Two Independent Sample Means: t Test

Cohen Chapter 7

EDUC/PSY 6600

"We cannot solve problems by using the same kind of thinking that we used when we created them."

-- Albert Einstein

Introduction

> Same continuous (interval, ratio) Dependent Variable (DV) compared across 2 independent (random) samples

Research Questions

- Is there a significant difference between the 2 group means?
- Do 2 samples come from different normal distributions with the same mean?

Also called

- Independent-groups design
- Between-subjects design
- Between-groups design
- Randomized-groups design

How to Compare Two Samples Using t Tests (11-1)

Hypothesis testing: step-by-step, p-value, t-test for difference of two means - Statistics Help

Hypothesis Test Steps

1. State the **Hypotheses**
    - Null: no mean difference *difference = 0*
    - Alternative: there *is* a mean difference
2. Select the **Statistical Test** & Significance Level
    - α level, *default = .05*
    - One vs. Two tails, *default = 2 tails*
3. Select random **samples** and collect data
    - 2 simple random samples, *independent*
    - 1 sample *divided* into independent groups
4. Find the **Region of Rejection**
    - Based on α & # of tails
    - *only really do if working by hand*
5. Calculate the **Test Statistic**
    - Examples include: z, t, F, x2
    - *use a p-value more by computer*
6. Make the **Statistical Decision**
    - big p-value: "no evidence of a difference"
    - tiny p-value: "evidence of a difference"
    - make sure it is **in context**

Test Statistic Format

$$\text{Test Statistic} = \frac{\text{Estimate} - \text{Hypothesis}}{SE}$$

For a Single MEAN

$$\text{Test Statistic} = \frac{\text{Estimate}_{\text{Mean}} - \text{Hypothesis}_{\text{Mean}}}{SE_{\text{Mean}}}$$

- Assume the population's SD...

$$z = \frac{\bar{x} - \mu_0}{\frac{\sigma}{\sqrt{N}}}$$

- Use the sample's SD...

$$t = \frac{\bar{x} - \mu_0}{\frac{s}{\sqrt{N}}}$$

$$df = N - 1$$

For the DIFFERENCE in Two Means

$$\text{Test Statistic} = \frac{\text{Estimate}_{\text{Difference}} - \text{Hypothesis}_{\text{Difference}}}{SE_{\text{Difference}}}$$

$$t = \frac{(\overline{x_1} - \overline{x_2}) - 0}{SED}$$

> Note: use z instead of t **IF** N's > 100

- Null Hypothesis is "No Difference"

$$H_0 : \overline{D} = 0$$

$$H_0 : \mu_1 - \mu_2 = 0$$

- The Standard Error for the Difference (SED) & degrees of freedom is more complex

Homogeneity of Variance (HOV)

> **HOV**: both populations have the SAME spread

Levene's Test used to check for evidence that HOV is violated (Null = nothing going on...HOV is fine)

$$H_0 : \sigma_1 = \sigma_2$$

$$H_1 : \sigma_1 \neq \sigma_2$$

> Note: Levene's doesn't work as well for small samples

IF p-value is BIGGER than alpha

- $F(1, 98) = 0.78$, $p = .377$

Does **NOT** provide evidence that HOV is violated

IF p-value is SMALLER than alpha

- $F(1, 77) = 4.58$, $p = .013$

DOES provide evidence that HOV is violated

Pooled Variance Test

Requirement

- groups have the **SAME SD's** (HOV)

Default in R's `t.test()`

- `var.equal = TRUE`

Degrees of Freedom

$$df_{pooled} = n_1 + n_2 - 2$$

Standard Error

$$SE_{pooled} = \sqrt{s_p^2 \left(\frac{1}{n_1} + \frac{1}{n_2} \right)}$$

> first, pool standard deviations
>
> $$s_p^2 = \frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}$$

Seperate Variance Test

Requirement

- groups may have **different SD's**

Optional in R's `t.test()`

- `var.equal = FALSE`

Degrees of Freedom

$$min(n_1, n_2) - 1 < df_{SV} < n_1 + n_2 - 2$$

Standard Error

$$SE_{SV} = \sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}$$

- Use is somewhat controversial
- Welch's *df* are more complex
- Easier to compute the SE by hand
- Use with unequal N's, especially small

Confidence Intervals

> We construct the confidence interval for the DIFFERENCE between the 2 means

General Form for All Confidence Intervals

$$\text{Point Estimate} \quad \pm \quad CV_{\text{Estimate}} \times SE_{\text{Estimate}}$$

General Form for CIs for the Difference in Means

$$(\ \overline{x_1} - \overline{x_2}\ ) \quad \pm \quad t_{CV} \times SE_{Diff}$$

Pooled Variance CI

- groups have the **SAME SD's** (HOV)

$$(\ \overline{x_1} - \overline{x_2}\ ) \quad \pm \quad t_{CV} \times \sqrt{s_p^2 \left(\frac{1}{n_1} + \frac{1}{n_2} \right)}$$

Seperate Variance CI

- groups may have **different SD's**

$$(\ \overline{x_1} - \overline{x_2}\ ) \quad \pm \quad t_{CV} \times \sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}$$

Comparing Means

Situation		Confidence Intervals: Estimate	C.V.	$SE_{estimate}$	Hypothesis Testing: Hypothesis	Test-statistic (df)	Notes
X = measurement in sample **μ = POPULATION MEAN**	1 SAMPLE	$\bar{x}$ Sample mean	± z*	$SE_{\bar{x}} = \frac{\sigma}{\sqrt{n}}$	$H_0: \mu_x = \mu_0$ $H_a: \mu_x [\neq><] \mu_0$	$z = \frac{\bar{x} - \mu_0}{\sigma / \sqrt{n}}$	Use if you know the population SD or when sample is very large
			± t*	$SE_{\bar{x}} = \frac{s}{\sqrt{n}}$		$t = \frac{\bar{x} - \mu_0}{s / \sqrt{n}}$ $df = n - 1$	Use with a small sample or using the sample's SD instead of the population's $d = \bar{X} / SE_{\bar{X}}$
	MATCHED PAIRS ($n = \#\ of\ pairs$)	$D = x_1 - x_2$	± t*	$SE_{\bar{D}} = \frac{s_D}{\sqrt{n}}$	$H_0: \mu_D = \mu_0$ $H_a: \mu_D [\neq><] \mu_0$ ---or---	$t = \frac{\bar{D} - \mu_0}{s_D / \sqrt{n}}$ $df = n - 1$	**"Direct-Differences Method"** First must subtract all pairs to create a new variable D and then find s_D which is the SD of D's
		$\bar{D} = \bar{x}_1 - \bar{x}_2$	± t*	$SE_{\bar{D}} = \sqrt{\frac{s_1^2 + s_2^2}{n} - \frac{2rs_1s_2}{n}}$	$H_0: \mu_1 - \mu_2 = 0$ $H_a: \mu_1 - \mu_2 [\neq><] 0$	$t = \frac{\bar{D} - \mu_0}{\sqrt{\frac{s_1^2 + s_2^2}{n} - \frac{2rs_1s_2}{n}}}$ $df = n - 1$	**"Correlation Method"** Instead of subtracting all pairs, find each variables' M & SD, as well as the r between the variables in the sample
	2 INDEPENDENT SAMPLES (not paired)	$\bar{D} = \bar{x}_1 - \bar{x}_2$ Difference in 2 sample means	± z*	$SE_{\bar{D}} = \sqrt{\frac{\sigma_1{}^2}{n_1} + \frac{\sigma_2{}^2}{n_2}}$	$H_0: \mu_1 - \mu_2 = 0$ $H_a: \mu_1 - \mu_2 [\neq><] 0$	$z = \frac{\bar{D}}{\sqrt{\frac{\sigma_1{}^2}{n_1} + \frac{\sigma_2{}^2}{n_2}}}$	Know both populations SD or when samples are large
			± t*	$SE_{\bar{D}} = \sqrt{\frac{s_1{}^2}{n_1} + \frac{s_2{}^2}{n_2}}$		$t = \frac{\bar{D}}{\sqrt{\frac{s_1{}^2}{n_1} + \frac{s_2{}^2}{n_2}}}$ $\min(n's) - 1 < df_{SV} < n_1 + n_2 - 2$	**"Separate Variances t-test"** Use with equal n's –or- if violated HOV (var.equal = FALSE). Also use with equal n's if the larger sample as the smaller SD $d = \bar{D} / SE_{\bar{D}}$
				$SE_{\bar{D}} = \sqrt{s_p^2 \left(\frac{1}{n_1} + \frac{1}{n_2}\right)}$	$s_p^2 = \frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}$ $s_p^2 \xRightarrow{n_1 = n_2} \frac{s_1^2 + s_2^2}{2}$	$t = \frac{\bar{D}}{\sqrt{s_p^2 \left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$ $df_{pooled} = n_1 + n_2 - 2$	**"Pooled Variance t-test"** Assumes the populations have equal SD's (test HOV w/Levene's Test, var.equal = TRUE). Also use then the n's are not equal and the larger sample has the larger SD $d = \bar{D} / s_p$

Comparing Means

Situation		Confidence Intervals: Estimate	C.V.	$SE_{estimate}$	Hypothesis Testing: Hypothesis	Test-statistic (df)	Notes
X = measurement in sample **μ = POPULATION MEAN**	1 SAMPLE	$\bar{x}$ Sample mean	± z*	$SE_{\bar{x}} = \frac{\sigma}{\sqrt{n}}$	$H_0: \mu_x = \mu_0$ $H_a: \mu_x [\neq><] \mu_0$	$z = \frac{\bar{x} - \mu_0}{\sigma / \sqrt{n}}$	Use if you know the population SD or when sample is very large
			± t*	$SE_{\bar{x}} = \frac{s}{\sqrt{n}}$		$t = \frac{\bar{x} - \mu_0}{s / \sqrt{n}}$ $df = n - 1$	Use with a small sample or using the sample's SD instead of the population's $d = \bar{X} / SE_{\bar{X}}$
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		$\bar{D} = \bar{x}_1 - \bar{x}_2$	± t*	$SE_{\bar{D}} = \sqrt{\frac{s_1^2 + s_2^2}{n} - \frac{2rs_1s_2}{n}}$	$H_0: \mu_1 - \mu_2 = 0$ $H_a: \mu_1 - \mu_2 [\neq><] 0$	$t = \frac{\bar{D} - \mu_0}{\sqrt{\frac{s_1^2 + s_2^2}{n} - \frac{2rs_1s_2}{n}}}$ $df = n - 1$	**"Correlation Method"** Instead of subtracting all pairs, find each variables' M & SD, as well as the r between the variables in the sample
	2 INDEPENDENT SAMPLES (not paired)	$\bar{D} = \bar{x}_1 - \bar{x}_2$ Difference in 2 sample means	± z*	$SE_{\bar{D}} = \sqrt{\frac{\sigma_1{}^2}{n_1} + \frac{\sigma_2{}^2}{n_2}}$	$H_0: \mu_1 - \mu_2 = 0$ $H_a: \mu_1 - \mu_2 [\neq><] 0$	$z = \frac{\bar{D}}{\sqrt{\frac{\sigma_1{}^2}{n_1} + \frac{\sigma_2{}^2}{n_2}}}$	Know both populations SD or when samples are large
			± t*	$SE_{\bar{D}} = \sqrt{\frac{s_1{}^2}{n_1} + \frac{s_2{}^2}{n_2}}$		$t = \frac{\bar{D}}{\sqrt{\frac{s_1{}^2}{n_1} + \frac{s_2{}^2}{n_2}}}$ $\min(n's) - 1 < df_{SV} < n_1 + n_2 - 2$	**"Separate Variances t-test"** Use with equal n's –or- if violated HOV (var.equal = FALSE). Also use with equal n's if the larger sample as the smaller SD $d = \bar{D} / SE_{\bar{D}}$
				$SE_{\bar{D}} = \sqrt{s_p^2 \left(\frac{1}{n_1} + \frac{1}{n_2}\right)}$	$s_p^2 = \frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}$ $s_p^2 \xRightarrow{n_1 = n_2} \frac{s_1^2 + s_2^2}{2}$	$t = \frac{\bar{D}}{\sqrt{s_p^2 \left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$ $df_{pooled} = n_1 + n_2 - 2$	**"Pooled Variance t-test"** Assumes the populations have equal SD's (test HOV w/Levene's Test, var.equal = TRUE). Also use then the n's are not equal and the larger sample has the larger SD $d = \bar{D} / s_p$

Comparing Means

X = measurement in sample

μ = POPULATION MEAN

Situation	Confidence Intervals: Estimate	Confidence Intervals: C.V.	Confidence Intervals: SE$_{estimate}$	Hypothesis Testing: Hypothesis	Hypothesis Testing: Test-statistic (df)	Notes
1 SAMPLE	$\bar{x}$ Sample mean	± z*	$SE_{\bar{x}} = \frac{\sigma}{\sqrt{n}}$	$H_0: \mu_x = \mu_0$ $H_a: \mu_x [\neq><] \mu_0$ chap. 5	$z = \frac{\bar{x} - \mu_0}{\sigma / \sqrt{n}}$	Use if you know the population SD or when sample is very large
		± t*	$SE_{\bar{x}} = \frac{s}{\sqrt{n}}$	chap. 6	$t = \frac{\bar{x} - \mu_0}{s / \sqrt{n}}$ $df = n - 1$	Use with a small sample or using the sample's SD instead of the population's $d = \bar{X} / SE_{\bar{X}}$
MATCHED PAIRS (n = # of pairs) Chapter 11	$D = x_1 - x_2$	± t*	$SE_{\bar{D}} = \frac{s_D}{\sqrt{n}}$	$H_0: \mu_D = \mu_0$ $H_a: \mu_D [\neq><] \mu_0$	$t = \frac{\bar{D} - \mu_0}{s_D / \sqrt{n}}$ $df = n - 1$	**"Direct-Differences Method"** First must subtract all pairs to create a new variable D and then find s_D which is the SD of D's
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chap7 2 INDEPENDENT SAMPLES (not paired)	$\bar{D} = \overline{x_1} - \overline{x_2}$ Difference in 2 sample means	± z*	$SE_{\bar{D}} = \sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}$	$H_0: \mu_1 - \mu_2 = 0$ $H_a: \mu_1 - \mu_2 [\neq><] 0$	$z = \frac{\bar{D}}{\sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}}$	Know both populations SD or when samples are large
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			$SE_{\bar{D}} = \sqrt{s_p^2 \left(\frac{1}{n_1} + \frac{1}{n_2}\right)}$	$s_p^2 = \frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}$ $s_p^2 \xrightarrow{n_1 = n_2} \frac{s_1^2 + s_2^2}{2}$	$t = \frac{\bar{D}}{\sqrt{s_p^2 \left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$ $df_{pooled} = n_1 + n_2 - 2$	**"Pooled Variance t-test"** Assumes the populations have equal SD's (test HOV w/Levene's Test, var.equal = TRUE). Also use then the n's are not equal and the larger sample has the larger SD $d = \bar{D} / s_p$

Example 1) A Fully Randomized Experiment

In order to assess the efficacy of a new antidepressant drug, 10 clinically depressed participants are **randomly assigned** to one of **TWO groups**.

- Assume that prior to introducing the treatments, the experimenter confirmed that the level of depression in the 2 groups was equal.

After 6 months, all participants are rated by a psychiatrist (**blind to participant assignment**) on their level of depression.

Five participants are assigned to Group 1, which is administered the **antidepressant drug** for 6 months.

11, 1, 0, 2, 0

The other five participants are assigned to Group 2, which is administered a **placebo** during the same 6 month period.

11, 11, 5, 8, 4

> **Research Question**: Is there evidence that the antidepressant drug reduces depression more than a placebo?

Example 1) Entering Small Dataset by Hand

Load Packages

```
library(tidyverse)
library(furniture)
library(car)
```

Enter the data

> Two people per line, but don't really pair up

```
df1_wide <- data.frame(drug    = c(11,  1, 3, 4, 0),
                       placebo = c(11, 11, 5, 8, 4))
```

View the data frame

```
df1_wide
```

```
  drug placebo
1   11      11
2    1      11
3    3       5
4    4       8
5    0       4
```


Example 1) Pivoting Wide-to-Long

Restructure the data frame

> We want one line per person

```
df1_long <- df1_wide %>%
  tidyr::pivot_longer(cols = c(drug, placebo),
                      names_to = "pill",
                      names_ptypes = list(group = factor()),
                      values_to = "depression")
```

View the data frame

```
df1_long
```

```
# A tibble: 10 x 2
   pill    depression
   <chr>        <dbl>
 1 drug            11
 2 placebo         11
 3 drug             1
 4 placebo         11
 5 drug             3
 6 placebo          5
 7 drug             4
 8 placebo          8
 9 drug             0
10 placebo          4
```

Example 1) Exploratory Data Analysis

Summarize: *N, M, SD*

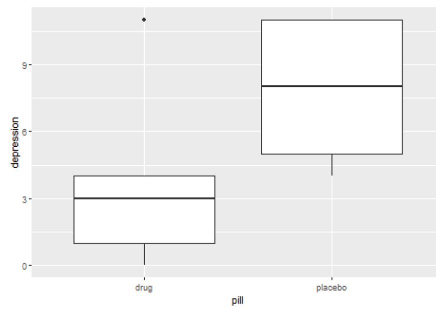
```
df1_long %>%
  dplyr::group_by(pill) %>%
  furniture::table1(depression,
                    digits = 2,
                    na.rm = FALSE,
                    output = "markdown")
```

	drug	placebo
	n = 5	n = 5
depression		
	3.80 (4.32)	7.80 (3.27)

Note: Normality is nearly impossible to assess in very small samples

Visualize: *boxplots*

```
df1_long %>%
  ggplot(aes(x = pill,
             y = depression)) +
  geom_boxplot()
```



Example 1) Levene's Test for HOV

BEFORE the t-test, check for violations of HOV

```
df1_long %>%                                    # name of the data
  car::leveneTest(depression ~ pill,           # continuous DV ~ 2-group IV
                  data = .,                    # pipe the data from above
                  center = mean)               # default is median
```

```
Levene's Test for Homogeneity of Variance (center = mean)
      Df F value Pr(>F)
group  1  0.0526 0.8244
       8
```

Conclusion

No evidence of violations of HOV were found, $F(1, 8) = 0.05$, $p = .824$.

> Choose to do the pooled variance t-test (`var.equal = TRUE`)

Example 1) Run a Pooled Variance t-Test

Run the POOLED variance t-test

```
df1_long %>%                    # name of the data
  t.test(depression ~ pill,    # continuous DV ~ 2-group IV
         data = .,             # pipe the data from above
         var.equal = TRUE)     # do the pooled-variance version
```

```
    Two Sample t-test

data:  depression by pill
t = -1.6496, df = 8, p-value = 0.1376
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 -9.591763  1.591763
sample estimates:
   mean in group drug mean in group placebo
                  3.8                   7.8
```

Conclusion

No evidence of a difference in depression was found, $t(8) = 1.80$, $p = .110$.

Example 1) Writing Methods & Results

Methods Section - analysis

To test the effectiveness of the drug at reducing depression, an **independent samples t-test** was performed, with pill type *(antidepressant drug vs. placebo)* functioning as the independent variable and depression score as the dependent variable.

Levene's test assessed for the assumption of homogeneity of variance to determine if a pooled or seperate variance test should be performed.

Results Section

After six months, the five participants taking the drug scored numerically lower on the depression scale (M = 2.80, SD = 4.66), compared their five counter parts taking placebo (M = 7.80, SD = 3.27).

The assumption of homogeneity of variances was tested and satisfied, $F(1, 8) = 0.05$, $p = .824$, thus the pooled test was conducted.

No evidence was found to support the claim that this antidepressant change depression, $t(8) = 1.80$, $p = .138$.

Assumptions of a 2-sample t-Test

1. BOTH Samples were drawn at RANDOM -AND- are INDEPENDENT of each other
(at least as representative as possible)

- Nothing can be done to fix NON-representative samples & you can **NOT** statistically test
- If not independent samples, use a *Paired-Samples t-Test*

2. The Continuous DV follows a NORMAL distribution in BOTH populations

- **NOT** as important if the sample is large, due to the **Central Limit Theorem**
- **CAN** statistically test:
  - Visual inspection of a histogram, boxplot, and/or QQ plot *(straight 45 degree line)*
  - Calculate the Skewness & Kurtosis... less clear guidelines
  - Conduct Shapiro-Wilks test *(p < .05 ??? not normal)*

3. Homogeneity of Variance (HOV)

- BOTH populations have the SAME spreads (*SD*s)
- Use Levene's Test to assess for HOV (Null Hypothesis is HOV is valid)

Violating the Assumptions

Equal Size Groups violations "hurt" less

Only violate HOV

- Small effect: p off by $\pm.02$

Only violate Normaity

- Small effect: p off by $\pm.02$
- **HOWEVER**: If samples are highly skewed or are skewed in opposite directions p-values can be **very** inaccurate!

Violate Both

- Moderate effects if N is large, p-value can be inaccurate
- Large effects if N is small, p-value can be **very** inaccurate

UN-equal Size Groups violations have "BIG" impacts

Only violate HOV

- Large effect

Only violate Normaity

- Large effect

Violate Both

- Huge effect

> p-values can be **very** inaccurate with unequal ns AND violations of assumptions, especially when N is small

Alternatives for when you Violate Assumptions

Violation of Normality or your DV is ordinal...

> None of these are covered in this class

- Two Sample Wilcoxon test *(aka, Mann-Whitney U Test)*
- Sample re-use methods
- Rely on empirical, rather than theoretical, probability distributions
    - Exact statistical methods
    - Permutation and randomization tests
    - Bootstrapping

Random Assignment & Limits on Conclusions

Random assignment to groups DECREASES experimenter biases & confounding

- Cases are enumerated and numbers drawn to assign groups

> Randomization does NOT ensure **equality** of group characteristics, but does allow for group differences to be **attributed** to the randomized factor.

True Experiment

- Random assignment & manipulation of IV
- Even better if it is double blind

Quasi-experiment

- Either randomization or manipulation
- Could randomize groups or clusters

Non-experiment or Observational Study

- Neither randomization or manipulation
- Participants self-select or form naturally occurring groups

Example 2) A Fully Randomized Experiment

An industrial psychologist is investigation the effects of different types of **motivation** on the performance of simulated clerical **tasks**.

The **ten** participants in the "individual motivation" sample are told that they will be rewarded according to how many tasks **they** successfully complete.

The **12** participants in the "group motivation" sample are told that they will be rewarded according to the average number of tasks completed **by all the participants** in their sample.

The number of tasks completed by each participant are as follows:

- Individual Motivation (`Self`): 11, 17, 14, 12, 11, 15, 13, 12, 15, 16
- Group Motivation (`Collective`): 10, 15, 4, 8, 9, 14, 6, 15, 7, 11, 13, 5

> **Research Question**: Is there evidence that performance on clerical tasks is effected by the type of motivation?

Example 2) Entering Small Dataset by Hand

> Do NOT worry about this...I will do this part in the assignments when needed

```
df_self <- data.frame(motivation = "Self",
                      tasks_done = c(11, 17, 14, 12, 11, 15, 13, 12, 15, 16))
```

```
df_coll <- data.frame(motivation = "Collective",
                      tasks_done = c(10, 15, 4, 8, 9, 14, 6, 15, 7, 11, 13, 5))
```

```
df2_long <- dplyr::full_join(df_self, df_coll) %>%
  dplyr::mutate(motivation = factor(motivation))
```

```
tibble::glimpse(df2_long)
```

```
Rows: 22
Columns: 2
$ motivation <fct> Self, Self, Self, Self, Self, Self, Self, Self, Self, Se...
$ tasks_done <dbl> 11, 17, 14, 12, 11, 15, 13, 12, 15, 16, 10, 15, 4, 8, 9,...
```

Example 2) Exploratory Data Analysis

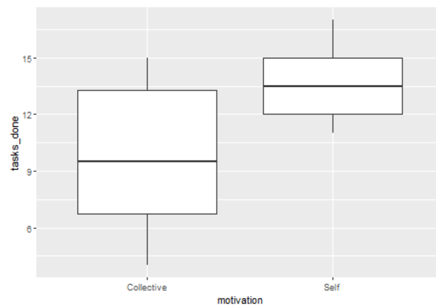
Summarize: *N, M, SD*

```
df2_long %>%
  dplyr::group_by(motivation) %>%
  furniture::table1(tasks_done,
                    digits = 2,
                    output = "markdown")
```

	Collective	Self
	n = 12	n = 10
tasks_done		
	9.75 (3.89)	13.60 (2.12)

Visualize: *boxplots*

```
df2_long %>%
  ggplot(aes(x = motivation,
             y = tasks_done)) +
  geom_boxplot()
```



Example 2) Levene's Test for HOV

BEFORE the t-test, check for violations of HOV

```
df2_long %>%                                    # name of the data
  car::leveneTest(tasks_done ~ motivation,      # continuous DV ~ 2-group IV
                  data = .,                     # pipe the data from above
                  center = mean)                # default is median
```

```
Levene's Test for Homogeneity of Variance (center = mean)
      Df F value  Pr(>F)
group  1  4.8287 0.03994 *
      20
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Conclusion

Evidence found of violations of HOV, $F(1, 20) = 4.83$, $p = .040$. Also, samples are both small and unequal in size.

> Choose to do the seperate variance t-test (`var.equal = FALSE`)

Example 2) Run a Seperate Variance t-Test

Run the SEPERATE variance t-test

```
df2_long %>%                        # name of the data
  t.test(tasks_done ~ motivation,   # continuous DV ~ 2-group IV
         data = .,                  # pipe the data from above
         var.equal = FALSE)         # do the seperate-variance version
```

```

    Welch Two Sample t-test

data:  tasks_done by motivation
t = -2.9456, df = 17.518, p-value = 0.008833
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 -6.601413 -1.098587
sample estimates:
mean in group Collective       mean in group Self
                    9.75                    13.60
```

Conclusion

Evidence of a difference in performace was found, $t(17.52) = 2.95$, $p = .009$.

Example 2) Writing Methods & Results

Methods Section - analysis

To test if performance on clerical tasks is effected by the type of motivation, an **independent samples t-test** was performed, with type of motivation *(self vs. collective)* functioning as the independent variable and number of tasks completed as the dependent variable.

Levene's test assessed for the assumption of homogeneity of variance to determine if a pooled or seperate variance test should be performed.

Results Section

The individually motivated participants completed more clerical tasks ($n = 10$, $M = 13.60$, $SD = 2.12$), compared to the participants being motivated by their group's collective results ($n = 12$, $M = 9.75$, $SD = 3.89$).

The assumption of homogeneity of variances was tested and evidence of violations were found, $F(1, 20) = 4.83$, $p = .040$, thus the seperated variance test was conducted.

Statistically significant evidence was found to support the claim that type of motivation effects performance. Thus, individual motivation does result in a mean 3.85 additional tasks completed compared to group motivation, $t(17.52) = 2.95$, $p = .009$, 95% CI [1.10, 6.60].