Stroop Effect – Statistical Analysis

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Date: 10-01-2016

Background Information

In a Stroop task, participants are presented with a list of words, with each word displayed in a color of ink. The participant's task is to say out loud the *color of the ink* in which the word is printed. The task has two conditions: a congruent words condition, and an incongruent words condition. In the *congruent words* condition, the words being displayed are color words whose names match the colors in which they are printed: for example RED, BLUE. In the *incongruent words* condition, the words displayed are color words whose names do not match the colors in which they are printed: for example, PURPLE, ORANGE. In each case, we measure the time it takes to name the ink colors in equally-sized lists. Each participant will go through and record a time from each condition.

Analysis

1. **What is our independent variable? What is our dependent variable?**

Independent variable is "different conditions of the word (congruent or incongruent)"

Dependent variable is the "time it takes to name, out loud the ink colors in which the words are displayed"

2. **What is an appropriate set of hypotheses for this task? What kind of statistical test do you expect to perform? Justify your choices.**

Now it's your chance to try out the Stroop task for yourself. Go to this link, which has a Java-based applet for performing the Stroop task. Record the times that you received on the task (you do not need to submit your times to the site.) Now, download this dataset which contains results from a number of participants in the task. Each row of the dataset contains the performance for one participant, with the first number their results on the congruent task and the second number their performance on the incongruent task.

Null Hypothesis - (H_o): $\mu_C - \mu_{IC} = 0$. There is no difference in the mean time it took to read

congruent words and to read incongruent words

Alternative Hypothesis - (H_A): $\mu_C - \mu_{IC} \neq 0$. There is a difference in the mean time it took to read congruent words and to read incongruent words.

μ_C: Population mean for time in seconds to read the congruent words
μ_{IC}: Population mean for time in seconds to read the incongruent words

Type of the statistical test we are performing here is two-tail(non-directional) dependent t-test. With t-test we can determine if there is a statistically significant difference between the two conditions. i.e., T-test will prove us whether the difference between the means of time it takes to read congruent vs. incongruent words is unlikely to have occurred by chance.

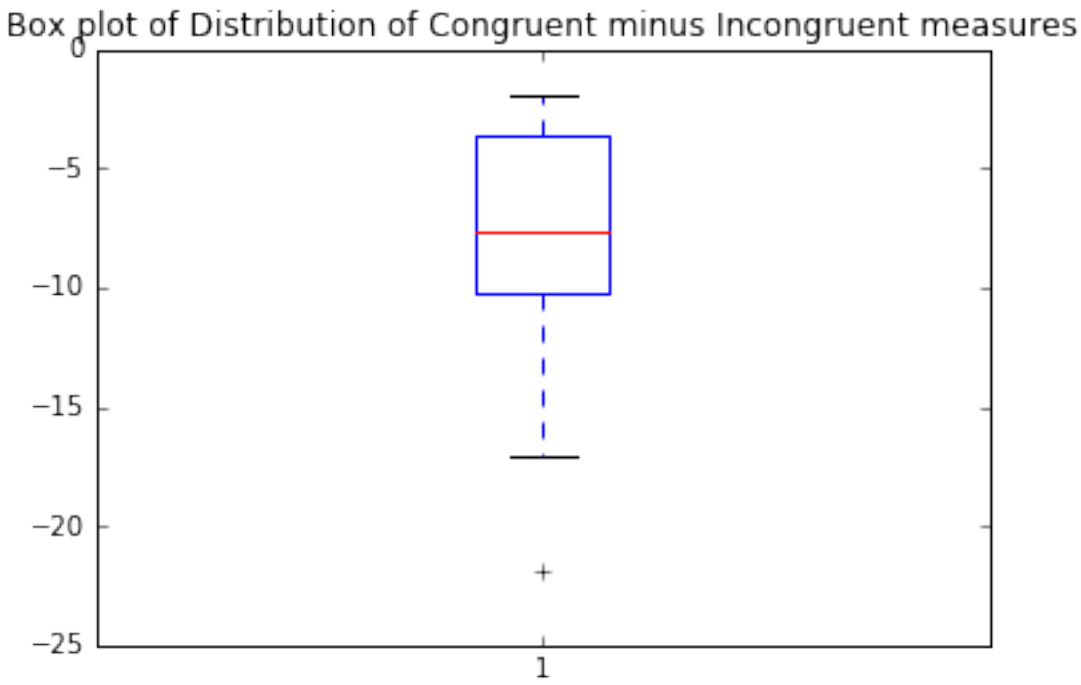
Reason I picked the two-tailed test is that I don't want to make assumptions yet on whether reading congruent words is faster that incongruent words and vice-versa. I would first like to know whether there is a significant difference in the mean time to read the list of congruent words vs incongruent words and do other directional tests later.

As an alternative, one-tailed test with alternative hypothesis $H_A: \mu_C - \mu_{IC} < 0$ would also have worked as well as we have some intuition into the effect that reading incongruent words take longer time than reading the congruent words.

Statistical tests of means assume that samples are drawn under certain conditions from populations with specific characteristics. These characteristics and conditions are expressed in the assumptions of the tests.

Detailed assumptions for conducting dependent t-test are the following.

- Assumption 1: Dependent variable should be measured on a continuous scale. Measure in Interval or ratio scale of measurement (approximately interval). In our analysis, dependent variable is measured in seconds which is continuous.
- Assumption 2: Samples or sets of data used to produce the difference scores are linked in the population through repeated measurement, natural association, or matching. Your independent variable should consist of two categorical, "related groups" or "matched pairs". Related group indicates that the same subjects are present in both groups. In our analysis, same subjects are shown both congruent words and incongruent words and their respective times are measured.
- Assumption 3: Random sampling from a defined population. Out study we had subjects randomly picked from the population.
- Assumption 4: Scores are normally distributed in the population; difference scores are normally distributed. From the below box plot, we can see that the difference scores are normally distributed.



3. **Report some descriptive statistics regarding this dataset. Include at least one measure of central tendency and at least one measure of variability.**

Distribution of congruent words:

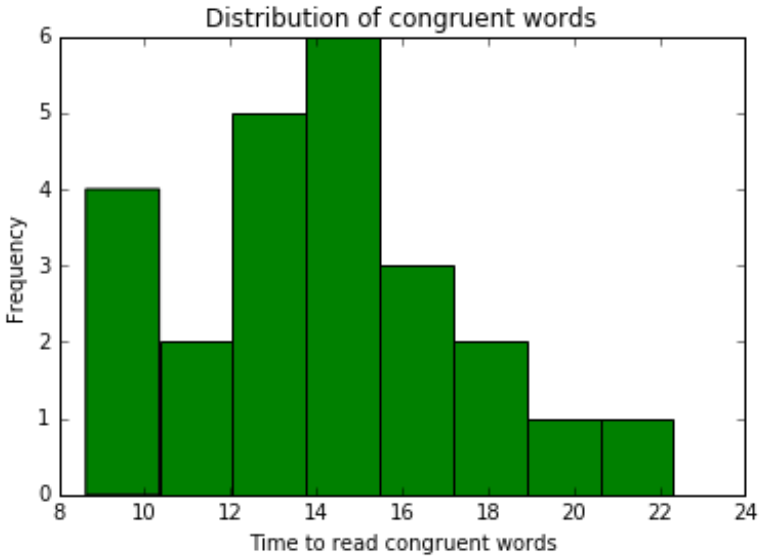
- Sample size (n_c) = 24
- Degrees of freedom (df_c)= 23
- Mean(μ_c) = 14.051125
- Standard Deviation ($\sigma_{c)}$ = 3.559357958
- Standard Error Mean ($SEM_{c)}$ = 0.726550901

Distribution of incongruent words:

- Sample size (n_{ic}) = 24
- Degrees of freedom (df_{ic})= 23
- Mean(μ_{ic}) = 22.01591667
- Standard Deviation ($\sigma_{ic)}$ = 4.797057122
- Standard Error Mean ($SEM_{ic)}$ = 0.979195185

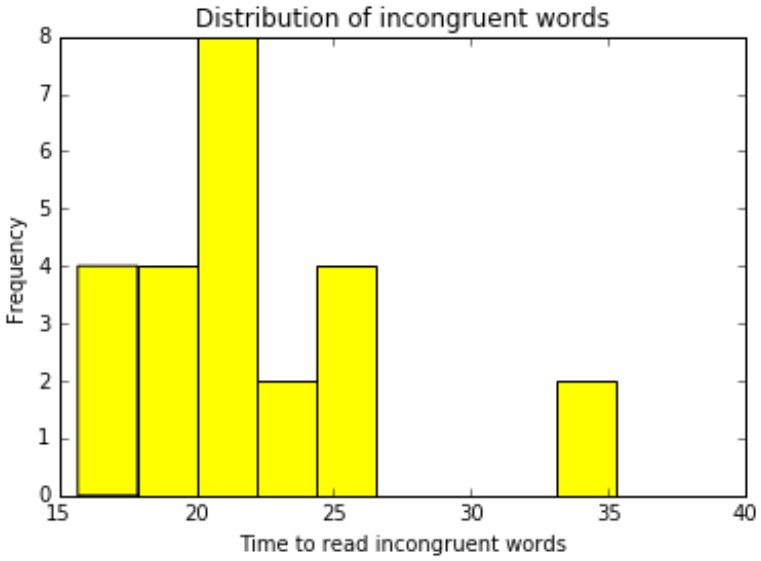
4. **Provide one or two visualizations that show the distribution of the sample data. Write one or two sentences noting what you observe about the plot or plots.**

Distribution of congruent words:



Here I see that the distribution is positively skewed as the tail is mostly on the right side. A large portion of users were able to list the colors for congruent words in between 12 seconds and 16 seconds.

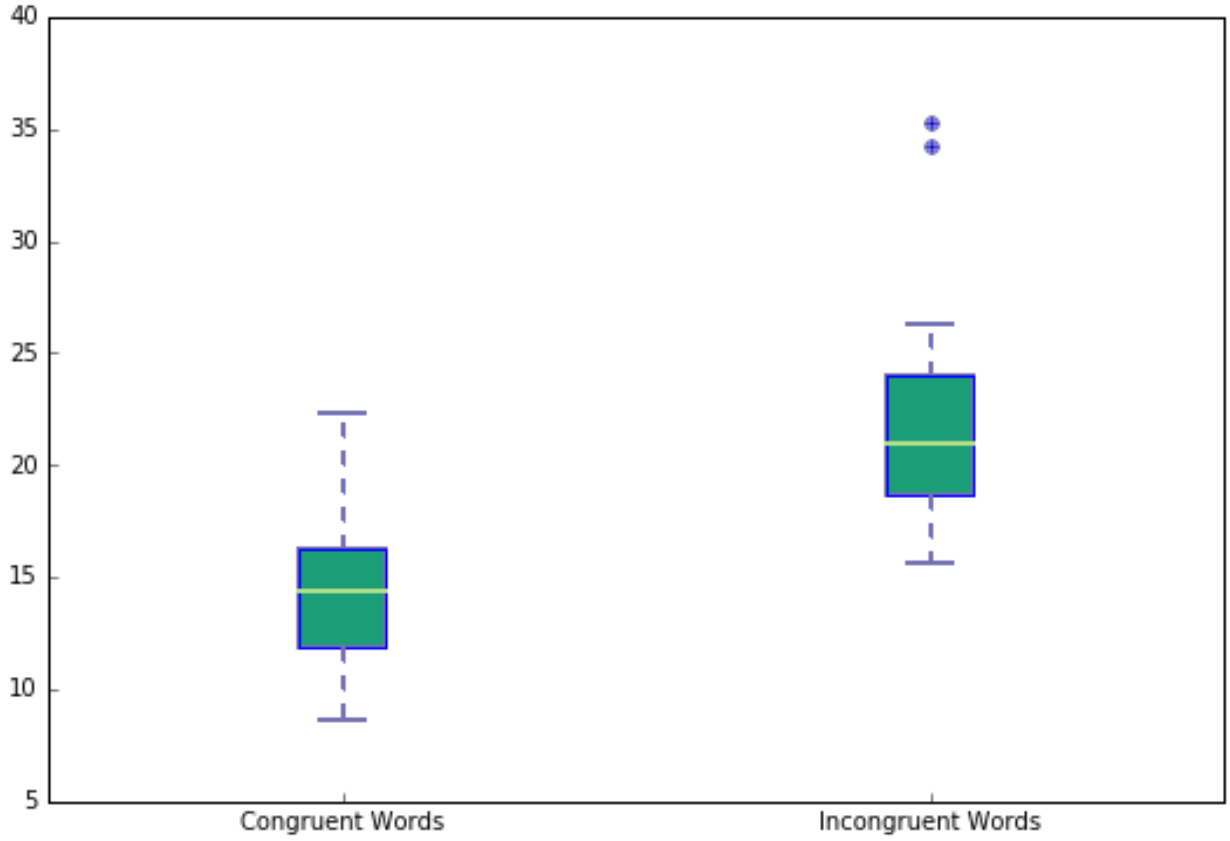
Distribution of incongruent words:



Here I see the distribution is positively skewed as the tail is mostly on the right side. A large portion of users were able to list the colors for incongruent words in between 20 seconds and

22.5 seconds.

Box plot is also a good way to visualize the distributions.

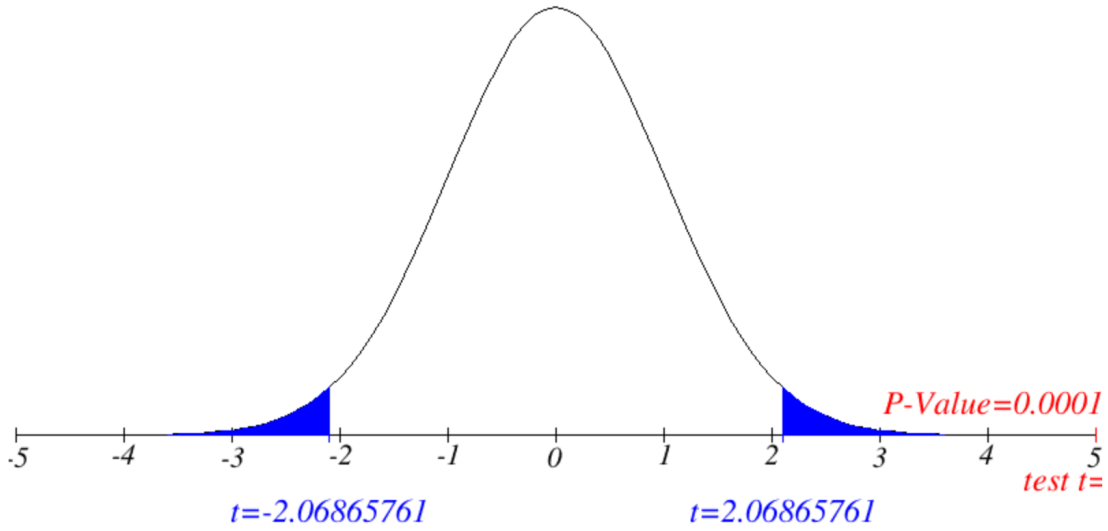


5. **Now, perform the statistical test and report your results. What is your confidence level and your critical statistic value? Do you reject the null hypothesis or fail to reject it? Come to a conclusion in terms of the experiment task. Did the results match up with your expectations?**

Here are the results from two-tailed paired t-test.

- Degrees of freedom ($df_{c\text{-}ic}$) = 23
- Confidence Interval = 95%
- Tail probability on both sides = 0.25
- $t_{critical}$ = +/- 2.0686576
- Mean($\mu_{c\text{-}ic}$) = μ_{c}-μ_{ic} = 14.051125 - 22.01591667 = -7.964791667
- Standard Deviation ($\sigma_{c\text{-}ic}$) = 4.865
- Standard Error Mean ($SEM_{c\text{-}ic}$) = $\sigma_{c\text{-}ic}/\sqrt{24}$ = 0.993

t-statistic for sample distribution of congruent minus incongruent words and vice-versa is:
t-statistic = +/- (($|\mu_{c-}\mu_{ic}|$)/ SEM_{c-ic}) = +/- 8.02



t-statistic 8.02 falls in the critical region with a p-value of less than 0.0001. By conventional criteria this means that the difference in the means of reading congruent and incongruent words is extremely statistically significant.

Since the $\mu_{c-}\mu_{ic}$ is statistically significant we can reject the null hypothesis. The difference in the means of reading times of congruent and incongruent words is not by chance.

From the above statistical test, we can conclude that the people on average did not take similar times to read congruent and incongruent words.

Yes, the results match up my expectations as in my own Stroop effect test I took 13 seconds to read the congruent words and 28.32 seconds to read the incongruent words.

6. **Optional: What do you think is responsible for the effects observed? Can you think of an alternative or similar task that would result in a similar effect? Some research about the problem will be helpful for thinking about these two questions!**

There are two main theories to explain what could be responsible for the effects we observed.

1. Speed of processing theory
2. Selective attention theory

Speed of processing theory: This theory suggests that it takes less time to process the words compared to colors. Our brain can read faster than recognizing colors. This slow processing of

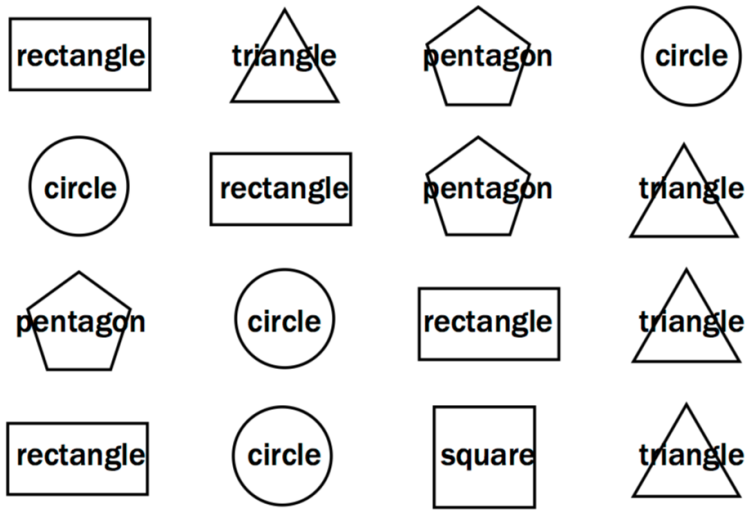
colors causes lag in the response times often leading to even wrong responses due to conflicts between the processed word and processed color at the response layer of the brain.

Selective attention theory: This theory simply suggests that our brain needs to pay more attention to recognize the colors than to simply read words. So it naturally takes longer to recognize colors during Stroop test.

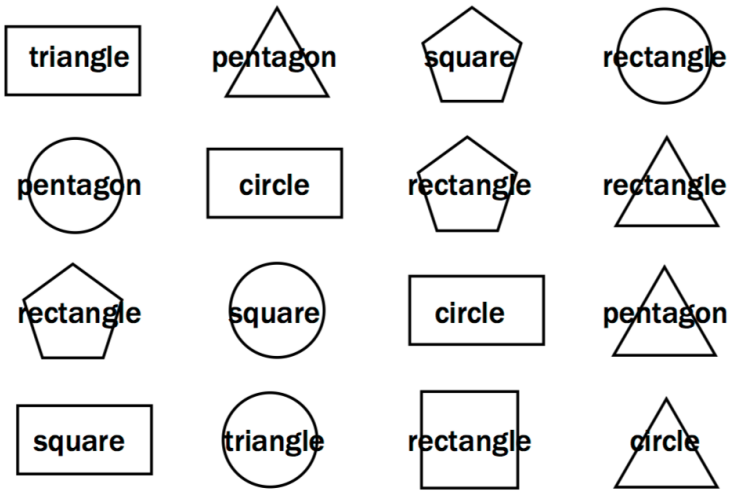
Between these two theories, 'Speed of processing theory' seems more appealing to me. During my own tests, I could feel the conflict in my brain at times giving both answers with a little bit delay for the color response compared to the word response.

An alternative task would be to perform Stroop effect with shapes & words instead of colors & words as shown below.

Word set 1:



Word set 2:



Software Used:

http://www.imathas.com/stattools/norm.html
http://www.shodor.org/interactivate/activities/Histogram/
http://graphpad.com/quickcalcs/pValue2/
https://s3.amazonaws.com/udacity-hosted-downloads/t-table.jpg
http://www.danielsoper.com/statcalc/calculator.aspx?id=10

Sources:

http://www.sciencebuddies.org/science-fair-projects/project_ideas/HumBeh_p028_StroopShapeWords.pdf
https://docs.google.com/document/d/1-OkpZLjG_kX9J6LIQ5IltsqMzVWjh36QpnP2RYpVdPU/pub?embedded=True
https://en.wikipedia.org/wiki/Stroop_effect
http://www.wisegeek.org/what-is-the-stroop-effect.htm
http://link.springer.com/article/10.3758%2FMC.38.7.893
https://www.khanacademy.org/math/algebra/introduction-to-algebra/alg1-dependent-independent/v/dependent-and-independent-variables-exercise-example-1
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http://support.minitab.com/en-us/minitab/17/topic-library/basic-statistics-and-graphs/hypothesis-tests/basics/what-is-a-hypothesis-test/
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http://support.minitab.com/en-us/minitab/17/topic-library/basic-statistics-and-graphs/hypothesis-tests/tests-of-means/why-use-paired-t/
http://blog.bharatbhole.com/creating-boxplots-with-matplotlib/
http://www.physics.csbsju.edu/stats/box2.html
https://www.getdatajoy.com/examples/python-plots/box-plots
https://en.wikipedia.org/wiki/Student%27s_t-test#Unpaired_and_paired_two-sample_t-tests
http://www.psychology.emory.edu/clinical/bliwise/Tutorials/TOM/meanstests/assump.htm

https://statistics.laerd.com/spss-tutorials/dependent-t-test-using-spss-statistics.php