

# Confidence Intervals and the t Distribution

Cohen Chapter 6

EDUC/PSY 6600

“It is common sense to take a method and try it.  
If it fails, admit it frankly and try another.  
But above all, try something.”

”

-- Franklin D. Roosevelt

# Problems with z-tests

Often don't know  $\sigma^2$ , so we cannot compute  $SE_M$ , *Standard Error for the Mean* or  $\sigma_{\bar{x}}$

$$\sigma_{\bar{x}} = \frac{\sigma_x}{\sqrt{n}}$$

Can you use  $s$  in place of  $\sigma$  in  $SE_{\bar{x}}$  and do  $z$  test?

- Small samples – No, **inaccurate** results
- Large samples – Yes (> 300 participants)

$$z = \frac{\bar{x} - \mu_x}{\frac{s}{\sqrt{n}}}$$

# Small samples

As samples get smaller:  $N \downarrow$

- the skewness of the sampling distribution of  $s^2 \uparrow$
- $s^2$  underestimates  $\sigma^2$
- $z$  will  $\uparrow$
- an overestimate  $\uparrow$  risk of **Type I error**

# Small samples

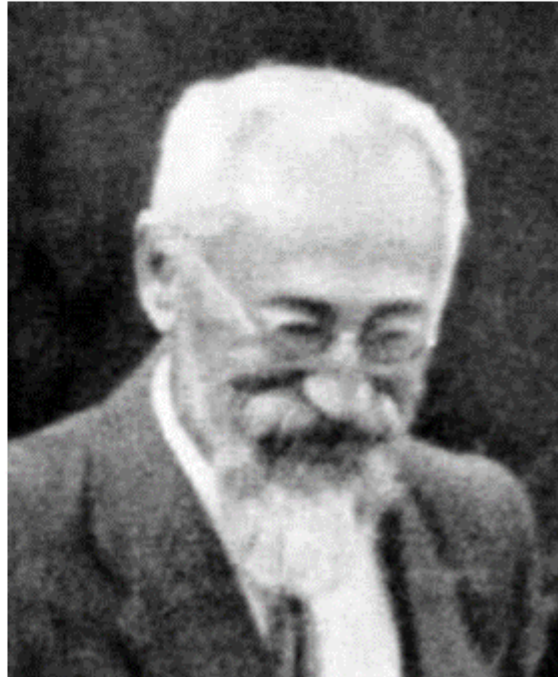
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## Comparatively... in **LARGE** samples

- $s^2$  **unbiased** estimate of  $\sigma^2$
- $\sigma$  is a constant, *unknown truth*
- $s$  is NOT a constant, since it varies from sample to sample
- As  $N$  increases,  $s \rightarrow \sigma$

# The t Distribution, “student’s t”



1908, William Gosset

- Guinness Brewing Company, England
- Invented t-test for **small** samples for brewing quality control

Wrote paper using moniker “a student” discussing nature of  $SE_M$  when using  $s^2$  instead of  $\sigma^2$

- Worked with Fisher, Neyman, Pearson, and Galton

# Student's t & Normal Distributions

## Similarities

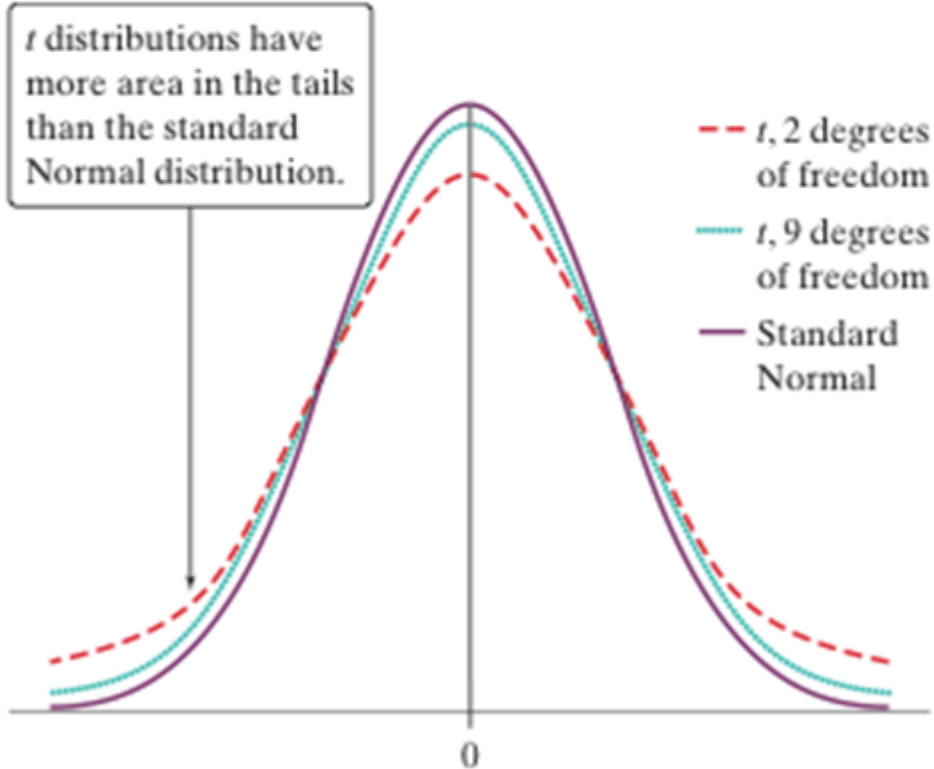
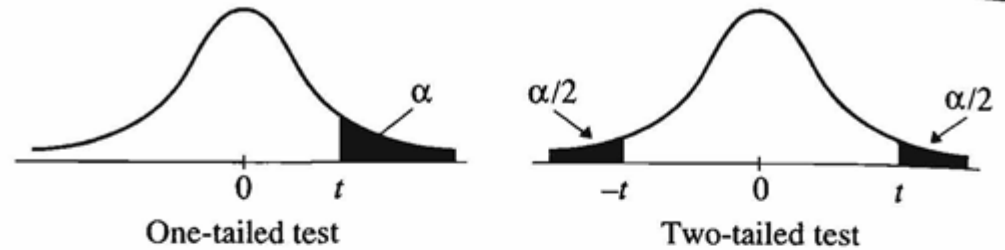
- Follows mathematical function
- Symmetrical, continuous, bell-shaped
- Continues to  $\pm$  infinity
- Mean:  $M = 0$
- Area under curve =  $p(event[s])$
- When  $N$  is large ---  $\approx 300$  ---  $t = z$

## Differences

- Family of distributions
- Different distribution for each  $N$  (or  $df$ )
- Larger area in **tails** (%) for any value of  $t$  corresponding to  $z$ 
  - $t_{cv} > z_{cv}$ , for a given  $\alpha$
- More difficult to reject  $H_0$  w/ t-distribution
  - $df = N - 1$
- As  $df \uparrow$ , the critical value of  $t \rightarrow z$

# The t Table

Table A-2  
Critical Values of the  
t Distribution



LEVEL OF SIGNIFICANCE FOR ONE-TAILED TEST						
	.10	.05	.025	.01	.005	.0005
LEVEL OF SIGNIFICANCE FOR TWO-TAILED TEST						
df	.20	.10	.05	.02	.01	.001
1	3.078	6.314	12.706	31.821	63.657	636.620
2	1.886	2.920	4.303	6.965	9.925	31.599
3	1.638	2.353	3.182	4.541	5.841	12.924
4	1.533	2.132	2.776	3.747	4.604	8.610
5	1.476	2.015	2.571	3.365	4.032	6.869
6	1.440	1.943	2.447	3.143	3.707	5.959
7	1.415	1.895	2.365	2.998	3.499	5.408
8	1.397	1.860	2.306	2.896	3.355	5.041
9	1.383	1.833	2.262	2.821	3.250	4.781
10	1.372	1.812	2.228	2.764	3.169	4.587
11	1.363	1.796	2.201	2.718	3.106	4.437
12	1.356	1.782	2.179	2.681	3.055	4.318
13	1.350	1.771	2.160	2.650	3.012	4.221
14	1.345	1.761	2.145	2.624	2.977	4.140
15	1.341	1.753	2.131	2.602	2.947	4.073



# Calculating the t-Statistic

$x$  is interval/ratio data (ordinal okay:  $\geq 10 - 16$  levels or values)

Like  $z$ ,  $t$ -statistic represents a **SD** score (the # of SE's that  $\bar{x}$  deviates from  $\mu$ )

$$t = \frac{\bar{x} - \mu_x}{\frac{s_x}{\sqrt{N}}}$$

$$df = N - 1$$

When  $\sigma$  is known,  $t$ -statistic is sometimes computed (rather than  $z$ -statistic) if  $N$  is small

Estimate the population  $SE_M$  with sample data:

Estimated  $SE_M$  is the amount a sample's observed **mean**  
may have deviated from  
the true or population value  
just due to random chance variation due to sampling.

# Assumptions (same as z tests)

Sample was drawn at **random** (at least as representative as possible)

- Nothing can be done to fix NON-representative samples!
- **Can not statistically test**

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Variables have a **normal** distribution

- Not as important if the sample is large (Central Limit Theorem)
- IF the sample is far from normal &/or small n, might want to transform variables
  - Look at plots: **histogram, boxplot, & QQ plot** (straight **45\degree** line)
  - Skewness & Kurtosis: Divided value by its SE &  **$> \pm 2$**  indicates issues
  - **Shapiro-Wilks** test (small N):  $p < .05$  ??? not normal
  - Kolmogorov-Smirnov test (large N)

## EX) 1 sample t Test: mean vs. *historic control*

A physician states that, in the past, the average number of times he saw each of his patients during the year was 5. However, he believes that his patients have visited him significantly **more frequently** during the past year. In order to validate this statement, he randomly selects 10 of his patients and determines the number of office visits during the past year. He obtains the values presented to the below.

9, 10, 8, 4, 8, 3, 0, 10, 15, 9

Do the data support his contention that the average number of times he has seen a patient in the last year is **different that 5**?

# EX) 1 sample t Test: mean vs. *historic control*

```
x = c(9, 10, 8, 4, 8, 3, 0, 10, 15, 9)
```

```
length(x)
```

```
[1] 10
```

```
sum(x)
```

```
[1] 76
```

```
mean(x)
```

```
[1] 7.6
```

```
sd(x)
```

```
[1] 4.247875
```

# EX) 1 sample t Test: mean vs. *historic control*

## 1. Null/Alt Hypotheses

$$H_0: \mu = 5$$

$$H_1: \mu \neq 5$$

## 2. Choose Test Stat, $\alpha$ , & # tails

CLT: mean of repeated SRS  $\rightarrow$   
normally dist. w/o pop SD known

$\rightarrow$  So use the t-stat

$\alpha = .05$  & 2 tails (default)

## 3. SRS data $\rightarrow$ Sample Mean

$$\bar{X} = \frac{\sum X}{n} = \frac{76}{10} = 7.6$$

$S = 4.25$

## 4. Rejection Region?

$$df = n - 1 = 10 - 1 = 9$$

$\rightarrow$  Critical t =  $\pm 2.262 \dots$

$\rightarrow$  Reject if t-score is  $> 2.262$  or  $< -2.262$

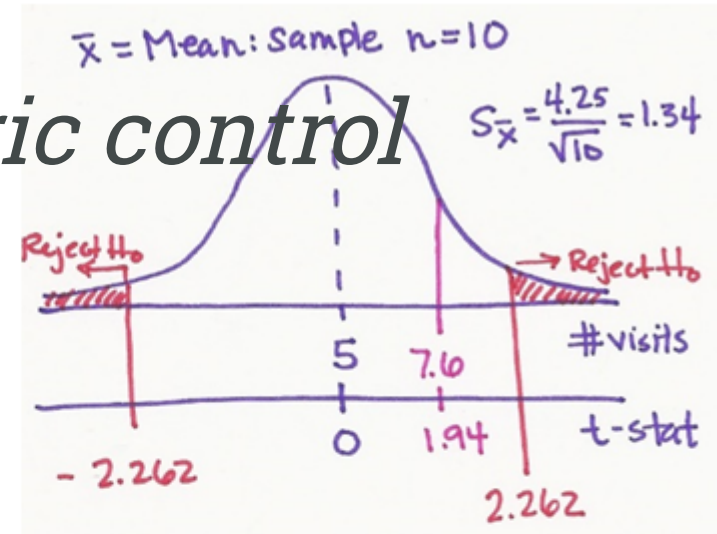
## 5. Calculate the Test Stat

Distribution of all sample means:

$$Mean_{mean} = \mu_{\bar{X}} = \mu_{pop} = 5$$

$$SE_{mean} = s_{\bar{X}} = \frac{s_{sample}}{\sqrt{n}} = \frac{4.25}{\sqrt{10}} = 1.34$$

$$t = \frac{\bar{X} - \mu_{\bar{X}}}{s_{\bar{X}}} = \frac{7.6 - 5}{1.34} = 1.94$$



## 6. Conclusion

t-stat does NOT fall in the rejection region  
No evidence the population's mean is not 5  
"FAIL to reject the Null"

**"Even though this sample's mean of 7.6 was more than 5, this could be due to random chance and another sample may find the opposite effect."**

# Confidence Intervals

Statistics are **point estimates**, or *population parameters*, **with error**

How **close** is estimate to population parameter?

- Confidence interval (CI) around point estimate (*Range of values*)
  - Upper limit: UL or UCL
  - Lower limit: LL or LCL

CI expresses our **confidence** in a statistic & the *width* depends on  $SE_M$  and  $t_{cv}$

- Both are function of  $N$ 
  - Larger  $N \rightarrow$  Smaller CI
- More confident that sample point estimate (statistic) approximates population parameter
  - **Narrow CI**: Less confidence, more precision (*less error*)
  - **Wide CI**: More confidence, less precision (*more error*)



# Steps to Construct a Confidence interval

1. Select your random sample size
2. Select the **Level of Confidence**
  - Generally 95% (*can by 80, 90, or even 99%*)
3. Select random sample and collect data
4. Find the **Region of Rejection**
  - Based on  $\alpha = 1 - Conf$  & # of tails = 2
5. Calculate the Interval **End Points**

$$Est \pm CV_{Est} \times SE_{Est}$$

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Narrow CI:

- large sample
- Lower %

Wider CI:

- smaller sample
- Higher %

95% CI with z score

$$\bar{x} \pm 1.96 \times \frac{\sigma}{\sqrt{N}}$$

99% CI with z score

$$\bar{x} \pm 2.58 \times \frac{\sigma}{\sqrt{N}}$$

## EX) Confidence Interval: for a Mean

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Construct a 95% confidence interval for the mean number of visits per patient.

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Construct a 95% confidence interval for the mean number of visits per patient.

## 1. Best estimate

$$\bar{X} = \frac{\sum X}{n} = \frac{76}{10} = 7.6$$

## 2. Critical Value

df = n - 1 = 10 - 1 = 9  
Always use TWO tails  
→ Critical t = 2.262

## 3. Standard Error for the Estimate

Sample standard deviation, S = 4.25

$$SE_{mean} = s_{\bar{X}} = \frac{s_{sample}}{\sqrt{n}} = \frac{4.25}{\sqrt{10}} = 1.34$$

## 4. Put it together

Est ± CV × SE<sub>est</sub> →

$$7.60 \pm 2.262 \times 1.34$$
$$7.60 \pm 3.03$$

**4.57, 10.63**

# Estimating the Population Mean

Point estimate (M) is in the center of CI

Degree of confidence determined by  $\alpha$  and corresponding critical value (CV)

- Commonly use 95% CI, so  $\alpha = .05$
- Can also compute a .90, .99, or any size CI

**z-distribution:**

Known population variance or N is large (about 300)

$$\bar{x} \pm z_{cv} \times \frac{\sigma}{\sqrt{N}}$$

**t-distribution:**

Do not know population variance or N is small

$$\bar{x} \pm t_{cv} \times \frac{s}{\sqrt{N}}$$

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## NOT the meaning of a 95% CI

There is **NOT** a 95% chance that the population M lies between the 2 CLs from your sample's CI !!!

Each random sample will have a different CI with different CLs and a different M value

## Meaning of a 95% CI

95% of the CIs that could be constructed over repeated sampling will contain M Yours **MAY** be one of them

5% chance our sample's 95% CI does not contain  $\mu$   
Related to **Type I Error**

# APA Style Writeup

## Z-test

*(happens to be a statistically significant difference)*

The hourly fee ( $M = \$72$ ) for our sample of current psychotherapists is significantly greater,  $z = 4.0, p < .001$ , than the 1960 hourly rate ( $M = \$63$ , in current dollars).

# APA Style Writeup

## Z-test

*(happens to be a statistically significant difference)*

The hourly fee ( $M = \$72$ ) for our sample of current psychotherapists is significantly greater,  $z = 4.0, p < .001$ , than the 1960 hourly rate ( $M = \$63$ , in current dollars).

## T-test

*(happens to not quite reach .05 significance level)*

Although the mean hourly fee for our sample of current psychotherapists was considerably higher ( $M = \$72$ ,  $SD = 22.5$ ) than the 1960 population mean ( $M = \$63$ , in current dollars), this difference only approached statistical significance,  $t(24) = 2.00, p = .06$ .



Let's Apply This to the Cancer Dataset

# Read in the Data

```
library(tidyverse)    # Loads several very helpful 'tidy' packages
library(haven)        # Read in SPSS datasets
library(psych)        # Lots of nice tid-bits
library(car)          # Companion to "Applied Regression"
```

```
cancer_raw <- haven::read_spss("cancer.sav")
```

## And Clean It

```
cancer_clean <- cancer_raw %>%
  dplyr::rename_all(tolower) %>%
  dplyr::mutate(id = factor(id)) %>%
  dplyr::mutate(trt = factor(trt,
                             labels = c("Placebo",
                                           "Aloe Juice"))) %>%
  dplyr::mutate(stage = factor(stage))
```

# 1 sample t Test vs. Historic Control

Do the patients weigh more than 165 pounds at intake, on average?

```
cancer_clean %>%  
  dplyr::pull(weighin) %>%  
  t.test(mu = 165)
```

One Sample t-test

```
data: .  
t = 2.0765, df = 24, p-value = 0.04872  
alternative hypothesis: true mean is not equal to 165  
95 percent confidence interval:  
 165.0807 191.4793  
sample estimates:  
mean of x  
 178.28
```

# ...Change the Confidence Level

Find a 99% confidence level for the population mean weight.

```
cancer_clean %>%  
  dplyr::pull(weighin) %>%  
  t.test(mu = 165,  
         conf.level = 0.99)
```

One Sample t-test

```
data: .  
t = 2.0765, df = 24, p-value = 0.04872  
alternative hypothesis: true mean is not equal to 165  
99 percent confidence interval:  
 160.3927 196.1673  
sample estimates:  
mean of x  
 178.28
```

# ...Restrict to a Subsample

Do the patients with **stage 3 & 4** cancer weigh more than 165 pounds at intake, on average?

```
cancer_clean %>%  
  dplyr::filter(stage %in% c("3", "4")) %>%  
  dplyr::pull(weighin) %>%  
  t.test(mu = 165)
```

One Sample t-test

```
data: .  
t = 0.82627, df = 5, p-value = 0.4463  
alternative hypothesis: true mean is not equal to 165  
95 percent confidence interval:  
 137.0283 219.4717  
sample estimates:  
mean of x  
 178.25
```

Questions?

# Next Topic

Independent Samples t Tests for Means