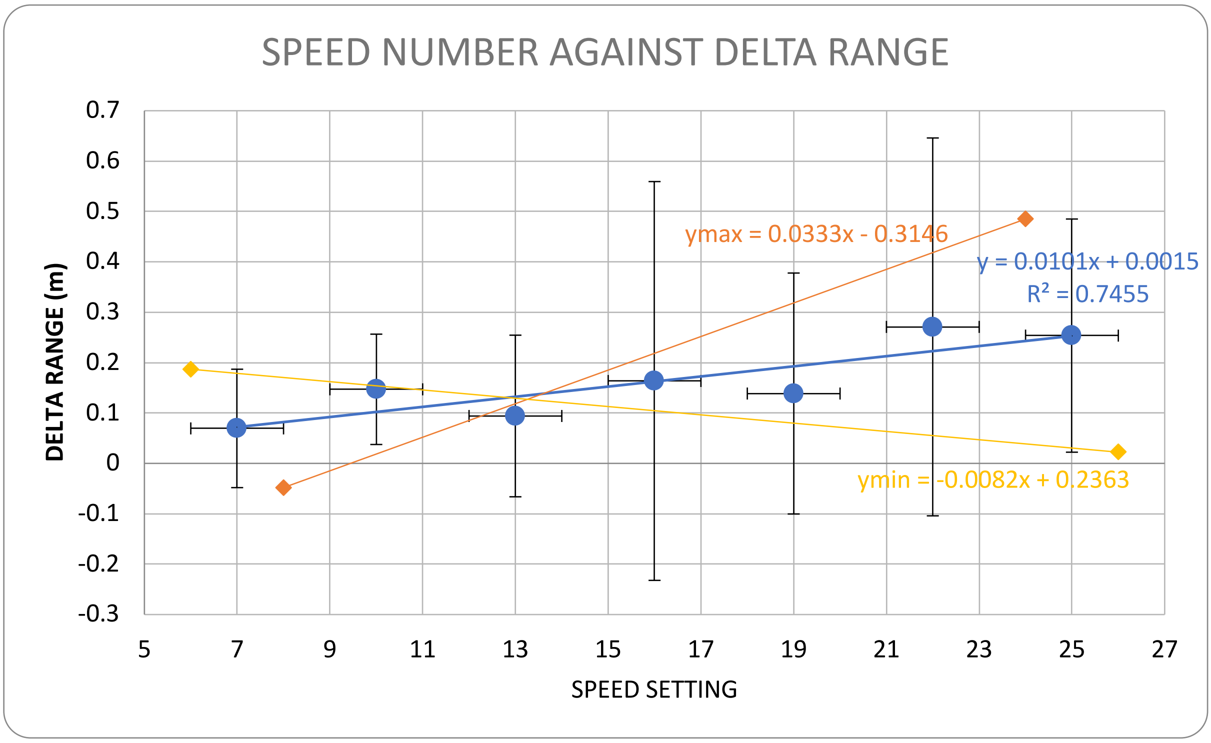
$$\text{Delta range} = 0.931 - 0.862$$

$$\text{Delta range} = 0.0690\text{m}$$

NB: A preliminary graph was created to display more clearly the change in range between the topspin and no-spin balls. This can be seen below in *Graph 1*. This graph is helpful to show how there is a difference in range between the topspin and no spin balls, however this graph does not display the relationship between the independent and dependent variable. This is seen in *Graph 2*.



Graph 1: Graph displaying visual representation of both the topspin range and the no-spin range



Graph 2: Graph displaying the delta range between topspin and no-spin ranges, including error bars and maximum and minimum slopes

Interpretation of Results

The R^2 value of 0.7455 seen in *Graph 2* suggests a positive relationship between speed and the difference in range. However, a value of 0.7455 as opposed to 0.99 indicates a decrease in precision, and this can be attributed to the presence of random error. As seen in *Graph 2*, an intercept of 0.0015 indicates that the trendline almost passes through the origin which makes the relationship between speed setting and the delta range almost directly proportional. This proves how, with an increase in speed, Magnus Effect brings the ball back (reduces the range) by a proportional amount. However, as there is not a completely direct proportionality, systematic error is still present, and the accuracy of the experiment is reduced. Despite this, the graph still shows how an increase in speed results in an increase in the delta range, and thus the hypothesis is supported.

Calculating the uncertainty in the y-intercept:

$$Uncertainty\ in\ c = \pm\left|\frac{c_{max} - c_{min}}{2}\right|$$

$$= \pm\left|\frac{-0.3146 - 0.2363}{2}\right|$$

$$c = 0.0015 \pm 0.3$$

Calculating the uncertainty in the slope:

$$Uncertainty\ in\ m = \pm\left|\frac{m_{max} - m_{min}}{2}\right|$$

$$= \pm \left| \frac{0.0333 - (-0.0082)}{2} \right|$$

$$m = 0.0101 \pm 0.02$$

The values for uncertainty in the y-intercept and slope of ±0.3 and ±0.02 respectively, also show how the range of values within which the true value of the y-intercept and slope exists is small. This further indicates a high degree of accuracy in the data.

Evaluation

<u>Conclusion</u>
The results in *Table 2*, as well as *Graph 2* show how faster topspin balls create a greater Magnus Effect and support the hypothesis that higher-velocity topspin balls will cause an increase in the difference in range, as there is a positive relationship between speed and difference in range. This difference in range can be attributed to Magnus Effect.

Applying this back to real life context, if a strategy to win table tennis games is to increase the speed of the stroke, table tennis players are able to strike the balls at faster speeds without them flying out of the table if they add topspin, as the faster their topspin stroke is, the more impact the Magnus Force has on the trajectory of the ball to shorten the range and make it difficult for opponents to return. Whilst many table tennis players are aware of Magnus Effect, this experiment quantified how it is more significant at higher speeds albeit with some degree of error.

<u>Strength and Weaknesses</u>

Systematic error:

This experiment was robust in terms of its methodology as it was more heavily based on technology. As the main piece of equipment used was the table tennis robot, the only consideration was keeping the angle of the machine-head consistent, and this was controlled at the beginning of the experiment by fixing it to a set angle. It was also beneficial to have the table tennis table at home, as this allowed for a large range of data to be collected within a short period of time. Using Logger Pro was beneficial, as manual lengths for the individual ranges did not need to be calculated and all necessary data was provided in the Logger Pro data analyser. However, as the line of best fit does not go through the origin, some systematic error was present.

Name of error	**Evidence**	**Level of impact on data**	**Improvement**
The angle of the camera	The angle of the camera was in a fixed position throughout the collection of all the data. However, a different angle could have caused for the table tennis table to be viewed from a different perspective (for example, higher, lower, sideways, from the corner), which may not have revealed its full trajectory accurately.	High. If the trajectories are not measured from the right perspective, each range may be skewed by a certain amount.	This can be improved by positioning the camera: 1. on the side of the table and not in the corner 2. around the middle of the table 3. at the same height as the table

The type of table tennis robot	The table tennis robot is at least six years old and was designed to operate on the previously standard celluloid balls, which were much lighter than the standard plastic balls used today.	As a D40+ plastic ball was used in this experiment, the wrong ball was used for the robot, and therefore it may have projected the balls to have shorter ranges compared to celluloid balls, affecting each individual result. However, the impact is minimal, as it still shows how Magnus Effect works, just not in a sense that can be applied to modern competitions.	A more recently built machine could be used, such as the Butterfly Amicus 300 Plus Robot (see *Figure 3*), which is tailored to plastic balls and not celluloid balls.

Table 3: Systematic error

Despite LoggerPro being an highly accurate form of apparatus, some of the data analysing that had to be done by hand (for example, tracing the trajectories of the balls) may have brought about random error. Additionally, whilst using the table tennis robot was much more precise than striking the table tennis balls myself, random error was still present in various forms by using the robot.

Random error:

Name of error	**Evidence**	**Level of impact on data**	**Improvement**
Type of camera used in Logger Pro analysis	As the balls were moving at such high velocities, it was difficult to place the ‘dot’ over the ball when trying to trace the trajectory as it blended in with the background. In an initial practice test, a white ball was used, and this turned out to be too difficult to trace. In the final experiment, an orange ball was used and, while this was more clearly visible than the white ball, it was still difficult see the exact points at which the ball was moving. Some estimating had to be done which might have affected the final range calculations.	High. Estimating the range is not accurate and may have been slightly different in comparison to how far the ball actually moved.	High-speed cameras could also be used to fix any errors regarding the Logger Pro video analyses, as a high-speed camera would be able to capture the positions of the ball at every second without being too blurry and relying on human judgement.
The angle of the robot head	Due to the low R^2 value and the visual scattering of the data points from the trendline, it is implied that random error was present. One example of this could be the angle of the machine-head. Even though it	High. If the angle of release is not constant, speed may have not been the only variable	The angle of the machine head could be fixed (beyond fixing it using the screw) by strapping it to the table tennis table using duct tape, so that it will not

	was adjusted to a fixed angle, the impact from projecting high-velocity balls may have caused it to shake a little and therefore affect not only its angle but also the angle for the next ball.	impacting the change in range.	move at all during any of the trials.
Error in the ‘speed settings’	Another random error could be the ball machine’s inability to produce balls of exactly the same speed, as seen in Table 1, which is why several trials were taken and averaged. Although the ball machine had speed numbers of ‘7’, ‘10’, ‘13’, ‘16’, ‘19’, 22’ and ‘25’ which constitute to certain speeds in ms^{-1}, it is not possible for the machine to produce the same speed for each ball exactly. This was further seen in the uncertainty of the ball machine, which was ±1, and this was visually evident because each ball was slightly different from the one before it, despite being within the same ‘speed setting’.	High. In real life, this average range may not reflect the effect of the Magnus Force to its maximum capacity.	The table tennis ball machine used was one that sits on the surface of the table, and thus it is not very stable in terms of the angle from which it shoots the balls. This issue could be solved by using a high-end machine, such as the Butterfly Amicus 300 Plus Robot (see Figure 3), which operates from a fixed position on the table and uses a different mechanism to the one used in this experiment. As this type of machine is readily fixed, the angle would have no influence over the trajectories measured, isolating speed to be the only independent variable.

Table 4: Random error

<u>Extension</u>

While this experiment investigated the effect of an increased speed on the impact of Magnus Effect, it would also be interesting to consider other factors such as mass, radius, and material of table tennis balls. For example, does Magnus Effect operate more significantly on celluloid balls than plastic balls and why? Previous research suggests that the impact of Magnus Effect is more significant when the material used is celluloid rather than plastic. The table tennis balls used in competitions today are plastic, as plastic balls have harder surfaces, making it difficult to impart as much spin as you could with previously used celluloid balls.

Figure 3 - (Webgenix, 1996-2021)

Summary

Overall, this experiment shows how Magnus Force operates at all speeds of a topspin ball but more significantly at higher speeds. The likelihood of a faster ball going out of the table is high, but because of Magnus Effect, the ball can land within the measure of the table. Therefore, if there is some means of hitting the ball faster and landing it on the table, when it would naturally go out, that is beneficial to one’s play because faster balls are harder to return. Therefore, players should aim to hit more faster topspin shots in their games with the benefit of Magnus Effect.

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2021 OLIPHANT LOGBOOK

Samadhi Chandrasena

1. Planning

15/12/20

As a very broad topic, I am interested in investigating some aspect concerning the physics of table tennis - more specifically, an aspect potentially advantageous to table tennis players. However, this is difficult to investigate because testing how to make table tennis shots more ‘effective’ is hard to quantify - it comes from not just the bat angle and speed, but also in the leg and waist movement. And even so, it is difficult to know if I, as a player, am hitting every shot with the same speed/power/force.

23/12/20

New idea - use table tennis ball machine because it will project the table tennis balls at similar speeds and spins that I can control, because it has both spin and speed settings. This covers the personal engagement - I can do table tennis - but still need to come up with a specific area of investigation.

21/01/21

Recorded my most recent matches and identified areas of weakness in my game. Main weakness identified is that most of the balls that I hit with a lot of speed (really effective to make opponent struggle with return) were flying out of the court, making me lose a lot of points.

23/01/21

Talked to my coach this week about how this could be improved, and he suggested adding more topspin, because topspin causes the ball to curve into the table, shortening its range - easier to land on the table. This was a really convenient tip because it prompted me to research why adding topspin caused the ball to curve onto the table, which I discovered was due to a force called ‘Magnus Force’.

06/02/21

Started developing aim for investigation. My problem is that I want to hit the table tennis balls at a higher speed because that makes it very difficult for the opponent to return, but most of them just fly out of the table. To this, I was told to add more topspin because topspin causes the range to decrease, which I now know is due to Magnus Force. I'm really interested in seeing how increasing the speed will affect how much Magnus Force acts - will it increase with speed, making the ball curve inwards more and shortening the range? If so, this would be extremely beneficial to table tennis players, like myself, to employ in their games to win more points.

23/03/21:

Investigation question was approved by teacher. I have decided to use the table tennis ball machine to vary the speeds and then measure the range. I will record each trajectory on LoggerPro to get the most accurate measure of the range. To investigate how much Magnus Force impacts the range, I will compare topspin balls to no-spin balls.

2. Risk Assessment

Whilst there are many table tennis tables at school, I have decided to use the table tennis table I have at home so that I can record more data within the provided experimenting time. Because there is not much equipment used in this experiment, apart from the table tennis table, ball machine, and table tennis balls. There is a small chance that one of the table tennis balls being projected at a high velocity may come into contact with an individual, which may cause slight bruising. In order to avoid this, the ball machine was controlled from behind with the remote control, out of the way, and there was also a net set up to catch all the balls.

3. Conducting the Experiment

27/03/21:

Completed both the topspin and no-spin SPEED 7 SETTING trials and videotaped them. Noticed that using white table tennis balls was not effective on camera because they were moving too fast and this would be too hard to track. Re-did all of the SPEED 7 SETTING trials using an orange table tennis ball - worked much better.

29/03/21:

Completed both the topspin and no-spin SPEED 10 SETTING trials and videotaped them.

02/04/21:

Completed both the topspin and no-spin SPEED 13 SETTING trials and videotaped them.

03/04/21:

Completed both the topspin and no-spin SPEED 16 SETTING trials and videotaped them.

05/04/21

Completed both the topspin and no-spin SPEED 19 SETTING trials and videotaped them.

06/04/21:

Completed both the topspin and no-spin SPEED 22 SETTING trials and videotaped them.

07/04/21:

Completed both the topspin and no-spin SPEED 25 SETTING trials and videotaped them.

08/04/21

Started video-analysing the data. Found that the data looked unrealistic. Did some research on LoggerPro and realised that some sort of measuring indicator had to be used. Luckily, the entire length of the table tennis table could be seen in the camera. I measured this and inserted the length into each video - there were 70 videos and so it took longer than expected but there was lots of data and trials which increases the overall accuracy.

5. Results

Raw Data

Speed setting ±1	Trials	Topspin ball range (m) ± 0.0001m	No spin Range (m) ± 0.0001m
7	1	0.8606	0.9293
	2	0.8312	0.9410
	3	0.9192	1.015
	4	0.8685	0.8992
	5	0.8286	0.8707
10	1	1.087	1.230
	2	1.119	1.301
	3	1.185	1.330
	4	1.105	1.272
	5	1.113	1.210
13	1	1.345	1.427
	2	1.390	1.504
	3	1.425	1.525
	4	1.417	1.483
	5	1.492	1.601
16	1	1.553	1.724
	2	1.446	1.483
	3	1.731	1.990
	4	1.489	1.656
	5	1.534	1.718
19	1	1.673	1.995
	2	1.659	1.737

	3	1.686	1.746
	4	1.801	1.878
	5	1.859	2.015
22	1	1.827	2.234
	2	1.686	2.006
	3	2.048	2.270
	4	1.790	1.883
	5	1.915	2.228
25	1	2.040	2.362
	2	1.827	2.192
	3	1.966	2.127
	4	1.950	2.112
	5	1.862	2.120

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