Week 2 (LAB1): Paper Airplanes Design

PSTAT122: Design and Analysis of Experiments

Winter 2026

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Due Date

Due Date: Wednesday, January 14, 2026, 11:59 PM

1 Methods

This lab aims to determine if a paperclip on the nose of a paper airplane make it fly further than without a paperclip.

In a group of five people, Lily, Jeff, Andrew, Renyu, and Delaney (myself), we each randomly throw a paper airplane with a paperclip and without a paperclip, made by Andrew. We measure the distance a given paper airplane is thrown by using two tape measures lined up and with the thrower standing at the start of the tape measures. Once the paper airplane hits the ground, we measure that distance as a projection to the tape measure from where it lands. If the paper airplane landed behind the start or parallel to the start of the tape measure, this is recorded as zero. All measurements are in inches.

We randomized the order of throws to account for any thrower having experience or being talented at throwing paper airplanes. This eliminates potential bias for throwers as the first thrower who gets the newly made paper airplane was chosen randomly. We randomized the order of throws using R:

```
trials <- c("Delaney_with", "Delaney_without", "Lily_with", "Lily_without",
            "Andrew_with", "Andrew_without", "Renyu_with", "Renyu_without",
            "Jeff_with", "Jeff_without")
```

```r

set.seed(3) # your group should decide on a number to put here
ordered_trials <- sample(trials)
print(ordered_trials)
```

```
[1] "Andrew_with"     "Renyu_with"      "Lily_without"    "Delaney_without"
[5] "Lily_with"       "Renyu_without"   "Jeff_with"       "Andrew_without"
[9] "Jeff_without"    "Delaney_with"
```

There were several technical issues to our experiment to address. First, as the paper airplane gets repeatedly thrown, it deteriorates. The nose becomes slightly damaged each time it hits the ground making the airplane different for each thrower. The only time the airplane was new was the first throw, which could potentially over estimate the first throw. This issue was accounted for by slightly fixing the nose before each new throw. Second, wind was a potential issue because we were throwing outside, but there was no wind in our chosen location. Third, measuring the distance each paper airplane landed was not exact. We eyeballed the spot the plane landed and projected its distance to the tape measures. This could lead to minor errors in the true distance of each throw.

2 Results

Here is a table of my raw data, with each person as a row, and three columns: with, without, and the difference.

```r
library(dplyr)
library(knitr)
```

```r
df <- read.csv("Lab 1.csv")

# Make the "difference" column

results_tbl <- df %>%
  mutate(difference = with - without)

kable(
  results_tbl,
  caption = "Raw data: with, without, and difference"
)
```

Table 1: Raw data: with, without, and difference

Name	with	without	X	difference
Andrew	207	294	NA	-87
Renyu	243	433	NA	-190
Jeff	235	250	NA	-15
Delaney	250	493	NA	-243
Lily	285	167	NA	118

```
kable(results_tbl, caption = "Raw data: with, without, and difference")
```

Table 2: Raw data: with, without, and difference

Name	with	without	X	difference
Andrew	207	294	NA	-87
Renyu	243	433	NA	-190
Jeff	235	250	NA	-15
Delaney	250	493	NA	-243
Lily	285	167	NA	118

Below are the summary statistics for my data.

```
summary_tbl <- results_tbl %>%
  summarise(
    n = n(),
    mean_with = mean(with, na.rm = TRUE),
    sd_with = sd(with, na.rm = TRUE),
    mean_without = mean(without, na.rm = TRUE),
    sd_without = sd(without, na.rm = TRUE),
    mean_difference = mean(difference, na.rm = TRUE),
    sd_difference = sd(difference, na.rm = TRUE)
  )

kable(
  summary_tbl,
  caption = "Summary statistics for with, without, and differences"
)
```

Table 3: Summary statistics for with, without, and differences

n	mean_with	sd_with	mean_without	sd_without	mean_difference	sd_difference
5	244	28.14249	327.4	133.6125	-83.4	143.2561

Null and Alternative Hypothesis:

$$H_0 : \mu_d = 0$$
$$H_a : \mu_d > 0$$

Null hypothesis: On average, paper airplanes with a paperclip do not fly farther than those without a paperclip.

Alternative hypothesis: On average, paper airplanes with a paperclip fly farther than those without a paperclip. The population difference in means between the distance a paper airplane with and without a paperclip flies is represented by:

$$\mu_d = \mu_{with} - \mu_{without}$$

This is the code used to preform a t-test.

```
test <- t.test(
  results_tbl$with,
  results_tbl$without,
  paired = TRUE,
  alternative = "greater"
)

test
```

```
    Paired t-test

data:  results_tbl$with and results_tbl$without
t = -1.3018, df = 4, p-value = 0.8686
alternative hypothesis: true mean difference is greater than 0
95 percent confidence interval:
 -219.979      Inf
sample estimates:
mean difference
          -83.4
```

```r
test_tbl <- data.frame(
  Test = "Paired t-test (with > without)",
  t = unname(test$statistic),
  df = unname(test$parameter),
  p_value = test$p.value,
  mean_with = mean(results_tbl$with, na.rm = TRUE),
  mean_without = mean(results_tbl$without, na.rm = TRUE),
  mean_difference = mean(results_tbl$with - results_tbl$without, na.rm = TRUE),
  conf_low = test$conf.int[1],
  conf_high = test$conf.int[2]
)

knitr::kable(
  test_tbl,
  digits = 4,
  caption = "Results of the paired t-test comparing flight distance with and without a pap
)
```

Table 4: Results of the paired t-test comparing flight distance with and without a paperclip

Test	t	df	p_value	mean_with	mean_without	mean_difference	conf_low	conf_high
Paired t-test (with > without)	-1.3018	4	0.8686	244	327.4	-83.4	-219.979	Inf

```r
print(test_tbl)
```

```
                            Test         t df   p_value mean_with mean_without
1 Paired t-test (with > without) -1.301781  4 0.8685507       244        327.4
  mean_difference conf_low conf_high
1           -83.4 -219.979       Inf
```

We fail to reject the null hypothesis that there is no mean difference in the distance a paper airplane is thrown with and without a paperclip on the nose of it at the 95% level because the p-value (0.8686) is greater than 0.05. We do not have sufficient evidence to conclude that paper airplanes with a paperclip on the nose fly farther, on average, than paper airplanes without a paperclip.

We are 95% confident that the true mean difference in flight distance (with paperclip minus without paperclip) is greater than -219.979. Because this interval includes 0, it is consistent with the hypothesis test result and supports failing to reject the null hypothesis.

3 Discussion

In running this t-test we assume that the data was collected via our random experiment. We randomized our experiment at the beginning using R. We assume that the difference in flight data across students are roughly normally distributed. We have a small sample size but we assume that this random sample is roughly normal. We assume each student's throws are independent of each other, which they are. We also assume that the experiment was carried out consistently for each trial. We ensured this by using the same set up for each thrower and trying to replicate the placement of the paperclip as best as possible.

Our random experiment contained several design issues. The sample size of 5 was quite low for our statistical test. This led to high variation and therefore a large p-value. Also, each student only threw once for each condition, which does not average out random throwing variation. For example, my first throw appeared to be a high outlier, but I only threw once so I am unable to determine if that fly distance was due to design, luck, skill, or because the airplane was still "new".

Measuring the actual distance the plane flew was not exact. We estimated where the plane landed, before it slid, and then projected its distance onto the measuring tape line. This was done by eye balling the projection. To improve the measuring part of the experiment, we can use a straight pole extending from where the plane lands to the tape measure in order to record a more accurate projection.

The use of a single airplane for each condition leads to small differences as the experiment goes on due to the deterioration of the planes. The experiment should use identically made paper airplanes, enough for each thrower to use a new one. The paperclip placement may have been altered after hitting the ground, which could change the flight distance. However we did use the same paperclip the entire time.