Statistics, The Science of Decision Making:

Stroop Effect Analysis

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1. Variables

independent variable: Condition of words–either congruent or incongruent.
dependent variable: time (t) in seconds to recite the colors of 24 words.

2. Hypotheses

$$\mathbf{H_0}: \mu_{incongruent} \leq \mu_{congruent}$$
$$\mathbf{H_a}: \mu_{incongruent} > \mu_{congruent}$$

For this experiment, the null hypothesis, H_0,is that the population's average response time, μ, for the incongruent condition will be less than or equal to that of the congruent condition. The alternate hypothesis, H_a, is that the population's average response time for the incongruent condition will be greater than that of the congruent condition.

I expect to conduct a **dependent, one-tailed t-test**. The t-test will be used because we do not know the population parameters, and it will be dependent because the same subject was subjected to both conditions of the Stroop test (repeated measures). A one-tailed t-test is preferred in this situation as it reasons that processing conflicting stimuli (incongruent condition) would take longer than agreeing stimuli (congruent condition). Assumptions for this test is the dependent variable is continuous. In this case the assumption holds as the dependent variable is time. Another assumption is that the two groups (congruent and incongruent) are approximately normally distributed. This will be tested prior to the t-test (see problems 4 and 5).

3. Descriptive Statistics

Descriptive Statistics

	Congruent	Incongruent	Difference
Mean	14.05	22.02	7.96
Std Dev	3.56	4.80	4.86
Min	8.63	15.69	1.95
Q1	11.90	18.72	3.65
Median	14.36	21.02	7.67
Q3	16.20	24.05	10.26
Max	22.33	35.26	21.92
IQR	4.31	5.33	6.61
Range	13.70	19.57	19.97
Size	24	24	24
SEM	0.73	0.98	0.99

For details on how these statistics were calculated, see Reproducibility section of appendix.

4. Visualizations

Looking at the boxplot in Fig 1(a), it is clear the incongruent condition has a greater response time with its median just below the maximum response time of the congruent condition and its minimum lies within the third quartile of the congruent condition response times. It is also evident that the two incongruent samples around 35 seconds (samples 15, 20) are significant outliers. This can also be seen in the histogram of the response times of the incongruent condition. There are three empty bins between the highest and value bin and the next nonempty bin. Additionally, the corresponding density curve shows a small bimodal distribution with the outliers.

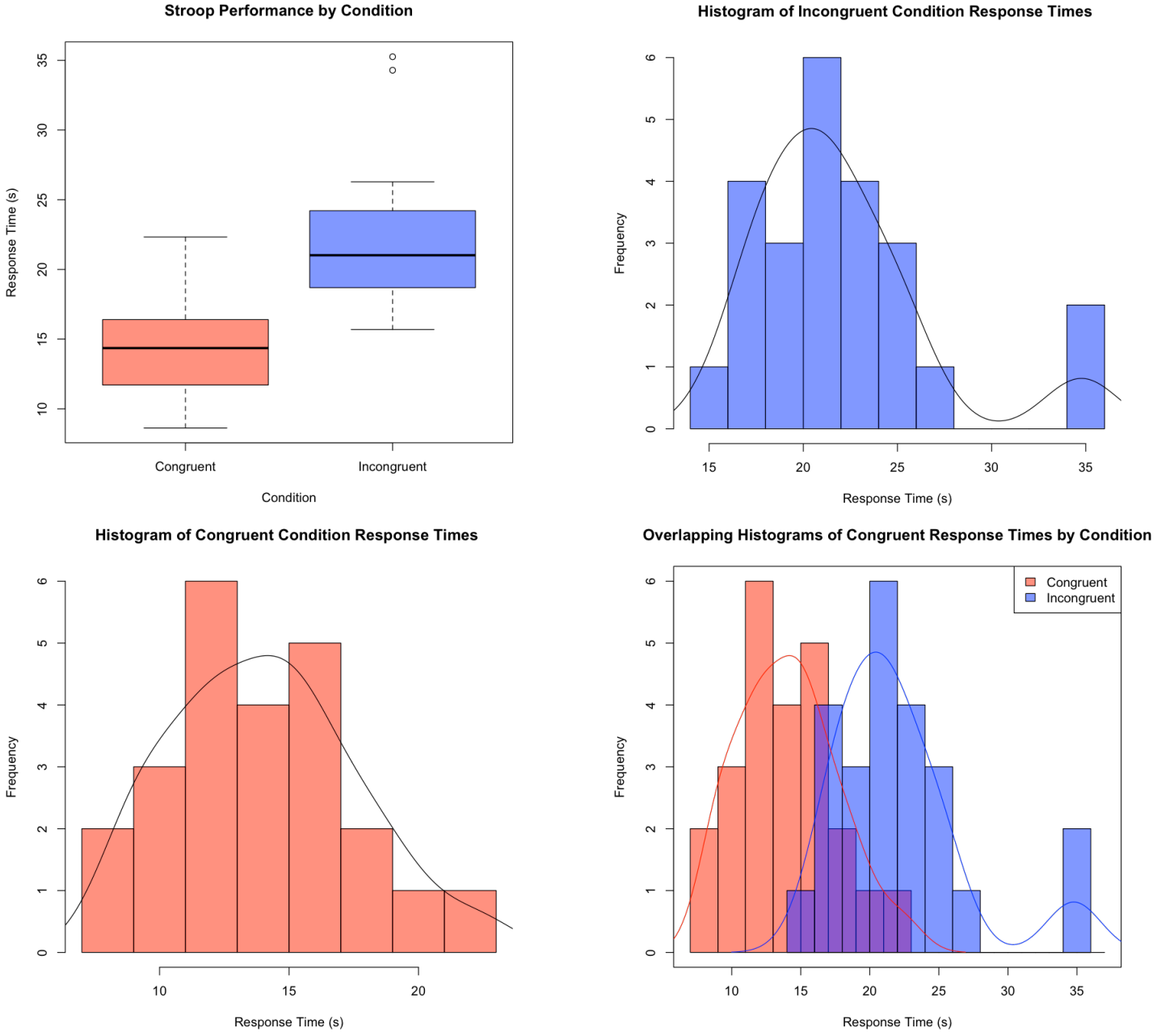

Figure 1: Distributions of Stroop Performances. a) Boxplot of Congruent and Incongruent Response Times, b) histogram of Incongruent response time (blue)s, c) histogram of congruent response times (red), d) overlapping histograms of response times.

The histograms of the response times (Fig. 2 show that both conditions (excluding the two outliers from the incongruent condition) follow an approximately normal distribution. This is emphasized by the overlayed density curves both of which are relatively normal Gaussian distributions, though that of the Congruent Condition has slightly greater variations. Overlaying the two histograms (Fig 1d) shows that while the two distributions overlap (purple region), they are two distinct distributions.

5. Statistical Test

Calculating by hand, we get a t-statistic of 8.02:

$$t = \frac{\bar{x}_{Inc} - \bar{x}_{Con}}{s_D/\sqrt{n}} = \frac{7.96}{4.86/\sqrt{24}} = \frac{7.96}{0.99} = 8.02$$

The t-statistic can also be obtained using R:

```
> t.test(stroop_data$Incongruent, stroop_data$Congruent, alt = 'greater',
         paired=T)


  Paired t-test

  data:  stroop_data$Incongruent and stroop_data$Congruent
  t = 8.0207, df = 23, p-value = 2.052e-08
  alternative hypothesis: true difference in means is greater than 0
  95 percent confidence interval:
   6.262868      Inf
  sample estimates:
  mean of the differences
                  7.964792
```

Using R, we also get a t-statistic of 8.02.

Calculating the confidence interval by hand we get a 95% confidence interval of (6.27, 9.66):

$$CI = M_D \pm t_{critical}\left(\frac{s_D}{\sqrt{n}}\right) = 7.96 \pm 1.714(0.99) = (6.27, 9.66)$$

This has the same lower-bound as that produced by the t.test function in R (6.27 compared to 6.26), but R only gives the upper limit as "Inf." whereas we manually determined it to be 9.66.

6. Conclusion and Further Experiments

Given the t-statistic of 8.02 (which is off the chart on the t-distribution critical values table) and a p-value of 2.052e-08, we can confidently reject the null hypothesis, $\mu_{incongruent} \leq \mu_{congruent}$, in favor of the alternate hypothesis, $\mu_{incongruent} > \mu_{congruent}$. Thus we can say that it takes longer, on average to respond to the incongruent set compared to the congruent set. On average, participants will spend between 6.3 and 9.7 more seconds to respond to the incongruent set than the congruent set.

The results match the expectations as one would expect conflicting stimuli would lead to the subject having to mentally process both stimuli and choose the specified one with which to respond. With the time pressure component of the experiment, it is possible the subjects make more mistakes because they can process the word at a faster rate than they can process the color. A similar experiment would involve having a words superimposed on a pictures of a common household objects (e.g., "BRUSH" over the picture of a knife) and having the subject identify the object, not the word.

.Appendix

Raw Data

Congruent	Incongruent
12.079	19.278
16.791	18.741
9.564	21.214
8.63	15.687
14.669	22.803
12.238	20.878
14.692	24.572
8.987	17.394
9.401	20.762
14.48	26.282
22.328	24.524
15.298	18.644
15.073	17.51
16.929	20.33
18.2	35.255
12.13	22.158
18.495	25.139
10.639	20.429
11.344	17.425
12.369	34.288
12.944	23.894
14.233	17.96
19.71	22.058
16.004	21.157

Reproducibility

Dependencies:

- stroopdata.csv

General

All tables and figures were produced in RStudio (Mac, Version 1.0.44) with R version 3.3.2.
Tables and figures use the data frame stroop_data that was created as follows:

```
stroop_data <- read.csv('stroopdata.csv')
stroop_data$Difference <- stroop_data$Incongruent - stroop_data$Congruent
```

Tables

Table 1[1]

```
> descriptive <- do.call(data.frame,
                  list(Mean = apply(stroop_data, 2, mean),
                       Std_Dev = apply(stroop_data, 2, sd),
                       Min = apply(stroop_data, 2, min),
                       Q1 = apply(stroop_data, 2, quantile, probs = 0.25),
                       Median = apply(stroop_data, 2, median),
                       Q1 = apply(stroop_data, 2, quantile, probs = 0.75),
                       Max = apply(stroop_data, 2, max),
                       IQR = apply(stroop_data, 2, IQR),
                       Range = apply(stroop_data, 2, max) -
                                apply(stroop_data, 2, min) ,
                       Size = apply(stroop_data, 2, length),
                       SEM = apply(stroop_data, 2, sd) /
                                sqrt(apply(stroop_data,2, length))
                      ))

> t(format(round(descriptive, 2), nsmall=2))
```

Figures

Figure 1(a)

```
>boxplot(stroop_data$Congruent, stroop_data$Incongruent,
         names = c('Congruent', 'Incongruent'),
         col = c(rgb(1, 0, 0, 0.5), rgb(0, 0, 1, 0.5)),
         main = 'Stroop Performance by Condition',
         xlab = 'Condition', ylab = 'Response Time (s)')
```

Figure 1(b–c)[2, 3]

```
> congruent_hist <- hist(stroop_data$Congruent, breaks = seq(7, 23, 2),
                         col = rgb(1,0,0,0.5), xlab = 'Response Time (s)', main =
                         'Histogram of Congruent Condition Response Times')

  congruent_multiplier <- congruent_hist$counts / congruent_hist$density
  congruent_density <- density(stroop_data$Congruent)
  congruent_density$y <- congruent_density$y * congruent_multiplier[1]

  lines(congruent_density)


> incongruent_hist <- hist(stroop_data$Incongruent, breaks = seq(14, 36, 2),
                           col = rgb(0,0,1,0.5), xlab = 'Response Time (s)', main =
                           'Histogram of Incongruent Condition Response Times')

  incongruent_multiplier <- incongruent_hist$counts / incongruent_hist$density
  incongruent_density <- density(stroop_data$Incongruent)
  incongruent_density$y <- incongruent_density$y * incongruent_multiplier[1]

  lines(incongruent_density)


> hist(stroop_data$Congruent, breaks = seq(7, 37, 2), col = rgb(1,0,0,0.5),
       xlab = 'Response Time (s)', main = 'Overlapping Histograms of Congruent Response
       Times by Condition')
  hist(stroop_data$Incongruent, breaks = seq(14, 36, 2), col = rgb(0,0,1,0.5), add = T)
  box()
  lines(incongruent_density, col = 'blue')
  lines(congruent_density, col = 'red')
  legend(x = 'topright', legend = c('Congruent', 'Incongruent'),
         fill = c(rgb(1,0,0,0.5), rgb(0,0,1,0.5)))
```

References

[1] The code to generate Table 1 was adapted from "Creating a summary statistical table from a data frame". Stack Overflow. January 8, 2014. <http://stackoverflow.com/a/20998008>.

[2] Overlapping histogram was created using the method described in: Arsalvacion, "Overlapping Histogram in R", R-Bloggers. March 1, 2013. <https://www.r-bloggers.com/overlapping-histogram-in-r/>.

[3] Code for superimposing the curves onto the histrograms was adapted from "Overlay normal curve to histogram in R". Stack Overflow. November 19, 2013. <http://stackoverflow.com/a/20078645>.