EVALUATION

Conclusion

From the results of the experiment and the analyzed data, it was evident that as the value of the Ping-Pong ball's spin rate increased, its deflection ratio increased as well. Clearly, the spin rate was directly proportional to the deflection ratio and in the end the following equation was derived to model the relationship between the two variables.

$$\frac{D}{x} = (0.0004 \pm 0.0003\ s)\omega + (0.00 \pm 0.02) \qquad \text{[Equation 4]}$$

The final graph was a proportional fit starting from the origin and steadily increasing in y-value, the deflection ratio, as the x-value, the spin rate, increased. This shows that the spin rate and deflection ratio are proportional to each other. As seen in the final graph, the fit managed to stay relatively close to all of the data points and within the uncertainty bars; therefore, a sufficient amount of confidence can be put onto the analyzed data points. Only about one or two data points didn't fit the proportional graph as well as the others did, which is most likely a bad data point possibly resulting from a bad hit. The uncertainties were pretty large due to the fact that the video analysis process was extremely sensitive. Although the same video was analyzed three times in a row, a slight difference in tracking the ball made a large difference. Despite the uncertainty, the data points collected in this experiment seemed to be accurate since they managed to keep true to the predicted type of graph and a final equation was able to be found from the relationship.

Comment [1]: A detailed conclusion is **described and justified** which is entirely relevant to the research question and fully supported by the data presented.

However, the slope of the graph did not match the calculated value. In fact, the calculated value was greater by roughly a factor of five, which suggests that there was either a flaw within the collected data or the original equation that was used to model the situation (Equation 1). Since the collected data seemed accurate to a decent extent, the equations used were analyzed. One assumption that Equation 1 had made was the fact that the surface of the ball had no effect on the ball as it spun through the air. However, the definition of Magnus Force, the force causing the curvature of the ball, states that there is a coefficient of air resistance, or more commonly known as the coefficient of drag, associated with it, which clearly shows that some constant was missing from the original equation. The assumption that the coefficient of drag was simply a value of one was refuted by the results of this investigation. Since drag coefficients are a value between zero and one, and the slope of the graph was $1/5^{\text{th}}$ of the calculated slope value, it can be predicted that the missing constant variable was what caused the calculated slope value to end up being to high. A constant k was inserted into derivation process and it showed that adding the constant along with the slope didn't disrupt the nature of the equation in representing the phenomenon. Therefore, the following equation would be a more accurate representation of the situation:

$$\frac{D}{x} = \frac{\pi R^3 \rho k t}{m}\omega \qquad \text{[Equation 5]}$$

where k is some constant that is acting on the ball during its flight. Nevertheless, it can be concluded that the spin rate of a Ping-Pong ball is directly proportional to the deflection ratio.

Comment [2]: A conclusion is correctly **described and justified** through relevant comparison to the accepted scientific context

Despite the differences in the slope values, it can be seen that the relationship between the two variables is proportional and this fact can be applied to spherical objects, most likely spherical sports balls, that gains enough air time to experience curvature during its flight. Although the slope values may differ, the general shape and nature of the graphs will be similar. For objects with small mass and size, and a smooth surface like that of Ping-Pong balls may share a similar slope value as well. The deflection ratio of other types of balls, such as golf balls, tennis balls, or baseballs, would increase with added spin, but the type of graph achieved is unknown since the surface of the ball may cause the final graph to be an increasing graph possibly linear, proportional, or even exponential. Although the proportionality of the two variables can be

applied to a wide range of spherical objects, the specific type of graph that would be created cannot be.

Evaluation

One weakness of the experiment was the fact that the camera's view wasn't exactly perpendicular to the hit since it was first connected to a tripod, which was clamped onto a shelf near the ceiling. The camera ended up being slightly crooked and the angle of its view was being affected by a small amount every time the record button was pressed when starting and stopping the video recordings. This would also be a random error since the angle in which the cameras are recording could affect the distances being analyzed. In order to keep the camera's view as constant and perpendicular to the field of hit as possible, a different tripod can be used. A larger tripod that would allow the camera to be bend at a 180 degree angle looking straight down would work much better since the tripod can be raised to its maximum height and placed onto a table, the camera can be put facing down, and the balls can be hit right under the table while they are being recorded. This adjustment would allow greater consistency and accuracy of the data points.

Another weakness is the fact that the ball's distance from the camera couldn't be controlled. A ruler was set up horizontally using a retort stand in the field of the hit in order to act as a reference guide to keep all the hits roughly around the same height; however, the positions were all off by a slight factor. This would cause the collected data to have random errors since the curvature of the balls that were hit further away from the camera lens would seem to curve less than if it had been closer to the camera due to the difference in distance. This was an inconsistency within all the trials and affected the distance measurements to be slightly inaccurate. A related, and very important issue, is the fact that the ball was moving in a vertical parabola while traveling across the camera view, and the vertical motion was different every time, coming closer or farther from the camera as it moved across, depending on angle and speed of hit. In order to decrease the level of inaccuracy and maintain the height of the ball as close to each other as possible, a wooden board can be set up horizontally instead of a ruler as this would act as a better guide in knowing where to hit the ball. With a ruler, the height was approximated but with a wooden board or a flat plane, it would be much easier to keep the height of the ball consistent, which would decrease the inaccuracies in the data.

A third weakness in the experiment was the fact the ball's path range was extremely limited. The high-speed camera only was able to detect a narrow pathway since the distance between the ball and the camera was limited by the height of the room. This only allowed minor curvatures to be recorded because optimum spin was only achievable if the ball was hit for a longer time period, as Ping-Pong balls tend to curve most during the second half of its flight, not the first. Due to the limited space and low camera resolution at high-speed settings, only the first half of the ball's flight was able to be detected which overall resulted in minor spin. In order to obtain trials with greater spin, an abundant amount of space is needed since this would allow the camera to be positioned at a higher spot and the last bits of the ball's curvature would be able to be seen as well, which would result in greater deflection ratios. This would ultimately allow a great range of data and even more accurate equations and graphs would be achieved.

Comment [3]: Strengths and weaknesses of the investigation, such as limitations of the data and sources of error, are **discussed** and provide evidence of a clear understanding of the **methodological issues** involved in establishing the conclusion.

The student has **discussed** realistic and relevant suggestions for the improvement and extension of the investigation.

Comment [4]: The presentation of the investigation is clear. Any errors do not hamper understanding of the focus, process and outcomes.

The report is well structured and clear: the necessary information on focus, process and outcomes is present and presented in a coherent way.

The report is relevant and concise thereby facilitating a ready understanding of the focus, process and outcomes of the investigation.

The use of subject specific terminology and conventions is appropriate and correct. Any errors do not hamper understanding.