Final Report
STAT 230 Dr. Blades (Sec 002)
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INTRODUCTION

Our group began with an interest in the effect that both type of paper and size of paperclip has on the descent time of a paper helicopter when dropped. We thought that helicopters made with thinner paper may descend faster because of less air resistance. Likewise, we thought that helicopters made with bigger paper clips may descend faster because they weigh a little more. Based off of this interest, we formulated a precise a research question: what is the effect that both type of paper and size of paperclip have on helicopter descent time, and what interaction occurs between the factor levels, if any? To answer this question, we designed and ran an experiment that we will describe in this paper.

METHODOLOGY

Design

The response variable in our experiment was the time that a paper helicopter replicate takes to hit the ground after being dropped from nine feet. The two factors we studied were paper type (copy paper, lined notebook paper), and paperclip size (1.75", 1.375"). The experimental unit was a trial in which a helicopter was dropped from nine feet.

In preparation for our experiment, we gathered the following materials:

- 10 pieces of copy paper
- 10 pieces of college ruled notebook paper (no chaff)
- 10 1.375" paperclips (metal)
- 10 1.75" paperclips (metal)
- 1 pair of safety scissors for cutting

Before beginning the experiment, we randomly assigned unique experimental responsibilities (cutting the paper, folding the helicopters, putting on the paperclip, timekeeping, dropping the helicopter, recording the time, clearing the ground) to the three of us. Cory was assigned to both fold and drop the helicopters, Sam was assigned to put on the paperclip and record the time, and Jacob was assigned to cut the paper, keep the time, and clearing the ground after each trial. This was done to control for any possible differences in the way we individually complete an experimental responsibility.

Finally, we used R to create a random run order for our replicates with the seed set to "1234" for the trials 1 – 20 without replacement. With our run order randomly generated, we followed the following experimental procedure.

Procedure

1. Obtain the required materials listed above: 10 pieces of copy paper, 10 pieces of lined college ruled paper, and 20 paper clips, 10 being 1.75" and the other 10 being 1.375". Finally, obtain a pair of scissors to cut the paper.
2. Line up all 20 pieces of paper and hold them together using the paper clips. Using scissors, cut the copy paper to be the same size as the lined college ruled paper.
3. Create 20 paper helicopter replicates, five of each factor combination, in the random run order generated previously. Start by cutting (using scissors) a 5-inch vertical line starting from the midpoint on the top edge of the paper, creating the helicopters two wings. Next, cut two 2⅔-inch horizontal lines on each side of the paper starting 2 inches from the bottom, creating the helicopters tail parts. Finally, fold the two wings in opposite directions, and fold both tail parts in the same direction, placing the paper clip over the folded tail parts in the center. [For clarification, see Figure 1 below]
4. For each replicate, have the designated dropper hold the helicopter 9 feet in the air with no obstacles below it. The designated timekeeper should count "3,2,1,Go," and on Go, the dropper lets go of the copter and the timekeeper starts the timer. The timekeeper should stop the timer as soon as no movement is observed anymore.
5. After stopping the timer, the timekeeper should tell the designated recorder the time observed on the timer. The recorder should record this time onto the check sheet.

Replicates & Control

For each treatment combination of the two factors, we created 5 replicates for a total of 20 replicates. This replicate number was chosen because the library only allowed us to take 20 pieces of paper and we all didn't have money to buy copier paper. In addition, one paper helicopter took around 2 minutes to create, giving us 40 minutes to create our replicates and the remainder to run the experiment. The library didn't have any rooms available for more than two hours when we all could meet to set up and perform the experiment, and we wanted to drop the helicopters from the same place in the same room every time as different rooms with vents in different places could skew the data.

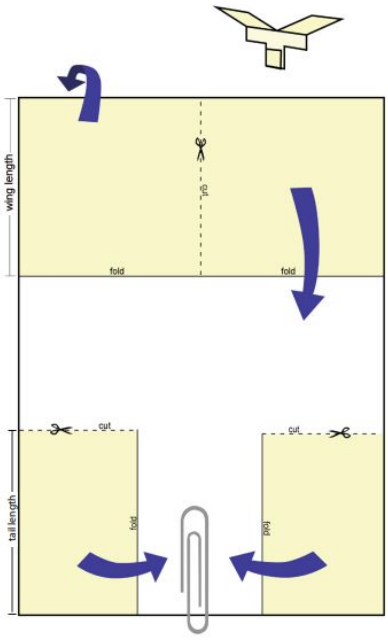

Figure 1. Helicopter Diagram

To help control the experiment, helicopters were dropped from the same place and by the same person in each trial. Each task was uniquely performed by the same team member for every trial, as mentioned before.

Performing the Experiment & Safety Checks

The experiment was performed at 5:30 on 11/13/18. Jacob cut each of the papers using the procedural guidelines found above. Cory folded each of the papers using the same method for all 20 helicopters. Before each trial, Sam clipped the tails together. Each helicopter took between 60 and 90 seconds to complete. Sam would pass the completed helicopters to Cory, who would then drop them from the ceiling. Cory would place the back of his hand in the same spot on the ceiling and drop them on "3, 2, 1, go". Jacob timed all 20 trials. Sam recorded the results. Jacob cleared the trial from the floor — so that Cory would not have to climb on and off the table — and passed the paper clip back to Sam. It took ten minutes to complete and record all 20 trials.

For safety purposes, we used safety scissors and Cory used a chair to step up onto the table, and made sure the table was heavy enough to support him without flipping.

Experiment Results

See Appendix *Table 1: Check Sheet* for the experiment results. Our first trial was an outlier because the timekeeper stopped the timer differently than he did for the remainder of the experiment. We removed this trial from our further calculation.

Summary Statistics

Table 2. Helicopter Summary Statistics

Material	Paper Clip Size	Mean Time (seconds)	Std Deviation (seconds)	# of Replicates
Copier	1.75"	1.728	0.061	5
Notebook	1.75"	1.796	0.138	5
Copier	1.375"	1.750	0.159	4
Notebook	1.375"	2.002	0.253	5

ANALYSIS

Model Specification

The model for the experiment is BF[2], which is defined by $y_{ijk} = \mu + \alpha_i + \beta_j + \gamma_{ij} + \varepsilon_{ijk}$, where y_{ijk} is the response for the k^{th} replicate of the i^{th} paper type and the j^{th} paperclip size, μ is the grand mean of the response, α_i is the treatment effect for the i^{th} paper type, β_j is the treatment effect for the j^{th} paperclip size, γ_{ij} is the interaction effect for the i^{th} paper type and the j^{th} paperclip size, ε_{ijk} is the error of the k^{th} replicate of the i^{th} paper type and the j^{th} paperclip size. In this model, i = {1, 2} = {Copier, Notebook} = indexes the level for paper type, j = {1, 2} = {1.375", 1.75"} = indexes the level for paperclip size, k = {1, 2, 3, 4, 5} = indexes the replicates of factor level i and j.

This model is appropriate since we are dealing with two different factors (Paper Type, Paperclip Size). Factors were combined into treatments on a check sheet and then the treatment order was randomized using R and put into a run sheet.

Assumptions

The index plot generated by our experimental results has no visible pattern, so we can assume our residuals are independent. We can assume that the residuals are normal since the sample quantiles follow the straight theoretical quantile line. The mean of the residuals is zero. Our constant variance assumption is not met since our standard deviation ratio requirement is not satisfied ($\frac{0.253}{0.061} = 4.15 > 2$).

ANOVA Table

Table 3. ANOVA Table for Helicopter Drop Time (Type III)

Source	Df	SS	F–Value	P–Value
Intercept	1	62.283	2210.2735	<0.001
Paper Type	1	0.120	4.2752	0.056
Paperclip Size	1	0.061	2.1704	0.161
Interaction	1	0.040	1.4135	0.253
Residuals	15	0.423		

RESULTS

Inference

From our ANOVA table (see Table 3 above), we can see that none of the effects have statistical significance, with the lowest p-value being 0.056 (corresponding to the main effect of the paper type factor) and our highest p-value being 0.253 (corresponding to the interaction effect between the two factors). With that known, we can conclude that there is no difference in or interaction between the descent time of helicopters with any combination of our factor levels. Thus the mean descent time of paper helicopters made with either copier or notebook paper and 1.75" or 1.375" paperclips dropped from 9 feet is simply our grand mean, 1.822 sec (95% CI: 1.732 to 1.912 sec).

SUMMARY

In summary, our group began with an interest in the effect that both type of paper and size of paperclip has on the descent time of a paper helicopter when dropped. We began our study by coming up with hypotheses, creating the helicopters for each trial, and performing the experiment. The factors to be tested were paper type (copier paper, notebook paper) and paperclip size (1.75", 1.375"). All controls were accounted for when creating and performing each trial, and the trial order was randomly assigned. After analyzing the data and looking at the QQ-plot, we removed an outlier (run 1, see Table 1 in the Appendix), causing the data to be unbalanced.

Notebook paper with 1.375" paperclips had the slowest mean drop time (2.002 sec) and the largest standard deviation (0.253 sec), whereas copier paper with 1.75" paperclips had the fastest mean drop time (1.728 sec) and the smallest standard deviation (0.061 sec).

We calculated the two–way ANOVA table using Type III sum of squares and found that none of the effects have statistical significance, with the lowest p-value being 0.056 (corresponding to the main effect of Paper Type factor) and our highest p-value being 0.253 (corresponding to the interaction effect between the two factors). With that known, we can conclude that there is no difference in or interaction between the descent time of helicopters with any combination of our factor levels. Thus the mean descent time of paper helicopters with either copier or notebook paper and 1.75" or 1.375" paperclips dropped from 9 feet is 1.822 sec (95% CI: 1.732 to 1.912 sec). Because none of the p-values in our ANOVA table (see Table 3 above) were statistically significant, there was no need to calculate pairwise comparisons.

APPENDIX

Table 1. Check Sheet

Run	Experiment	Factor Level 1: Paper Type	Factor Level 2: Paper Clip Size	Time (seconds)
1*	3	Copier	Small	2.62
2	12	Notebook	Small	2.10
3	11	Notebook	Small	1.98
4	18	Notebook	Big	1.86
5	14	Notebook	Small	2.24
6	10	Copier	Big	1.79
7	1	Copier	Small	1.64
8	4	Copier	Small	1.65
9	8	Copier	Big	1.72
10	6	Copier	Big	1.71
11	7	Copier	Big	1.64
12	5	Copier	Small	1.98
13	20	Notebook	Big	1.84
14	15	Notebook	Small	2.11
15	2	Copier	Small	1.73
16	9	Copier	Big	1.78
17	17	Notebook	Big	1.65
18	16	Notebook	Big	1.97
19	19	Notebook	Big	1.66
20	13	Notebook	Small	1.58

***** Outlier; excluded from analysis.