STAT 425 - Statistical Design and Analysis of Experiments

Assignment 1

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1. Thirty trainees are randomly divided into three groups of 10 and each group is given instruction on the use of a different word-processing system. At the end of the training period, each trainee is given the same "benchmark" word-processing project to complete and the time required for completion is recorded.

   (a) Is the above study an experimental study or an observational study? Explain your answer.
   Solution: This is a randomized experimental study since the participants are randomly divided into each of the three groups and each group is given a different input.

   (b) Describe the response variable in this study and identify the factor/variable and the factor/variable levels.
   Solution: The response variable is the time required to complete the "benchmark" word-processing project of each participant. The factor is the particular word-processing system used by each trainee. There are three different levels for this factor and it depends on which word-processing system the trainee used.

   (c) Is this factor categorical or numerical? Explain. Would your answer differ if each trainee has been allowed to select the word-processing system of his or her choice?
   Solution: The factor is categorical since the factor can take on only three values based on a qualitative property, that is the specific type of word-processing system the trainee has undergone. If each trainee has been allowed to select the word-processing system of his or her choice, the categorical nature of the factor would remain the same.

2. In a study of subliminal advertising, subjects are brought to a studio and shown a film with one of three types of subliminal advertising for the product. Each subjects attitude towards the product before and after the film viewing are measured. Construct a frame work to design a study on how three different subliminal advertising approaches affect the after measurements. In your description, describe the response variable, the factor/variable (or factors/variables) under study; is your study an experimental study or an observational study (and why); the different factor levels; whether these factors are categorical or numerical.

   Solution:

   - Study:Each participant would be randomly assigned to one of the three types of subliminal advertising. The attitude of each participant will be recorded on a nominal scale where 0 - happy, 1 - sad, 2 - fear, 3 - disgust, 4 - anger, and 5 - surprised both before and after they watch the advertising.
   - The response variable is the nominal value of their attitude after watching the adverstiment. The factors in this study are the nominal value of their attitude before they watch the advertisement as well as the nominal value based on the advertisement the participant watched. The study is a randomized experimental study and the factors are experimental.
   - The factor levels for the attitude before each participant watches the advertising is composed of 6 levels where 0 - happy, 1 - sad, 2 - fear, 3 - disgust, 4 - anger, and 5 - surprised. The factor levels for the advertisement each participant watches is composed of 3 levels and it is based on the particular advertising each participant watches.

3. Refer to data in Chapter 2, end-of-chapter exercise 2.30. Use the data to answer the questions below:

   (a) State the statistical hypotheses that will address the idea that IQ score depends on birth order.
   Solution:

$$H_o : \mu_{BirthOrder1} - \mu_{BirthOrder2} = 0$$
$$H_a : \mu_{BirthOrder1} - \mu_{BirthOrder2} \neq 0$$

   Where $\mu_{BirthOrder1}$ is the mean IQ score from children with Birth Order 1 and $\mu_{BirthOrder2}$ is the mean IQ score from children with Birth Order 2.

(b) Carry out the statistical test. Ensure you provide the value of the test statistic, the P-value, along with provision of code/worked-through-formulae to demonstrate how you obtained your result. If you do not, earned marks here will be equal to 0.

Solution: We perform a matched paired t-test to determine if there is a difference in mean IQ given birth order:

```
b.order <-read.csv("p3.csv")
b.order[1] <- seq(1:10)
names(b.order) <- c("pair", "twin1", "twin2")
t.test(b.order$twin1, b.order$twin2, paired=TRUE, alternative = "two.sided")
```

```
##
##  Paired t-test
##
## data:  b.order$twin1 and b.order$twin2
## t = -0.36577, df = 9, p-value = 0.723
## alternative hypothesis: true difference in means is not equal to 0
## 95 percent confidence interval:
##  -0.3664148  0.2644148
## sample estimates:
## mean of the differences
##                  -0.051
```

From the output we get that:

$$T_{obs} = -0.36577$$
$$p - value = P(|T_9| < -0.36577) = 0.723$$

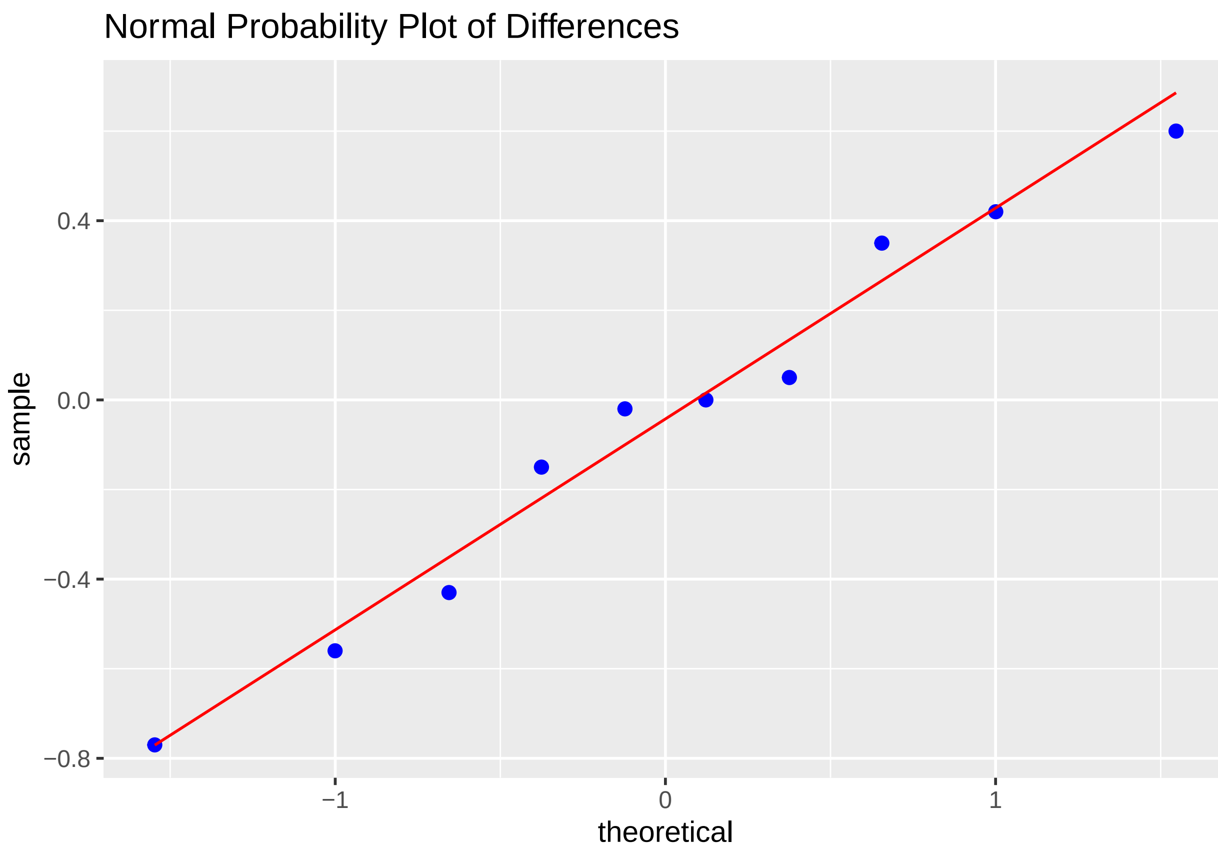
(c) What can you conclude from these data? State your decision and conclusion.

Solution: According to the t-test, the p-value is 0.723. Since this is greater than 0.05, we do not reject the null hypothesis and conclude that on average, there is no difference between mono zygotic twin IQ's based on their birth order.

(d) What assumption is required from your method in (a)? Does it hold? Demonstrate through the conduction of the necessary visual diagnostic (boxplot, histogram, normal probability plot, etc. Use only one of these.)

Solution: In order to perform the hypothesis test as stated in (a), the difference between the two twin IQ's must follow a normal distribution. Furthermore, since the number of pairs is less than 25, Central Limit Theorem cannot be applied–hence, the difference in the paired data must follow a normal distributiob.

```
b.order[4] <- b.order$twin1 - b.order$twin2
names(b.order)[4] <- "diff"
ggplot(data=b.order, aes(sample = diff)) + stat_qq(col="blue", size=2) + stat_qqline(col="red") + gg
```



From the R output above, the data points all fall evenly around the theoretical line. Thus, the normal distribution condition is satisfied. Therefore, the statistical test performed in (a) is valid.

(e) Refer to the P-value of in part (b). Interpret its meaning in the context of these data. (Remember, I am looking for an interpretation here. What does the P-value measure???)

Solution: From (b) we have that the p-value is 0.723. The p-value measures the probability of obtaining a sample as extreme as the observed sample given that the mono zygotic twin mean IQ's are equal. Since this is a high p-value, then it is very likely that we observe stronger evidence supporting the claim that the mean IQ between birth order 1 and 2 are the same.

(f) Compute a 95% confidence interval for the "parameter" of interest, then interpret its meaning in the context of these data.

Solution:

```
t.test(b.order$twin1, b.order$twin2, paired=TRUE, alternative = "two.sided")$conf
```

```
## [1] -0.3664148  0.2644148
## attr(,"conf.level")
## [1] 0.95
```

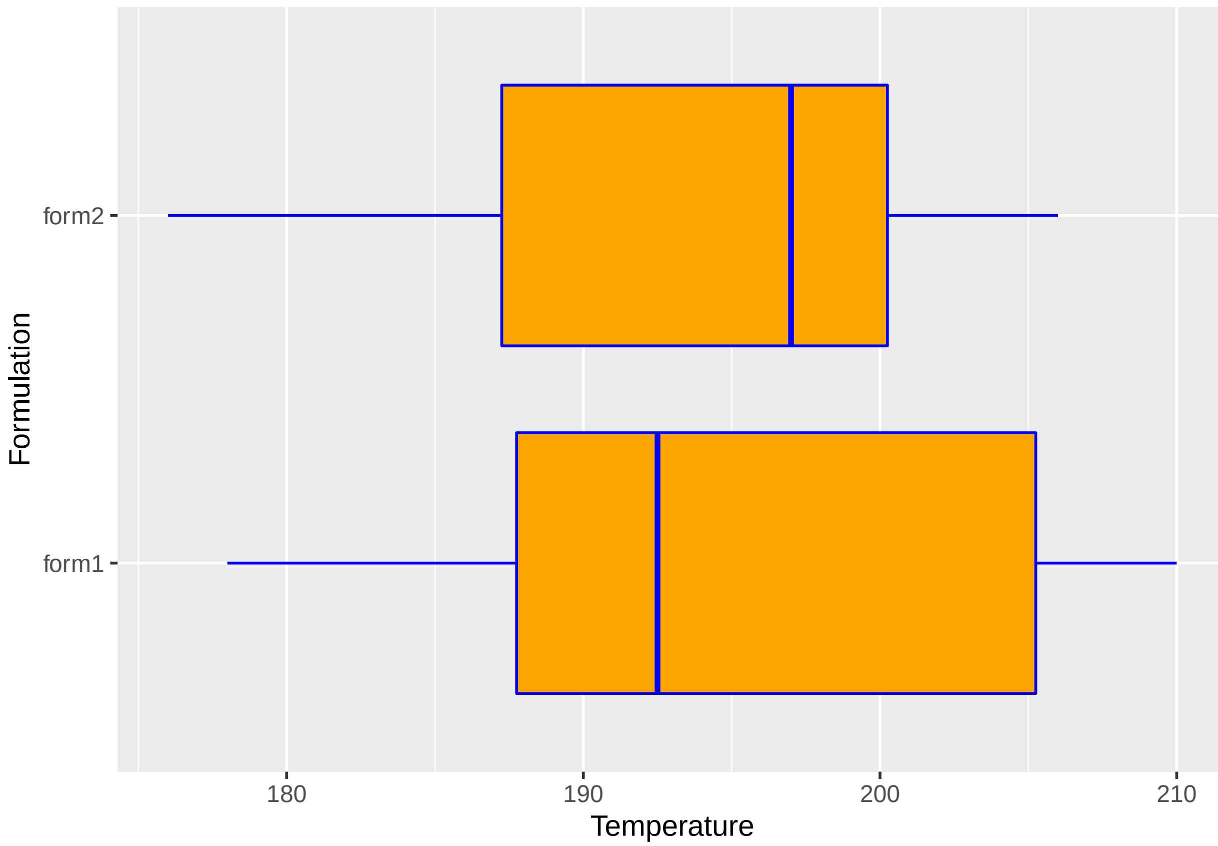
From the result above, we are 95% confident that the difference between the first and second order child IQ is between -0.3664148 and 0.2644148. This means that if the same test was carried out around 100 times, 95 of the computed averages would be within -0.3664148 and 0.2644148. Since the confidence interval encloses 0, this strengthens the conclusion that there is no difference between the mean IQ of monozygotic twins based on their birth order.

4. Refer to the data in end-of-Chapter 2 exercises, Exercise 2.32.

(a) Use gglot to create boxplots. From these boxplots, does Formulation 1 and Formulation 2 seem to have different variances/standard deviations? Comment.

Solution:

```r
p4 <- read.csv("p4.csv")
form <- c(rep("form1", 12), rep("form2", 12))
temp <- c(p4[,1], p4[,2])
p4 <- data.frame(form, temp)
ggplot(data=p4, aes(x = form, y = temp)) + geom_boxplot(col="blue", fill="orange") + xlab("Formulati
```



From the boxplot, the variances between the two populations seem equal because the interquartile range looks similar.

(b) Is the variance in the deflection temperature is the same for the two formulations? State the appropriate statistical hypotheses, then test. Ensure you provide/point out the value of the test statistic and the P-value.

Solution: To test for equal variances, a Levene test will be performed with the following test of hypothesis:

$$H_o : \sigma^2_{Formulation1} = \sigma^2_{Formulation2}$$
$$H_a : \sigma^2_{Formulation1} \neq \sigma^2_{Formulation2}$$

Performing this test on R we get:

```r
levene.test(temp, form)
```

```
##
##  Modified robust Brown-Forsythe Levene-type test based on the absolute
##  deviations from the median
##
## data:  temp
## Test Statistic = 0.0084942, p-value = 0.9274
```

From the output above we get that:

$$T_{obs} = \sqrt{0.0084942} = 0.09216$$
$$p - value = P(|T_{22}| > 0.09216) = 0.9274$$

Since the $p - value = P(|T_{22}| > 0.09216) = 0.9274$ is greater than 0.05, we do not reject the null hypothesis and we conclude that the variance between the two formulations are the same.

(c) Using your results in (b), does the data support the claim that the mean deflection temperature under load for formulation 1 exceeds that of formulation 2? State the appropriate statistical hypotheses, compute or provide the value of the test statistic and its corresponding P-value.

Solution: A t-test with a pooled standard deviation will be used to carry out the following test of hypothesis:

$$H_o : \mu_{Formulation1} = \mu_{Formulation2} \quad (1)$$
$$H_a : \mu_{Formulation1} > \mu_{Formulation2} \quad (2)$$

Performing this test on R we get that:

```r
t.test(temp~form, alternative="greater", var.equal=T, data=p4)
```

```
##
##  Two Sample t-test
##
## data:  temp by form
## t = 0.34483, df = 22, p-value = 0.3667
## alternative hypothesis: true difference in means is greater than 0
## 95 percent confidence interval:
##  -5.637883       Inf
## sample estimates:
## mean in group form1 mean in group form2
##            194.5000            193.0833
```

From the output, we get that:

$$T_{obs} = 0.34483$$
$$p - value = P(T_{22} > 0.34483) = 0.3667$$

(d) Consult the P-value you computed in part (c). Interpret the meaning of this P-value in the context of these data.

Solution: From (c) we have that the p-value= $P(T_{22} > 0.34483) = 0.3667$. The p-value measures the probability of obtaining a sample as extreme as the observed sample given that the mean deflection temperature from both formulations are equal. Since this is greater than 0.05, then it is very likely that we observe stronger evidence supporting the claim that the mean deflection temperature from both formulations are the same.

5. A study conducted by Youmans and Jee1 looked at students who took a research methods class in psychology. Two lecture sections of the same course were taught by the same instructor. Students in each lecture section were required to register in one of two Friday afternoon discussion sections, or a tutorial. During the ninth week of instruction, all students were asked to fill out an informal mid-semester evaluation in their Friday afternoon discussion session. In half of the Friday afternoon discussion sections, the experimenter (not the professor/instructor!) passed around a bag containing small bars of chocolate that he simply had left-over and wanted to get rid of so that students would not think the chocolate was a gift from their professor/instructor. The evaluation was a survey that contained nine questions. For each question the student provided a rating from 1 (very poor) to 5 (excellent). Question 9 posed the following: "Compared to other instructors you have had at this university, this instructor is: 1 (very poor) to 5 (excellent)." Compliments to the authors, they have provided me with the data in this particular study. In the file sourced below, you will find the raw data providing the student responses for Question 9 (Q9) and the overall average response for Questions 1 through 9 (Overall) for each student. Use these data to answer the following questions:

(a) How were these data collected? Describe the type of study and point out interesting aspects of the study.

Solution: The data was collected through a survey given to the students during their Friday session. This is an experimental study design because the students are divided into two groups—one with chocolate and the other with no chocolate.

An interesting aspect of the study is that there could be the existence of a confounding effect in the group who took the chocolate. If the experimenter hands out the chocolate starting from the front of the class, the people who get the chocolate are most likely the first half of the class. Those students who sit in the front might be those who are usually optimistic and hard-working, while the students in the back who did not receive chocolate, might be those who do not pay attention in class or try too hard in the course. This causes a confounding effect because the students who get the chocolate (ie. the students who work hard in the class) might give the professor a higher rating because they might have an overall better understanding of the material and thus understand the professor better. While as the students who do not receive chocolate, might not rate the professor too well since they do not understand the material and thus conclude that the professor is not that good.

(b) Pertaining to Question 9: Do these data suggest there is a treatment effect? State the statistical hypotheses then test the existence of a treatment effect using the relevant statistical test. If a treatment effect is discovered, explain its meaning in the context of these data. Ensure you provide a justification for the statistical procedure you employ.

Solution: We use the following test of hypothesis:

$$H_o : \mu_{choc} = \mu_{nochoc}$$
$$H_a : \mu_{choc} > \mu_{nochoc}$$

Where μ_{choc} is the mean student rating for students who received chocolate and μ_{nochoc} is the mean student rating for students who did not receive chocolate. First, we must perform a test of equal variance using Levene's test to determine if the variances of the two populations are the same:

```r
p5 <- read.csv("http://people.ucalgary.ca/~jbstall/DataFiles/chocnochocratings.csv")
levene.test(p5$Q9, p5$GroupName)
```

```
##
##  Modified robust Brown-Forsythe Levene-type test based on the absolute
##  deviations from the median
##
## data:  p5$Q9
## Test Statistic = 0.6443, p-value = 0.4241
```

From the R output, since the p-value=0.4241 which is greater than 0.05, we conclude that the variances are the same and so we perform a pooled 2-sample t-test. We perform this test because the two samples seem to be drawn from the same population as well as it tests the hypothesis test mentioned above.

```r
t.test(Q9~GroupName, alternative="greater", var.equal=T, data=p5)
```

```
##
##  Two Sample t-test
##
## data:  Q9 by GroupName
## t = 1.0958, df = 96, p-value = 0.138
## alternative hypothesis: true difference in means is greater than 0
## 95 percent confidence interval:
##  -0.1048505        Inf
## sample estimates:
## mean in group Chocolate    mean in group NOChoc
##                4.120000                3.916667
```

From the R output above we have that:

$$T_{obs} = 1.0958$$
$$p - value = P(T_{96} > 1.0958) = 0.138$$

Notice how the p-value=$P(T_{96} > 1.0958) = 0.138$ is greater than 0.05 and so we do not reject the null hypothesis. This means that on average, there is not enough statistical evidence to suggest that giving students chocolate increases their professor rating.

(c) Consider the variable Overall. Is there a treatment effect with respect to the professors overall rating as a teacher? Carry out the appropriate statistical test providing the value of the test statistic and the P-value. What conclusion(s) can you draw from these data?

Solution: We want to test the following hypotheses:

$$H_o : \mu_{chocOverall} = \mu_{nochocOverall}$$
$$H_a : \mu_{chocOverall} > \mu_{nochocOverall}$$

First, we need to determine if the variances between the two samples are equal using a Levene's test:

```
levene.test(p5$Overall, p5$GroupName)
```

```
##
##  Modified robust Brown-Forsythe Levene-type test based on the absolute
##  deviations from the median
##
## data:  p5$Overall
## Test Statistic = 0.49594, p-value = 0.483
```

From the R output, we have the p-value=0.483 which is greater than 0.05. Hence, we do not reject the null hypothesis and conclude that the variances between these two samples are the same. Now, we perform pooled 2-sample t-test to test our hypothesis. We use this test because the two samples are drawn from the same population and it gives us a p-value that tests the hypothesis correctly.

```
t.test(Overall~GroupName, alternative="greater", var.equal=T, data=p5)
```

```
##
##  Two Sample t-test
##
## data:  Overall by GroupName
## t = 1.6593, df = 96, p-value = 0.05016
## alternative hypothesis: true difference in means is greater than 0
## 95 percent confidence interval:
##  -0.0002168203           Inf
## sample estimates:
## mean in group Chocolate    mean in group NOChoc
##                4.072000                3.849792
```

From the R output above, we have that:

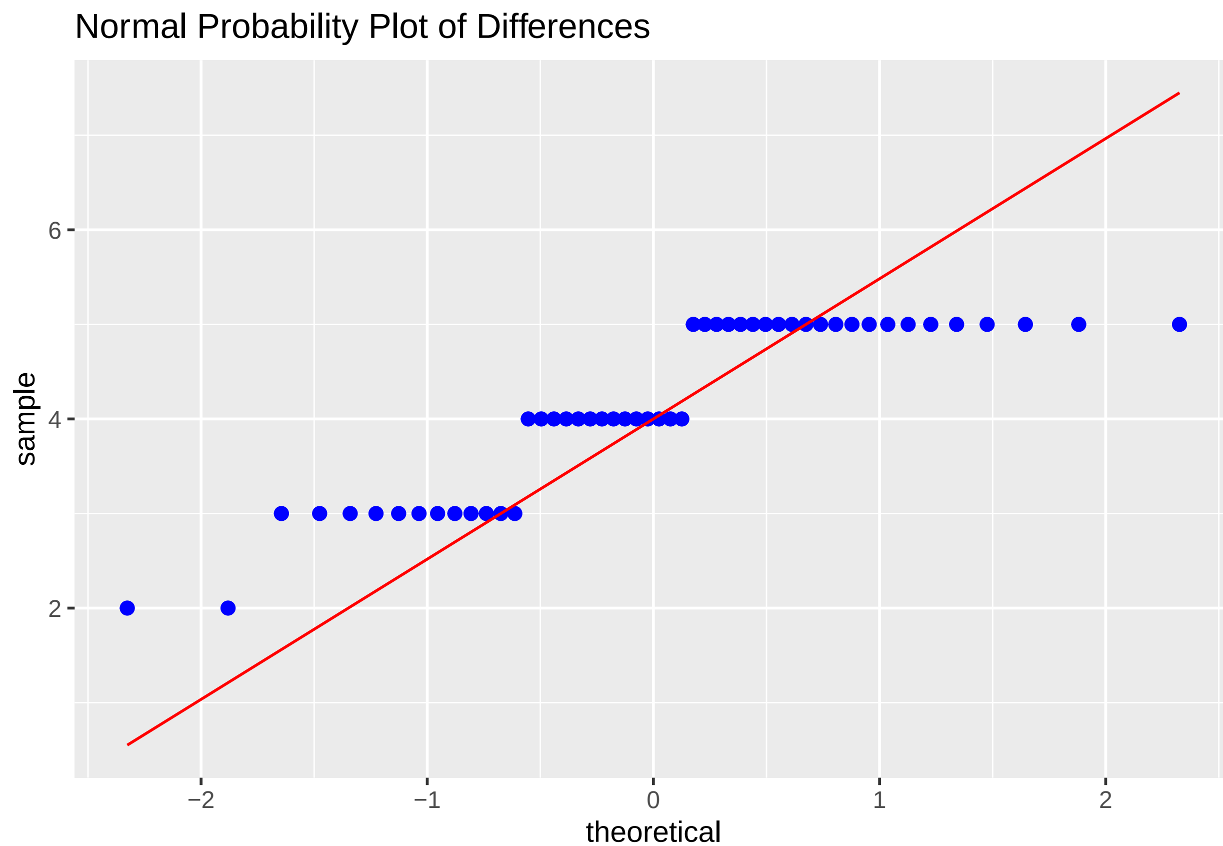
$$T_{obs} = 1.6593$$
$$p - value = P(T_{96} > 1.6593) = 0.0516$$

Notice how the $p - value = P(T_{96} > 1.6593) = 0.0516$ is greater than 0.05 and so we do not reject the null hypothesis. This means that on average, there is not enough statistical evidence to suggest that giving students chocolate increases their overall professor rating.

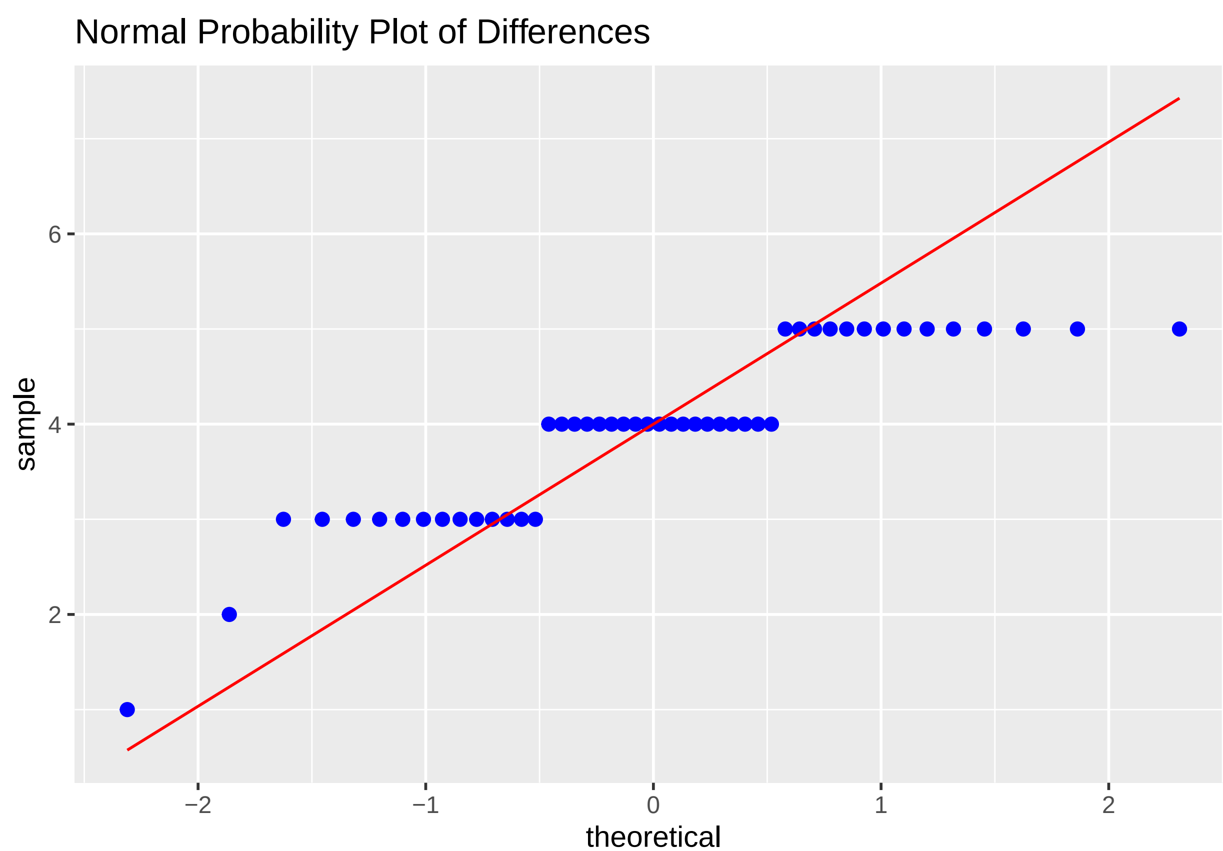
(d) Consider the test suggested in part (b). What are the conditions of this test? Do these condition(s) seem to hold? Carry out the appropriate visual diagnostic(s) that check this condition. Ensure that your data visualization is accompanied by a brief statement/comment regarding the validity/invalidity of the condition(s).

Solution: In order to carry out the statistical test in (b), the data must follow a normal distribution.

```
choc <- data.frame(a=p5$Q9[which(p5$GroupName=="Chocolate")])
nochoc <- data.frame(a=p5$Q9[which(p5$GroupName=="NOChoc")])
ggplot(data=choc, aes(sample = a)) + stat_qq(col="blue", size=2) + stat_qqline(col="red") + ggtitle(
```




```
ggplot(data=nochoc, aes(sample = a)) + stat_qq(col="blue", size=2) + stat_qqline(col="red") + ggtitl
```



From the plots above, we see that the points all lie equally on both sides of the theoretical line. This means that the data is approximately normal. Hence, the test in (b) is valid.

(e) Is there a difference in the variation/standard deviation in the Overall response between students who received chocolate and those that did not receive chocolate? Carry out the appropriate statistical test providing the (i) statistical hypotheses (ii) value of the test statistic (iii) P-value and (iv) your decision/conclusion. Again, ensure you provide justification for your choice of statistical test to apply.

Solution:

(i) We want to test the following hypothesis:

$$H_o : \sigma^2_{chocOverall} = \sigma^2 nochocOverall$$
$$H_a : \sigma^2_{chocOverall} \neq \sigma^2 nochocOverall$$

(ii) and (iii) We perform the test using Levene's test because this test allows us to determine if the two sample variances are the same or not.

```
levene.test(p5$Overall, p5$GroupName)
```

```
##
##  Modified robust Brown-Forsythe Levene-type test based on the absolute
##  deviations from the median
##
## data:  p5$Overall
## Test Statistic = 0.49594, p-value = 0.483
```

From the output above, we have that

$$T_{obs} = \sqrt{0.49594} = 0.70423$$
$$p - value = P(|T_{96}| > 0.70423) = 0.483$$

(iv) From the test above, We get that the $p - value = P(T_{48} > 0.70423) = 0.483$ which is greater than 0.05 and so we do not reject the null hypothesis. This means that the variance between the two samples are the same.

6. Twenty patients who suffer from severe epilepsy participated in a study of a new anticonvulsant drug, valproate. Ten of these patients were chosen at random and were started on a daily regime of receiving valproate on a daily basis, the other ten received a placebo. During the eight-week observation period, the number of major and minor epiletpc seizures were counted for each patient. After this, patients were "crossedover" to the other treatment, and seizure counts were made during the second eight-week observation period. The numbers of minor seizures are provided in the .csv data file found in the link.

(a) State the statistical hypotheses that will test the efficacy, or effectiveness, of valproate.

Solution:

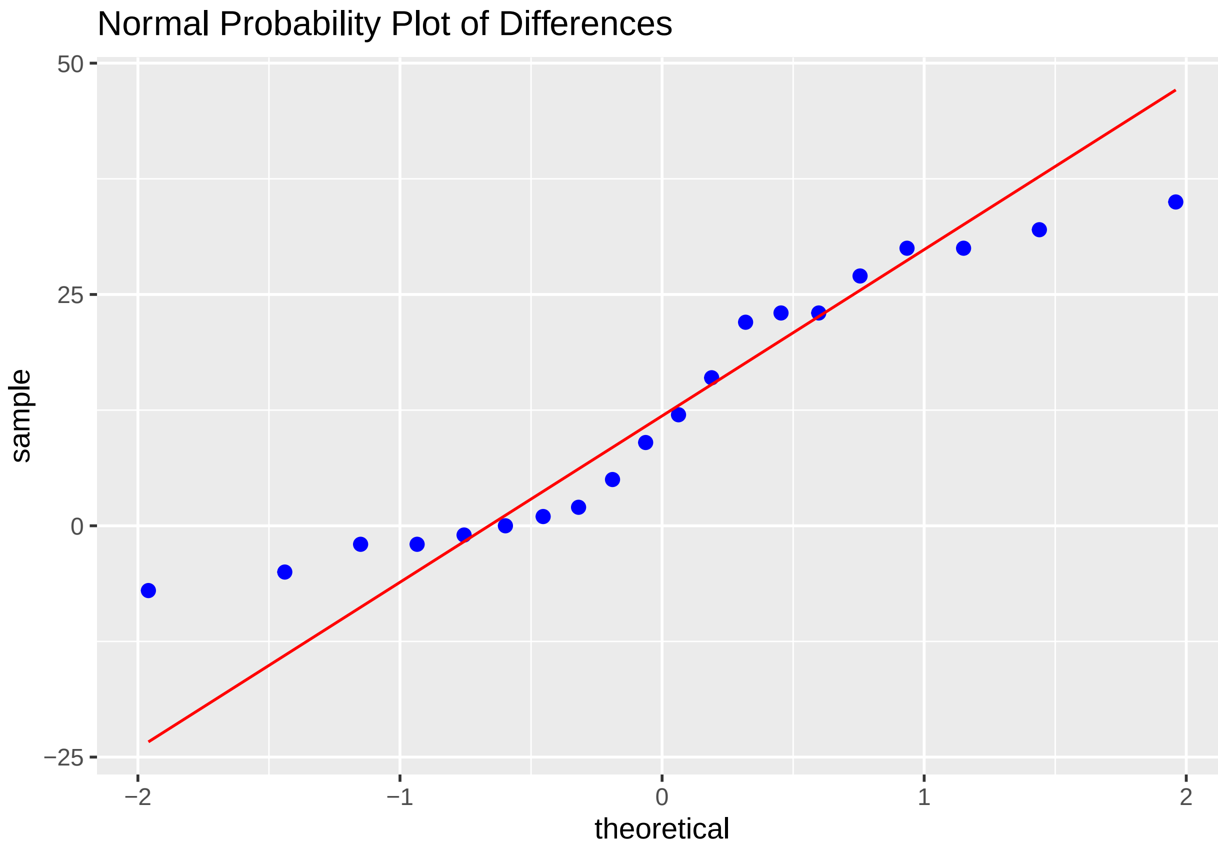
$$H_o : \mu_{Valproate} - \mu_{Placebo} = 0$$
$$H_a : \mu_{Valproate} - \mu_{Placebo} < 0$$

Where $\mu_{Valproate}$ is the mean number of minor seizures for participants that have taken Valproate and $\mu_{Placebo}$ is the mean number of minor seizures for participants that received the placebo.

(b) Carry out the statistical testing using the appropriate statistical method. Ensure you provide the motivation for the test, compute/provide your test statistic and the P-value.

Solution: The appropriate statistical testing is a matched pair t-test. This is because there is data on each patient's number of minor seizures both when they took Valproate and when they took the placebo. This means that data for each patient is comparable since they are from the same population (ie. the same patient). Before we perform the test, since n < 20, we must check if the difference between the two samples follow a normal distribution.

```r
seiz <- read.csv("seizure_data.csv")
seiz[4] <- seiz[2] - seiz[3]
names(seiz)[4] <- "diff"
ggplot(data= seiz, aes(sample = diff)) + stat_qq(col="blue", size=2) + stat_qqline(col="red") + ggti
```



From the plot, the sample almost fits throughout the line and so we will proceed with the matched paired t-test:

```r
seiz <- read.csv("seizure_data.csv")
t.test(seiz$Valproate_period, seiz$Placebo_period, paired=T, alternative="less")
```

```
##
##  Paired t-test
##
## data:  seiz$Valproate_period and seiz$Placebo_period
## t = -3.9586, df = 19, p-value = 0.0004211
## alternative hypothesis: true difference in means is less than 0
## 95 percent confidence interval:
##       -Inf -7.039922
## sample estimates:
## mean of the differences
##                   -12.5
```

From the R code above, we have that:

$$T_{obs} = -3.9586$$
$$p - value = P(T_{19} < -3.9586) = 0.0004211$$

(c) What can you conclude from these data? Also, if you find that valproate is effective, provide a 95% confidence interval that will capture its effect when compared to the placebo.

Solution:

```r
t.test(seiz$Valproate_period, seiz$Placebo_period, paired=T, alternative="two.sided")$conf
```

```
## [1] -19.109137  -5.890863
## attr(,"conf.level")
## [1] 0.95
```

Since the p-value is $P(T_{19} < -3.9586) = 0.0004211$ is less than 0.05 which means that we reject the null hypothesis and conclude that Valproate is effective in decreasing the mean number of minor seizures in epileptic patients. The 95% confidence interval when compared to the placebo is -19.109137 to -5.890863. This means that if the same test was performed 100 times, 95 of the averages computed will be within -19.109137 to -5.890863. As well, Notice how this interval does not cover 0. Hence, Valproate is has an effect with minor seizures.

7. Refer to the data in Question 2.29.

(a) Is there any evidence to support a claim that there is a difference in the mean measurements between the two calipers? Test using $\alpha = 0.05$, using the P-value as a basis for your decision. Assume data is normally distributed.

Solution: We must perform a matched paired t-test since each pair of data is gathered from the same population (ie. the same inspector). We will test the following test of hypothesis:

$$H_o : \mu_{Caliper1} - \mu_{Caliper2} = 0$$
$$H_a : \mu_{Caliper1} - \mu_{Caliper2} \neq 0$$

Where $\mu_{Caliper1}$ is the mean diameter using caliper 1 and $\mu_{Caliper}$ is the mean diamter using caliper 2. Assuming that the data is normally distributed, we perform the test below:

```r
p7 <- read.csv("p7.csv")
p7[1] <- seq(1:nrow(p7))
t.test(p7$Caliper.1, p7$Caliper.2, paired=T, alternative="two.sided")
```

```
##
##  Paired t-test
##
## data:  p7$Caliper.1 and p7$Caliper.2
## t = 0.43179, df = 11, p-value = 0.6742
## alternative hypothesis: true difference in means is not equal to 0
## 95 percent confidence interval:
##  -0.001024344  0.001524344
## sample estimates:
## mean of the differences
##                 0.00025
```

From the R output, we have that:

$$T_{obs} = 0.43179$$
$$p - value = P(|T_{11}| > 0.43179) = 0.6742$$

Since the p-value is $P(|T_{11}| > 0.43179) = 0.6742$ is greater than 0.05, we do not reject the null and conclude that there is no significant evidence that there is a difference between the average diameter measurements between caliper 1 and 2.

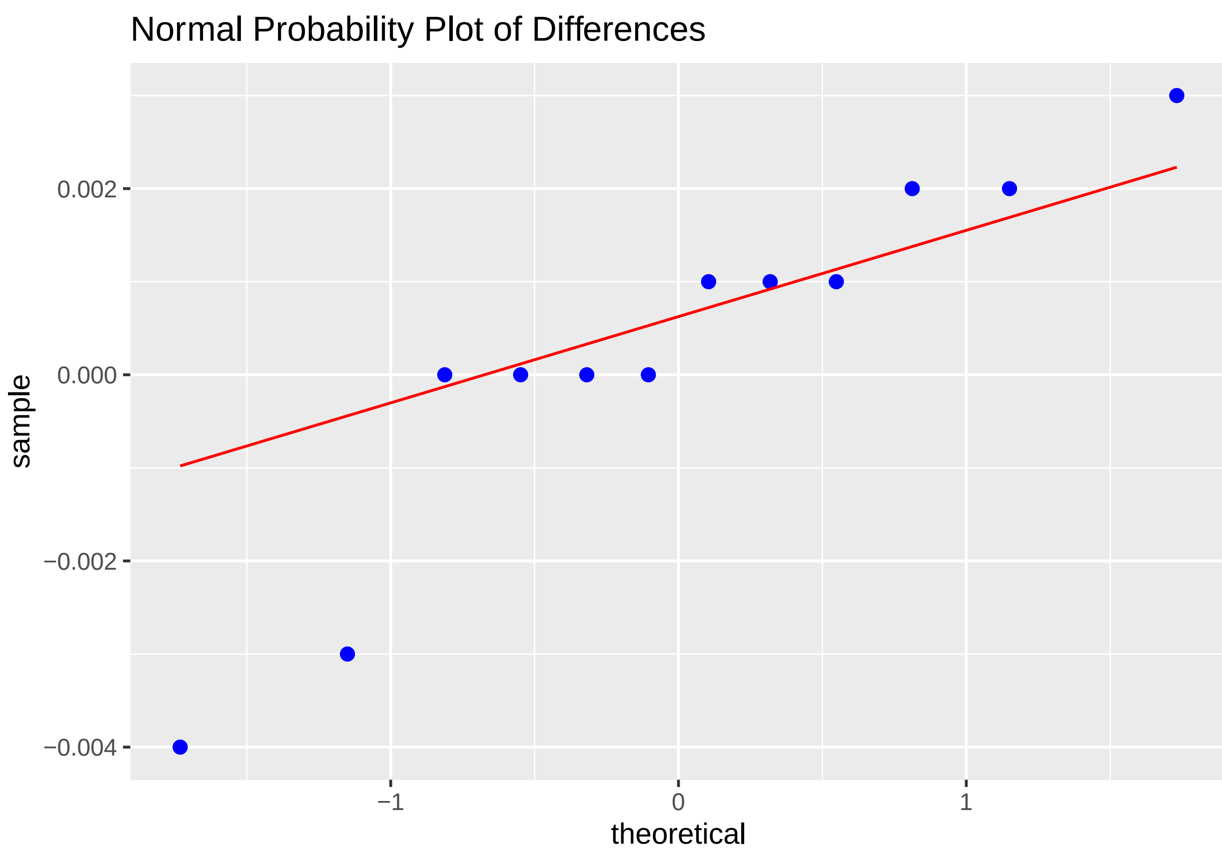
(b) In the context of the data, interpret the meaning of the P-value found in (a).

Solution: From (a) we have that the p-value is $P(|T_{11}| > 0.43179) = 0.6742$. The p-value measures the probability of obtaining a sample as extreme as the observed sample given that the mean diameter measurements given by caliper 1 and 2 are the same. Since this is greater than 0.05, then it is very likely that we observe stronger evidence supporting the claim that the mean diameter measurements are equal.

(c) The test you employed in (a) is based on the assumption that the data is normal. Create a normal probability plot/normal quantile plot, and provide commentary. Ensure you provide your plot.

Solution: The normal qq plot is given by:

```
p7[4] <- p7[2] - p7[3]
names(p7)[4] <- "diff"
ggplot(data=p7, aes(sample = diff)) + stat_qq(col="blue", size=2) + stat_qqline(col="red") + ggtitle
```



The data points all lie around the theoretical line. However, it is hard to to determine whether the difference between the two samples is normal and so we will run a Shapiro-Wilk test of normality:

```
shapiro.test(p7$diff)
```

```
##
##  Shapiro-Wilk normality test
##
## data:  p7$diff
## W = 0.88154, p-value = 0.09172
```

The result from this test gives us a p-value of 0.09 which is greater than 0.05. And so, we can conclude that the population in which this sample is drawn from is normal. Hence, the statistical test we performed in (a) is valid.

(d) Discuss 'why' the normality condition is required for the test you applied in (a).

Solution: In order to use the tests in (a), the normality condition must hold because the sample size (n=12) is less than 25. This means that the sample is not large enough for the central limit theorem to apply. Hence, the sample should first be normally distributed. **MUST REDO**

8. The data appearing in the file resulted from data being collected from various books. For each book, the price of a "used-copy" was observed from the university bookstore's webpage and Amazon.ca.

(a) State the statistical hypothesis that will test that the price of a used-text is higher at the university bookstore's webpage than from Amazon.ca.

Solution: The following is the statistical hypothesis:

$$H_o : \mu_{Amazon} - \mu_{University} = 0$$
$$H_a : \mu_{Amazon} - \mu_{University} < 0$$

Where μ_{Amazon} is the mean price of a used textbook from Amazon and $\mu_{University}$ is the mean price of used textbook from the University bookstore.

(b) Carry out the statistical test relevant to your hypotheses in part (a). Ensure you provide the value of the test statistic andwhere you obtained/computed it from, as well as the P-value.

Solution: A matched paired t-test must be used to determine if the price of a used-text is higher at university. A matched paired t-test is used because each data point in a pair is comparable since they are the same textbook.

```
p8 <- read.csv("bookprices.csv")
t.test(p8$UsedAmazon, p8$UsedBkStore, paired=T, alternative="less")
```

```
##
##  Paired t-test
##
## data:  p8$UsedAmazon and p8$UsedBkStore
## t = -3.0357, df = 14, p-value = 0.004449
## alternative hypothesis: true difference in means is less than 0
## 95 percent confidence interval:
##       -Inf -10.69172
## sample estimates:
## mean of the differences
##                 -25.468
```

From the output above, we have that:

$$T_{obs} = -3.0357$$
$$p - value = P(T_{14} < -3.0357) = 0.004449$$

(c) State your decision and conclusion, in the context of these data.

Solution: From (b) we have that the p-value is 0.004449 which is less than 0.05.Since this is less than 0.05, then it is not likely that we observe stronger evidence supporting the claim that the average textbook prices are the same. This means that we reject the null hypothesis and conclude that there is evidence that on average, used textbook from Amazon are cheaper than used textbooks from the University bookstore.

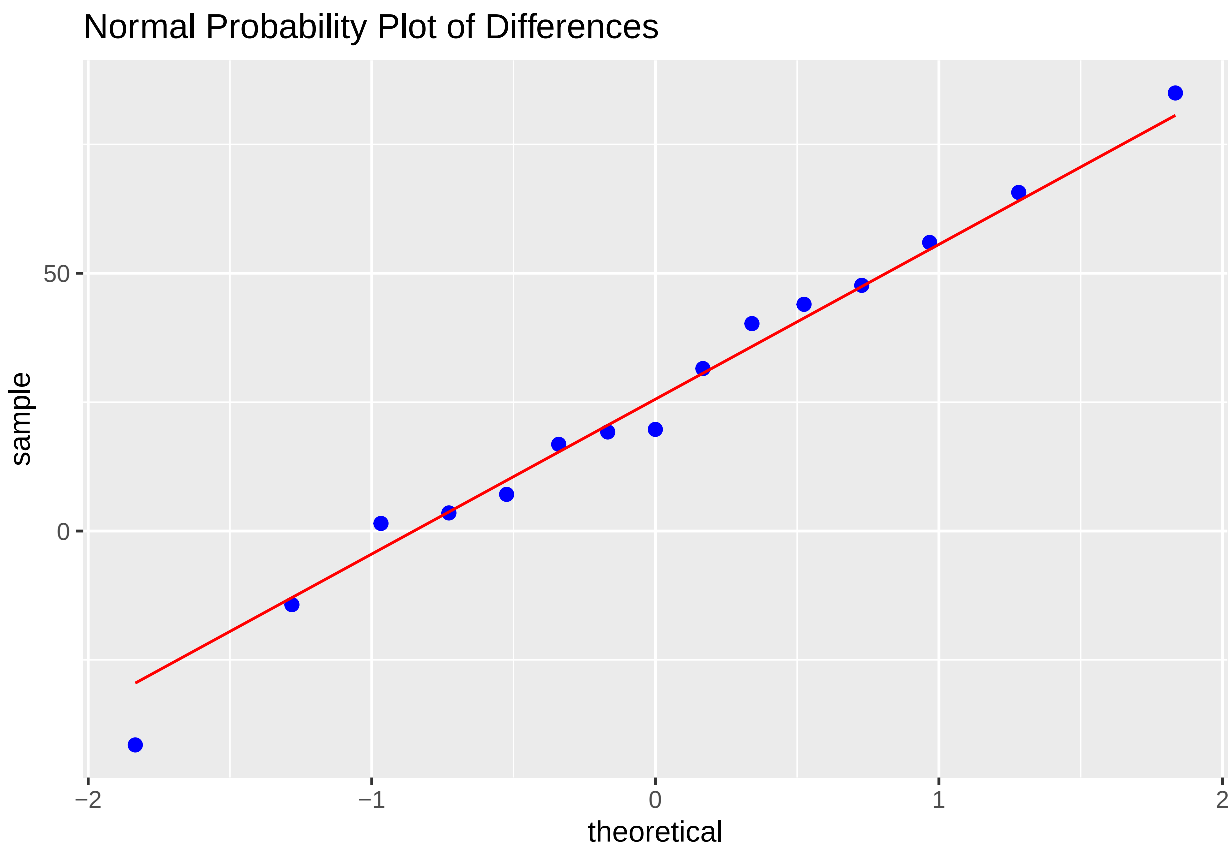
(d) The statistical test carried out in part (b) has a condition. State this condition in the context of these data.

Solution: The condition that must hold in part (b) is that the data must be approximately normally distributed. This is because the sample size (n=12) is less than 25 and so the central limit theorem cannot be applied.

(e) Refer to part (d): Does the condition appear to be satisfied? Ensure you completely justify your answer, providing supporting data visualization(s). No justification = no marks.

Solution:

```
p8 <- read.csv("bookprices.csv")
p8[3] <- p8[1] - p8[2]
names(p8)[3] <- "diff"
ggplot(data=p8, aes(sample = diff)) + stat_qq(col="blue", size=2) + stat_qqline(col="red") + ggtitle
```



From the plot above, we can say that the normal condition is met because the closely to the theoretical line. Hence, the test in (b) is valid.