Chapter 9: Two-Sample Inference

Chapter 7 discussed methods of hypothesis testing about one-population parameters. Chapter 8 discussed methods of estimating population parameters from one sample using confidence intervals. This chapter will look at methods of confidence intervals and hypothesis testing for two populations. Since there are two populations, there are two random variables, two means or proportions, and two samples (though with paired samples you usually consider there to be one sample with pairs collected). Examples of where you would do this are:

Testing and estimating the difference in testosterone levels of men before and after they had children (Gettler, McDade, Feranil & Kuzawa, 2011).

Testing the claim that a diet works by looking at the weight before and after subjects are on the diet.

Estimating the difference in proportion of those who approve of President Obama in the age group 18 to 26 year olds and the 55 and over age group.

All of these are examples of hypothesis tests or confidence intervals for two populations. The methods to conduct these hypothesis tests and confidence intervals will be explored in this method. As a reminder, all hypothesis tests are the same process. The only thing that changes is the formula that you use. Confidence intervals are also the same process, except that the formula is different.

Section 9.1 Two Proportions

There are times you want to test a claim about two population proportions or construct a confidence interval estimate of the difference between two population proportions. As with all other hypothesis tests and confidence intervals, the process is the same though the formulas and assumptions are different.

Hypothesis Test for Two Population Proportion (2-Prop Test)

1. State the random variables and the parameters in words.
   \[ x_1 = \text{number of successes from group 1} \]
   \[ x_2 = \text{number of successes from group 2} \]
   \[ p_1 = \text{proportion of successes in group 1} \]
   \[ p_2 = \text{proportion of successes in group 2} \]

2. State the null and alternative hypotheses and the level of significance
   \[ H_o : p_1 = p_2 \quad \text{or} \quad H_o : p_1 - p_2 = 0 \]
   \[ H_A : p_1 < p_2 \quad H_A : p_1 - p_2 < 0 \]
   \[ H_A : p_1 > p_2 \quad H_A : p_1 - p_2 > 0 \]
   \[ H_A : p_1 \neq p_2 \quad H_A : p_1 - p_2 \neq 0 \]
   Also, state your \( \alpha \) level here.
3. State and check the assumptions for a hypothesis test
   a. A simple random sample of size $n_1$ is taken from population 1, and a simple
      random sample of size $n_2$ is taken from population 2.
   b. The samples are independent.
   c. The assumptions for the binomial distribution are satisfied for both
      populations.
   d. To determine the sampling distribution of $\hat{p}_1$, you need to show that $n_1p_1 \geq 5$
      and $n_1q_1 \geq 5$, where $q_1 = 1 - p_1$. If this requirement is true, then the sampling
      distribution of $\hat{p}_1$ is well approximated by a normal curve. To determine the
      sampling distribution of $\hat{p}_2$, you need to show that $n_2p_2 \geq 5$ and $n_2q_2 \geq 5$,
      where $q_2 = 1 - p_2$. If this requirement is true, then the sampling distribution of
      $\hat{p}_2$ is well approximated by a normal curve. However, you do not know $p_1$
      and $p_2$, so you need to use $\hat{p}_1$ and $\hat{p}_2$ instead. This is not perfect, but it is the
      best you can do. Since $n_1\hat{p}_1 = n_1 \frac{x_1}{n_1} = x_1$ (and similar for the other
      calculations) you just need to make sure that $x_1$, $n_1 - x_1$, $x_2$, and $n_2 - x_2$ are
      all more than 5.

4. Find the sample statistics, test statistic, and p-value

   Sample Proportion:
   
   $n_1$ = size of sample 1
   $n_2$ = size of sample 2
   
   $\hat{p}_1 = \frac{x_1}{n_1}$ (sample 1 proportion)
   $\hat{p}_2 = \frac{x_2}{n_2}$ (sample 2 proportion)
   
   $\hat{q}_1 = 1 - \hat{p}_1$ (complement of $\hat{p}_1$)
   $\hat{q}_2 = 1 - \hat{p}_2$ (complement of $\hat{p}_2$)

   Pooled Sample Proportion, $\bar{p}$:
   
   $\bar{p} = \frac{x_1 + x_2}{n_1 + n_2}$
   $\bar{q} = 1 - \bar{p}$

   Test Statistic:
   
   $z = \frac{(\hat{p}_1 - \hat{p}_2) - (p_1 - p_2)}{\sqrt{\frac{\bar{p}\bar{q}}{n_1} + \frac{\bar{p}\bar{q}}{n_2}}}$

   Usually $p_1 - p_2 = 0$, since $H_0 : p_1 = p_2$

   p-value:
   
   On TI-83/84: use normalcdf(lower limit, upper limit, 0, 1)
   (Note: if $H_A : p_1 < p_2$, then lower limit is $-1E99$ and upper limit is your
   test statistic. If $H_A : p_1 > p_2$, then lower limit is your test statistic and the
   upper limit is $1E99$. If $H_A : p_1 \neq p_2$, then find the p-value for
   $H_A : p_1 < p_2$, and multiply by 2.)
On R: use `pnorm(z, 0, 1)`
(Note: if \( H_A: p_1 < p_2 \), then use `pnorm(z, 0, 1)`. If \( H_A: p_1 > p_2 \), then use \( 1 - \text{pnorm}(z, 0, 1) \). If \( H_A: p_1 \neq p_2 \), then find the p-value for \( H_A: p_1 < p_2 \), and multiply by 2.)

5. Conclusion
This is where you write reject \( H_o \) or fail to reject \( H_o \). The rule is: if the p-value < \( \alpha \), then reject \( H_o \). If the p-value \( \geq \alpha \), then fail to reject \( H_o \).

6. Interpretation
This is where you interpret in real world terms the conclusion to the test. The conclusion for a hypothesis test is that you either have enough evidence to show \( H_A \) is true, or you do not have enough evidence to show \( H_A \) is true.

### Confidence Interval for the Difference Between Two Population Proportion (2-Prop Interval)

The confidence interval for the difference in proportions has the same random variables and proportions and the same assumptions as the hypothesis test for two proportions. If you have already completed the hypothesis test, then you do not need to state them again. If you haven’t completed the hypothesis test, then state the random variables and proportions and state and check the assumptions before completing the confidence interval step.

1. Find the sample statistics and the confidence interval
   Sample Proportion:
   \[
   n_1 = \text{size of sample 1} \quad n_2 = \text{size of sample 2}
   \]
   \[
   \hat{p}_1 = \frac{x_1}{n_1} \quad \text{(sample 1 proportion)} \quad \hat{p}_2 = \frac{x_2}{n_2} \quad \text{(sample 2 proportion)}
   \]
   \[
   \hat{q}_1 = 1 - \hat{p}_1 \quad \text{(complement of } \hat{p}_1) \quad \hat{q}_2 = 1 - \hat{p}_2 \quad \text{(complement of } \hat{p}_2)
   \]
   Confidence Interval:
   The confidence interval estimate of the difference \( p_1 - p_2 \) is
   \[
   (\hat{p}_1 - \hat{p}_2) - E < p_1 - p_2 < (\hat{p}_1 - \hat{p}_2) + E
   \]
   where the margin of error \( E \) is given by \( E = z_c \sqrt{\frac{\hat{p}_1 \hat{q}_1}{n_1} + \frac{\hat{p}_2 \hat{q}_2}{n_2}} \)
   \( z_c \) = critical value

2. Statistical Interpretation: In general this looks like, “there is a C% chance that
   \( (\hat{p}_1 - \hat{p}_2) - E < p_1 - p_2 < (\hat{p}_1 - \hat{p}_2) + E \) contains the true difference in proportions.”

3. Real World Interpretation: This is where you state how much more (or less) the first proportion is from the second proportion.
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The critical value is a value from the normal distribution. Since a confidence interval is found by adding and subtracting a margin of error amount from the sample proportion, and the interval has a probability of being true, then you can think of this as the statement

\[ P\left( (\hat{p}_1 - \hat{p}_2) - E < p_1 - p_2 < (\hat{p}_1 - \hat{p}_2) + E \right) = C. \]

So you can use the invNorm command on the TI-83/84 calculator or qnorm on R to find the critical value. These are always the same value, so it is easier to just look at the table A.1 in the Appendix.

Example #9.1.1: Hypothesis Test for Two Population Proportions

Do husbands cheat on their wives more than wives cheat on their husbands ("Statistics brain," 2013)? Suppose you take a group of 1000 randomly selected husbands and find that 231 had cheated on their wives. Suppose in a group of 1200 randomly selected wives, 176 cheated on their husbands. Do the data show that the proportion of husbands who cheat on their wives are more than the proportion of wives who cheat on their husbands. Test at the 5% level.

Solution:

1. State the random variables and the parameters in words.
   \[ x_1 = \text{number of husbands who cheat on his wife} \]
   \[ x_2 = \text{number of wives who cheat on her husband} \]
   \[ p_1 = \text{proportion of husbands who cheat on his wife} \]
   \[ p_2 = \text{proportion of wives who cheat on her husband} \]

2. State the null and alternative hypotheses and the level of significance
   \[ H_o : p_1 = p_2 \quad \text{or} \quad H_o : p_1 - p_2 = 0 \]
   \[ H_A : p_1 > p_2 \quad H_A : p_1 - p_2 > 0 \]
   \[ \alpha = 0.05 \]

3. State and check the assumptions for a hypothesis test
   a. A simple random sample of 1000 responses about cheating from husbands is taken. This was stated in the problem. A simple random sample of 1200 responses about cheating from wives is taken. This was stated in the problem.
   b. The samples are independent. This is true since the samples involved different genders.
   c. The properties of the binomial distribution are satisfied in both populations. This is true since there are only two responses, there are a fixed number of trials, the probability of a success is the same, and the trials are independent.
   d. The sampling distributions of \( \hat{p}_1 \) and \( \hat{p}_2 \) can be approximated with a normal distribution.
   \[ x_1 = 231, \; n_1 - x_1 = 1000 - 231 = 769, \; x_2 = 176, \text{ and} \]
   \[ n_2 - x_2 = 1200 - 176 = 1024 \] are all greater than or equal to 5. So both sampling distributions of \( \hat{p}_1 \) and \( \hat{p}_2 \) can be approximated with a normal distribution.
4. Find the sample statistics, test statistic, and p-value

Sample Proportion:

\[ n_1 = 1000 \]
\[ \hat{p}_1 = \frac{231}{1000} = 0.231 \]
\[ \hat{q}_1 = 1 - \frac{231}{1000} = \frac{769}{1000} = 0.769 \]
\[ n_2 = 1200 \]
\[ \hat{p}_2 = \frac{176}{1200} \approx 0.1467 \]
\[ \hat{q}_2 = 1 - \frac{176}{1200} = \frac{1024}{1200} \approx 0.8533 \]

Pooled Sample Proportion, \( \bar{p} \):

\[ \bar{p} = \frac{231 + 176}{1000 + 1200} = \frac{407}{2200} = 0.185 \]
\[ \bar{q} = 1 - \frac{407}{2200} = \frac{1793}{2200} = 0.815 \]

Test Statistic:

\[ z = \frac{(0.231 - 0.1467) - 0}{\sqrt{\frac{0.185 \times 0.815}{1000} + \frac{0.185 \times 0.815}{1200}}} = 5.0704 \]

p-value:

On TI-83/84: \( \text{normalcdf}(5.0704,1E99,0,1) = 1.988 \times 10^{-7} \)

On R: \( 1 - \text{pnorm}(5.0704,0,1) = 1.988 \times 10^{-7} \)
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2-PropZTest
P1 > P2
z=5.072404516
P=1.9674319E-7
P1=.231
P2=.1466666667
ΔP=.185

On R: prop.test(c(x1,x2),c(n1,n2),alternative = "less" or "greater"). For this example, prop.test(c(231,176), c(1000, 1200), alternative="greater")

2-sample test for equality of proportions with continuity correction

data:  c(231, 176) out of c(1000, 1200)
X-squared = 25.173, df = 1, p-value = 2.621e-07
alternative hypothesis: greater
95 percent confidence interval:
0.05579805 1.00000000
sample estimates:
prop 1    prop 2
0.2310000 0.1466667

Note: the answer from R is the p-value. It is different from the formula or the TI-83/84 calculator due to a continuity correction that R does.

5. Conclusion
   Reject \( H_0 \), since the p-value is less than 5%.

6. Interpretation
   This is enough evidence to show that the proportion of husbands having affairs is more than the proportion of wives having affairs.

Example #9.1.2: Confidence Interval for Two Population Proportions
Do more husbands cheat on their wives more than wives cheat on the husbands ("Statistics brain," 2013)? Suppose you take a group of 1000 randomly selected husbands and find that 231 had cheated on their wives. Suppose in a group of 1200 randomly selected wives, 176 cheated on their husbands. Estimate the difference in the proportion of husbands and wives who cheat on their spouses using a 95% confidence level.

Solution:
1. State the random variables and the parameters in words.
   These were stated in example #9.3.1, but are reproduced here for reference.
2. State and check the assumptions for the confidence interval
   The assumptions were stated and checked in example #9.1.1.

3. Find the sample statistics and the confidence interval

   **Sample Proportion:**
   \[
   n_1 = 1000 \quad \quad \quad \quad n_2 = 1200 \\
   \hat{p}_1 = \frac{231}{1000} = 0.231 \quad \quad \quad \quad \hat{p}_2 = \frac{176}{1200} \approx 0.1467 \\
   \hat{q}_1 = 1 - \frac{231}{1000} = 0.769 \quad \quad \quad \quad \hat{q}_2 = 1 - \frac{176}{1200} = \frac{1024}{1200} \approx 0.8533
   \]

   **Confidence Interval:**
   \[
   z_c = 1.96 \\
   E = 1.96 \sqrt{\frac{0.231 \times 0.769 + 0.1467 \times 0.8533}{1000} + \frac{0.1467 \times 0.8533}{1200}} = 0.033
   \]

   The confidence interval estimate of the difference \( p_1 - p_2 \) is
   \[
   (\hat{p}_1 - \hat{p}_2) - E < p_1 - p_2 < (\hat{p}_1 - \hat{p}_2) + E \\
   (0.231 - 0.1467) - 0.033 < p_1 - p_2 < (0.231 - 0.1467) + 0.033 \\
   0.0513 < p_1 - p_2 < 0.1173
   \]

**Figure #9.1.3: Setup for 2-PropZInt on TI-83/84 Calculator**
Figure #9.1.4: Results for 2-PropZInt on TI-83/84 Calculator

\[
\begin{array}{c}
\text{2-PropZInt} \\
(0.05142, 0.11724) \\
\hat{p}_1 = .231 \\
\hat{p}_2 = .1466666667 \\
n_1 = 1000 \\
n_2 = 1200
\end{array}
\]

On R: \( \text{prop.test}(c(x_1, x_2), c(n_1, n_2), \text{conf.level} = C) \), where \( C \) is in decimal form. For this example, \( \text{prop.test}(c(231,176), c(1000, 1200), \text{conf.level}=0.95) \)

2-sample test for equality of proportions with continuity correction

data: \( c(231, 176) \) out of \( c(1000, 1200) \)
X-squared = 25.173, df = 1, p-value = 5.241e-07
alternative hypothesis: two.sided
95 percent confidence interval:
0.05050705 0.11815962
sample estimates:
prop 1  prop 2
0.2310000 0.1466667

Note: the answer from R is the confidence interval. It is different from the formula or the TI-83/84 calculator due to a continuity correction that R does.

4. Statistical Interpretation: There is a 95% chance that \( 0.0505 < p_1 - p_2 < 0.1182 \) contains the true difference in proportions.

5. Real World Interpretation: The proportion of husbands who cheat is anywhere from 5.05% to 11.82% higher than the proportion of wives who cheat.
Section 9.1: Homework
In each problem show all steps of the hypothesis test or confidence interval. If some of
the assumptions are not met, note that the results of the test or interval may not be correct
and then continue the process of the hypothesis test or confidence interval.

1.) Many high school students take the AP tests in different subject areas. In 2007, of
the 144,796 students who took the biology exam 84,199 of them were female. In
that same year, of the 211,693 students who took the calculus AB exam 102,598
of them were female ("AP exam scores," 2013). Is there enough evidence to
show that the proportion of female students taking the biology exam is higher
than the proportion of female students taking the calculus AB exam? Test at the
5% level.

2.) Many high school students take the AP tests in different subject areas. In 2007, of
the 144,796 students who took the biology exam 84,199 of them were female. In
that same year, of the 211,693 students who took the calculus AB exam 102,598
of them were female ("AP exam scores," 2013). Estimate the difference in the
proportion of female students taking the biology exam and female students taking
the calculus AB exam using a 90% confidence level.

3.) Many high school students take the AP tests in different subject areas. In 2007, of
the 211,693 students who took the calculus AB exam 102,598 of them were
female and 109,095 of them were male ("AP exam scores," 2013). Is there
enough evidence to show that the proportion of female students taking the
calculus AB exam is different from the proportion of male students taking the
calculus AB exam? Test at the 5% level.

4.) Many high school students take the AP tests in different subject areas. In 2007, of
the 211,693 students who took the calculus AB exam 102,598 of them were
female and 109,095 of them were male ("AP exam scores," 2013). Estimate using
a 90% level the difference in proportion of female students taking the calculus AB
exam versus male students taking the calculus AB exam.

5.) Are there more children diagnosed with Autism Spectrum Disorder (ASD) in
states that have larger urban areas over states that are mostly rural? In the state of
Pennsylvania, a fairly urban state, there are 245 eight year olds diagnosed with
ASD out of 18,440 eight year olds evaluated. In the state of Utah, a fairly rural
state, there are 45 eight year olds diagnosed with ASD out of 2,123 eight year
olds evaluated ("Autism and developmental," 2008). Is there enough evidence to
show that the proportion of children diagnosed with ASD in Pennsylvania is more
than the proportion in Utah? Test at the 1% level.
6.) Are there more children diagnosed with Autism Spectrum Disorder (ASD) in states that have larger urban areas over states that are mostly rural? In the state of Pennsylvania, a fairly urban state, there are 245 eight year olds diagnosed with ASD out of 18,440 eight year olds evaluated. In the state of Utah, a fairly rural state, there are 45 eight year olds diagnosed with ASD out of 2,123 eight year olds evaluated ("Autism and developmental," 2008). Estimate the difference in proportion of children diagnosed with ASD between Pennsylvania and Utah. Use a 98% confidence level.

7.) A child dying from an accidental poisoning is a terrible incident. Is it more likely that a male child will get into poison than a female child? To find this out, data was collected that showed that out of 1830 children between the ages one and four who pass away from poisoning, 1031 were males and 799 were females (Flanagan, Rooney & Griffiths, 2005). Do the data show that there are more male children dying of poisoning than female children? Test at the 1% level.

8.) A child dying from an accidental poisoning is a terrible incident. Is it more likely that a male child will get into poison than a female child? To find this out, data was collected that showed that out of 1830 children between the ages one and four who pass away from poisoning, 1031 were males and 799 were females (Flanagan, Rooney & Griffiths, 2005). Compute a 99% confidence interval for the difference in proportions of poisoning deaths of male and female children ages one to four.
Section 9.2 Paired Samples for Two Means
Are two populations the same?  Is the average height of men taller than the average height of women?  Is the mean weight less after a diet than before?

You can compare populations by comparing their means.  You take a sample from each population and compare the statistics.

Anytime you compare two populations you need to know if the samples are independent or dependent.  The formulas you use are different for different types of samples.

If how you choose one sample has no effect on the way you choose the other sample, the two samples are independent.  The way to think about it is that in independent samples, the individuals from one sample are overall different from the individuals from the other sample.  This will mean that sample one has no affect on sample two.  The sample values from one sample are not related or paired with values from the other sample.

If you choose the samples so that a measurement in one sample is paired with a measurement from the other sample, the samples are dependent or matched or paired.  (Often a before and after situation.)  You want to make sure the there is a meaning for pairing data values from one sample with a specific data value from the other sample.  One way to think about it is that in dependent samples, the individuals from one sample are the same individuals from the other sample, though there can be other reasons to pair values.  This makes the sample values from each sample paired.

Example #9.2.1: Independent or Dependent Samples
Determine if the following are dependent or independent samples.

a.) Randomly choose 5 men and 6 women and compare their heights

Solution:
Independent, since there is no reason that one value belongs to another.  The individuals are not the same for both samples.  The individuals are definitely different.  A way to think about this is that the knowledge that a man is chosen in one sample does not give any information about any of the woman chosen in the other sample.

b.) Choose 10 men and weigh them. Give them a new wonder diet drug and later weigh them again.

Solution:
Dependent, since each person’s before weight can be matched with their after weight.  The individuals are the same for both samples.  A way to think about this is that the knowledge that a person weighs 400 pounds at the beginning will tell you something about their weight after the diet drug.
c.) Take 10 people and measure the strength of their dominant arm and their non-dominant arm.

**Solution:**
Dependent, since you can match the two arm strengths. The individuals are the same for both samples. So the knowledge of one person’s dominant arm strength will tell you something about the strength of their non-dominant arm.

To analyze data when there are matched or paired samples, called dependent samples, you conduct a paired t-test. Since the samples are matched, you can find the difference between the values of the two random variables.

**Hypothesis Test for Two Sample Paired t-Test**

1. State the random variables and the parameters in words.
   
   \[ x_1 = \text{random variable 1} \]
   
   \[ x_2 = \text{random variable 2} \]
   
   \[ \mu_1 = \text{mean of random variable 1} \]
   
   \[ \mu_2 = \text{mean of random variable 2} \]

2. State the null and alternative hypotheses and the level of significance

   The usual hypotheses would be
   
   \[ H_0 : \mu_1 = \mu_2 \quad \text{or} \quad H_0 : \mu_1 - \mu_2 = 0 \]
   
   \[ H_A : \mu_1 < \mu_2 \]
   
   \[ H_A : \mu_1 - \mu_2 < 0 \]
   
   \[ H_A : \mu_1 > \mu_2 \]
   
   \[ H_A : \mu_1 - \mu_2 > 0 \]
   
   \[ H_A : \mu_1 \neq \mu_2 \]
   
   \[ H_A : \mu_1 - \mu_2 \neq 0 \]

   However, since you are finding the differences, then you can actually think of \[ \mu_1 - \mu_2 = \mu_d, \ \mu_d = \text{population mean value of the differences} \]

   So the hypotheses become
   
   \[ H_0 : \mu_d = 0 \]
   
   \[ H_1 : \mu_d < 0 \]
   
   \[ H_A : \mu_d > 0 \]
   
   \[ H_A : \mu_d \neq 0 \]

   Also, state your \( \alpha \) level here.

3. State and check the assumptions for the hypothesis test
   
   a. A random sample of \( n \) pairs is taken.
   
   b. The population of the difference between random variables is normally distributed. In this case the population you are interested in has to do with the differences that you find. It does not matter if each random variable is normally distributed. It is only important if the differences you find are normally distributed. Just as before, the t-test is fairly robust to the assumption if the sample size is large. This means that if this assumption isn’t
met, but your sample size is quite large (over 30), then the results of the t-test are valid.

4. Find the sample statistic, test statistic, and p-value

Sample Statistic:
Difference: \( d = x_1 - x_2 \) for each pair

Sample mean of the differences: \( \bar{d} = \frac{\sum d}{n} \)

Standard deviation of the differences: \( s_d = \frac{\sum(d - \bar{d})^2}{n-1} \)

Number of pairs: \( n \)

Test Statistic:
\[
t = \frac{\bar{d} - \mu_d}{\frac{s_d}{\sqrt{n}}}\]
with degrees of freedom = \( df = n - 1 \)

Note: \( \mu_d = 0 \) in most cases.

p-value:
On TI-83/84: Use \( \text{tcdf} \) (lower limit, upper limit, \( df \))
(Note: if \( H_A : \mu_d < 0 \), then lower limit is \(-1E99\) and upper limit is your test statistic. If \( H_A : \mu_d > 0 \), then lower limit is your test statistic and the upper limit is \( 1E99 \). If \( H_A : \mu_d \neq 0 \), then find the p-value for \( H_A : \mu_d < 0 \), and multiply by 2.)

On R: Use \( \text{pt} \) (\( t, \ df \))
(Note: if \( H_A : \mu_d < 0 \), use \( \text{pt} \) (\( t, \ df \)). If \( H_A : \mu_d > 0 \), use \( 1 - \text{pt} \) (\( t, \ df \)). If \( H_A : \mu_d \neq 0 \), then find the p-value for \( H_A : \mu_d < 0 \), and multiply by 2.)

5. Conclusion
This is where you write reject \( H_o \) or fail to reject \( H_o \). The rule is: if the p-value < \( \alpha \), then reject \( H_o \). If the p-value \( \geq \alpha \), then fail to reject \( H_o \).

6. Interpretation
This is where you interpret in real world terms the conclusion to the test. The conclusion for a hypothesis test is that you either have enough evidence to show \( H_A \) is true, or you do not have enough evidence to show \( H_A \) is true.
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Confidence Interval for Difference in Means from Paired Samples (t-Interval)
The confidence interval for the difference in means has the same random variables and means and the same assumptions as the hypothesis test for two paired samples. If you have already completed the hypothesis test, then you do not need to state them again. If you haven’t completed the hypothesis test, then state the random variables and means, and state and check the assumptions before completing the confidence interval step.

1. Find the sample statistic and confidence interval
   Sample Statistic:
   Difference: \( d = x_1 - x_2 \)
   Sample mean of the differences: \( \bar{d} = \frac{\sum d}{n} \)
   Standard deviation of the differences: \( s_d = \sqrt{\frac{\sum (d - \bar{d})^2}{n-1}} \)
   Number of pairs: \( n \)
   Confidence Interval:
   The confidence interval estimate of the difference \( \mu_d = \mu_1 - \mu_2 \) is
   \( \bar{d} - E < \mu_d < \bar{d} + E \)
   \( E = t_c \frac{s_d}{\sqrt{n}} \)
   \( t_c \) is the critical value where degrees of freedom \( df = n - 1 \)

2. Statistical Interpretation: In general this looks like, “there is a \( C\% \) chance that the statement \( \bar{d} - E < \mu_d < \bar{d} + E \) contains the true mean difference.”

3. Real World Interpretation: This is where you state what interval contains the true mean difference.

The critical value is a value from the Student’s t-distribution. Since a confidence interval is found by adding and subtracting a margin of error amount from the sample mean, and the interval has a probability of containing the true mean difference, then you can think of this as the statement \( P(\bar{d} - E < \mu_d < \bar{d} + E) = C \). To find the critical value, you use table A.2 in the Appendix.

How to check the assumptions of t-test and confidence interval:
In order for the t-test or confidence interval to be valid, the assumptions of the test must be met. So whenever you run a t-test or confidence interval, you must make sure the assumptions are met. So you need to check them. Here is how you do this:

1. For the assumption that the sample is a random sample, describe how you took the samples. Make sure your sampling technique is random and that the samples were dependent.
2. For the assumption that the population of the differences is normal, remember the process of assessing normality from chapter 6.
Example #9.2.2: Hypothesis Test for Paired Samples Using the Formula

A researcher wants to see if a weight loss program is effective. She measures the weight of 6 randomly selected women before and after the weight loss program (see table #9.2.1). Is there evidence that the weight loss program is effective? Test at the 5% level.

Table #9.2.1: Data of Before and After Weights

<table>
<thead>
<tr>
<th>Person</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight before</td>
<td>165</td>
<td>172</td>
<td>181</td>
<td>185</td>
<td>168</td>
<td>175</td>
</tr>
<tr>
<td>Weight after</td>
<td>143</td>
<td>151</td>
<td>156</td>
<td>161</td>
<td>152</td>
<td>154</td>
</tr>
</tbody>
</table>

Solution:
1. State the random variables and the parameters in words.
   \( x_1 = \) weight of a woman after the weight loss program
   \( x_2 = \) weight of a woman before the weight loss program
   \( \mu_1 = \) mean weight of a woman after the weight loss program
   \( \mu_2 = \) mean weight of a woman before the weight loss program

2. State the null and alternative hypotheses and the level of significance
   \( H_0 : \mu_d = 0 \)
   \( H_A : \mu_d < 0 \)
   \( \alpha = 0.05 \)

3. State and check the assumptions for the hypothesis test
   a. A random sample of 6 pairs of weights before and after was taken. This was stated in the problem, since the women were chosen randomly.
   b. The population of the difference in after and before weights is normally distributed. To see if this is true, look at the histogram, number of outliers, and the normal probability plot. (If you wish, you can look at the normal probability plot first. If it doesn’t look linear, then you may want to look at the histogram and number of outliers at this point.)
Chapter 9: Two-Sample Inference

Figure #9.2.1: Histogram of Differences in Weights

This histogram looks somewhat bell shaped.

Figure #9.2.2: Modified Box Plot of Differences in Weights

There is only one outlier in the difference data set.

Figure #9.2.3: Normal Quantile Plot of Differences in Weights

The probability plot on the differences looks somewhat linear. So you can assume that the distribution of the difference in weights is normal.
4. Find the sample statistic, test statistic, and p-value

Sample Statistics:

<table>
<thead>
<tr>
<th>Person</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight after, $x_1$</td>
<td>143</td>
<td>151</td>
<td>156</td>
<td>161</td>
<td>152</td>
<td>154</td>
</tr>
<tr>
<td>Weight before, $x_2$</td>
<td>165</td>
<td>172</td>
<td>181</td>
<td>185</td>
<td>168</td>
<td>175</td>
</tr>
<tr>
<td>$d = x_1 - x_2$</td>
<td>−22</td>
<td>−21</td>
<td>−25</td>
<td>−24</td>
<td>−16</td>
<td>−21</td>
</tr>
</tbody>
</table>

The mean and standard deviation are

\[
\bar{d} = -21.5 \\
\sigma_d = 3.15
\]

Test Statistic:

\[
t = \frac{\bar{d} - \mu_d}{\sigma_d / \sqrt{n}} = \frac{-21.5 - 0}{3.15 / \sqrt{6}} = -16.779
\]

p-value:

There are six pairs so the degrees of freedom are

\[df = n - 1 = 6 - 1 = 5\]

Since $H_1: \mu_d < 0$, then p-value

Using TI-83/84: $tcdf(-1E99, -16.779, 5) \approx 6.87 \times 10^{-6}$

Using R: $pt(-16.779, 5) = 6.87 \times 10^{-6}$

5. Conclusion
Since the p-value < 0.05, reject $H_o$.

6. Interpretation
There is enough evidence to show that the weight loss program is effective.

Note: Just because the hypothesis test says the program is effective doesn’t mean you should go out and use it right away. The program has statistical significance, but that doesn’t mean it has practical significance. You need to see how much weight a person loses, and you need to look at how safe it is, how expensive, does it work in the long term, and other type questions. Remember to look at the practical significance in all situations. In this case, the average weight loss was 21.5 pounds, which is very practically significant. Do remember to look at the safety and expense of the drug also.

Example #9.2.3: Hypothesis Test for Paired Samples Using Technology

The New Zealand Air Force purchased a batch of flight helmets. They then found out that the helmets didn’t fit. In order to make sure that they order the correct size helmets, they measured the head size of recruits. To save money, they wanted to use cardboard calipers, but were not sure if they will be accurate
enough. So they took 18 recruits and measured their heads with the cardboard calipers and also with metal calipers. The data in centimeters (cm) is in table #9.2.3 ("NZ helmet size," 2013). Do the data provide enough evidence to show that there is a difference in measurements between the cardboard and metal calipers? Use a 5% level of significance.

**Table #9.2.3: Data for Head Measurements**

<table>
<thead>
<tr>
<th>Cardboard</th>
<th>Metal</th>
</tr>
</thead>
<tbody>
<tr>
<td>146</td>
<td>145</td>
</tr>
<tr>
<td>151</td>
<td>153</td>
</tr>
<tr>
<td>163</td>
<td>161</td>
</tr>
<tr>
<td>152</td>
<td>151</td>
</tr>
<tr>
<td>151</td>
<td>145</td>
</tr>
<tr>
<td>151</td>
<td>150</td>
</tr>
<tr>
<td>149</td>
<td>150</td>
</tr>
<tr>
<td>166</td>
<td>163</td>
</tr>
<tr>
<td>149</td>
<td>147</td>
</tr>
<tr>
<td>155</td>
<td>154</td>
</tr>
<tr>
<td>155</td>
<td>150</td>
</tr>
<tr>
<td>156</td>
<td>156</td>
</tr>
<tr>
<td>162</td>
<td>161</td>
</tr>
<tr>
<td>150</td>
<td>152</td>
</tr>
<tr>
<td>156</td>
<td>154</td>
</tr>
<tr>
<td>158</td>
<td>154</td>
</tr>
<tr>
<td>149</td>
<td>147</td>
</tr>
<tr>
<td>163</td>
<td>160</td>
</tr>
</tbody>
</table>

**Solution:**

1. State the random variables and the parameters in words.
   \[ x_1 = \text{head measurement of recruit using cardboard caliper} \]
   \[ x_2 = \text{head measurement of recruit using metal caliper} \]
   \[ \mu_1 = \text{mean head measurement of recruit using cardboard caliper} \]
   \[ \mu_2 = \text{mean head measurement of recruit using metal caliper} \]

2. State the null and alternative hypotheses and the level of significance
   \[ H_0 : \mu_d = 0 \]
   \[ H_A : \mu_d \neq 0 \]
   \[ \alpha = 0.05 \]

3. State and check the assumptions for the hypothesis test
   a. A random sample of 18 pairs of head measures of recruits with cardboard and metal caliper was taken. This was not stated, but probably could be safely assumed.
b. The population of the difference in head measurements between cardboard and metal calipers is normally distributed. To see if this is true, look at the histogram, number of outliers, and the normal probability plot. (If you wish, you can look at the normal probability plot first. If it doesn’t look linear, then you may want to look at the histogram and number of outliers at this point.)

**Figure #9.2.4: Histogram of Differences in Head Measurements**

This histogram looks bell shaped.

**Figure #9.2.5: Modified Box Plot of Differences in Head Measurements**

There are no outliers in the difference data set.
The probability plot on the differences looks somewhat linear. So you can assume that the distribution of the difference in weights is normal.

4. Find the sample statistic, test statistic, and p-value
Using the TI-83/84, put $x_1$ into L1 and $x_2$ into L2. Then go onto the name L3, and type $L1 - L2$. The calculator will calculate the differences for you and put them in L3. Now go into STAT and move over to TESTS. Choose T-Test. The setup for the calculator is in figure #9.2.7.

Figure #9.2.7: Setup for T-Test on Ti-83/84 Calculator

Once you press ENTER on Calculate you will see the result shown in figure #9.2.8.
Chapter 9: Two-Sample Inference

Figure #9.2.8: Results of T-Test on TI-83/84 Calculator

Using R: command is `t.test(variable1, variable2, paired = TRUE, alternative = "less" or "greater")`. For this example, the command would be `t.test(cardboard, metal, paired = TRUE)`

Paired t-test

data:  cardboard and metal
t = 3.1854, df = 17, p-value = 0.005415
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
0.5440163 2.6782738
sample estimates:
mean of the differences
1.611111

The $t = 3.185$ is the test statistic. The p-value is 0.0054147206.

5. Conclusion
Since the p-value < 0.05, reject $H_0$.

6. Interpretation
There is enough evidence to show that the mean head measurements using the cardboard calipers are not the same as when using the metal calipers. So it looks like the New Zealand Air Force shouldn’t use the cardboard calipers.

Example #9.2.4: Confidence Interval for Paired Samples Using the Formula
A researcher wants to estimate the mean weight loss that people experience using a new program. She measures the weight of 6 randomly selected women before and after the weight loss program (see table #9.2.1). Find a 90% confidence interval for the mean the weight loss using the new program.

Solution:
1. State the random variables and the parameters in words.
   These were stated in example #9.2.2, but are reproduced here for reference.
2. State and check the assumptions for the confidence interval
   The assumptions were stated and checked in example #9.2.2.

3. Find the sample statistic and confidence interval
   Sample Statistics:
   From example #9.2.2
   \( \bar{d} = -21.5 \)
   \( s_d = 3.15 \)

   The confidence level is 90%, so
   \( C = 90\% \)
   There are six pairs, so the degrees of freedom are
   \( df = n - 1 = 6 - 1 = 5 \)
   Now look in table A.2. Go down the first column to 5, then over to
   the column headed with 90%.
   \( t_c = 2.015 \)
   \[ E = t_c \frac{s_d}{\sqrt{n}} = 2.015 \frac{3.15}{\sqrt{6}} \approx 2.6 \]
   \( \bar{d} - E < \mu_d < \bar{d} + E \)
   \( -21.5 - 2.6 < \mu_d < -21.5 + 2.6 \)
   \( -24.1 \text{ pounds} < \mu_d < -18.9 \text{ pounds} \)

4. Statistical Interpretation: There is a 90% chance that
   \( -24.1 \text{ pounds} < \mu_d < -18.9 \text{ pounds} \) contains the true mean difference in weight loss.

5. Real World Interpretation: The mean weight loss is between 18.9 and 24.1 pounds. (Note, the negative signs tell you that the first mean is less than the second mean, and thus a weight loss in this case.)

Example #9.2.5: Confidence Interval for Paired Samples Using Technology
   The New Zealand Air Force purchased a batch of flight helmets. They then found
   out that the helmets didn’t fit. In order to make sure that they order the correct
   size helmets, they measured the head size of recruits. To save money, they
   wanted to use cardboard calipers, but were not sure if they will be accurate
   enough. So they took 18 recruits and measured their heads with the cardboard
   calipers and also with metal calipers. The data in centimeters (cm) is in table
#9.2.3 ("NZ helmet size," 2013). Estimate the mean difference in measurements between the cardboard and metal calipers using a 95% confidence interval.

**Solution:**

1. State the random variables and the parameters in words.
   These were stated in example #9.2.3, but are reproduced here for reference.
   \( x_1 = \) head measurement of recruit using cardboard caliper
   \( x_2 = \) head measurement of recruit using metal caliper
   \( \mu_1 = \) mean head measurement of recruit using cardboard caliper
   \( \mu_2 = \) mean head measurement of recruit using metal caliper

2. State and check the assumptions for the hypothesis test
   The assumptions were stated and checked in example #9.2.3.

3. Find the sample statistic and confidence interval
   Using the TI-83/84, put \( x_1 \) into L1 and \( x_2 \) into L2. Then go onto the name L3, and type \( L1 - L2 \). The calculator will now calculate the differences for you and put them in L3. Now go into STAT and move over to TESTS. Then chose TInterval. The setup for the calculator is in figure #9.2.9.

**Figure #9.2.9: Setup for TInterval on Ti-83/84 Calculator**

Once you press ENTER on Calculate you will see the result shown in figure #9.2.10.

**Figure #9.2.10: Results of TInterval on TI-83/84 Calculator**

\[
\text{TInterval} \\
\text{Inpt: Univ Stats} \\
\text{List:L3} \\
\text{Freq:1} \\
\text{C-Level:.95} \\
\text{Calculate}
\]

\[
(1.54402, 2.6782) \\
\bar{x}=1.61111111 \\
Sx=2.145827384 \\
n=18
\]
Using R: the command is `t.test(variable1, variable2, paired = TRUE, conf.level = C)`, where C is in decimal form. For this example the command would be `t.test(cardboard, metal, paired = TRUE, conf.level=0.95)`

Paired t-test

data:  cardboard and metal
t = 3.1854, df = 17, p-value = 0.005415
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
0.5440163 2.6782060
sample estimates:
mean of the differences
1.611111

So
0.54 cm < μd < 2.68 cm

4. Statistical Interpretation: There is a 95% chance that 0.54 cm < μd < 2.68 cm contains the true mean difference in head measurements between cardboard and metal calibers.

5. Real World Interpretation: The mean difference in head measurements between the cardboard and metal calibers is between 0.54 and 2.68 cm. This means that the cardboard calibers measure on average the head of a recruit to be between 0.54 and 2.68 cm more in diameter than the metal calibers. That makes it seem that the cardboard calibers are not measuring the same as the metal calibers. (The positive values on the confidence interval imply that the first mean is higher than the second mean.)

Examples #9.2.2 and #9.2.4 use the same data set, but one is conducting a hypothesis test and the other is conducting a confidence interval. Notice that the hypothesis test’s conclusion was to reject $H_0$ and say that there was a difference in the means, and the confidence interval does not contain the number 0. If the confidence interval did contain the number 0, then that would mean that the two means could be the same. Since the interval did not contain 0, then you could say that the means are different just as in the hypothesis test. This means that the hypothesis test and the confidence interval can produce the same interpretation. Do be careful though, you can run a hypothesis test with a particular significance level and a confidence interval with a confidence level that is not compatible with your significance level. This will mean that the conclusion from the confidence interval would not be the same as with a hypothesis test. So if you want to estimate the mean difference, then conduct a confidence interval. If you want to show that the means are different, then conduct a hypothesis test.
Section 9.2: Homework
In each problem show all steps of the hypothesis test or confidence interval. If some of the assumptions are not met, note that the results of the test or interval may not be correct and then continue the process of the hypothesis test or confidence interval.

1.) The cholesterol level of patients who had heart attacks was measured two days after the heart attack and then again four days after the heart attack. The researchers want to see if the cholesterol level of patients who have heart attacks reduces as the time since their heart attack increases. The data is in table #9.2.4 ("Cholesterol levels after," 2013). Do the data show that the mean cholesterol level of patients that have had a heart attack reduces as the time increases since their heart attack? Test at the 1% level.

Table #9.2.4: Cholesterol Levels (in mg/dL) of Heart Attack Patients

<table>
<thead>
<tr>
<th>Patient</th>
<th>Cholesterol Level Day 2</th>
<th>Cholesterol Level Day 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>270</td>
<td>218</td>
</tr>
<tr>
<td>2</td>
<td>236</td>
<td>234</td>
</tr>
<tr>
<td>3</td>
<td>210</td>
<td>214</td>
</tr>
<tr>
<td>4</td>
<td>142</td>
<td>116</td>
</tr>
<tr>
<td>5</td>
<td>280</td>
<td>200</td>
</tr>
<tr>
<td>6</td>
<td>272</td>
<td>276</td>
</tr>
<tr>
<td>7</td>
<td>160</td>
<td>146</td>
</tr>
<tr>
<td>8</td>
<td>220</td>
<td>182</td>
</tr>
<tr>
<td>9</td>
<td>226</td>
<td>238</td>
</tr>
<tr>
<td>10</td>
<td>242</td>
<td>288</td>
</tr>
<tr>
<td>11</td>
<td>186</td>
<td>190</td>
</tr>
<tr>
<td>12</td>
<td>266</td>
<td>236</td>
</tr>
<tr>
<td>13</td>
<td>206</td>
<td>244</td>
</tr>
<tr>
<td>14</td>
<td>318</td>
<td>258</td>
</tr>
<tr>
<td>15</td>
<td>294</td>
<td>240</td>
</tr>
<tr>
<td>16</td>
<td>282</td>
<td>294</td>
</tr>
<tr>
<td>17</td>
<td>234</td>
<td>220</td>
</tr>
<tr>
<td>18</td>
<td>224</td>
<td>200</td>
</tr>
<tr>
<td>19</td>
<td>276</td>
<td>220</td>
</tr>
<tr>
<td>20</td>
<td>282</td>
<td>186</td>
</tr>
<tr>
<td>21</td>
<td>360</td>
<td>352</td>
</tr>
<tr>
<td>22</td>
<td>310</td>
<td>202</td>
</tr>
<tr>
<td>23</td>
<td>280</td>
<td>218</td>
</tr>
<tr>
<td>24</td>
<td>278</td>
<td>248</td>
</tr>
<tr>
<td>25</td>
<td>288</td>
<td>278</td>
</tr>
<tr>
<td>26</td>
<td>288</td>
<td>248</td>
</tr>
<tr>
<td>27</td>
<td>244</td>
<td>270</td>
</tr>
<tr>
<td>28</td>
<td>236</td>
<td>242</td>
</tr>
</tbody>
</table>
2.) The cholesterol level of patients who had heart attacks was measured two days after the heart attack and then again four days after the heart attack. The researchers want to see if the cholesterol level of patients who have heart attacks reduces as the time since their heart attack increases. The data is in table #9.2.4 ("Cholesterol levels after," 2013). Calculate a 98% confidence interval for the mean difference in cholesterol levels from day two to day four.

3.) All Fresh Seafood is a wholesale fish company based on the east coast of the U.S. Catalina Offshore Products is a wholesale fish company based on the west coast of the U.S. Table #9.2.5 contains prices from both companies for specific fish types ("Seafood online," 2013) ("Buy sushi grade," 2013). Do the data provide enough evidence to show that a west coast fish wholesaler is more expensive than an east coast wholesaler? Test at the 5% level.

**Table #9.2.5: Wholesale Prices of Fish in Dollars**

<table>
<thead>
<tr>
<th>Fish</th>
<th>All Fresh Seafood Prices</th>
<th>Catalina Offshore Products Prices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cod</td>
<td>19.99</td>
<td>17.99</td>
</tr>
<tr>
<td>Tilapi</td>
<td>6.00</td>
<td>13.99</td>
</tr>
<tr>
<td>Farmed Salmon</td>
<td>19.99</td>
<td>22.99</td>
</tr>
<tr>
<td>Organic Salmon</td>
<td>24.99</td>
<td>24.99</td>
</tr>
<tr>
<td>Grouper Fillet</td>
<td>29.99</td>
<td>19.99</td>
</tr>
<tr>
<td>Tuna</td>
<td>28.99</td>
<td>31.99</td>
</tr>
<tr>
<td>Swordfish</td>
<td>23.99</td>
<td>23.99</td>
</tr>
<tr>
<td>Sea Bass</td>
<td>32.99</td>
<td>23.99</td>
</tr>
<tr>
<td>Striped Bass</td>
<td>29.99</td>
<td>14.99</td>
</tr>
</tbody>
</table>

4.) All Fresh Seafood is a wholesale fish company based on the east coast of the U.S. Catalina Offshore Products is a wholesale fish company based on the west coast of the U.S. Table #9.2.5 contains prices from both companies for specific fish types ("Seafood online," 2013) ("Buy sushi grade," 2013). Find a 95% confidence interval for the mean difference in wholesale price between the east coast and west coast suppliers.
5.) The British Department of Transportation studied to see if people avoid driving on Friday the 13\textsuperscript{th}. They did a traffic count on a Friday and then again on a Friday the 13\textsuperscript{th} at the same two locations ("Friday the 13th," 2013). The data for each location on the two different dates is in table #9.2.6. Do the data show that on average fewer people drive on Friday the 13\textsuperscript{th}? Test at the 5\% level.

Table #9.2.6: Traffic Count

<table>
<thead>
<tr>
<th>Dates</th>
<th>6th</th>
<th>13th</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990, July</td>
<td>139246</td>
<td>138548</td>
</tr>
<tr>
<td>1990, July</td>
<td>134012</td>
<td>132908</td>
</tr>
<tr>
<td>1991, September</td>
<td>137055</td>
<td>136018</td>
</tr>
<tr>
<td>1991, September</td>
<td>133732</td>
<td>131843</td>
</tr>
<tr>
<td>1991, December</td>
<td>123552</td>
<td>121641</td>
</tr>
<tr>
<td>1991, December</td>
<td>121139</td>
<td>118723</td>
</tr>
<tr>
<td>1992, March</td>
<td>128293</td>
<td>125532</td>
</tr>
<tr>
<td>1992, March</td>
<td>124631</td>
<td>120249</td>
</tr>
<tr>
<td>1992, November</td>
<td>124609</td>
<td>122770</td>
</tr>
<tr>
<td>1992, November</td>
<td>117584</td>
<td>117263</td>
</tr>
</tbody>
</table>

6.) The British Department of Transportation studied to see if people avoid driving on Friday the 13\textsuperscript{th}. They did a traffic count on a Friday and then again on a Friday the 13\textsuperscript{th} at the same two locations ("Friday the 13th," 2013). The data for each location on the two different dates is in table #9.2.6. Estimate the mean difference in traffic count between the 6\textsuperscript{th} and the 13\textsuperscript{th} using a 90\% level.
To determine if Reiki is an effective method for treating pain, a pilot study was carried out where a certified second-degree Reiki therapist provided treatment on volunteers. Pain was measured using a visual analogue scale (VAS) immediately before and after the Reiki treatment (Olson & Hanson, 1997). The data is in table #9.2.7. Do the data show that Reiki treatment reduces pain? Test at the 5% level.

**Table #9.2.7: Pain Measures Before and After Reiki Treatment**

<table>
<thead>
<tr>
<th>VAS before</th>
<th>VAS after</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
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<tr>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
</tr>
</tbody>
</table>

Compute a 90% confidence level for the mean difference in VAS score from before and after Reiki treatment.
9.) The female labor force participation rates (FLFPR) of women in randomly selected countries in 1990 and latest years of the 1990s are in table #9.2.8 (Lim, 2002). Do the data show that the mean female labor force participation rate in 1990 is different from that in the latest years of the 1990s using a 5% level of significance?

Table #9.2.8: Female Labor Force Participation Rates

<table>
<thead>
<tr>
<th>Region and country</th>
<th>FLFPR 25-54 1990</th>
<th>FLFPR 25-54 Latest year of 1990s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iran</td>
<td>22.6</td>
<td>12.5</td>
</tr>
<tr>
<td>Morocco</td>
<td>41.4</td>
<td>34.5</td>
</tr>
<tr>
<td>Qatar</td>
<td>42.3</td>
<td>46.5</td>
</tr>
<tr>
<td>Syrian Arab Republic</td>
<td>25.6</td>
<td>19.5</td>
</tr>
<tr>
<td>United Arab Emirates</td>
<td>36.4</td>
<td>39.7</td>
</tr>
<tr>
<td>Cape Verde</td>
<td>46.7</td>
<td>50.9</td>
</tr>
<tr>
<td>Ghana</td>
<td>89.8</td>
<td>90.0</td>
</tr>
<tr>
<td>Kenya</td>
<td>82.1</td>
<td>82.6</td>
</tr>
<tr>
<td>Lesotho</td>
<td>51.9</td>
<td>68.0</td>
</tr>
<tr>
<td>South Africa</td>
<td>54.7</td>
<td>61.7</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>73.5</td>
<td>60.6</td>
</tr>
<tr>
<td>Malaysia</td>
<td>49.0</td>
<td>50.2</td>
</tr>
<tr>
<td>Mongolia</td>
<td>84.7</td>
<td>71.3</td>
</tr>
<tr>
<td>Myanmar</td>
<td>72.1</td>
<td>72.3</td>
</tr>
<tr>
<td>Argentina</td>
<td>36.8</td>
<td>54</td>
</tr>
<tr>
<td>Belize</td>
<td>28.8</td>
<td>42.5</td>
</tr>
<tr>
<td>Bolivia</td>
<td>27.3</td>
<td>69.8</td>
</tr>
<tr>
<td>Brazil</td>
<td>51.1</td>
<td>63.2</td>
</tr>
<tr>
<td>Colombia</td>
<td>57.4</td>
<td>72.7</td>
</tr>
<tr>
<td>Ecuador</td>
<td>33.5</td>
<td>64</td>
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<tr>
<td>Nicaragua</td>
<td>50.1</td>
<td>42.5</td>
</tr>
<tr>
<td>Uruguay</td>
<td>59.5</td>
<td>71.5</td>
</tr>
<tr>
<td>Albania</td>
<td>77.4</td>
<td>78.8</td>
</tr>
<tr>
<td>Uzbekistan</td>
<td>79.6</td>
<td>82.8</td>
</tr>
</tbody>
</table>

10.) The female labor force participation rates of women in randomly selected countries in 1990 and latest years of the 1990s are in table #9.2.8 (Lim, 2002). Estimate the mean difference in the female labor force participation rate in 1990 to latest years of the 1990s using a 95% confidence level?
11.) Table #9.2.9 contains pulse rates collected from males, who are non-smokers but do drink alcohol ("Pulse rates before," 2013). The before pulse rate is before they exercised, and the after pulse rate was taken after the subject ran in place for one minute. Do the data indicate that the pulse rate before exercise is less than after exercise? Test at the 1% level.

Table #9.2.9: Pulse Rate of Males Before and After Exercise

<table>
<thead>
<tr>
<th>Pulse before</th>
<th>Pulse after</th>
</tr>
</thead>
<tbody>
<tr>
<td>76</td>
<td>88</td>
</tr>
<tr>
<td>56</td>
<td>110</td>
</tr>
<tr>
<td>64</td>
<td>126</td>
</tr>
<tr>
<td>50</td>
<td>90</td>
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<tr>
<td>49</td>
<td>83</td>
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<tr>
<td>68</td>
<td>136</td>
</tr>
<tr>
<td>68</td>
<td>125</td>
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<tr>
<td>88</td>
<td>150</td>
</tr>
<tr>
<td>80</td>
<td>146</td>
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<tr>
<td>78</td>
<td>168</td>
</tr>
<tr>
<td>59</td>
<td>92</td>
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<td>60</td>
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<td>65</td>
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<tr>
<td>76</td>
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<tr>
<td>145</td>
<td>155</td>
</tr>
<tr>
<td>84</td>
<td>140</td>
</tr>
<tr>
<td>78</td>
<td>141</td>
</tr>
<tr>
<td>85</td>
<td>131</td>
</tr>
<tr>
<td>78</td>
<td>132</td>
</tr>
</tbody>
</table>

12.) Table #9.2.9 contains pulse rates collected from males, who are non-smokers but do drink alcohol ("Pulse rates before," 2013). The before pulse rate is before they exercised, and the after pulse rate was taken after the subject ran in place for one minute. Compute a 98% confidence interval for the mean difference in pulse rates from before and after exercise.
Section 9.3 Independent Samples for Two Means

This section will look at how to analyze when two samples are collected that are independent. As with all other hypothesis tests and confidence intervals, the process is the same though the formulas and assumptions are different. The only difference with the independent t-test, as opposed to the other tests that have been done, is that there are actually two different formulas to use depending on if a particular assumption is met or not.

Hypothesis Test for Independent t-Test (2-Sample t-Test)

1. State the random variables and the parameters in words.
   \( x_1 \) = random variable 1
   \( x_2 \) = random variable 2
   \( \mu_1 \) = mean of random variable 1
   \( \mu_2 \) = mean of random variable 2

2. State the null and alternative hypotheses and the level of significance
   The normal hypotheses would be
   \( H_o : \mu_1 = \mu_2 \) \quad or \quad \( H_o : \mu_1 - \mu_2 = 0 \)
   \( H_A : \mu_1 < \mu_2 \)
   \( H_A : \mu_1 - \mu_2 < 0 \)
   \( H_A : \mu_1 > \mu_2 \)
   \( H_A : \mu_1 - \mu_2 > 0 \)
   \( H_A : \mu_1 \neq \mu_2 \)
   \( H_A : \mu_1 - \mu_2 \neq 0 \)
   Also, state your \( \alpha \) level here.

3. State and check the assumptions for the hypothesis test
   a. A random sample of size \( n_1 \) is taken from population 1. A random sample of size \( n_2 \) is taken from population 2. Note: the samples do not need to be the same size, but the test is more robust if they are.
   b. The two samples are independent.
   c. Population 1 is normally distributed. Population 2 is normally distributed. Just as before, the t-test is fairly robust to the assumption if the sample size is large. This means that if this assumption isn’t met, but your sample sizes are quite large (over 30), then the results of the t-test are valid.
   d. The population variances are unknown and not assumed to be equal. The old assumption is that the variances are equal. However, this assumption is no longer an assumption that most statisticians use. This is because it isn’t really realistic to assume that the variances are equal. So we will just assume the assumption of the variances being unknown and not assumed to be equal is true, and it will not be checked.

4. Find the sample statistic, test statistic, and p-value
   Sample Statistic:
   Calculate \( \bar{x}_1, \bar{x}_2, s_1, s_2, n_1, n_2 \)
Chapter 9: Two-Sample Inference

Test Statistic:
Since the assumption that $\sigma_1^2 = \sigma_2^2$ isn’t being satisfied, then
\[
t = \frac{\bar{x}_1 - \bar{x}_2 - (\mu_1 - \mu_2)}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}
\]
Usually $\mu_1 - \mu_2 = 0$, since $H_0: \mu_1 - \mu_2 = 0$

Degrees of freedom: (the Welch–Satterthwaite equation)
\[
df = \frac{(A + B)^2}{\frac{A^2}{n_1 - 1} + \frac{B^2}{n_2 - 1}}
\]
where $A = \frac{s_1^2}{n_1}$ and $B = \frac{s_2^2}{n_2}$

p-value:
Using the TI-83/84: tcdf(lower limit, upper limit, df)
(Note: if $H_A: \mu_1 - \mu_2 < 0$, then lower limit is $-1E99$ and upper limit is your test statistic. If $H_A: \mu_1 - \mu_2 > 0$, then lower limit is your test statistic and the upper limit is $1E99$. If $H_A: \mu_1 - \mu_2 \neq 0$, then find the p-value for $H_A: \mu_1 - \mu_2 < 0$, and multiply by 2.)
Using R: pt(t, df)
(Note: if $H_A: \mu_1 - \mu_2 < 0$, then use pt(t, df). If $H_A: \mu_1 - \mu_2 > 0$, then use $1 - pt(t, df)$. If $H_A: \mu_1 - \mu_2 \neq 0$, then find the p-value for $H_A: \mu_1 - \mu_2 < 0$, and multiply by 2.)

5. Conclusion
This is where you write reject $H_o$ or fail to reject $H_o$. The rule is: if the p-value $< \alpha$, then reject $H_o$. If the p-value $\geq \alpha$, then fail to reject $H_o$.

6. Interpretation
This is where you interpret in real world terms the conclusion to the test. The conclusion for a hypothesis test is that you either have enough evidence to show $H_A$ is true, or you do not have enough evidence to show $H_A$ is true.

Confidence Interval for the Difference in Means from Two Independent Samples (2 Samp T-Int)
The confidence interval for the difference in means has the same random variables and means and the same assumptions as the hypothesis test for independent samples. If you have already completed the hypothesis test, then you do not need to state them again. If you haven’t completed the hypothesis test, then state the random variables and means and state and check the assumptions before completing the confidence interval step.
1. Find the sample statistic and confidence interval

Sample Statistic:
Calculate $\bar{x}_1$, $\bar{x}_2$, $s_1$, $s_2$, $n_1$, $n_2$

Confidence Interval:
The confidence interval estimate of the difference $\mu_1 - \mu_2$ is

Since the assumption that $\sigma^2_1 = \sigma^2_2$ isn’t being satisfied, then

$$(\bar{x}_1 - \bar{x}_2) - E < \mu_1 - \mu_2 < (\bar{x}_1 - \bar{x}_2) + E$$

where $E = t_{\alpha} \sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}$

where $t_{\alpha}$ is the critical value with degrees of freedom:

Degrees of freedom: (the Welch–Satterthwaite equation)

$$df = \frac{(A + B)^2}{\frac{A^2}{n_1-1} + \frac{B^2}{n_2-1}}$$

where $A = \frac{s_1^2}{n_1}$ and $B = \frac{s_2^2}{n_2}$

2. Statistical Interpretation: In general this looks like, “there is a C% chance that

$$(\bar{x}_1 - \bar{x}_2) - E < \mu_1 - \mu_2 < (\bar{x}_1 - \bar{x}_2) + E$$

contains the true mean difference.”

3. Real World Interpretation: This is where you state what interval contains the true
difference in means, though often you state how much more (or less) the first
mean is from the second mean.

The critical value is a value from the Student’s t-distribution. Since a confidence interval
is found by adding and subtracting a margin of error amount from the difference in
sample means, and the interval has a probability of containing the true difference in
means, then you can think of this as the statement

$$P\left((\bar{x}_1 - \bar{x}_2) - E < \mu_1 - \mu_2 < (\bar{x}_1 - \bar{x}_2) + E\right) = C.$$ To find the critical value you use table A.2 in the Appendix.

**How to check the assumptions of two sample t-test and confidence interval:**
In order for the t-test or confidence interval to be valid, the assumptions of the test must
be true. So whenever you run a t-test or confidence interval, you must make sure the
assumptions are true. So you need to check them. Here is how you do this:

1. For the random sample assumption, describe how you took the two samples.
   Make sure your sampling technique is random for both samples.
2. For the independent assumption, describe how they are independent samples.
3. For the assumption about each population being normally distributed, remember
   the process of assessing normality from chapter 6. Make sure you assess each
   sample separately.
4. You do not need to check the equal variance assumption since it is not being assumed.

Example #9.3.1: Hypothesis Test for Two Means
The cholesterol level of patients who had heart attacks was measured two days after the heart attack. The researchers want to see if patients who have heart attacks have higher cholesterol levels over healthy people, so they also measured the cholesterol level of healthy adults who show no signs of heart disease. The data is in table #9.3.1 ("Cholesterol levels after," 2013). Do the data show that people who have had heart attacks have higher cholesterol levels over patients that have not had heart attacks? Test at the 1% level.

Table #9.3.1: Cholesterol Levels in mg/dL

<table>
<thead>
<tr>
<th>Cholesterol Level of Heart Attack Patients</th>
<th>Cholesterol Level of Healthy Individual</th>
</tr>
</thead>
<tbody>
<tr>
<td>270</td>
<td>196</td>
</tr>
<tr>
<td>236</td>
<td>232</td>
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<td>210</td>
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<td>142</td>
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<td>236</td>
<td>170</td>
</tr>
<tr>
<td></td>
<td>200</td>
</tr>
<tr>
<td></td>
<td>176</td>
</tr>
</tbody>
</table>
Solution:

1. State the random variables and the parameters in words.
   \( x_1 \) = Cholesterol level of patients who had a heart attack
   \( x_2 \) = Cholesterol level of healthy individuals
   \( \mu_1 \) = mean cholesterol level of patients who had a heart attack
   \( \mu_2 \) = mean cholesterol level of healthy individuals

2. State the null and alternative hypotheses and the level of significance
   The normal hypotheses would be
   \( H_0 : \mu_1 = \mu_2 \) or \( H_0 : \mu_1 - \mu_2 = 0 \)
   \( H_A : \mu_1 > \mu_2 \)
   \( H_A : \mu_1 - \mu_2 > 0 \)
   \( \alpha = 0.01 \)

3. State and check the assumptions for the hypothesis test
   a. A random sample of 28 cholesterol levels of patients who had a heart attack is taken. A random sample of 30 cholesterol levels of healthy individuals is taken. The problem does not state if either sample was randomly selected. So this assumption may not be valid.
   b. The two samples are independent. This is because either they were dealing with patients who had heart attacks or healthy individuals.
   c. Population of all cholesterol levels of patients who had a heart attack is normally distributed. Population of all cholesterol levels of healthy individuals is normally distributed.

Patients who had heart attacks:

**Figure #9.3.1: Histogram of Cholesterol Levels of Patients who had Heart Attacks**

![Histogram of Cholesterol Levels of Patients who had Heart Attacks](image)

This looks somewhat bell shaped.
Figure #9.3.2: Modified Box Plot of Cholesterol Levels of Patients who had Heart Attacks

There are no outliers.

Figure #9.3.3: Normal Quantile Plot of Cholesterol Levels of Patients who had Heart Attacks

This looks somewhat linear.
So, the population of all cholesterol levels of patients who had heart attacks is probably somewhat normally distributed.
Healthy individuals:

**Figure #9.3.4: Histogram of Cholesterol Levels of Healthy Individuals**

This does not look bell shaped.

**Figure #9.3.5: Modified Box Plot of Cholesterol Levels of Healthy Individuals**

There are no outliers.

**Figure #9.3.6: Normal Quantile Plot of Cholesterol Levels of Healthy Individuals**

This doesn’t look linear.
So, the population of all cholesterol levels of healthy individuals is probably not normally distributed.

This assumption is not valid for the second sample. Since the sample is fairly large, and the t-test is robust, it may not be an issue. However, just realize that the conclusions of the test may not be valid.

4. Find the sample statistic, test statistic, and p-value

Sample Statistic:
\[ \bar{x}_1 \approx 252.32, \bar{x}_2 \approx 193.13, s_1 \approx 47.0642, s_2 \approx 22.3000, n_1 = 28, n_2 = 30 \]

Test Statistic:
\[
t = \frac{(\bar{x}_1 - \bar{x}_2) - (\mu_1 - \mu_2)}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} = \frac{(252.32 - 193.13) - 0}{\sqrt{\frac{47.0642^2}{28} + \frac{22.3000^2}{30}}} \approx 6.051
\]

Degrees of freedom: (the Welch–Satterthwaite equation)
\[
A = \frac{s_1^2}{n_1} = \frac{47.0642^2}{28} = 79.1085
\]
\[
B = \frac{s_2^2}{n_2} = \frac{22.3000^2}{30} = 16.5763
\]
\[
df = \frac{(A + B)^2}{\frac{A^2}{n_1-1} + \frac{B^2}{n_2-1}} = \frac{(79.1085 + 16.5763)^2}{\frac{79.1085^2}{28-1} + \frac{16.5763^2}{30-1}} \approx 37.9493
\]

p-value:
Using TI-83/84: tcdf(6.051,1E99,37.9493) \approx 2.44 \times 10^{-7}

Using R: 1 - pt(6.051,37.9493) \approx 2.44 \times 10^{-7}

Using Technology: Using the TI-83/84:
Figure #9.3.7: Setup for 2-SampTTest on TI-83/84 Calculator
Note: the Pooled question on the calculator is for whether you are assuming the variances are equal. Since this assumption is not being made, then the answer to this question is no. Pooled means that you assume the variances are equal and can pool the sample variances together.

Figure #9.3.8 Results for 2-SampTTest on TI-83/84 Calculator

Using R: command in general: `t.test(variable1, variable2, alternative = "less" or "greater")`

For this example, the R command is:
`t.test(heartattack, healthy, alternative="greater")`

Welch Two Sample t-test

data: heartattack and healthy
t = 6.1452, df = 37.675, p-value = 1.86e-07
alternative hypothesis: true difference in means is greater than 0
95 percent confidence interval:
  44.1124     Inf
sample estimates:
mean of x mean of y
 253.9286  193.1333

The test statistic is t = 6.1452. The p-value is $1.86 \times 10^{-7}$

5. Conclusion
   Reject $H_0$ since the p-value < $\alpha$.

6. Interpretation
   This is enough evidence to show that patients who have had heart attacks have higher cholesterol level on average from healthy individuals. (Though do realize that some of assumptions are not valid, so this interpretation may be invalid.)
Example #9.3.2: Confidence Interval for $\mu_1 - \mu_2$

The cholesterol level of patients who had heart attacks was measured two days after the heart attack. The researchers want to see if patients who have heart attacks have higher cholesterol levels over healthy people, so they also measured the cholesterol level of healthy adults who show no signs of heart disease. The data is in table #9.3.1 ("Cholesterol levels after," 2013). Find a 99% confidence interval for the mean difference in cholesterol levels between heart attack patients and healthy individuals.

Solution:
1. State the random variables and the parameters in words.
   These were stated in example #9.3.1, but are reproduced here for reference.
   $x_1 =$ Cholesterol level of patients who had a heart attack
   $x_2 =$ Cholesterol level of healthy individuals
   $\mu_1 =$ mean cholesterol level of patients who had a heart attack
   $\mu_2 =$ mean cholesterol level of healthy individuals

2. State and check the assumptions for the hypothesis test
   The assumptions were stated and checked in example #9.3.1.

3. Find the sample statistic and confidence interval
   Sample Statistic:
   $\bar{x}_1 \approx 252.32,$ $\bar{x}_2 \approx 193.13,$ $s_1 \approx 47.0642,$ $s_2 \approx 22.3000,$ $n_1 = 28,$ $n_2 = 30$
   Test Statistic:
   Degrees of freedom: (the Welch–Satterthwaite equation)
   \[ A = \frac{s_1^2}{n_1} = \frac{47.0642^2}{28} \approx 79.1085 \]
   \[ B = \frac{s_2^2}{n_2} = \frac{22.3000^2}{30} \approx 16.5763 \]
   \[ df = \frac{(A + B)^2}{\frac{A^2}{n_1-1} + \frac{B^2}{n_2-1}} = \frac{(79.1085 + 16.5763)^2}{\frac{79.1085^2}{28-1} + \frac{16.5763^2}{30-1}} \approx 37.9493 \]
   Since this df is not in the table, round to the nearest whole number.
   \[ t_c = 2.712 \]
   \[ E = t_c \sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}} = 2.712 \sqrt{\frac{47.0642^2}{28} + \frac{22.3000^2}{30}} \approx 26.53 \]
   \[ (\bar{x}_1 - \bar{x}_2) - E < \mu_1 - \mu_2 < (\bar{x}_1 - \bar{x}_2) + E \]
   \[ (252.32 - 193.13) - 26.53 < \mu_1 - \mu_2 < (252.32 - 193.13) + 26.53 \]
   \[ 32.66 \text{ mg/dL} < \mu_1 - \mu_2 < 85.72 \text{ mg/dL} \]
Using Technology:

Using TI-83/84:

**Figure #9.3.9: Setup for 2-SampTInt on TI-83/84 Calculator**

![TI-83/84 Setup](image)

Note: the Pooled question on the calculator is for whether you are assuming the variances are equal. Since this assumption is not being made, then the answer to this question is no. Pooled means that you assume the variances are equal and can pool the sample variances together.

**Figure #9.3.10: Results for 2-SampTInt on TI-83/84 Calculator**

![TI-83/84 Results](image)

Using R: the commands is `t.test(variable1, variable2, conf.level=C)`, where C is in decimal form.

For this example, the command is `t.test(heartattack, healthy, conf.level=.99)`
Output:
    Welch Two Sample t-test

data:  heartattack and healthy
    t = 6.1452, df = 37.675, p-value = 3.721e-07
alternative hypothesis: true difference in means is not equal to 0
99 percent confidence interval:
    33.95750 87.63298
sample estimates:
    mean of x mean of y
    253.9286  193.1333

The confidence interval is $33.96 < \mu_1 - \mu_2 < 87.63$.

4. Statistical Interpretation: There is a 99% chance that
    $32.66 \text{ mg/dL} < \mu_1 - \mu_2 < 85.72 \text{ mg/dL}$ contains the true difference in means.

5. Real World Interpretation: The mean cholesterol level for patients who had heart
    attacks is anywhere from $32.66 \text{ mg/dL}$ to $85.72 \text{ mg/dL}$ more than the mean
    cholesterol level for healthy patients. (Though do realize that many of
    assumptions are not valid, so this interpretation may be invalid.)

If you do assume that the variances are equal, that is $\sigma_1^2 = \sigma_2^2$, then the test statistic is:

$$t = \frac{(\bar{x}_1 - \bar{x}_2) - (\mu_1 - \mu_2)}{s_p \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}$$

where $s_p = \sqrt{\frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{(n_1 - 1) + (n_2 - 1)}}$

$s_p$ = pooled standard deviation

The Degrees of Freedom is: $df = n_1 + n_2 - 2$

The confidence interval if you do assume that $\sigma_1^2 = \sigma_2^2$ has been met, is

$$(\bar{x}_1 - \bar{x}_2) - E < \mu_1 - \mu_2 < (\bar{x}_1 - \bar{x}_2) + E$$

where $E = t_c s_p \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}$

and $s_p = \sqrt{\frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{(n_1 - 1) + (n_2 - 1)}}$

Degrees of Freedom: $df = n_1 + n_2 - 2$

$t_c$ is the critical value where $C = 1 - \alpha$
To show that the variances are equal, just show that the ratio of your sample variances is not unusual (probability is greater than 0.05). In other words, make sure the following is true.

\[ P(F > s_1^2 / s_2^2) \geq 0.05 \quad \text{(or } P(F > s_2^2 / s_1^2) \geq 0.05 \text{ so that the larger variance is in the numerator). This probability is from an F-distribution. To find the probability on the TI-83/84 calculator use } \text{Fcdf} \left( s_1^2 / s_2^2, 1E99, n_1 - 1, n_2 - 1 \right) \text{. To find the probability on R, use } 1 - \text{pf} \left( s_1^2 / s_2^2, n_1 - 1, n_2 - 1 \right) \text{.}

Note: the F-distribution is very sensitive to the normal distribution. A better test for equal variances is Levene's test, though it is more complicated. It is best to do Levene’s test when using statistical software (such as SPSS or Minitab) to perform the two-sample independent t-test.

**Example #9.3.3: Hypothesis Test for Two Means**

The amount of sodium in beef hotdogs was measured. In addition, the amount of sodium in poultry hotdogs was also measured ("SOCR 012708 id," 2013). The data is in table #9.3.2. Is there enough evidence to show that beef has less sodium on average than poultry hotdogs? Use a 5% level of significance.

**Table #9.3.2: Hotdog Data**

<table>
<thead>
<tr>
<th>Sodium in Beef Hotdogs</th>
<th>Sodium in Poultry Hotdogs</th>
</tr>
</thead>
<tbody>
<tr>
<td>495</td>
<td>430</td>
</tr>
<tr>
<td>477</td>
<td>375</td>
</tr>
<tr>
<td>425</td>
<td>396</td>
</tr>
<tr>
<td>322</td>
<td>383</td>
</tr>
<tr>
<td>482</td>
<td>387</td>
</tr>
<tr>
<td>587</td>
<td>542</td>
</tr>
<tr>
<td>370</td>
<td>359</td>
</tr>
<tr>
<td>322</td>
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</tr>
<tr>
<td>479</td>
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<tr>
<td>375</td>
<td>513</td>
</tr>
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<td>330</td>
<td>426</td>
</tr>
<tr>
<td>300</td>
<td>513</td>
</tr>
<tr>
<td>386</td>
<td>358</td>
</tr>
<tr>
<td>401</td>
<td>581</td>
</tr>
<tr>
<td>645</td>
<td>588</td>
</tr>
<tr>
<td>440</td>
<td>522</td>
</tr>
<tr>
<td>317</td>
<td>545</td>
</tr>
<tr>
<td>319</td>
<td>430</td>
</tr>
<tr>
<td>298</td>
<td>375</td>
</tr>
<tr>
<td>253</td>
<td>396</td>
</tr>
</tbody>
</table>
Solution:
1. State the random variables and the parameters in words.
   \[ x_1 = \text{sodium level in beef hotdogs} \]
   \[ x_2 = \text{sodium level in poultry hotdogs} \]
   \[ \mu_1 = \text{mean sodium level in beef hotdogs} \]
   \[ \mu_2 = \text{mean sodium level in poultry hotdogs} \]

2. State the null and alternative hypotheses and the level of significance.
   The normal hypotheses would be
   \[ H_o : \mu_1 = \mu_2 \quad \text{or} \quad H_o : \mu_1 - \mu_2 = 0 \]
   \[ H_A : \mu_1 < \mu_2 \]
   \[ H_A : \mu_1 - \mu_2 < 0 \]
   \[ \alpha = 0.05 \]

3. State and check the assumptions for the hypothesis test:
   a. A random sample of 20 sodium levels in beef hotdogs is taken. A random sample of 20 sodium levels in poultry hotdogs. The problem does not state if either sample was randomly selected. So this assumption may not be valid.
   b. The two samples are independent since these are different types of hotdogs.
   c. Population of all sodium levels in beef hotdogs is normally distributed.
      Population of all sodium levels in poultry hotdogs is normally distributed.

   **Beef Hotdogs:**
   **Figure #9.3.11: Histogram of Sodium Levels in Beef Hotdogs**

   ![Histogram of Sodium Levels in Beef Hotdogs](image)

   This looks somewhat bell shaped.
Figure #9.3.12: Modified Box Plot of Sodium Levels in Beef Hotdogs

There are no outliers.

Figure #9.3.13: Normal Quantile Plot of Sodium Levels in Beef Hotdogs

This looks somewhat linear.
So, the population of all sodium levels in beef hotdogs may be normally distributed.

Poultry Hotdogs:
Figure #9.3.14: Histogram of Sodium Levels in Poultry Hotdogs

This does not look bell shaped.
There are no outliers.

This does not look linear.
So, the population of all sodium levels in poultry hotdogs is probably not normally distributed.

This assumption is not valid. Since the samples are fairly large, and the t-test is robust, it may not be a large issue. However, just realize that the conclusions of the test may not be valid.

d. The population variances are equal, i.e. $\sigma_1^2 = \sigma_2^2$. 
\[ s_1 \approx 102.4347 \]
\[ s_2 \approx 81.1786 \]
\[ \frac{s_1^2}{s_2^2} = \frac{102.4347^2}{81.1786^2} \approx 1.592 \]
Using TI-83/84: \( F_{cdf}(1.592, 1E99, 19) \approx 0.1597 \geq 0.05 \)
Using R: \( 1 - pf(1.592, 19) \approx 0.1597 \geq 0.05 \)
So you can say that these variances are equal.

4. Find the sample statistic, test statistic, and p-value
Sample Statistic:
\[ \bar{x}_1 = 401.15, \bar{x}_2 = 450.2, s_1 \approx 102.4347, s_2 = 81.1786, n_1 = 20, n_2 = 20 \]
Test Statistic:
The assumption \( \sigma_1^2 = \sigma_2^2 \) has been met, so
\[ s_p = \sqrt{\frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 - 1 + n_2 - 1}} \]
\[ = \sqrt{\frac{102.4347^2 \times 19 + 81.1786^2 \times 19}{20 - 1 + 20 - 1}} \]
\[ \approx 92.4198 \]
Though you should try to do the calculations in the problem so you don’t create round off error.
\[ t = \frac{(\bar{x}_1 - \bar{x}_2) - (\mu_1 - \mu_2)}{s_p \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}} \]
\[ = \frac{401.15 - 450.2 - 0}{92.4198 \sqrt{\frac{1}{20} + \frac{1}{20}}} \]
\[ \approx -1.678 \]
df = 20 + 20 - 2 = 38
p-value:
Using TI-83/84: \( t_{cdf}(-1E99, -1.678, 38) \approx 0.0508 \)
Using R: \( pt(-1.678, 38) = 0.0508 \)
Using technology to find the t and p-value:

Using TI-83/84:

**Figure #9.3.17: Setup for 2-SampTTest on TI-83/84 Calculator**

Note: the Pooled question on the calculator is for whether you are using the pooled standard deviation or not. In this example, the pooled standard deviation was used since you are assuming the variances are equal. That is why the answer to the question is Yes.

**Figure #9.3.18: Results for 2-SampTTest on TI-83/84 Calculator**

Using R: the command is `t.test(variable1, variable2, alternative="less" or "greater")`

For this example, the command is

`t.test(beef, poultry, alternative="less", equalvar=TRUE)`
Welch Two Sample t-test

data:  beef and poultry
\[ t = -1.6783, \text{df} = 36.115, p\text{-value} = 0.05096 \]

alternative hypothesis: true difference in means is less than 0

95 percent confidence interval:
\[-\text{Inf} \, 0.2875363 \]
sample estimates:
mean of x  mean of y
401.15  450.20

The \( t = -1.6783 \) and the p-value = 0.05096.

5. Conclusion
   Fail to reject \( H_0 \) since the p-value > \( \alpha \).

6. Interpretation
   This is not enough evidence to show that beef hotdogs have less sodium than poultry hotdogs. (Though do realize that many of assumptions are not valid, so this interpretation may be invalid.)

Example #9.3.4: Confidence Interval for \( \mu_1 - \mu_2 \)
   The amount of sodium in beef hotdogs was measured. In addition, the amount of sodium in poultry hotdogs was also measured ("SOCR 012708 id," 2013). The data is in table #9.3.2. Find a 95% confidence interval for the mean difference in sodium levels between beef and poultry hotdogs.

Solution:
1. State the random variables and the parameters in words.
   These were stated in example #9.3.1, but are reproduced here for reference.
   \( x_1 \) = sodium level in beef hotdogs
   \( x_2 \) = sodium level in poultry hotdogs
   \( \mu_1 \) = mean sodium level in beef hotdogs
   \( \mu_2 \) = mean sodium level in poultry hotdogs

2. State and check the assumptions for the hypothesis test
   The assumptions were stated and checked in example #9.3.3.

3. Find the sample statistic and confidence interval
   Sample Statistic:
   \( \bar{x}_1 = 401.15, \bar{x}_2 = 450.2, s_1 = 102.4347, s_2 = 81.1786, n_1 = 20, n_2 = 20 \)
   Confidence Interval:
   The confidence interval estimate of the difference \( \mu_1 - \mu_2 \) is
   \( \bar{x}_1 - \bar{x}_2 \pm t_{\alpha/2, df} \sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}} \)
   The assumption \( \sigma_1^2 = \sigma_2^2 \) has been met, so
\[ s_p = \sqrt{\frac{(n_1-1)s_1^2 + (n_2-1)s_2^2}{(n_1-1) + (n_2-1)}} \]

\[ = \sqrt{\frac{102.4347^2 \times 19 + 81.1786^2 \times 19}{(20-1) + (20-1)}} \]

\[ = 92.4198 \]

Though you should try to do the calculations in the formula for \( E \) so you don’t create round off error.

\( df = n_1 + n_2 - 2 = 20 + 20 - 2 = 38 \)

\( t_c = 2.024 \)

\[ E = t_c s_p \sqrt{\frac{1}{n_1} + \frac{1}{n_2}} \]

\[ = 2.024 \times 92.4198 \sqrt{\frac{1}{20} + \frac{1}{20}} \]

\[ = 59.15 \]

\((\bar{x}_1 - \bar{x}_2) - E < \mu_1 - \mu_2 < (\bar{x}_1 - \bar{x}_2) + E\)

\((401.15 - 450.2) - 59.15 < \mu_1 - \mu_2 < (401.15 - 450.2) + 59.15\)

\(-108.20 \text{ g} < \mu_1 - \mu_2 < 10.10 \text{ g}\)

Using technology:

Using the TI-83/84:

**Figure #9.3.19: Setup for 2-SampTInt on TI-83/84 Calculator**

Note: the Pooled question on the calculator is for whether you are using the pooled standard deviation or not. In this example, the pooled standard deviation was used since you are assuming the variances are equal. That is why the answer to the question is Yes.
Using R: the command is `t.test(variable1, variable2, equalvar=TRUE, conf.level=C)`, where C is in decimal form.

For this example, the command is

t.test(beef, poultry, conf.level=.95, equalvar=TRUE)

**Welch Two Sample t-test**

data:  beef and poultry

\[ t = -1.6783, \, df = 36.115, \, p\text{-value} = 0.1019 \]

alternative hypothesis: true difference in means is not equal to 0

95 percent confidence interval:

\[ -108.31592 \, \text{to} \, 10.21592 \]

sample estimates:

\[
\begin{align*}
\text{mean of } x &= 401.15 \\
\text{mean of } y &= 450.20 \\
\end{align*}
\]

The confidence interval is \( -108.32 < \mu_1 - \mu_2 < 10.22 \).

4. **Statistical Interpretation:** There is a 95% chance that
\[ -108.20 \, \text{g} < \mu_1 - \mu_2 < 10.10 \, \text{g} \]
contains the true difference in means.

5. **Real World Interpretation:** The mean sodium level of beef hotdogs is anywhere from 108.20 g less than the mean sodium level of poultry hotdogs to 10.10 g more. (The negative sign on the lower limit implies that the first mean is less than
the second mean. The positive sign on the upper limit implies that the first mean is greater than the second mean.)

Realize that many of assumptions are not valid in this example, so the interpretation may be invalid.

**Section 9.3: Homework**

In each problem show all steps of the hypothesis test or confidence interval. If some of the assumptions are not met, note that the results of the test or interval may not be correct and then continue the process of the hypothesis test or confidence interval. Unless directed by your instructor, do not assume the variances are equal (except in problems 11 through 16).

1.) The income of males in each state of the United States, including the District of Columbia and Puerto Rico, are given in table #9.3.3, and the income of females is given in table #9.3.4 ("Median income of," 2013). Is there enough evidence to show that the mean income of males is more than of females? Test at the 1% level.

**Table #9.3.3: Data of Income for Males**

<table>
<thead>
<tr>
<th>Income</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$42,951</td>
<td>$52,379</td>
<td>$42,544</td>
<td>$37,488</td>
<td>$49,281</td>
<td>$50,987</td>
<td>$60,705</td>
</tr>
<tr>
<td>$50,411</td>
<td>$66,760</td>
<td>$40,951</td>
<td>$43,902</td>
<td>$45,494</td>
<td>$41,528</td>
<td>$50,746</td>
</tr>
<tr>
<td>$45,183</td>
<td>$43,624</td>
<td>$43,993</td>
<td>$41,612</td>
<td>$46,313</td>
<td>$43,944</td>
<td>$56,708</td>
</tr>
<tr>
<td>$60,264</td>
<td>$50,053</td>
<td>$50,580</td>
<td>$40,202</td>
<td>$43,146</td>
<td>$41,635</td>
<td>$42,182</td>
</tr>
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<td>$41,803</td>
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<td>$40,285</td>
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<td>$44,057</td>
<td>$52,805</td>
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<tr>
<td>$42,125</td>
<td>$46,214</td>
<td>$51,630</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table #9.3.4: Data of Income for Females**

<table>
<thead>
<tr>
<th>Income</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$31,862</td>
<td>$40,550</td>
<td>$36,048</td>
<td>$30,752</td>
<td>$41,817</td>
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<td>$47,476</td>
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<td>$60,332</td>
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<td>$37,242</td>
<td>$31,238</td>
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<td>$34,023</td>
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<tr>
<td>$33,269</td>
<td>$32,684</td>
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<td>$34,599</td>
<td>$48,748</td>
<td>$46,185</td>
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<td>$29,548</td>
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<td>$42,113</td>
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<td>$32,462</td>
<td>$35,746</td>
<td>$31,274</td>
<td>$36,027</td>
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<td>$41,412</td>
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<td>$31,329</td>
<td>$33,184</td>
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<td>$40,993</td>
<td>$29,688</td>
<td>$35,890</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.) The income of males in each state of the United States, including the District of Columbia and Puerto Rico, are given in table #9.3.3, and the income of females is given in table #9.3.4 ("Median income of," 2013). Compute a 99% confidence interval for the difference in incomes between males and females in the U.S.
3.) A study was conducted that measured the total brain volume (TBV) (in mm\(^3\)) of patients that had schizophrenia and patients that are considered normal. Table #9.3.5 contains the TBV of the normal patients and table #9.3.6 contains the TBV of schizophrenia patients ("SOCR data oct2009," 2013). Is there enough evidence to show that the patients with schizophrenia have less TBV on average than a patient that is considered normal? Test at the 10% level.

**Table #9.3.5: Total Brain Volume (in mm\(^3\)) of Normal Patients**

<table>
<thead>
<tr>
<th></th>
<th>1663407</th>
<th>1583940</th>
<th>1299470</th>
<th>1535137</th>
<th>1431890</th>
<th>1578698</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1453510</td>
<td>1650348</td>
<td>1288971</td>
<td>1366346</td>
<td>1326402</td>
<td>1503005</td>
</tr>
<tr>
<td></td>
<td>1474790</td>
<td>1317156</td>
<td>1441045</td>
<td>1463498</td>
<td>1650207</td>
<td>1523045</td>
</tr>
<tr>
<td></td>
<td>1441636</td>
<td>1432033</td>
<td>1420416</td>
<td>1480171</td>
<td>1360810</td>
<td>1410213</td>
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<tr>
<td></td>
<td>1574808</td>
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<tr>
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<td>1288971</td>
<td>1366346</td>
<td>1326402</td>
<td>1503005</td>
</tr>
</tbody>
</table>

**Table #9.3.6: Total Brain Volume (in mm\(^3\)) of Schizophrenia Patients**

<table>
<thead>
<tr>
<th></th>
<th>1331777</th>
<th>1487886</th>
<th>1066075</th>
<th>1297327</th>
<th>1499983</th>
<th>1861991</th>
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<td></td>
<td>1368378</td>
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<tr>
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<td>1563593</td>
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<tr>
<td></td>
<td>1636119</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4.) A study was conducted that measured the total brain volume (TBV) (in mm\(^3\)) of patients that had schizophrenia and patients that are considered normal. Table #9.3.5 contains the TBV of the normal patients and table #9.3.6 contains the TBV of schizophrenia patients ("SOCR data oct2009," 2013). Compute a 90% confidence interval for the difference in TBV of normal patients and patients with Schizophrenia.

5.) The length of New Zealand (NZ) rivers that travel to the Pacific Ocean are given in table #9.3.7 and the lengths of NZ rivers that travel to the Tasman Sea are given in table #9.3.8 ("Length of NZ," 2013). Do the data provide enough evidence to show on average that the rivers that travel to the Pacific Ocean are longer than the rivers that travel to the Tasman Sea? Use a 5% level of significance.

**Table #9.3.7: Lengths (in km) of NZ Rivers that Flow into the Pacific Ocean**

<table>
<thead>
<tr>
<th></th>
<th>209</th>
<th>48</th>
<th>169</th>
<th>138</th>
<th>64</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>97</td>
<td>161</td>
<td>95</td>
<td>145</td>
<td>90</td>
</tr>
<tr>
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<td>121</td>
<td>80</td>
<td>56</td>
<td>64</td>
<td>209</td>
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<tr>
<td></td>
<td>64</td>
<td>72</td>
<td>288</td>
<td>322</td>
<td></td>
</tr>
</tbody>
</table>

**Table #9.3.8: Lengths (in km) of NZ Rivers that Flow into the Tasman Sea**

<table>
<thead>
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6.) The length of New Zealand (NZ) rivers that travel to the Pacific Ocean are given in table #9.3.7 and the lengths of NZ rivers that travel to the Tasman Sea are given in table #9.3.8 ("Length of NZ," 2013). Estimate the difference in mean lengths of rivers between rivers in NZ that travel to the Pacific Ocean and ones that travel to the Tasman Sea. Use a 95% confidence level.

7.) The number of cell phones per 100 residents in countries in Europe is given in table #9.3.9 for the year 2010. The number of cell phones per 100 residents in countries of the Americas is given in table #9.3.10 also for the year 2010 ("Population reference bureau," 2013). Is there enough evidence to show that the mean number of cell phones in countries of Europe is more than in countries of the Americas? Test at the 1% level.

Table #9.3.9: Number of Cell Phones per 100 Residents in Europe

| 100 | 76 | 100 | 130 | 75 | 84 |
| 112 | 84 | 138 | 133 | 118 | 134 |
| 126 | 188 | 129 | 93 | 64 | 128 |
| 124 | 122 | 109 | 121 | 127 | 152 |
| 96 | 63 | 99 | 95 | 151 | 147 |
| 123 | 95 | 67 | 67 | 118 | 125 |
| 110 | 115 | 140 | 115 | 141 | 77 |
| 98 | 102 | 102 | 112 | 118 | 118 |
| 54 | 23 | 121 | 126 | 47 |

Table #9.3.10: Number of Cell Phones per 100 Residents in the Americas

| 158 | 117 | 106 | 159 | 53 | 50 |
| 78 | 66 | 88 | 92 | 42 | 3 |
| 150 | 72 | 86 | 113 | 50 | 58 |
| 70 | 109 | 37 | 32 | 85 | 101 |
| 75 | 69 | 55 | 115 | 95 | 73 |
| 86 | 157 | 100 | 119 | 81 | 113 |
| 87 | 105 | 96 |

8.) The number of cell phones per 100 residents in countries in Europe is given in table #9.3.9 for the year 2010. The number of cell phones per 100 residents in countries of the Americas is given in table #9.3.10 also for the year 2010 ("Population reference bureau," 2013). Find the 98% confidence interval for the difference in mean number of cell phones per 100 residents in Europe and the Americas.
9.) A vitamin K shot is given to infants soon after birth. Nurses at Northbay Healthcare were involved in a study to see if how they handle the infants could reduce the pain the infants feel ("SOCR data nips," 2013). One of the measurements taken was how long, in seconds, the infant cried after being given the shot. A random sample was taken from the group that was given the shot using conventional methods (table #9.3.11), and a random sample was taken from the group that was given the shot where the mother held the infant prior to and during the shot (table #9.3.12). Is there enough evidence to show that infants cried less on average when they are held by their mothers than if held using conventional methods? Test at the 5% level.

**Table #9.3.11: Crying Time of Infants Given Shots Using Conventional Methods**

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**Table #9.3.12: Crying Time of Infants Given Shots Using New Methods**

<table>
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<td>25</td>
<td>18</td>
</tr>
</tbody>
</table>

10.) A vitamin K shot is given to infants soon after birth. Nurses at Northbay Healthcare were involved in a study to see if how they handle the infants could reduce the pain the infants feel ("SOCR data nips," 2013). One of the measurements taken was how long, in seconds, the infant cried after being given the shot. A random sample was taken from the group that was given the shot using conventional methods (table #9.3.11), and a random sample was taken from the group that was given the shot where the mother held the infant prior to and during the shot (table #9.3.12). Calculate a 95% confidence interval for the mean difference in mean crying time after being given a vitamin K shot between infants held using conventional methods and infants held by their mothers.

11.) Redo problem 1 testing for the assumption of equal variances and then use the formula that utilizes the assumption of equal variances (follow the procedure in example 9.3.3).

12.) Redo problem 2 testing for the assumption of equal variances and then use the formula that utilizes the assumption of equal variances (follow the procedure in example 9.3.3).

13.) Redo problem 7 testing for the assumption of equal variances and then use the formula that utilizes the assumption of equal variances (follow the procedure in example 9.3.3).
14.) Redo problem 8 testing for the assumption of equal variances and then use the formula that utilizes the assumption of equal variances (follow the procedure in example 9.3.3).

15.) Redo problem 9 testing for the assumption of equal variances and then use the formula that utilizes the assumption of equal variances (follow the procedure in example 9.3.3).

16.) Redo problem 10 testing for the assumption of equal variances and then use the formula that utilizes the assumption of equal variances (follow the procedure in example 9.3.3).
Section 9.4 Which Analysis Should You Conduct?

One of the most important concepts that you need to understand is deciding which analysis you should conduct for a particular situation. To help you to figure out the analysis to conduct, there are a series of questions you should ask yourself.

1.) Does the problem deal with mean or proportion?
   Sometimes the problem states explicitly the words mean or proportion, but other times you have to figure it out based on the information you are given. If you counted number of individuals that responded in the affirmative to a question, then you are dealing with proportion. If you measured something, then you are dealing with mean.

2.) Does the problem have one or two samples?
   So look to see if one group was measured or if two groups were measured. If you have the data sets, then it is usually easy to figure out if there is one or two samples, then there is either one data set or two data sets. If you don’t have the data, then you need to decide if the problem describes collecting data from one group or from two groups.

3.) If you have two samples, then you need to determine if the samples are independent or dependent.
   If the individuals are different for both samples, then most likely the samples are independent. If you can’t tell, then determine if a data value from the first sample influences the data value in the second sample. In other words, can you pair data values together so you can find the difference, and that difference has meaning. If the answer is yes, then the samples are paired. Otherwise, the samples are independent.

4.) Does the situation involve a hypothesis test or a confidence interval?
   If the problem talks about "do the data show", "is there evidence of", "test to see", then you are doing a hypothesis test. If the problem talks about "find the value", "estimate the" or "find the interval", then you are doing a confidence interval.

So if you have a situation that has two samples, independent samples, involving the mean, and is a hypothesis test, then you have a two-sample independent t-test. Now you look up the assumptions and the formula or technology process for doing this test. Every hypothesis test involves the same six steps, and you just have to use the correct assumptions and calculations. Every confidence interval has the same five steps, and again you just need to use the correct assumptions and calculations. So this is why it is so important to figure out what analysis you should conduct.
Data Sources:


