BYU Statistics 230 Fall 2018
Analysis of Variance

Contents

BYU STATISTICS 230 ANALYSIS OF VARIANCE SYLLABUS

Course Description

Scientific method, statistical thinking, sources of variation, completely randomized design, ANOVA, power and sample size considerations, multiple testing, randomized complete blocks, factorial designs, interactions. Introduction to statistical software. (3 credits)
Prereq: Stat 121 or Stat 201.
Rec: Math 112.

Expected Learning Outcomes

A student completing Stat 230: Analysis of Variance will be able to:

1. create datasets in R and SAS from space-, comma-, tab-delimited text files;
2. compute summary statistics from R and SAS datasets;
3. create graphics in R and SAS for exploratory data analysis and communicating results;
4. understand the concept of variability in data and the attempt to identify sources of that variability;
5. practice writing statistical models;
6. understand the basics of experimental design, including the definition of the experimental unit, response, variable, factor(s), and level(s) of a basic experiment, and the role of randomization and replication to permit causal inference;
7. analyze data from 'Treatment-Control' or 'A/B' experiments using professional statistical software;
8. analyze data from completely randomized designs using professional statistical software;
9. analyze data from randomized complete block designs using professional statistical software;
10. analyze data from two-factor factorial designs using professional statistical software;
11. demonstrate the impact of increasing the number of replicates on confidence intervals and hypothesis tests; and
12. work in a team to write a technical report and make a technical presentation of a designed experiment.

Textbook and references

Useful references include:

Cobb, G. (2008). *Introduction to Design and Analysis of Experiments*, Wiley.
BYU Bookstore: $176.00/$132.00. Amazon: $129.74.

Oehlert, G.W. (2010). *A First Course in Design and Analysis of Experiments.* Freely available at `http://users.stat.umn.edu/~gary/book/fcdae.pdf`

Montgomery, D. C. (2012). *Design and Analysis of Experiments*, Hoboken, NJ: Wiley.

Hicks, C. R., and Turner, K. V. (1999). *Fundamental Concepts in the Design of Experiments*, New York: Oxford University Press.

Instructor Information

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Class Schedule

A schedule with topics and reading assignments is available under the schedule tab on learning suite. Adjustments to the schedule may be made during the semester.

Homework will be due before midnight on the due date. Homework will be submitted through learning suite. Homework should be submitted as a pdf file. Supplemental code should be submitted as an .r or .sas file, as requested.

We will have two midterm exams (Thursday, 18 October, in the testing center, and Thursday, 15 November, in class).

The final will be held in the testing center (Saturday, 15 December, through Thursday, 20 December).

Assessment

Grades: Grades will be calculated using the following weights:

Homework	15%
Midterm 1	15%
Midterm 2	20%
Final	30%
Project	15%
Class Participation/Preparation	5%

Late work/Illness/Absence/Vacation: No late work will be accepted; however, to accomodate life events that may interfere with your coursework, your lowest homework score will be dropped **if** you submit the course evalution.

Show Your Work: In order to give feedback on where you are going wrong, you need to show your work. For problems done by hand, this means showing intermediate steps in your calculations.

Scanning: While many parts of your homework lend themselves to a typewritten response, I do not want you to try to type your hand calculations. Instead, please scan your handwritten work and include it with your full solution for submission through learning suite. A list of copiers where you can scan and email your homework for free is available at `https://lib.byu.edu/services/copy-machines/`. There are also scanning apps for smartphones. Digital photos of hand calculations may also be used; however, if you choose this route, you must incorporate these photos with the correct orientation and at a size sufficient for meaningful grading.

Final Exam: Failure to take the final will result in failure of the course. The final exam is kept on file for one semester.

Miscellany: Class attendance and helpfulness may be used in determining final grades in borderline situations.

Computing

We will be using both R and SAS in this class.

Local versus Server.

- Instructions at `http://statistics.byu.edu/content/r-and-rstudio` on downloading R and using rstudio2.byu.edu.
- Instructions at `http://statistics.byu.edu/content/sas-demand` on using SAS on demand.

Annotate code. Make notes about code during class.

Run class example code on your own before starting the homework. Run class code a line at a time to see what it does. Don't start the homework until you understand the code in the class examples.

Use help. In R: help(command). In SAS there is a pull-down help menu.

Course Materials

Statistics 230 was originally developed by Professor William Christensen. Some course materials have been adapted from materials used by Professor William Christensen and Professor Scott Grimshaw.

Honor Code

In keeping with the principles of the BYU Honor Code, students are expected to be honest in all of their academic work. Academic honesty means, most fundamentally, that any work you present as your own must in fact be your own work and not that of another. Violations of this principle may result in a failing grade in the course and additional disciplinary action by the university. Students are also expected to adhere to the Dress and Grooming Standards. Adherence demonstrates respect for yourself and others and ensures an effective learning and working environment. It is the university's expectation, and every instructor's expectation in class, that each student will abide by all Honor Code standards. Please call the Honor Code Office at 422-2847 if you have questions about those standards.

Academic Integrity

You are encouraged to discuss the course assignments with your classmates but the work you submit (including computer code) must be your sole work. You may not consult solutions distributed in any other course—at BYU or at other institutions. You may study together and discuss ideas but this should not result in submission of identical or largely identical work. Blatant or verbatim copying, for example, is against the Honor Code and will result in both the copier and the person whose paper is being copied getting a 0 for that assignment. More than one offense will result in dismissal from the class and a report to the Honor Code Office.

Students with Disabilities

Brigham Young University is committed to providing a working and learning atmosphere that reasonably accommodates qualified persons with disabilities. If you have any disability which may impair your ability to complete this course successfully, please contact the University Accessibility Center (UAC), 2170 WSC or 422-2767. Reasonable academic accommodations are reviewed for all students who have qualified, documented disabilities. The UAC can also assess students for learning, attention, and emotional concerns. Services are coordinated with the student and instructor by the UAC. If you need assistance or if you feel you have been unlawfully discriminated against on the basis of disability, you may seek resolution through established grievance policy and procedures by contacting the Equal Employment Office at 422-5895, D-285 ASB.

Inappropriate Use of Course Materials

All course materials (e.g., outlines, handouts, syllabi, exams, quizzes, PowerPoint presentations, lectures, audio and video recordings, etc.) are proprietary. Students are prohibited from posting or selling any such course materials without the express written permission of the professor teaching this course. To do so is a violation of the Brigham Young University Honor Code.

Mental Health Services

Barriers to learning are created by stress, anxiety, family and relationship concerns, and personal crises. If stressful life events or mental health concerns are inhibiting your ability to participate in daily activities or leading to diminished academic performance, please contact the BYU Counseling and Psychological Services (CAPS) (1500 WSC, 801 422 3035, caps.byu.edu). CAPS provides individual, couples, and group counseling to students. These services are confidential and are provided by the university at no added cost to you. Professional psychologists and counselors who specialize in helping college students are available 24-hours a day to assist students in crisis; if you have an emergency during non-business hours (5 p.m.–8 a.m.), please contact BYU Police Dispatch (801 422 2222) who will put you in touch with a counselor. For general information please visit `https://caps.byu.edu`; for more immediate concerns please visit `http://help.byu.edu`.

Basic Needs

If you have difficulty affording groceries, accessing sufficient food to eat every day, or lack a safe and stable place to live, it may affect your ability to perform well in this course. If you feel that this is the case, please contact the Dean of Students (`deanofstudents.byu.edu`, phone: 801-422-2731, e- mail: deanofstudents@byu.edu, location: 3500 WSC) for support. In addition, please discuss any needs with Dr. Blades, if you feel comfortable doing so. I will do my best to connect you to available resources, as well. For students who are both LDS and not LDS, please consider speaking with your local LDS bishop regarding church welfare assistance if you are having difficulty with basic needs security.

Preventing & Responding to Sexual Misconduct

In accordance with Title IX of the Education Amendments of 1972, Brigham Young University prohibits unlawful sex discrimination against any participant in its education programs or activities. The university also prohibits sexual harassment—including sexual violence—committed by or against students, university employees, and visitors to campus. As outlined in university policy, sexual harassment, dating violence, domestic violence, sexual assault, and stalking are considered forms of "Sexual Misconduct" prohibited by the university. University policy requires all university employees in a teaching, managerial, or supervisory role to report all incidents of Sexual Misconduct that come to their attention in any way, including but not limited to face-to-face conversations, a written class assignment or paper, class discussion, email, text, or social media post. Incidents of Sexual Misconduct should be reported to the Title IX Coordinator at `t9coordinator@byu.edu` or (801) 422-8692. Reports may also be submitted through EthicsPoint at `https://titleix.byu.edu/report` or 1-888-238-1062 (24-hours a day).
BYU offers confidential resources for those affected by Sexual Misconduct, including the university's Victim Advocate, as well as a number of non-confidential resources and services that may be helpful. Additional information about Title IX, the university's Sexual Misconduct

Policy, reporting requirements, and resources can be found at `http://titleix.byu.edu` or by contacting the university's Title IX Coordinator.

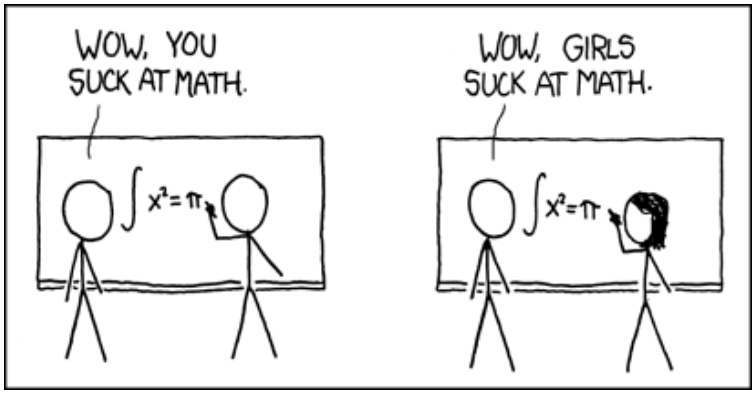


Figure 1: That is, **don't** be like this... (How it Works, `https://xkcd.com/385/`)

HOMEWORK

Objectives

A student completing Stat 230: Analysis of Variance will be able to

- understand the basics of experimental design, including the definition of the experimental unit, response, variable, factor(s), and level(s) of a basic experiment, and the role of randomization and replication to permit causal inference.

Towards that end, in this assignment you will

- identify the response variable and factor and factor levels for a basic one factor experiment.

Problems

1. 

The Art of Oreo Dunking

- Consider the Oreo data your group collected in class to answer this question.

a) Identify the response variable and treatment factor (with factor levels explicitly stated).

b) Is this study an experiment or an observational study? Justify your answer.

c) Submit a copy of the Check Sheet for your group's data.

Objectives

A student completing Stat 230: Analysis of Variance will be able to

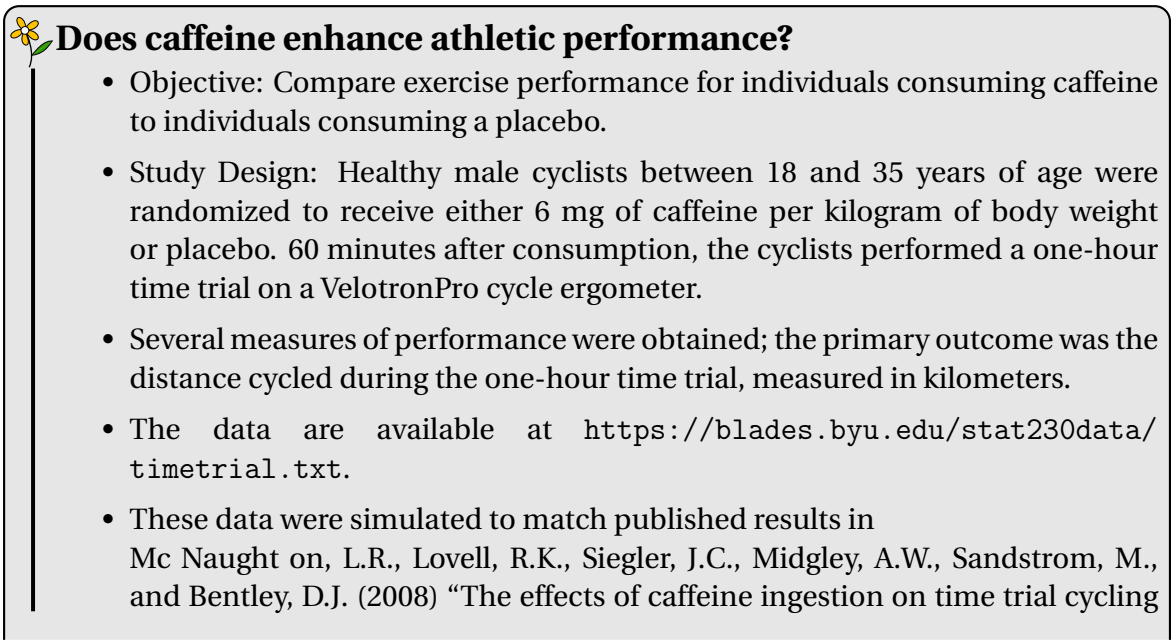
- create datasets in R and SAS from space-, comma-, tab-delimited text files,
- compute summary statistics from R and SAS datasets;
- create graphics in R and SAS for exploratory data analysis and communicating results; and
- understand the basics of experimental design, including the definition of the experimental unit, response, variable, factor(s), and level(s) of a basic experiment, and the role of randomization and replication to permit causal inference.

Towards that end, in this assignment you will

- read existing datasets into R and SAS;
- enter your own data into R;
- calculate basic univariate statistics for continuous data;
- produce boxplots and dotplots for for continuous data; and
- identify the response variable, factor and factor levels, and experimental unit for a basic one factor experiment;

Problems

0. This problem is included to provide information about how to submit your work. Please review the included solution. No work needs to be submitted for this problem.



performance." *J Sports Med Phys Fitness*, 48(3): 320–325. The actual design used in the paper is slightly more efficient (and thereby more complicated) than the completely randomized design described here.

a) Identify the response variable, factor (with factor levels explicitly stated), and the experimental unit.

b) Is this study an experiment or an observational study? Justify your answer.

c) Look at the data. What is the delimiter? Is there a header? If so, what information is in the header?

d) Create a file named caffeine.R. Write well-documented, reproducible code to create a data frame in R using the text= option. Submit the line of code used in your caffeine.R file to read the data into R. (For your homework submission, you may replace the middle of the text= section with an ellipsis—but you should include the first few and last few rows of the data. These lines should still be included in your caffeine.R file or it won't run...)

e) Use the `head`, `tail`, and `str` commands to look at the data. Does your data object in R look like what you saw when you looked at the data file? Comment on the agreement between the original data file and your data object in R (How many variables appear in each? Do the variable names agree? How many observations do you have in each? What are the variable types?)

f) Create and submit side-by-side boxplots of the distance cycled for data from caffeine and placebo groups. Do the distributions look the same? Are they symmetric or skewed? Comment on the shape. Are there any unusual observations?

g) Upload your caffeine.R file to learning suite.

Sample solution:

a) **response variable:** distance cycled during the one-hour time trial, measured in kilometers

factor: supplement (caffeine, placebo)

experimental unit: the individual male cyclist

b) This study is an experiment because the treatments (supplement ingested—either caffeine or placebo) were randomly assigned to the cyclists by the study investigator. Cyclists did not choose whether to ingest caffeine or placebo.

c) The data have commas separating the information in each column (also, it is a .txt file). There is a header containing the variable names.

d)

e) The data object in R looks like the original data file: There are three variables in each (id, treatment, and distance). The variable names in R are meaningful and descriptive. There are 16 observations in the original data file and in the R

data object. The id variable is a number. The treatment variable is a factor with 2 levels. The distKM variable is numeric.

f) Create and submit side-by-side boxplots of the distance cycled for data from caffeine and placebo groups. Do the distributions look the same? Are they symmetric or skewed? Comment on the shape. Are there any unusual observations?

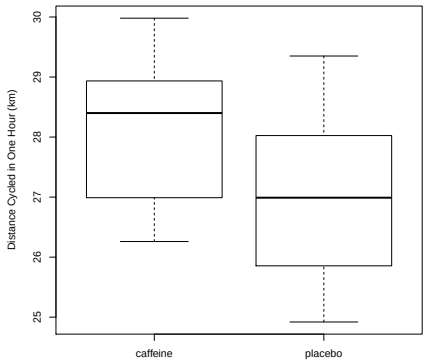


Figure 2.0.f. Boxplots of Distance Cycled in One Hour. Boxplots for the distance cycled in one hour (measured in kilometers) by cyclists who consumed caffeine (left) or placebo (right).

Cyclists who consumed caffeine cycled farther in one hour than cyclists who consumed the placebo. The spread of distances cycled is similar in both groups. The distribution is fairly symmetric in the placebo group and slightly left-skewed in the caffeine group. There are no outliers in either group.

(Notice there is a title and caption beneath the figure.)

g) I submitted my code to learning suite. (Below are the contents of the file caffeine.R which was submitted to learning suite—this file does **NOT** need to be printed out and submitted with the hard-copy of your homework.)

```
> #caffeine experiment
+ #distance cycled during one-hour time trial
+ #measured in km
+ #data available at
+ #https://blades.byu.edu/stat230data/timetrial.csv

+ #read in the data
+ timetrial <- read.table(text="
id,treatment,distKM
1,caffeine,26.26
2,caffeine,27.63
3,caffeine,26.35
4,caffeine,28.86
5,caffeine,29.01
6,caffeine,28.86
7,caffeine,29.98
8,caffeine,27.94
9,placebo,28.64
10,placebo,24.92
11,placebo,27.27
12,placebo,26.23
13,placebo,29.35
14,placebo,26.71
15,placebo,27.41
16,placebo,25.48
", header=TRUE, sep=",")
> #check whether data appear to have been read correctly
+ head(timetrial)
+ tail(timetrial)
+ str(timetrial)
> #create side-by-side boxplots
+ boxplot(distKM~treatment, data=timetrial,
+         ylab="Distance Cycled in One Hour (km)")
```

1.

Glyburide versus Insulin

- Lain, K.Y., Garabedian, M.J., Daftary, A., Jeyabalan, A. (2009) "Neonatal adiposity following maternal treatment of gestational diabetes with glyburide compared to insulin." *Am J Obstet Gynecol*, 200:501.e1-501.e6.
- `doi:10.1016/j.ajog.2009.02.038`
- Objective: "We hypothesized that body composition would be similar among neonates of women with gestational diabetes (GDM) treated with glyburide or insulin."
- Study Design: "Women with GDM requiring medical therapy were randomized to insulin or glyburide."
- Glyburide is an oral hypoglycemic agent.
- There were 82 infants—41 born to mothers receiving glyburide and 41 born to mothers receiving insulin.
- Many anthropometric measures of growth were obtained; the primary outcome was the percent fat mass, measured using total body electrical conductivity.
- The data are available at `https://blades.byu.edu/stat230data/neonataladiposity.txt`. Data are simulated to match published results. The actual design used in the paper is slightly more complicated than the completely randomized design described here.

a) Identify the response variable, factor (with factor levels explicitly stated), and the experimental unit.

b) Is this study an experiment or an observational study? Justify your answer.

c) Look at the data. What is the delimiter? Is there a header? If so, what information is in the header?

d) Create a file named glyburide.sas. Write well-documented, reproducible code to read the data into SAS using datalines. Submit the data step used in your glyburide.sas file to read the data into SAS. (For your homework submission, you may replace the middle of the datalines section with an ellipsis—but you should include the first few and last few rows of the datalines. These lines should still be included in your glyburide.sas file or it won't run...)

e) Use proc print and proc contents to look at the data in SAS. Confirm that the data look similar to what you saw in the original data file. Comment on the agreement between the original data file and your data object in SAS (How many variables appear in each? Do the variable names agree? How many observations do you have in each? What are the variable types?)

f) Separately for women treated with insulin and women treated with glyburide, calculate the mean and standard deviation for the neonate's percent fat mass. Make

a table to display these summary statistics. Does it look like the groups have equal means and/or equal standard deviations? Write a sentence comparing the center and spread of the percent fat mass for the two treatments.

g) Create and submit side-by-side boxplots of the neonate's percent fat mass for data from insulin and glyburide treatment groups. Do the distributions look the same? Are they symmetric or skewed? Comment on the shape. Are there any unusual observations?

h) Upload your glyburide.sas file to learning suite.

2.

Finnish Fish

- 159 fish of 7 species are caught and measured.
- All the fish are caught in lake Laengelmavesi near Tampere in Finland.
- Brofeldt, Pekka (1917). "Bidrag till kaennedom on fiskbestondet i vaera sjoear" via Juha Puranen/JSE.
- Columns in the data set:
  - observation number
  - species—Finnish (English)
    - **1:** Lahna (Bream)
    - **2:** Siika (Whitewish)
    - **3:** Saerki (Roach)
    - **4:** Parkki (Silver Bream)
    - **5:** Norssi (Smelt)
    - **6:** Hauki (Pike)
    - **7:** Ahven (Perch)
  - Weight (in grams)
  - Length1 (nose to beginning of tail, in cm)
  - Length2 (nose to notch of tail, in cm)
  - Length3 (nose to end of tail, in cm)
  - Maximal height as percent of Length3
  - Maximal width as percent of Length3
  - Sex (1=male, 0=female)
- We are primarily interested in the relationship between species and weight.
- The data are available at `http://ww2.amstat.org/publications/jse/datasets/fishcatch.dat.txt`.

a) Identify the response variable, factor (with factor levels explicitly stated), and the experimental unit.

b) Is this study an experiment or an observational study? Justify your answer.

c) Look at the data. What is the delimiter? Is there a header? If so, what information is in the header?

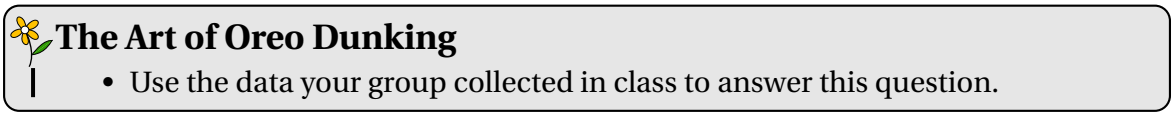
d) Create a file named finnishfish.R. Write well-documented, reproducible code to create a data frame in R using the text= option. Submit the line of code used in your finnishfish.R file to read the data into R. Did the delimiter you identified in part 2c work for reading in the data? If not, what delimiter did you specify instead? (For your homework submission, you may replace the middle of the text= section with an ellipsis—but you should include the first few and last few rows of the data. These lines should still be included in your finnishfish.R file or it won't run...)

e) Use the following command to add variable names:
`colnames(fish) <- c("obs", "species", "wtgrams", "length1cm", "length2cm", "length3cm", "heightperc","widthperc","male")`
What is the benefit of calling the sex variable "male"?

f) Use the `head`, `tail`, and `str` commands to look at the data. Does your data object in R look like what you saw when you looked at the data file? Comment on the agreement between the original data file and your data object in R (How many variables appear in each? Do the variable names agree? How many observations do you have in each? Are the variable types what you expected?)

g) Upload your finnishfish.R file to learning suite.

3.



a) Identify the response variable and factor (with factor levels explicitly stated).

b) Is this study an experiment or an observational study? Justify your answer.

c) Create a file named myoreos.R. Write well-documented, reproducible code to create a data frame in R using the text= option. Submit the line of code used in your myoreos.R file to read the data into R. (For your homework submission, you may replace the middle of the text= section with an ellipsis—but you should include the first few and last few rows of the data. These lines should still be included in your myoreos.R file or it won't run...)

d) Use the `head`, `tail`, and `str` commands to look at the data. Does your data object in R look like what you saw when you looked at the data file? Comment on the agreement between the original data file and your data object in R (How many variables appear in each? Do the variable names agree? How many observations do you have in each? Are the variable types what you expected?)

e) Adapt the following code to subset your data so that it only includes data for Regular Oreos and Trader Joe's Joe-Joe's:

```
oreos <- read.table(...) #this is your full read.table code
oreosSUB <- subset(oreos, treatment %in% c("Reg", "TJ"))
            #Reg and TJ must be the labels you used in creating your data
oreosSUB$treatment <- droplevels(oreosSUB$treatment)
```

Submit the output from using the `str` command on your new data object to confirm that your treatment variable is now a factor with just 2 levels.

f) Create a new variable which holds amount of milk absorbed in 10 seconds by including the following command in your myoreos.R:

```
oreosSUB$milkabsgram <- oreosSUB$after - oreosSUB$before
```

Then, separately for Regular Oreos and Trader Joe's Joe-Joe's, calculate the mean and standard deviation for the amount of milk absorbed in 10 seconds. Make a table to display these summary statistics. Does it look like the groups have equal means and/or equal standard deviations? Write a sentence comparing the center and spread of the amount of milk absorbed in 10 seconds for the two treatments.

g) Create and submit side-by-side boxplots of the amount of milk absorbed in 10 seconds for data from the Regular Oreos and Trader Joe's Joe-Joe's. Describe the graph. Do the distributions look the same? Are they symmetric or skewed? Comment on the shape. Are there any unusual observations?

h) Create and submit dotplots of the amount of milk absorbed in 10 seconds for data from the Regular Oreos and Trader Joe's Joe-Joe's. Describe the graph. Do the distributions look the same? Are they symmetric or skewed? Comment on the shape. Are there any unusual observations?

i) Submit a copy of your R script myoreos.R to learningsuite.

Objectives

A student completing Stat 230: Analysis of Variance will be able to

- analyze data from 'Treatment-Control' or 'A/B' experiments using professional statistical software.

Towards that end, in this assignment you will

- calculate and interpret confidence intervals and hypothesis tests for
  - means from one-sample,
  - differences in means from two independent samples.

Problems

1. **Glyburide versus Insulin.** Using the same data that you worked with in homework 2 (`https://blades.byu.edu/stat230data/neonataladiposity.txt`), add to your glyburide.sas file in order to answer the following tasks.

   a) Add a comment to your code to indicate the beginning of your work on homework 3.

   ```
   *Homework 3;
   ```

   b) Separately for each group, calculate a confidence interval for the mean neonatal percent fat mass. Write one sentence to interpret each confidence interval.

   c) Write out (in words and symbols) appropriate null and alternative hypotheses for a two-sample t-test to compare the mean percent fat mass between the two groups. Define your notation. (This corresponds to the State and Plan steps from the four-step procedure used in your introductory course.)

   d) Identify n_1, n_2, $y_{1,4}$, $y_{2,10}$, $\hat{\epsilon}_{1,4}$, and $\hat{\epsilon}_{2,10}$.

   e) Conduct a two-sample t-test by hand (assuming equal variances). (This corresponds to the Solve step from the four-step procedure used in your introductory course. Use code help 1 to find the p-value in R.)

   f) Use proc ttest to conduct a two-sample t-test using SAS. (Refer to code help 2.) Submit only the table with the test statistic and p-value. Identify which row in the table corresponds to the test you performed in part 1e. Do your test statistic and p-value from part 1e agree with the values given by SAS? If not, why not.

   g) Based on the p-value, what can you conclude about the mean percent fat mass of neonates born to mothers taking glyburide and insulin? (This corresponds to the Conclude step of the four-step procedure used in your introductory course.)

   h) Calculate a confidence interval for the difference in mean percent fat mass of neonates born to mothers taking glyburide and insulin. Write one sentence to interpret the confidence interval.

i) Write a one paragraph summary describing the problem, analysis, and results to a collaborator. Your answer should incorporate the sentences you wrote in 1b, 1g, and 1h.

j) Upload your glyburide.sas file to learning suite.

2. **The Art of Oreo Dunking.** Using R and the Oreo data collected by your group, perform the following tasks:

   a) Add a comment to your code to indicate the beginning of your work on homework 3.

   ```
   *Homework 3;
   ```

   b) Separately for each group, calculate a confidence interval for the mean amount of milk absorbed. Write one sentence to interpret each confidence interval.

   c) Write down the null and alternative hypotheses for a two-sample t-test to compare the mean amount of milk absorbed for the two cookie types.

   d) Identify n_1, n_2, $y_{1,4}$, $y_{2,3}$, $\hat{\epsilon}_{1,4}$, and $\hat{\epsilon}_{2,3}$.

   e) Conduct a two-sample t-test by hand (assuming equal variances). (Use code help 1 to find the p-value.)

   f) Conduct a two-sample t-test using R. (Refer to code help 3.) Submit the output from your t-test. Do the test statistic and p-value from R agree with the values you calculated in 2e? If not, why not?

   g) Based on the p-value, what can you conclude about the mean amount of milk absorbed for Regular Oreos and Trader Joe's Joe-Joe's?

   h) Calculate a confidence interval for the difference in mean amount of milk absorbed in 10 seconds for the two cookie types. Write one sentence to interpret the confidence interval.

   i) Write a one paragraph summary of your experiment (continue to ignore the DoubleStuf Oreos trials), analysis, and results to a collaborator. Your answer should incorporate the sentences you wrote in parts 2b, 2g, and 2h.

   j) Submit a copy of your R script myoreos.R to learningsuite.

Objectives

A student completing Stat 230: Analysis of Variance will be able to

- create graphics in R and SAS for exploratory data analysis and communicating results;
- analyze data from 'Treatment-Control' or 'A/B' experiments using professional statistical software; and
- demonstrate the impact of increasing the number of replicates on confidence intervals and hypothesis tests.

Towards that end, in this assignment you will

- evaluate assumptions for two-sample t-tests;
- explore normal QQ plots for both normal and non-normal data;
- estimate sample size for testing a difference in means from two independent samples; and
- calculate power for testing a difference in means from two independent samples.

Problems

1. **Assumptions.** List the assumptions underlying the two-sample t-test and indicate how you can check whether each assumption is satisfied.
2. **Glyburide versus Insulin.** Consider the same data with which you worked in homeworks 2 and 3 (`https://blades.byu.edu/stat230data/neonataladiposity.txt`).

    a) A plot of the residuals versus the order in which the data were collected is displayed below. What assumption is checked by examining this plot? Comment on whether you see any patterns in this plot that suggest this assumption is violated.

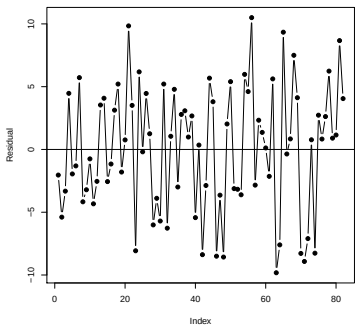


Figure 0.2: Index Plot of Residuals for Glyburide/Insulin Trial.

b) The mean of the residuals is $1.8352105 \times 10^{-17}$. Which assumption is verified by this calculation?

c) A normal QQ plot of the residuals is displayed below. What assumption is checked by examining this plot? Comment on whether you see anything in this plot that suggests this assumption is violated.

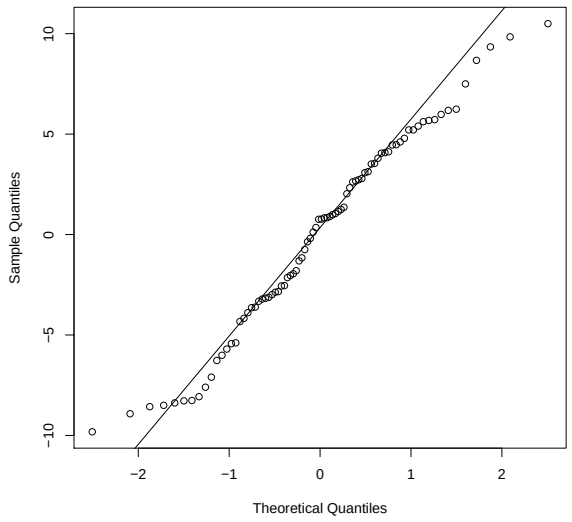


Figure 0.3: Normal QQ Plot of Residuals for Glyburide/Insulin Trial.

d) Calculate the ratio of the standard deviations from the two groups. Is the equal variance assumption satisfied? If it is not, redo your t-test from Homework 3 using the unequal variances option.

e) In a paragraph, describe your evaluation of the model assumptions.

3. **The Art of Oreo Dunking.** Using the Oreo data collected by your group:

a) Add a comment to your code to indicate the beginning of your work on homework 4.

b) Calculate the residuals and report their mean. Which assumption is verified by this calculation? Calculate and report the standard deviation of the residuals. (Refer to code help 4.)

c) Create and submit a plot of the residuals versus the order in which the data were collected. What assumption is checked by examining this plot? Comment on whether you see any patterns in this plot that suggest this assumption is violated (Use code help 5.)

d) Create and submit a normal QQ plot of the residuals. What assumption is checked by examining this plot? Comment on whether you see anything in this plot that suggests this assumption is violated. (Use code help 6.)

e) Calculate and report the ratio of the standard deviations from the two groups. What assumption is checked by calculating this ratio? Comment on whether this assumption is satisfied. If it is not, redo your t-test from Homework 3 using the unequal variances option.

f) In a paragraph, describe your evaluation of the model assumptions.

g) Submit a copy of your R script myoreos.R to learning suite.

4. **More QQ plot practice.**

a) Create an R script called qqpractice.R.

b) Using the data set found at `https://blades.byu.edu/stat230data/isitnormal.txt`:

i. Submit a histogram and normal QQ plot of these data. (Use code help 6 and 7.)

ii. What distributional shape do you observe in the histogram? What characteristic of the shape in the normal QQ plot identifies the distributional shape?

c) Using the data set found at `https://blades.byu.edu/stat230data/isitnormal2.txt`:

i. Submit a normal QQ plot and a histogram of these data. (Use code help 6 and 7.)

ii. What distributional shape do you observe in the histogram? What characteristic of the shape of the normal QQ plot trend identifies the distributional shape?

d) In small samples, a common misjudgment of the QQ plot is falsely identifying outliers. To train your eye, generate random normal data with the same number of observations as you had in your Oreo experiment ($n = 8$). Make a normal QQ plot of the simulated data. Repeat this 10 times. What features do you observe in these normal QQ plots for simulated data? Describe whether or not the QQ plot from your residuals in the Oreo experiment looks similar to the QQ plots from simulated normal data? Submit the plot that you judge looks the most like your QQ plot from 3d. Submit another plot which you would have judged as the most problematic had you not known the simulated data satisfies the assumptions.
Use the following code to simulate independent standard normal data and create a normal QQ plot in R:

```
set.seed(?) #pick a number to substitute for the ?
y <- rnorm(8) #there are 8 observations in your Oreo experiments
qqnorm(y)
qqline(y)
```

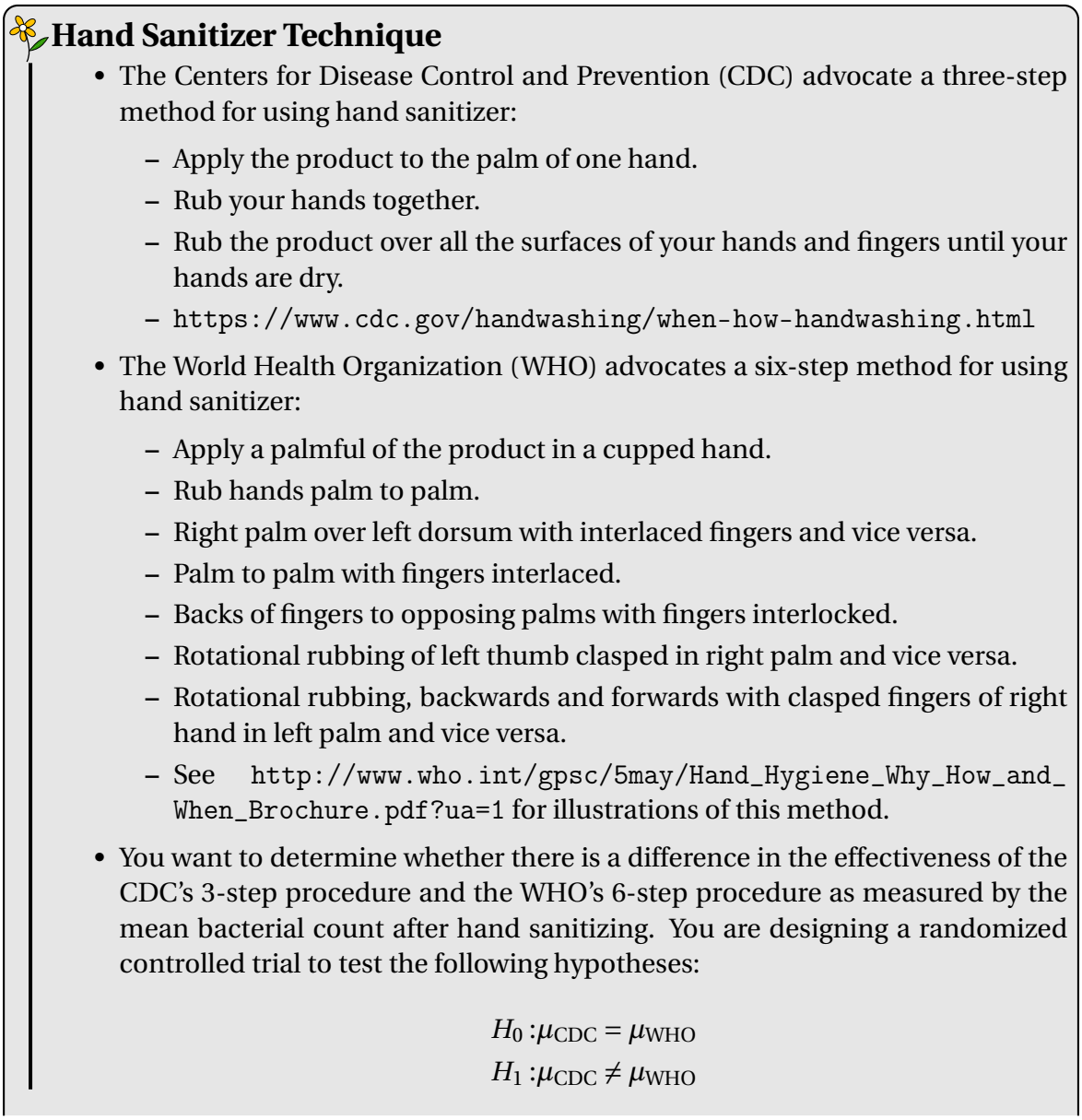
e) In large samples, a common misjudgment of the QQ plot is falsely judging nonlinear curves. To train your eye, generate random normal data with the same number of observations as you had in the glyburide/insulin problem ($n = 82$). Make a normal QQ plot of the simulated data. Repeat this 10 times. What features do you observe in these normal plots for simulated data? Describe whether or not the QQ plot from your residuals in the glyburide/insulin problem looks similar to the QQ plots from simulated normal data? Submit the plot that you judge looks the most like your

QQ plot from 2c. Submit another plot which you would have judged as the most problematic had you not known the simulated data satisfies the assumptions.
Use the following code to simulate standard normal data and create a normal QQ plot in R:

```
set.seed(?) #pick a number to substitute for the ?
y <- rnorm(82) #there are 82 observations in the glyburide dataset
qqnorm(y)
qqline(y)
```

f) Submit a copy of your R script qqpractice.R to learning suite.

5.



Hand Sanitizer Technique

- The Centers for Disease Control and Prevention (CDC) advocate a three-step method for using hand sanitizer:
  - Apply the product to the palm of one hand.
  - Rub your hands together.
  - Rub the product over all the surfaces of your hands and fingers until your hands are dry.
  - `https://www.cdc.gov/handwashing/when-how-handwashing.html`
- The World Health Organization (WHO) advocates a six-step method for using hand sanitizer:
  - Apply a palmful of the product in a cupped hand.
  - Rub hands palm to palm.
  - Right palm over left dorsum with interlaced fingers and vice versa.
  - Palm to palm with fingers interlaced.
  - Backs of fingers to opposing palms with fingers interlocked.
  - Rotational rubbing of left thumb clasped in right palm and vice versa.
  - Rotational rubbing, backwards and forwards with clasped fingers of right hand in left palm and vice versa.
  - See `http://www.who.int/gpsc/5may/Hand_Hygiene_Why_How_and_When_Brochure.pdf?ua=1` for illustrations of this method.
- You want to determine whether there is a difference in the effectiveness of the CDC's 3-step procedure and the WHO's 6-step procedure as measured by the mean bacterial count after hand sanitizing. You are designing a randomized controlled trial to test the following hypotheses:

$$H_0 : \mu_{\text{CDC}} = \mu_{\text{WHO}}$$
$$H_1 : \mu_{\text{CDC}} \neq \mu_{\text{WHO}}$$

where μ_{CDC} is the mean bacterial count after hand sanitizing using the CDC's 3-step method and μ_{WHO} is the mean bacterial count after hand sanitizing using the WHO's 6-step method.

a) Describe a type I error in the context of your handwashing experiment.

b) Describe a type II error in the context of your handwashing experiment.

c) Would it be more important to minimize α or β in this case? Explain.

d) A previous study of the CDC's 3-step method yielded the following bacterial counts:

	Bacterial Count
1	700.67
2	420.82
3	278.78
4	647.36
5	361.25
6	164.19
7	154.06
8	356.10
9	274.30
10	319.89

What sample size do we need in order to detect a 20% reduction in the mean bacterial count when using the WHO's 6-step method with 80% power and an $\alpha = .05$? To estimate the variability for your study, use the sample sd from the old study as an estimate of the common sd σ. (Use code help 8.) Submit the command you used to calculate sample size and the output from this command.

e) How does the sample size change if we want to perform this hypothesis test with 90% power? Submit the command you used to calculate sample size and the output from this command.

6. **The Art of Oreo Dunking.** Using the Oreo data collected by your group:

a) Calculate the power in your experiment to detect a difference in the mean amount of milk absorbed in 10 seconds for Regular Oreos and Trader Joe's Joe-Joe's as large as the difference you observed. Use your estimate of the pooled sd as an estimate of the common sd σ and an $\alpha = .05$. (Use code help 9.)

b) Calculate the sample size needed to achieve 80% power to detect a difference in the mean amount of milk absorbed in 30 second for Regular Oreos and Trader Joe's Joe-Joe's as large as the difference you observed. Use your estimate of the pooled sd as an estimate of the common sd σ and an $\alpha = .05$. (Use code help 8.)

c) Submit a copy of your R script myoreos.R to learningsuite (this file should include your code from this problem and from problem 3).

Objectives

A student completing Stat 230: Analysis of Variance will be able to

- analyze data from completely randomized designs using professional statistical software.

Towards that end, in this assignment you will

- perform a one-way ANOVA for a BF[1] design with two levels; and
- compare results of a two-sample t-test and one-way ANOVA.

Problems

1. **Toothbrush Wars**

   - Objective: Compare efficacy of an advanced rotation/oscillation power toothbrush (Oral-B Triumph with Smart Guide) and a sonic toothbrush (Sonicare DiamondClean) in reducing gingivitis and plaque.
   - Design: "This was a single-center, open-label, examiner-blind, two-treatment, parallel group, randomized study in which subjects brushed with their assigned toothbrush and a marketed dentifrice for 2 minutes twice daily at home for 12 weeks."
   - "130 subjects were randomized to treatment and completed the study (65 per group)."
   - Gingivitis was evaluated at baseline and week 12 using the Modified Gingival Index (MGI). The MGI is an index in which higher scores indicate more inflammation. These baseline and week 12 measurements were used to calculate the change in MGI after 12 weeks (calculated as baseline MGI minus week 12 MGI).
   - Klukowska, M., Grender, J.M., Goyal, C.R., Mandl, C., Biesbrock, A.R. (2012). "12-week Clinical Evaluation of a Rotation/Oscillation Power Toothbrush versus a New Sonic Power Toothbrush in Reducing Gingivitis and Plaque," *American Journal of Dentistry*, 25(5): 287–292.
   - The data are available at `https://blades.byu.edu/stat230data/toothbrushes.txt`. Data were simulated to match published results.

   a) Identify the response variable, factor (with factor levels explicitly stated), and the experimental unit.

   b) Is this study an experiment or an observational study? Justify your answer.

   c) Look at the data. What is the delimiter? Is there a header? If so, what information is in the header?

d) Create a file named toothbrush.sas. Write well-documented, reproducible code to read the data into SAS using datalines. Submit the data step used in your toothbrush.sas file to read the data into SAS. (For your homework submission, you may replace the middle of the datalines section with an ellipsis—but you should include the first few and last few rows of the datalines. These lines should still be included in your toothbrush.sas file or it won't run...)

e) Separately for the Oral-B and Sonicare toothbrush groups, calculate the mean and standard deviation for the change in MGI. Make a table to display these summary statistics. Does it look like the groups have equal means and/or equal standard deviations? Write a sentence comparing the center and spread of the change in MGI for the two treatment groups.

f) Separately for the Oral-B and Sonicare toothbrush groups, calculate 95% confidence intervals for the mean change in MGI. Write one sentence to interpret each confidence interval.

g) Create and submit side-by-side boxplots of the change in MGI for data from Oral-B and Sonicare toothbrush groups. Describe what you see. (Do the distributions look the same? Are they symmetric or skewed? Are there any unusual observations?)

h) Write down the two-sample t-test model for the i, jth observation, defining all notation.

i) Write down appropriate null and alternative hypotheses for a two-sample t-test to compare the mean MGI between the two groups.

j) Conduct a two-sample t-test using SAS. Submit the SAS table with the test statistic and p-value. (Refer to code help 2.)

k) Based on the p-value from the two-sample t-test, what can you conclude about the mean MGI for individuals brushing with the Oral-B and Sonicare toothbrushes?

l) Calculate a 95% confidence interval for the difference in mean MGI for individuals brushing with the Oral-B and Sonicare toothbrushes. Write one sentence to interpret this confidence interval.

m) Write down the ANOVA model for the i, jth observation, defining all notation.

n) Write down the null and alternative hypotheses for a one-way ANOVA to compare the change in mean MGI between the two groups.

o) Conduct a one-way ANOVA using SAS. Submit the ANOVA table. (Refer to code help 12.)

p) Based on the p-value from the one-way ANOVA, what can you conclude about the mean MGI for individuals brushing with the Oral-B and Sonicare toothbrushes?

q) How does the p-value from the one-way ANOVA compare to the p-value you found for the two-sample t-test?

r) Calculate and report the square root of the F-statistic in the ANOVA table. Explain why this value looks familiar.

s) Calculate the residuals. (Use code help 13.) Plot the residuals versus the order in which the data were collected. Submit this plot. Do you see any patterns in this plot that suggest the observations are not independent? (Use code help 14.)

t) Create and submit a normal QQ plot of the residuals. Comment on whether the residuals appear to be normally distributed.(Use code help 14.)

u) Calculate and report the ratio of the standard deviations from the two groups. Is the equal variance assumption satisfied? If it is not, redo your t-test using the unequal variances option.

v) Write a one paragraph summary describing the problem, analysis, and results to a collaborator.

w) Upload your tootbrush.sas file to learning suite.

Objectives

A student completing Stat 230: Analysis of Variance will be able to

- analyze data from completely randomized designs using professional statistical software; and
- demonstrate the impact of increasing the number of replicates on confidence intervals and hypothesis tests.

Towards that end, in this assignment you will

- perform a one-way ANOVA for a BF[1] design with three levels;
- choose and perform an appropriate multiple comparison adjustment; and
- calculate power and sample size for a one-way ANOVA;

Problems

1. **The Art of Oreo Dunking.** For this problem you will use the Oreo data collected by your group—but you will use all **three** cookie types.

   a) Add a comment to your code to indicate the beginning of your work on homework 6.

   b) Separately for each cookie type, calculate the mean and standard deviation for the amount of milk absorbed. Make a table to display these summary statistics. Does it look like the groups have equal means and/or equal standard deviations? Write a sentence comparing the center and spread of the amount of milk absorbed for the three treatment groups.

   c) Separately for each cookie type, calculate 95% confidence intervals for the mean amount of milk absorbed. Write one sentence to interpret each confidence interval.

   d) Create and submit side-by-side boxplots of the amount of milk absorbed for data from the three cookie types. Describe what you see. (Do the distributions look the same? Are they symmetric or skewed? Are there any unusual observations?)

   e) Create and submit dotplots of the amount of milk absorbed for data from the three cookie types. Describe the graph. (Do the distributions look the same? Are they symmetric or skewed? Are there any unusual observations?)

   f) Write down the ANOVA model for the i, jth observation, defining all notation.

   g) Write down appropriate null and alternative hypotheses for a one-way ANOVA to compare the mean amount of milk absorbed for the three cookie types.

   h) Conduct a one-way ANOVA using R. Submit the ANOVA table.

   i) Based on the p-value from the one-way ANOVA, what can you conclude about the mean amount of milk absorbed for the three cookie types?

j) If we want to ensure that the family-wise error rate is no greater than 0.05, which multiple-comparison approach is most appropriate? Use your chosen approach to calculate and interpret this set of pairwise comparisons to assess which means are significantly different from each other?

k) Calculate the residuals.

l) Create and submit a plot of the residuals versus the order in which the data were collected. Do you see any patterns in this plot that suggest the observations are not independent?

m) Create and submit a normal QQ plot of the residuals. Comment on whether the residuals appear to be normally distributed.

n) Calculate and report the ratio of the largest to smallest standard deviation from the three groups. Is the equal variance assumption satisfied?

o) Write a one paragraph summary describing the problem, analysis, and results to a collaborator.

p) Upload your myoreos.R file to learning suite.

2. Suppose you want to compare 4 types of Oreos (golden, regular, double-stuff, and thins). List all six pairwise comparisons you could consider. Assuming the null hypotheses are true and that each test is independent, what is the probability that at least one of the six tests will inappropriately reject H_0. Use $\alpha = .05$ and show your work.

3. We are interested in comparing 4 types of Oreos (golden, regular, double-stuff, and thins). You are interested in assessing the power of the F test (in ANOVA) for detecting differences in mean time to cookie breakage for the four cookies when the significance level is $\alpha = 0.05$.

   a) Suppose that cookie breakage times have a standard deviation of 5, and suppose we would like to evaluate the possibility that the group means are $\mu_G = 22, \mu_R = 23, \mu_{DS} = 29$, and $\mu_T = 30$. In R, make a plot that shows the power of the F test when $n = 2, 3, \ldots, 20$. Submit this plot with your homework.

```
##### Calculate Power for Varying Sample Sizes
n.options = seq(2,20,by=1)
res.power = NA

for(i in 1:length(n.options)) {
  res = power.anova.test(groups=?,
                         between.var=var(c(?, ?, ?, ?)),
                         within.var=?,
                         sig.level=0.05,
                         n=n.options[i])
  res.power[i] = res$power
}

plot(n.options,res.power,type="l",
```

```
        xlab="Sample Size",
        ylab="Power",
        main="Power Curve for Cookie Type Study")
```

b) What is the smallest value for the group size (n) that gives 85% power?

c) What happens to your power curve if your hypothesized means were $\mu_A = 30, \mu_B = 29, \mu_C = 23$, and $\mu_D = 22$. Submit this plot with your homework.

d) What happens to your power curve if your hypothesized means were $\mu_A = 21, \mu_B = 26, \mu_C = 26$, and $\mu_D = 31$. Submit this plot with your homework.

e) Compare the curves you created in parts (a), (c), and (d). Explain why you saw these differences or similarities.

Objectives

A student completing Stat 230: Analysis of Variance will be able to

- analyze data from two-factor factorial designs using professional statistical software.

Towards that end, in this assignment you will

- design a factorial experiment with two factors;
- define the experimental unit, response variable, factor(s), and level(s) for a BF[2] design;
- perform the randomization for this design; and
- create interaction graphs to describe the structure of an observed interaction.

Problems

1. 

Perfect Cookies

- Objective: A home chemist / baker is striving to mass produce the optimal chocolate chip cookie. Two factors are thought to impact the cookie shape. The first is temperature of the oven. The second is whether butter or margarine is used as the fat ingredient in the recipe. A randomized designed experiment will investigate these factors.
- Experimental Unit and Experimental Procedure:
  For assigned factor levels a **batch** of cookie dough is mixed. From a batch of dough, nine cookies are formed using a #60 ice cream scoop, placed on a cookie sheet in a 3×3 grid, and baked at the specified temperature for 10 minutes. The center cookie on the 3×3 grid will be measured.
- Response Variable: Cookie Diameter (in)
  nb: We don't need to measure both diameter and thickness since all cookies are formed with a #60 ice cream scoop. That is, the small diameter cookies will have high thickness and the large diameter cookies will be thin.
- Temperature Factor: There are four levels of temperature at which the cookies are baked: $370, 375, 380, 385^\circ F$.
- Fat Ingredient Factor: There are two levels: butter and margarine.
- Replicates:
  There are materials, refrigerators, and time to have **3 replicates** of each experimental combination.
- This problem was developed by Dr. Scott Grimshaw based on years of variations of this project in Stat 201 project proposals.

a) Identify the response variable, factors (with factor levels explicitly stated), and the treatments.

b) Create a randomized experiment to investigate the effect of Temperature and Fat Ingredient on Cookie Diameter. Provide the check sheet specifying the run order and the experimental combinations.

- You can use the following R code to generate the run order:
```
set.seed(?)
sample(1:numruns, replace=FALSE)
```

c) A colleague looks at the table in (1b) and suggests, "It would be faster to do all the experiments at each temperature together because it takes time to raise and lower the oven temperature." How do you respond?

d) A colleague looks at the table in (1b) and suggests, "Why don't we use four ovens, one set at each temperature?" How do you respond?

e) A colleague looks at the instructions for the experimental procedure and suggests "Why don't we just make two large batches of cookie dough: one batch with butter and one batch with margarine. That way we save time from making so many batches and we don't waste leftover cookie dough." How do you respond?

f) Write the model for this experiment, defining all notation.

g) What is the test of H_0 : no interaction between Temperature and Fat Ingredient on Cookie Diameter vs. H_a : interaction between Temperature and Fat Ingredient on Cookie Diameter in terms of the model?

h) What is the test of H_0 : no effect of Temperature on Cookie Diameter vs. H_a : Temperature has an effect on Cookie Diameter in terms of the model?

i) What is the test of H_0 : no effect of Fat Ingredient on Cookie Diameter vs. H_a : Fat Ingredient has an effect on Cookie Diameter in terms of the model?

Note: You may feel that the 8 cookies on each baking sheet that aren't measured are wasted. This is a great insight on your part — unfortunately at this point in the course we still assume that each experimental unit results in a single measurement of the response variable. More sophisticated statistical methods are available for richer experiments and datasets—we will soon be able to use all 9 cookies!

2.

Receipt Personalization and Tipping Behavior

- Rind and Bordia (1996) studied whether receipt personalization was related to tipping behavior—and whether the gender of the server modified the effect of receipt personalization.
- Subjects were eighty-nine dining parties eating lunch at an upscale restaurant in Philadelphia.
- A male or female server drew a happy, smiling face on the backs of checks before delivering them to customers, or simply delivered checks with nothing drawn on the back.
- "Each server was given a stack of fifty 3×5 cards. Half of these cards were blank and the other half had a happy, smiling face drawn on them. This face consisted of a circle with two dots representing eyes and a upward curved line below the dots representing the smiling mouth. The cards were thoroughly shuffled, such that the order of blank and face cards was random. At the end of a dining party's meal, when it came time for the server to present the dining party with a check, the server reached into his or her pocket and randomly selected one of the cards. This procedure ensured random assignment of dining parties to the experimental and control conditions. If the server selected a card with a happy, smiling face, then he or she drew this picture on the back of the dining party's check, and then delivered it back-side up so that the dining party would see the drawing. If the server selected a blank card, then he or she simply delivered the check back-side up without drawing anything on it. To avoid potential confounding, servers were instructed to behave in the same way, regardless of condition, when delivering the check. Each server delivered the check with a neutral facial expression, while saying 'Here's your check,' and then immediately left to avoid further contact with the dining party. After the dining party left, the server recorded on the same 3×5 card used to determine the dining party's condition the amount of tip left by the party, the amount of the bill before taxes, and the number of customers in the dining party. The dependent measure was the tip percentage."

  Table 1: Tip Percents by Server's Gender and Whether a Happy, Smiling Face was Drawn on the Check. Table entries are mean (SD).

	Server Gender	
	Male	Female
Control	21.41 (12.64)	27.78 (7.77)
Happy, Smiling Face	17.78 (5.57)	33.04 (14.02)

- Rind, B., and Bordia, P. (1996). "Effect on Restaurant Tipping of Male and Female Servers Drawing a Happy, Smiling Face on the Backs of Customers' Checks," *Journal of Applied Social Psychology*, 26(3): 218–225.

a) Draw both interaction graphs to present the information in Table 1. Explain which graph you prefer. Submit both graphs.

b) Describe the pattern you observe in the interaction plot you prefer.

Objectives

A student completing Stat 230: Analysis of Variance will be able to

- analyze data from two-factor factorial designs using professional statistical software.

Towards that end, in this assignment you will

- conduct a two-way ANOVA in R; and
- create interaction graphs to describe the structure of an observed interaction.
- Compare Type I and Type III SS for analyses of unbalanced data.

Problems

1.

Caffeine-free Beverages

- A chemist is investigating factors that influence the taste of a caffeine-free beverage. After carefully constructing the recipe, the marketing group asks about a diet version and whether it will be marketed as a soda or an energy drink. The chemist interprets this to mean investigating the factors 'Sweetener' (with levels Sugar, Corn Syrup, Aspartame, Ace-K) and 'Carbonation' (with levels Yes, No). The response variable is the sum of twenty beverage taste judges, where each judge scores on a 1–10 scale (meaning higher Taste Scores reflect a better beverage). To represent batch-to-batch variation in the beverage, two batches of each possible experimental combination are created for replication. The order that each experimental combination is presented to the judges was randomized.
- The data are available at https://blades.byu.edu/stat230data/caffeine.txt.
- This problem was developed by Dr. Scott Grimshaw.

a) Identify the response variable, factors (with factor levels explicitly stated), treatments, and the experimental unit.

b) Is this study an experiment or an observational study? Justify your answer.

c) Create a file named caffeine.R. Write well-documented, reproducible code to read the data into R using the text= option. Submit the line of code used in your caffeine.R file to read the data into R. (For your homework submission, you may replace the middle of the text= section with an ellipsis—but you should include the first few and last few rows of the data. These lines should still be included in your caffeine.R file or it won't run...)

d) Separately for each treatment, calculate the mean and standard deviation of the response. Make a table to display those summary statistics. Does it look like the groups have equal means and/or equal standard deviations? Write a sentence comparing the center and spread for the different treatments.

e) Create and submit side-by-side dotplots of the response for the different treatments. Describe the graph. Do the distributions look the same? Are there any unusual observations?

f) Write the ANOVA model for the i, j, kth observation, defining all notation.

g) Write reproducible code to create the ANOVA Table and the table of overall 95% confidence intervals for all possible pair-wise comparisons of factor and interaction levels. (Use code help 11 to obtain the ANOVA table from R when you have an interaction effect in the model.) Submit the code you used, the resulting ANOVA table, and table of pair-wise comparisons.

h) Is there a significant interaction at the 0.05 significance level and if so, which 'Sweetener' and 'Carbonation' levels are the best, worst, and same? Use the p-value of H_o : no interaction, specific pair-wise difference overall 95% confidence intervals, and create a graphic to support your answer.

i) Evaluate whether the assumptions are met for this model and comment on the validity of the assumptions.

j) Submit a copy of your R script caffeine.R to learning suite.

2. **Choir Heights.**

- The file singerheights.txt (available at `https://blades.byu.edu/stat230data/singerheights.txt`) contains information on the heights of choir members (in inches).
- Columns in the data set:
  - height (in inches),
  - sex ("f" or "m"), and
  - singing part ("low" or "high").
- Note that the low part for females is generally called alto, high part for females is soprano, low part for males is bass, and high part for males is tenor; however, we are interested in the association between singing the high/low part and height, so we are treating this as a 2×2 factorial instead of a one-way anova with 4 levels of "singing part."
- Data from W.F. Christensen.

a) Identify the response variable, factors (with factor levels explicitly stated), conditions, and the experimental (or observational) unit.

b) Is this study an experiment or an observational study? Justify your answer.

c) Create a file named singers.sas. Write well-documented, reproducible code to read the data into SAS using datalines. Submit the data step used in your singers.sas file to read the data into SAS. (For your homework submission, you may replace the middle of the datalines section with an ellipsis—but you should include the first few and last few rows of the datalines. These lines should still be included in your singers.sas file or it won't run...)

d) Separately for each condition, calculate the mean and standard deviation for height. Additionally, determine the number of observations at each condition. Make a table to display these summary statistics. Does it look like the groups have equal means and/or equal standard deviations? Write a sentence comparing the center and spread of the heights for the different conditions.

e) Create and submit side-by-side boxplots of the heights for the different conditions. Desribe the graph. Do the distributions look the same? Are they symmetric or skewed? Comment on the shape. Are there any unusual observations. (In `proc boxplot`, use `plot (responsevar)*factor1var (factor2var)=factor1var / boxstyle=schematic` to get the side-by-side boxplot organized by the levels of `factor2var`.)

f) Write the ANOVA model for the i, j, kth observation, defining all notation.

g) Fit an ANOVA model that includes terms for sex, singing part, and the interaction between sex and part. Report the complete ANOVA table using TYPE I SS. Carry out the complete analysis. Give a full interpretation for each of the terms in the model.

h) Report the complete ANOVA table using TYPE III SS. Carry out the complete analysis. Give a full interpretation for each of the terms in the model.

i) Why is the SS for sex so much smaller with Type III SS? Explain.

j) Submit a copy of your SAS script singers.sas to learning suite.

Objectives

- Design a randomized complete block experiment.
- Define the experimental unit, response variable, factor(s), and level(s) for a CB design.
- Perform the randomization for a CB design.
- Describe the purpose of blocking.
- Construct the ANOVA table in SAS and R for a randomized complete block design.

Problems

1. **Stroop Effect.**
   - Stroop, J. (1935) "Studies of Interference in Serial Verbal Reactions," *Journal of Experimental Psychology*, 18(6): 643–662.
   - Stroop studied the reaction time of college students in identifying colors: He found that it takes longer time to identify the color when the ink was used to spell a different color.
     For example, it took longer to identify the second word below is typed in blue ink:
     blue versus green.
   - Familiarize yourself with the Shapesplosion game found at `http://kuiper.pearsoncmg.com/shapesplosion/`.
   - This problem has been modified from a problem developed by Kuiper and Sklar.

   a) Read the paper Stroop, J. (1935) "Studies of Interference in Serial Verbal Reactions," *Journal of Experimental Psychology*, 18(6): 643–662. (This article is available on LearningSuite under assignment 9. The version of the paper posted there is a reprint from the *Journal of Experimental Psychology* from 1992 which has slightly more appealing formatting than the original printing.) For the second experiment in the paper, identify:
      i. the objective of the experiment,
      ii. the design,
      iii. the response variable(s),
      iv. the factors and levels that were studied,
      v. variables held constant during the experiment,
      vi. nuisance factors, and
      vii. whether any interactions were tested and, if so, what was observed.

   b) With your group, define a problem and state the objectives of your experiment.

   c) State the null and alternative hypotheses.

d) Identify the response variable, factors, levels of each factor, and experimental unit.

e) Identify what factors need to be controlled to eliminate potential biases.

f) Design a randomized complete block experiment to address the objectives of your experiment. Provide the check sheet specifying the run order and the experimental combinations.

g) Why is it helpful to use a block design for this experiment?

h) Collect the data. Create a file named stroopGroupX.R (where X is replaced with your group number). Write well-documented, reproducible code to create a data frame in R using the text= option. Submit the line of code used in your stroopGroupX.R file to read the data into R. (For your homework submission, you may replace the middle of the text= section with an ellipsis—but you should include the first few and last few rows of the data. These lines should still be included in your stroopGroupX.R file or it won't run...)

i) Calculate and present a table of relevant summary statistics. Write a sentence comparing the summary statistics you chose.

j) Visually display your data. Describe the graph you submit. Do the distributions look the same? Are they symmetric or skewed? Comment on the shape. Are there any unusual observations?

k) Write the ANOVA model for the i,j,kth observation, defining all notation.

l) Write reproducible code in R to create the ANOVA table to analyze your data. Submit the ANOVA table and comment on which factors are significant.

m) Does the blocking factor turn out to be an important source of variability? Justify your answer.

n) Ignore the blocks and re-run the analysis. Submit the new ANOVA table. How do your conclusions change? Why are the results different from the CB analysis?

o) Evaluate whether the assumptions are met for CB[·] model and comment on the validity of the assumptions.

p) Write a paragraph summarizing the results of the model which (correctly) accounted for blocking.

q) Submit a copy of your R script stroopGroupX.R to learning suite.

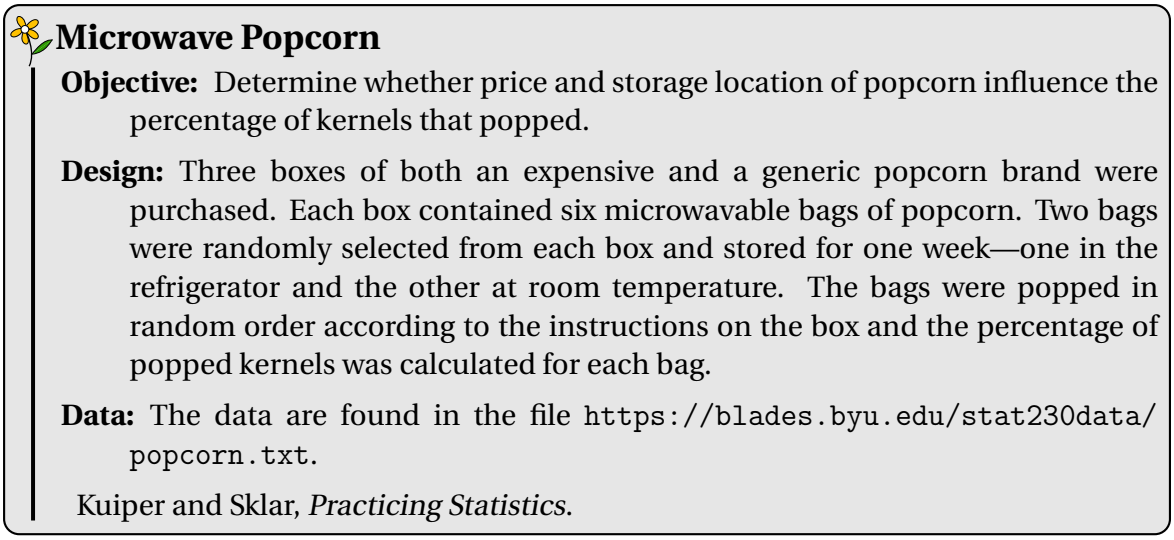
r) Repeat your analysis in SAS. Submit a copy of your SAS script stroopGroupX.sas to learning suite.

nb: You will design your analysis and collect your data as a group; however, each student must submit an independent analysis which addresses the points requested above. Group assignments will be posted on learning suite.

Objectives

- Identify whole-plot and split-plot factors.
- Identify crossed and nested factors.
- Construct the ANOVA table in SAS and R for a SP/RM design.

Problems

1. 

Microwave Popcorn

Objective: Determine whether price and storage location of popcorn influence the percentage of kernels that popped.

Design: Three boxes of both an expensive and a generic popcorn brand were purchased. Each box contained six microwavable bags of popcorn. Two bags were randomly selected from each box and stored for one week—one in the refrigerator and the other at room temperature. The bags were popped in random order according to the instructions on the box and the percentage of popped kernels was calculated for each bag.

Data: The data are found in the file `https://blades.byu.edu/stat230data/popcorn.txt`.

Kuiper and Sklar, *Practicing Statistics*.

a) Identify the response variable.

b) Identify the whole-plot factor (with levels explicitly stated) and the experimental unit for the whole-plot factor.

c) Identify the split plot factor (with levels explicitly stated) and the experimental unit for the split-plot factor.

d) Is Box crossed with or nested within Brand? Justify your answer.

e) Is Bag crossed with or nested within Box? Justify your answer.

f) Is Temperature crossed with or nested within Brand? Justify your answer.

g) Write the ANOVA model for the i, j, kth observation, defining all notation.

h) State the null and alternative hypotheses for testing Brand.

i) State the null and alternative hypotheses for testing Temperature.

j) State the null and alternative hypotheses for testing the Brand×Temperature interaction.

k) Create a file named popcorn.R. Write well-documented, reproducible code to read the data into R using the text= option. Submit the data step used in your popcorn.R file to read the data into R. Use the `str` command to check the format

of each variable; ensure the variable formats are appropriate. (For your homework submission, you may replace the middle of the text= section with an ellipsis—but you should include the first few and last few rows of the data. These lines should still be included in your popcorn.R file or it won't run...)

l) Create and submit a plot to illustrate the observed data. Your plot should account for repeated measures.

m) Produce and submit the ANOVA table for the popcorn data.

n) State your conclusions for all three sets of hypotheses.

o) Create and submit main effects plots for Brand and Temperature and an interaction plot for Brand and Temperature. Describe what you see in these plots (which brand and temperature produce a higher proportion of popped kernels?).

p) Calculate the grand mean, the mean for each Brand, and the Brand effects for the popcorn data. Identify these estimates on the main effects plot.

q) Calculate the grand mean, the mean for each Temperature, and the Temperature effects for the popcorn data. Identify these estimates on the main effects plot.

r) Calculate the grand mean, the mean for each Brand×Temperature, and the interaction effects. Identify these estimates on the interaction plot.

s) Submite a copy of your R script popcorn.R to learning suite.

Objectives

- Explore an alternative parameterization of ANOVA model.
- Determine response type: nominal, ordinal, interval, ratio.
- Perform χ^2 and Fisher's exact tests on hypotheses involving proportions.
- Calculate a 95% CI for a difference in proportions.

Problems

1. **The Art of Oreo Dunking.** Return to the Oreo data collected by your group.

   a) Add a comment to your myoreos.R script indicating the beginning of work on homework 11.

   b) Provide estimates for μ, α_1, α_2, and α_3 for the model

   $$Y_{ij} = \mu + \alpha_i + \epsilon_{ij},$$

   where
   Y_{ij} is the amount of milk absorbed in 30 seconds (in grams) for the jth cookie of cookie type i, where $i = 1$ indicates Regular Oreos, $i = 2$ indicates Trader Joe's Joe-Joe's, and $i = 3$ indicates DoubleStuf Oreos, and $j = 1, \ldots, 6$,
   α_i is the main effect of cookie type i, and
   ϵ_{ij} is the error for replicate j of cookie type i.

   c) Interpret your estimates, $\hat{\mu}$, $\hat{\alpha_1}$, $\hat{\alpha_2}$, and $\hat{\alpha_3}$.

   d) Provide estimates for β_0, β_1, and β_2 for the model

   $$Y_i = \beta_0 + \beta_1 \times \text{TJ}_i + \beta_2 \times \text{DS}_i + \epsilon_i,$$

   where
   Y_i is the amount of milk absorbed in 30 seconds (in grams) for the ith cookie, $i = 1, \ldots, 18$,
   $\text{TJ}_i = \begin{cases} 1 & \text{if the } i\text{th cookie is a Trader Joe's Joe-Joe's} \\ 0 & \text{if not} \end{cases}$
   $\text{DS}_i = \begin{cases} 1 & \text{if the } i\text{th cookie is a DoubleStuf Oreos} \\ 0 & \text{if not} \end{cases}$

   e) Interpret your estimates, $\hat{\beta_0}$, $\hat{\beta_1}$, and $\hat{\beta_2}$.

   f) Express each β_i as
   a function of (some subset) of μ, α_1, α_2, and α_3.

   g) Express each $\hat{\beta}_i$ as a function of the appropriate sample means. Show that your estimates in part 1d are equal to these functions of the sample means.

   h) Submit a copy of your R script myoreos.R to learning suite.

2.

Randomized Trial of Peanut Consumption in Infants at Risk for Peanut Allergy

- The prevalence of peanut allergy among children in Western countries has doubled in the past 10 years and peanut allergy is becoming apparent in Africa and Asia. Researchers evaluated strategies of peanut consumption and avoidance to determine which strategy is most effective in preventing the development of peanut allergy in infants at high risk for the allergy.
- 640 infants at high risk for allergy were randomly assigned to either a peanut consumption or avoidance treatment group. Some participants were excluded due to inconclusive results, missing data, voluntary withdrawal, or other reasons. In the end, 550 infants—280 in the peanut avoidance group and 270 in the peanut consumption group—were analyzed.
- Participants assigned to avoidance were instructed to avoid the consumption of peanut protein until they reached 60 months of age.
- Participants assigned to peanut consumption were fed at least 6 g of peanut protein per week, distributed in three or more meals per week, until they reached 60 months of age.
- The primary outcome was whether or not each participant had peanut allergy at 60 months of age. Participants who passed the oral food challenge (OFC) did not have peanut allergy and those who failed the OFC did.
- The data are available at `https://blades.byu.edu/stat230data/peanutBinData.txt`.
- Du Toit, G., Graham Roberts, Sayre, P.H., Bahnson, H.T., Radulovic, S., Santos, A.F., Brough, H.A., Phippard, D., Basting, M., Feeney, M., Turcanu, V., Sever, M.L., Lorenzo, M.G., Plaut, M., and Lack, G. (2015) "Randomized Trial of Peanut Consumption in Infants at Risk for Peanut Allergy." *New England Journal of Medicine* 372(9): 803-13.
- `https://www.nytimes.com/2017/01/12/well/family/parents-view-new-peanut-guidelines-with-guilt-and-skepticism.html`
- Special thanks to Celeste Ingersoll for winnowing the data for use in this assignment.

a) Identify the response variable in this experiment.

b) What type of variable is the response variable? Justify your answer.

c) Identify the factor(s) and factor levels.

d) Identify the experimental design used. Justify your answer.

e) Create a file named peanut.R. Write well-documented, reproducible code to read the data into R using the text= option. Submit the data step used in your peanut.R

file to read the data into R. (For your homework submission, you may replace the middle of the text= section with an ellipsis—but you should include the first few and last few rows of the data. These lines should still be included in your peanut.R file or it won't run...)

f) Create a 2-by-2 table of counts organized as in the following template:

		Fail OFC	Pass OFC	
Treatment Group	Peanut Avoidance			280
	Peanut Consumption			270

g) Calculate the proportion with a peanut allergy in each group.

h) Perform a χ^2 test and a Fisher's Exact Test to assess whether the proportions with peanut allergy in the two treatment groups are equal. Compare the results from these two tests. Why are the results similar?

i) Calculate a 95% confidence interval for the difference in proportions.

j) Write a sentence reporting your results.

k) Submite a copy of your R script peanut.R to learning suite.

Code Help

1 Finding the p-value for a t-statistic

Inputs:

`tstat`	t-statistic
`df`	degrees of freedom

Commands:

```
2*(1-pt(abs(tstat),df))
```

2 t-tests in SAS

Inputs:

`y`	the response variable
`x`	the factor variable
`dataset`	the SAS dataset input via a `data` step

Commands:

```
proc ttest data=dataset;
 class x;
 var y;
run;
```

3 t tests for μ (μ_d, $\mu_1 - \mu_2$)

Inputs:

`x`	a numeric vector of data values
`y`	(optional) a second numeric vector of data values if two-sample or matched-pairs intervals are desired
`paired=`	(default `FALSE`) if `TRUE`, a matched-pairs t-test and confidence interval are produced
`conf.level=`	(default 0.95) confidence level for accompanying interval
`var.equal=`	(default `FALSE`) if `TRUE`, then the pooled variance is used
`data=`	(optional) name of dataset in which the vectors `x` and `y` are located

Commands:

```
t.test(x,y,...)
```

Examples:

```
t.test(mycatsages, mydogsages, var.equal=TRUE)
```

Formula version of *t*-test:

Inputs:

`x`	a numeric vector of data values
`y`	a vector that holds group assignments corresponding to the measurements in `x`
`conf.level=`	(default 0.95) confidence level for accompanying interval
`var.equal=`	(default `FALSE`) if `TRUE`, then the pooled variance is used
`data=`	(optional) name of dataset in which the vectors `x` and `y` are located

Commands:

```
t.test(y~x, data=dataset, var.equal=TRUE)
```

4 Calculating the residuals

Inputs:

`dataset`	the dataframe holding your data
`y`	the column holding the response variable
`x`	the column holding the explanatory factor

Commands:

```
resids <- resid(aov(y ~ x, data=dataset))
```

Or, if you want to place the residuals in a new column in your dataset:

Commands:

```
dataset$resids <- resid(mod)
```

5 Plot residuals against order

Inputs:

`resids`	the vector holding the residuals

Commands:

```
plot(resids, type='b')
```

6 Drawing a normal QQ plot

Inputs:

`resids`	vector of residuals

Commands:

```
qqnorm(resids)
qqline(resids)
```

7 Drawing a histogram

Inputs:

`dataset`	the dataframe holding your data
`y`	the column holding the variable for which you would like a histogram

Commands:

```
hist(dataset$y, xlab="Name of Y Variable", main="Histogram of Y Variable")
```

8 Sample Size for Two-Sample t-test

Inputs:

`d`	smallest difference of interest ($\mu_1 - \mu_2$)
`commonsig`	estimate of pooled sd
`alpha`	desired significance level
`powerwanted`	desired power

Commands:

```
power.t.test(delta=d,
 sd=commonsig,
 sig.level=alpha,
 power=powerwanted)
```

9 Power for Two-Sample t-test

Inputs:

`d`	smallest difference of interest ($\mu_1 - \mu_2$)
`commonsig`	estimate of pooled sd
`alpha`	desired significance level
`neachgroup`	number of observations in each group

Commands:

```
power.t.test(delta=d,
 sd=commonsig,
 sig.level=alpha,
 n=neachgroup)
```

10 Create a boxplot

Inputs:

`dataset`	dataset from which the variables come
`y`	the column holding the response variable
`x`	the column holding the explanatory factor

Commands:

```
boxplot(y~x, data=dataset, ylab="Meaningful label for Response Variable",
 xlab="Meaningful label for Factor Variable", main="Plot Title")
```

11 ANOVA table in R with Interaction

Inputs:

`y`	the response variable
`x1`	the first factor variable
`x2`	the second factor variable
`dataset`	the data frame holding y and x

Commands:

```
#to fit a model with both main effects and the interaction
#you can use either of the following commands
#with :
anova(aov(yx1+x2+x1:x2, data=dataset))
#with *
anova(aov(yx1+x2+x1*x2, data=dataset))
```

12 ANOVA table in SAS

Inputs:

`y`	the response variable
`x`	the factor variable
`dataset`	the SAS dataset input via a `data` step

Commands:

```
proc glm data=dataset;
 class x;
 model y = x;
 means x;
run;
```

13 Calculate residuals for ANOVA in SAS

Inputs:

`y`	the response variable
`x`	the factor variable
`dataset`	the SAS dataset input via a `data` step

Commands:

```
proc glm data=dataset;
 class x;
 model y = x;
 output out=resData residual=res;
run;
```

This creates a dataset called `resData` with a variable called res holding the ordinary residuals.

14 Index Plot and Normal QQ Plot of Residuals in SAS

Inputs:

`res`	the name of the variable holding your residuals
`resData`	the SAS dataset holding the residuals

Commands:

```
*this data step adds indices to your residual data;
*so that you can plot the residuals against the indices;
data resData;
 set resData;
 id=_N_;
*create the index plot;
proc gplot data=resData;
 symbol1 color=black interpol=join value=dot;
 plot res*id / vref=0;
run;
*create the normal QQ plot;
proc univariate data=resData;
 var res;
 probplot / normal(mu=est sigma=est color=red);
run;
```

15 Creating boxplots in SAS

Inputs:

`dataset`	the SAS dataset input via a `data` step
`responsevar`	the variable holding the quantitative response variable
`factorvar1`	the variable holding the first factor
`factorvar2`	the variable holding the second factor

Commands:

```
proc boxplot data=dataset;
 plot (responsevar)*factor1var (factor2var)=factor1var / boxstyle=schematic;
run;
```

PROJECT

Project

Objectives

- Demonstrate understanding of statistical problem solving.
- Conduct a designed experiment.
- Write a technical report describing a designed experiment.
- Collaborate with a group of peers (3 people per group).

Notes

- You will explore a research topic that can be investigated using the methods learned in this class.
- Your project will require original data collection.
- The analysis and graphics will be conducted using reproducible code.
- The project consists of three deliverables: data, analysis, and report. The professor may require revision of any of these deliverables.
- You will work in a group of 3 classmates. All members of the group will receive the same grade. My only concern with group work is when participation is more extreme than the usual variation around equal. I suggest that the consequences of either shirking your assignments or hogging all the responsibilities should be addressed when forming the group. Any changes to group composition must include the professor's permission.

Paper Helicopters

1. The basic design of a paper helicopter is given below in Figure .4. These paper helicopters ideally can delicately descend to a chosen target. You may choose to evaluate the effect of the **wing length, tail length, tail width, material, or type of paper clip** on the **descent time**.
2. Choose two factors to compare using a BF[2] design:
   (a) wing length
   (b) tail length
   (c) tail width
   (d) material
   (e) type of paper clip
3. For each factor you chose, select at least two levels.
4. Determine number of replicates.

5. Create check sheet.
6. Perform experiment as a group.

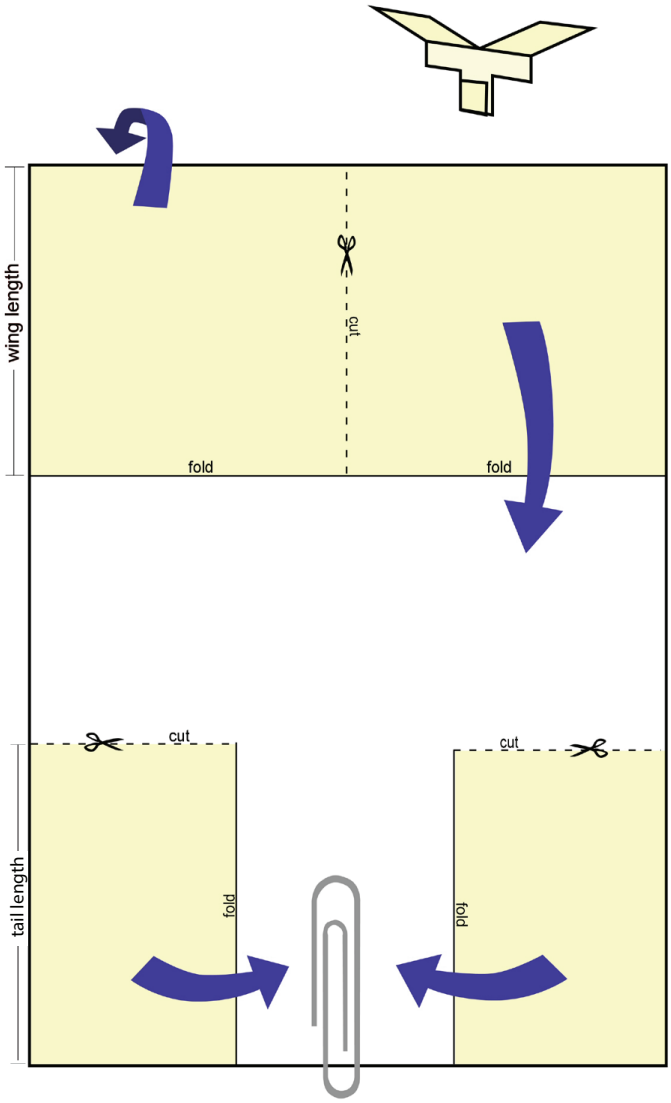


Figure .4: Paper Helicopter Design. Image from Scott D Grimshaw

Project Data Summary (Due: November 27, 2018)

For this assignment you will perform the experiment and report the results and summary statistics in well-organized tables.

Sections: The Project Data Summary should include four components: Design, Perform the Experiment, Experiment Results, and Summary Statistics.

Design: In this section you should describe:

- the phenomenon and why there may be an effect of the levels of the factor on the response variable;
- the experiment's response variable, factors, and levels;
- the experimental procedure in enough detail that it could be replicated;
- the experimental unit and the randomization procedure; and
- justification of the replication (*nb:* To justify the replication you should address the cost of one replicate and the time to complete one replicate. In general, I expect you to spend two to three hours performing your experiment.).

Provide a table of the randomized order of the experimental combinations.

Perform the Experiment: In this section, present when the experiment was performed, who performed what tasks, and how long it took to complete. Include at least one picture of the group performing the experiment.

Experiment Results: Provide a table of the data collected by performing the experiment. Write reproducible code to create the dataset. Turn in all code in a single file to Learning Suite.

Summary Statistics: In this section you should present a summary table of the experimental combination with means and standard deviation.

Revision: The professor reserves the right to **require revision** of the Project Data Summary by a specified date.

Rubric: Please review the attached Project Data Summary rubric.

Exceeds Standard	Meets Standard	Does Not Meet Standard	No/Limited Evidence
Design			
Effective design which would allow the experimenter to achieve all goals. Design has two experimental factors. Each factor has at least two levels. Response variable is quantitative and measurable. Measurement units for response variable are reported. Experimental unit clearly conveyed. Experimental controls discussed. Representative sample used. Randomization procedure used. Justification of number of replicates. Check sheet of randomized experimental combinations included (in an appendix if more than 12 trials). Design poses little or no risk to students or others.	Somewhat effective design which would allow the experimenter to achieve most goals. Deficiencies in one or two elements. or Design has one factor.	Somewhat ineffective design which would allow the experimenter to achieve some goals. Deficiencies in more than two elements.	Ineffective design which would not allow experimenters to achieve any of their goals.

Exceeds Standard	Meets Standard	Does Not Meet Standard	No/Limited Evidence
Performing the Experiment			
Photo evidence of all group members participating in collecting data together. Lists steps in a detailed, sequential order that could be reproduced. Lists all materials and equipment. All safety precautions and warnings are provided. Provides diagrams of all set ups. Collected all the appropriate data. Table of experiment results included (in appendix if more than 12 trials). Summary table included with means and standard deviations for all experimental combinations.	All group members participated in collecting data together. Lists all steps in a sequential order that is not easily followed. Lists most materials and equipment. All safety precautions and warnings are provided. Provides diagrams of all set ups. Collected most of the needed data. Table of experiment results included (in appendix if more than 12 trials). Summary table included with means and standard deviations for all experimental combinations.	Students parsed out tasks instead of collecting data together. Lists all steps in a sequential order that is not easily followed. Lists some of the materials and equipment. Some safety precautions and warnings are missing. Provides some diagrams of set ups. Collected some meaningful data. Table of experiment results omitted. Summary table with means and standard deviations for all experimental combinations is omitted.	Lists steps in an order that is not sequential, not easily followed, or incomplete. No list of materials. Some safety precautions and warnings are not provided. Provides some diagrams of set ups. Did not collect meaningful data.
Tables			
Information accurately presented in a suitable format. All tables have titles, row and column labels, and are well formatted. All tables are referenced in the text.	All necessary information is presented but the table is poorly formatted (extraneous lines, injudicious use of grouping or spacing, too many or inconsistent decimal places preserved).	Information not presented in an appropriate format.	Tables are missing.
Documentation			
Well-documented code which runs without errors. Sufficiently detailed to reproduce entire report.	Code runs without errors. Sufficiently detailed to reproduce entire report. Sparse or no documentation.	Code contains errors. Substantial parts of the report cannot be recreated.	Code submitted is not a recognized SAS or R file. or No code submitted.
Spelling/Grammar			
No errors in: punctuation, capitalization, spelling, sentence structure, and word usage.	Errors are rare and do not detract from the paper. (Fewer than 3 errors)	Numerous and distracting errors interfere with reading the paper.	Grammatical, spelling, or punctuation errors substantially detract from the paper. Names of group members were misspelled.

Project Analysis (Due: December 5 , 2018)

This assignment requires fitting an appropriate model and reporting the results.

Sections: The Project Analysis should include three sections: Model Specification, ANOVA Table, and Inference. Write reproducible code to perform the analysis. Turn in all code in a single file to Learning Suite.

Model Specification: Write the model for this experiment defining all notation. Explain why it is appropriate for the experiment you performed. Report results of residual analysis.

ANOVA Table: Report the ANOVA Table.

Inference: Identify the the statistically significant effect(s). Report the 95% overall confidence intervals for pairwise differences of statistically significant effects. Create a graphic demonstrating the statistically significant effect(s).

Revision: The professor reserves the right to **require revision** of the Project Analysis by a specified date.

Rubric: Please review the attached Project Analysis rubric.

Exceeds Standard	Meets Standard	Does Not Meet Standard	No/Limited Evidence
Analysis			
Model presented with all notation defined. Model used aligns with design performed. Explanation of why the model is appropriate for the experiment performed. Reports results of residual analysis.	Model presented without all notation defined. Model used aligns with design performed. No justification regarding appropriateness of model. Includes extraneous graphs from residual analysis which could be conveyed in text.	Model used does not align with the design performed. No attempt to verify whether the assumptions appear to be met.	No model is presented. No mention of assumptions.
Results			
Data appropriately analyzed. Correctly calculated ANOVA table presented. Includes table of pair-wise comparisons for important effects. Includes graphical presentation of important effects.	Data are appropriately analyzed. Some tables/graphs are omitted or are extraneously included.	Presents confusing or inappropriate results.	Lack of statistical results.
Tables			
Information accurately presented in a suitable format. All tables have titles, row and column labels, and are well formatted. All tables are referenced in the text.	All necessary information is presented but the table is poorly formatted (extraneous lines, injudicious use of grouping or spacing, too many or inconsistent decimal places preserved).	Information not presented in an appropriate format.	Tables are missing.
Graphics			
Graphs summarize data in clear and meaningful way. Points plotted accurately. Scale appropriate to range of data with suitable tick increments. Graphs have correct titles, axis titles with units, axis labels, and legends or data labels (as appropriate).	Deficiencies in one element.	Deficiencies in 2 elements.	Deficiencies in 3 or more elements. Poor print quality of graphs.
Documentation			
Well-documented code which runs without errors. Sufficiently detailed to	Code runs without errors. Sufficiently detailed to reproduce entire report. Sparse/no	Code contains errors. Substantial parts of the report cannot be recreated.	Code submitted is not a recognized SAS or R file. or No code submitted.

Project Report (Due: December 13, 2018)

Below are sections of what should be included in the Project Report. While there may be exceptions, it is usually difficult to be complete with fewer than 7 to 10 pages, but don't just make it 10 pages just to reach 10 pages. You have already written most of these sections as part of your previous project asssignments; consequently, you should be able to compile these pieces easily. Submit reproducible code for your complete analysis in a single file to Learning Suite.

Introduction. In this section you should motivate the investigation into this problem and provide a precise statement of the research question.

Methods.

- Design
- Performing the Experiment
- Experiment Results
- Summary Statistics

Analysis.

- Model Specification
- ANOVA Table

Results.

- Inference

Summary. This section presents the most important results of the analysis (identify and describe important effects—what factors are 'statistically significant,' what is the nature of the relationship between the factor levels and and the response variable). Also discuss how the results from your experiment generalize and describe the impact of the results.

Rubric. Please review the attached Project Report rubric.

Exceeds Standard	Meets Standard	Does Not Meet Standard	No/Limited Evidence
Introduction			
Engaging introduction that grabs interest of reader. Summarizes important findings from the review of the literature. Precise and concise statement of the research question. Explains significance of the problem. Introduces key vocabulary.	Interesting introduction. Clear statement of the research question. Summarizes important findings from the review of the literature.	Basic introduction that states question but lacks interest. States the question in a single sentence. Incomplete or unfocused. Sources insignificant or unsubstantiated.	Weak or no introduction of topic. Research question not clearly stated. Does not adequately convey topic or key question. No external literature referenced.
Summary			
Restates the hypothesis, supports or refutes it, and explains the role of the analysis in making the decision. Insightful discussion of the impact of the research on the topic. Results and discussion well focused. Presents a logical explanation for the findings. Presents clear recommendations and/or implications for future research. Thoughtful reflection and consideration of the data. The conclusion is engaging and restates personal learning. Accurately and creatively interprets the patterns inherent in the data.	Restates the hypothesis and supports or refutes it. Presents a logical explanation for findings. Strong review of key conclusions. Discusses impact of research on topic. Missed some important points. Focuses on numbers and briefly considers the implications.	Supports or refutes the hypothesis without restating it. Review of key conclusions. Discusses impact of research on topic. Analyzed only the most basic points. Missing numerical data or reflection on the data. Little or no discussion and interpretation of the patterns inherent in the analysis.	Does not adequately explain findings. Does not address the hypothesis. Does not discuss the impact of the research on topic. The conclusion fails to mention numbers or give any conclusions.
Depth of Discussion			
In-depth discussion and elaboration in all sections.	In-depth discussion and elaboration in most sections.	Pertinent content missing. or Content runs-on excessively.	Cursory discussion in all sections. or Brief discussion in only a few sections.

Exceeds Standard	Meets Standard	Does Not Meet Standard	No/Limited Evidence
Spelling/Grammar			
No errors in: punctuation, capitalization, spelling, sentence structure, and word usage.	Errors are rare and do not detract from the paper. (Fewer than 3 errors)	Numerous and distracting errors interfere with reading the paper.	Grammatical, spelling, or punctuation errors substantially detract from the paper. Names of group members were misspelled.
Organization and Appearance			
Clear organization. Readable and neat. Excellent flow from one section to the next.	Findings well-organized but flow is lacking.	Poorly organized and difficult to read. Lacks neatness.	Font sizes vary throughout report. Inconsistent formatting. Report lurches haphazardly from one topic to the next.
Previous Components			
Problems from previous project components corrected.	Most problems from previous project components corrected.	Some problems identified in previous project components corrected.	Problems from previous project components repeated.
Documentation			
Well-documented code which runs without errors. Sufficiently detailed to reproduce entire report.	Code runs without errors. Sufficiently detailed to reproduce entire report. Sparse/no documentation.	Code contains errors. Substantial parts of the report cannot be recreated.	Code submitted is not a recognized SAS or R file. or No code submitted.

EXAM STUDY GUIDES

Study Guide: Exam 1

Calculations:

- Standard deviation
- Confidence interval for a single mean
- Test statistic for a two-sample t-test
- Pooled variance estimate for the two-sample t-test
- Confidence interval for a difference in means
- Fill in blanks in a one-way ANOVA table
- Construct F-statistic for one-way ANOVA table
- Calculate estimates of main effects in a BF[1] model
- Calculate a residual

Concepts:

- Distinguish between experimental and observational studies.
- Distinguish between statistics and parameters.
- Identify the response variable, factors, factor levels, and experimental unit.
- Two-sample t-test:
  - Statistical model
  - How to estimate μ_1, μ_2, and ϵ_{ij}
  - Hypotheses (stated precisely)
  - Assumptions
- One-way ANOVA
  - Statistical model
  - how to estimate: μ, α_1, α_2, ..., α_I, and ϵ_{ij}
  - Hypotheses (stated precisely)
  - Assumptions
- Describe how the two-sample t-test and one-way ANOVA are related.
- Interpret a p-value.

- Interpret a confidence interval.
- State how assumptions are checked (that is, which plot or calculation checks each assumption).
- Define Type I and Type II errors.
- Identify features which influence power.
- Define the family-wise error rate.
- Explain the purpose of multiple comparison adjustments.

Computing:

- Read data into R using text= option.
- Read data into SAS using datalines option.
- Calculate group-specific means and sds in R and SAS.
- Perform two-sample t-test in R and SAS.
- Obtain a p-value using pt or pf in R.
- Produce an ANOVA table in R and SAS.

Study Guide: Exam 2

Calculations:

- Standard deviation
- Fill in blanks in an ANOVA table
- Construct F-statistics to test for significance of main effects and interaction terms
- Calculate estimates of main effects in a BF[1] model
- Calculate estimates of main effects and interaction effects in a BF[2] model
- Given estimates of an effect, calculate the respective SS (that is, given $\hat{\alpha}_1$ and $\hat{\alpha}_2$, calculate the SS for the first factor).

Concepts:

- Identify key design features
  - Response variable
  - Factors
  - Factor levels
  - Treatments
  - Experimental unit
  - Blocking variable
  - Nuissance factors
  - Crossing
  - Balance
- Distinguish between basic factorial and complete block designs with one or two factors.
  - Know when to use each design.

    Randomized Basic Factorial Design: BF[·] Good choice for design when experimental material is relatively uniform (i.e., no systematic differences in experimental material)

    Randomized Complete Block Design: CB[·] Useful when experimental units can be divided into similar groups that may have systematically different responses to treatment
  - Understand the characteristics of each design.
  - Recognize each design in practice.
- Two-factor experiments
  - Define model (with all notation)
  - Estimate model parameters
  - State (with precision) hypotheses about model parameters
    - Identify/label all notation
    - Articulate (with words) these hypotheses in the context of the problem
  - State model assumptions and describe how you might evaluate whether they are satisfied

  - Interactions
    * Describe the interaction in the context of the problem
    * Draw an interaction plot given relevant group means
    * Preliminary assessment of significance of interaction based on interaction plot
    * Determine whether an interaction is significant
    * Interpretation of main effects when an interaction is significant/nonsignificant
- Randomized Block Design
  - Randomization for complete block designs
  - List the three ways to get blocks
  - Define model (with all notation)
  - Model inference and summarization as for two-factor experiments (above)
- What does the mean square error estimate?
- Interpret confidence intervals for pairwise differences.

Computing:

- In R and SAS:
  - Produce code to obtain the ANOVA table for a BF[1] or BF[2] design.
  - Produce code to obtain the ANOVA table for a CB[1] or CB[2] design.
  - Produce code to obtain marginal means and cell means.
  - Produce code to obtain a boxplot of the response variable.

Miscellany:

- This exam is cumulative—you should review the material from exam 1.
- Please bring a calculator; you may not use your phone as a calculator.
- Some things you can do to practice:
  - Load one of the class datasets into R. Calculate the ANOVA table. Print it out. Cover up some ANOVA table entries with little bitty (custom-trimmed) post-it notes. Swap your ANOVA table with your partner and try to fill in the missing cells. The answer key will then live right beneath your post-it notes.
  - Pick your favorite factor with two levels. (It is not necessary that it only have two levels, but it is easier to start here.) Pick another favorite factor with two or more levels. Pick a quantitative response variable. Draw an interaction plot; you could draw parallel lines that are far apart, parallel lines that are close together, non-parallel lines, crossing lines, flat lines. Label your plot well. Swap with your partner and describe the interaction displayed in your partner's plot.
  - To practice your SAS and R code: By hand write out code to obtain {ANOVA table in R, ANOVA table in SAS, ...}. Swap code with your partner. Try to find any errors in his/her code. Once you feel good about the code, type your partner's code into R/SAS and see if it works.

Study Guide: Final Exam

Calculations:

- Construct F-statistics for factors in SP/RM designs
- 95% CI for proportion
- χ^2 test for $r \times c$ contingency table

Concepts:

- SP/RM designs
  - Identify the experimental unit for any factor
  - Terminology for SP/RM
  - Nesting and Crossing
  - Model and ANOVA table for SP/RM designs
  - F-tests for factors in SP/RM designs
- Identify differences between scenarios for BF[1], BF[2], CB[1], CB[2], SP/RM[1;1] designs
- Unbalanced data
  - Type I versus Type III sums of squares
  - When is it appropriate to use Type III sums of squares?
  - When does order matter when including factors in model?
- Reference group parameterization for BF[1]
- Identify response type
- Binary response
  - Why is it inappropriate to use an ANOVA?
  - How can you summarize a binary response?
  - How can you compare a binary response from a BF[1] design?
  - Sample size considerations for confidence intervals and hypothesis tests

Computing:

- In R and SAS:
  - Produce code to obtain the ANOVA table for a CB[1] design.
  - Produce code to obtain the ANOVA table for a SP/RM design.
  - Produce code to perform pairwise comparisons of means.
- In R:
  - Produce code to perform a χ^2 or Fisher's exact test on proportions

Miscellany:

- This exam is cumulative—you should review the material from exams 1 and 2.
- Please bring a calculator; you may not use your phone as a calculator.