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STA 320

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Experiment Lab Report

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The Influences on the Flight of a Paper Airplane

Abstract

This experiment was conducted to determine how the weight, size, and fold of paper effect the flight distance of a paper airplane. Each of these three factors had two levels, and the response variable was distance in inches, measured from launch until stop. Two students threw the planes 16 times each for a total of 32 trials. Through design meetings and a pilot study, the experiment was able to be successfully completed and the results reflected the hypothesis that the weight, size, and fold of paper interact to fly a paper airplane. Executing the experiment emphasized the impact of the initial steps of planning an experiment on experimental design.

Introduction

The goal of this experiment was to discover which paper airplane treatment would fly the furthest. After the discussion of several alternative experiments at design meetings, this study was decided upon due to its simplicity, capability to be carried out in a scholastic atmosphere, and its ability to be manipulated to conduct a 2^3 factorial design. Given the result that there was found to be a statistically significant three-way interaction between weight, size, and fold, this experiment emphasized the fact that different forces balance each other to make a paper airplane fly. It demonstrated that we were correct in deciding on the factors that were chosen to create eight different treatments. The pilot study was decided upon to exemplify the design plan efficiently and determine whether changes were necessary.

Methods

The steps that were taken before experiment day included several design meetings in which the group determined an experimental design plan, established a research question, along with the factors and levels, response, materials, location, and lurking effects of the experiment. The factors of interest were set to be paper size with two levels, small (6.8 x 8.8 in.) and large (8.5 x 11 inches), paper weight with two levels, low (copy paper) and high (book paper), and paper fold/design with two levels, “Easy Peasy” and “Javelin,” two designs from the reference book used, *The New World Champion Paper Airplane Book* by John M. Collins. Materials to be gathered included directions on creating the airplanes, copy paper and book paper, tape, and measuring tapes. Lurking variables were discussed and identified as draft/air circulation, temperature of the room, variability in the creator and launcher of the planes, and malfunction in launch.

The final design meeting was used to create the airplanes and randomization tables. A randomization table was used to ensure that each of the two plane throwers flew each treatment twice, while eliminating selection bias and forming a basis for the statistical analysis (Suresh, 2011). Then a pilot study was conducted in which students practiced launching the airplanes to determine if the experiment could be successfully conducted using the plan that was created. From the pilot study, it became clear that a blocking variable, force, was necessary to be included in our model to reduce the variability of the response. Since a pilot study is typically underpowered, this pilot study allowed us to recognize that the experiment must have enough power to draw accurate conclusions.

Tasks were assigned to the participants of the study. On Monday, December 6th, the participants of the experiment met at 12:00 PM in the Syke’s Ballroom. At this point, those students who were assigned the tasks of measurers taped the starting point onto the floor, and then went on to mark places every 120 inches. To begin the experiment, the student in charge of recording set up his phone to have a side view of the entire experiment layout. The appointed director read from the randomization table to the selector of the planes to ensure that the correct planes were thrown in the correct order. The selector then gave the specified plane to the launcher of the plane. From the starting point, the launcher threw the airplane. At this point, the measurers measured both the vertical and horizontal distances of which the plane traveled. At this point in the study, the measurements were read off to the data entry team. These measurements were used to calculate the hypotenuse of which the plane traveled. This value was used as the response variable measured in inches because it was determined to be the most accurate measure of the distance the plane traveled. Once the data entry was complete, the retrievers worked together to organize the planes back into their box.

Once the study was complete, the group went on to develop a statistical analysis plan. This experiment was a 2^3 factorial design (8 treatments). A three-way ANOVA with a blocking variable was to be ran. Assumptions were to be checked with Shapiro-Wilk test of normality and Levene’s test of homogeneity of variances. Summary statistics, tables and graphs were to be included.

Results

A three-way ANOVA was conducted to determine the effects of paper weight, size, and fold on the flight distance of a paper airplane. There was one outlier assessed as a value less than one box one box length from the edge of the box in large javelin planes. Flight distances were normally distributed ($p > .10$), as assessed by Shapiro-Wilk's test of normality. There was a homogeneity of variances, as assessed by Levene's test for equality of variances, $p = .883$. There was a statistically significant three-way interaction between fold, size, and paper, $F = 4.22$, $p = .052$. There were not found to be any statistically significant two-way interactions, $p > .10$. Flight distance was statistically different between the two plane throwers, $F = 16.90$, $p < .001$ (see figure 1 in the appendix), along with paper size (see figure 2 in the appendix), $F = 9.16$, $p < .001$. Statistical power was calculated to be 0.71 shown in figure 3 in appendix. See figure 4 in the appendix for means and standard deviations of flight distance for all three factors of paper, size, and fold.

Discussion

This experiment has revealed to me extensive knowledge about experimental design and the importance of the steps taken in developing an effective experiment. Determining factors to use for the experiment taught me to choose factors based upon what most accurately answers the research question. We needed to define the variables and make predictions about how they would relate to the response. For example, originally the group added "launch type" as a factor. We were interested to see whether there was a difference in flight distance between a store-bought launcher or student throwing the plane. After further discussion, we decided that adding this factor into the dependent variables was unnecessary and more costly when we could allow two different students to throw the planes. We determined that the response would be more influenced by the paper type, size, and design of the planes than the launcher. Our blocking variable of force could still be used considering replication in plane throwers.

Performing a pilot study was helpful in defining flaws in our original experimental design plan. To be specific, we originally planned on creating three planes with twelve treatments. The pilot study exhibited that there may have not been enough time to complete 36 total runs. Also, we originally were going to measure the response at the closest point of the plane to the starting point. The pilot study helped us discern that the planes should be measured at their furthest points from the start, due to sliding and other malfunctions during flight. Overall, the pilot study provided me with a better understanding of our design and how it would work.

This experiment taught me more about blocking, randomization, and replication. Using the blocking variable of force allowed us to reduce the variation of our results. Randomizing within block was an approach we used to prevent variability within blocks, such that it is less than the variability between blocks. Replication was used to discover more information from the results we drew from the statistical analysis. Blocking, randomization, and replication helped make this experiment more successful.

The various methods of designing paper airplanes point to real life significance. In designing each plane, the goal is to make it fly the furthest. Because different forces affect flight, taking into consideration the forces of drag, lift, and thrust is necessary. With too much drag or weight, the plane won't fly as far. All three forces must be in balance for a successful flight distance. Therefore, it is logical that shorter, heavier planes do not fly as far as longer and lighter planes. These facts help one understand more about physics and aerodynamics.

Conclusion

Developing this experiment using strategic planning techniques helped draw specific conclusions from the statistical analysis. Defining factors and the response to be used, assigning tasks, and forming a date entry team made carrying out the experiment efficient and effective. With applying experimental design, it was clear to see a relationship established between the factors and the response. By incorporating the blocking variable of force, we reduced variability in the response to see that the weight, size, and fold of a paper airplane have an interactive effect on its flight distance.

References

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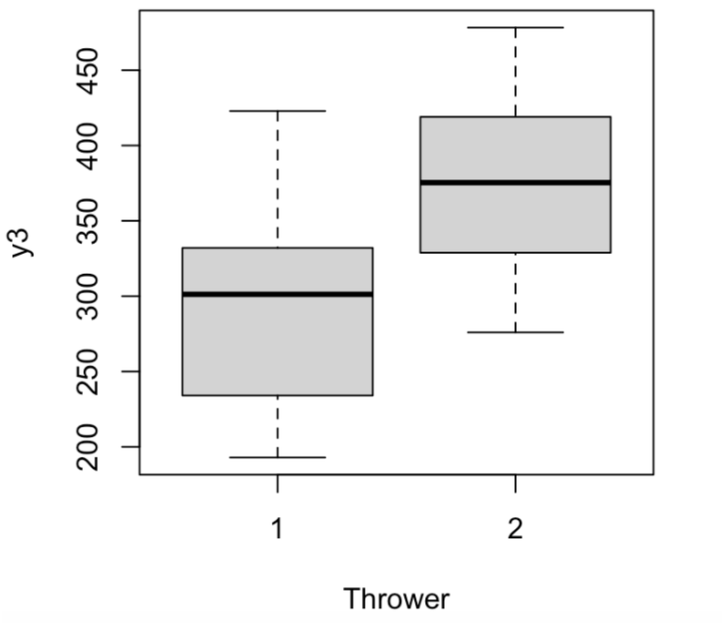
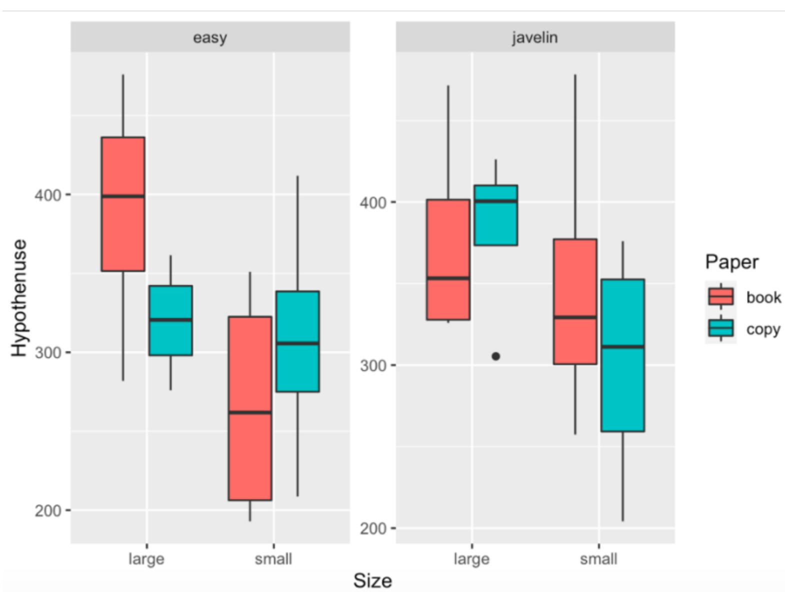
Appendix

Figure 1



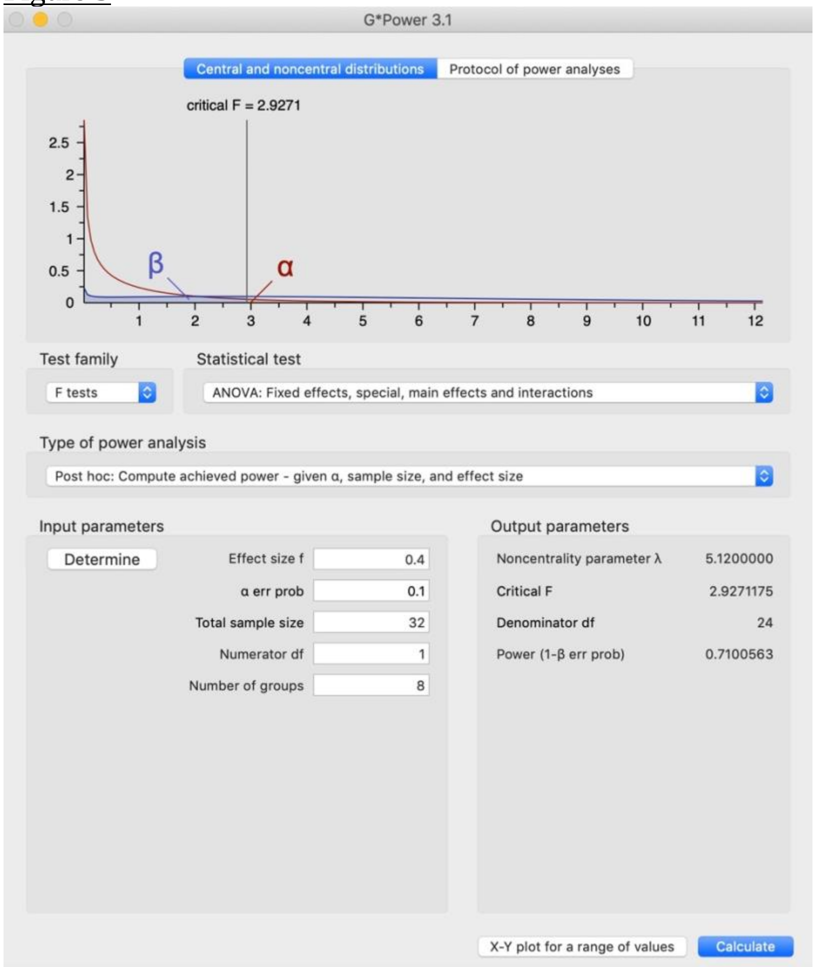
The figure to the left represents the statistical significance between paper airplane thrower and flight distance.

Figure 2



The boxplots to the left represent the statistical significance between paper size and flight distance.

Figure 3



Power was calculated in G*Power to be 0.71 using a large effect size, alpha = .10, a sample size of 32 planes, and 8 treatment groups.

Figure 4

Treatment	Mean	Standard Deviation
Easy, Large, Book	388.86	82.45
Javelin, Large, Book	375.98	68.08
Easy, Small, Book	266.92	77.06
Javelin, Small, Book	348.52	93.60
Easy, Large, Copy	319.63	37.03
Javelin, Large, Copy	383.15	53.36
Easy, Small, Copy	307.93	83.27
Javelin, Small, Copy	300.63	76.28

The table above presents the means and standard deviations for each treatment.

Figure 5

```
> anova(model_y3)
Analysis of Variance Table

Response: y3
                Df Sum Sq Mean Sq F value    Pr(>F)    
Thrower          1  54774   54774 16.9008 0.0004268 ***
Fold             1   7804    7804  2.4079 0.1343802    
Size             1  29674   29674  9.1560 0.0060130 ** 
Paper            1   2377    2377  0.7333 0.4006438    
Fold:Size        1    280     280  0.0865 0.7713351    
Fold:Paper       1     78      78  0.0241 0.8779141    
Size:Paper       1   1522    1522  0.4698 0.4999471    
Fold:Size:Paper  1  13663   13663  4.2158 0.0515914 .  
Residuals       23  74540    3241                      
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Above is the ANOVA table for the response, the flight distance of a paper airplane.