Class 21

Daniel B. Rowe, Ph.D.

Department of Mathematical and Statistical Sciences

Agenda:

Recap Chapter 10.1 and 10.2

Lecture Chapter 10.3

Recap Chapter 10.1 and 10.2

10: Inferences Involving Two Populations

10.2 Inference for Mean Difference Two Dependent Samples

We form a paired difference from the data

Paired Difference

$$d = x_1 - x_2 \tag{10.1}$$

This means that we are subtracting the sample value from population 2 from the sample value from population 1.

10: Inferences Involving Two Populations

10.2 Inference for Mean Difference Two Dependent Samples

So if the d_i's are approximately normally distributed

with a mean of μ_d and a standard deviation of σ_d, then

$\bar{d} = \frac{1}{n}\sum_{i=1}^{n} d_i$ is normally distributed (recall CLT)

with a mean $\mu_{\bar{d}} = \mu_d$, and standard deviation $\sigma_{\bar{d}} = \frac{\sigma_d}{\sqrt{n}}$.

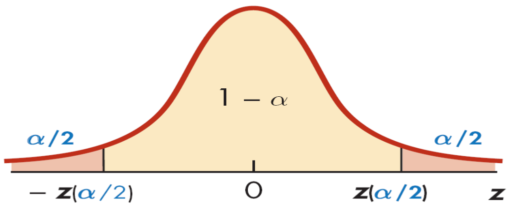
10: Inferences Involving Two Populations

10.2 Inference for Mean Difference Two Dependent Samples

This would allow us to form a z statistic for the mean of differences $\bar{d}$, $z = \dfrac{\bar{d} - \mu_d}{\sigma_d / \sqrt{n}}$ with a standard normal distribution.

assuming known

We can then look up probabilities in the table,



find critical values $z(\alpha/2)$, construct confidence intervals

$$\bar{d} \pm z(\alpha/2)\frac{\sigma_d}{\sqrt{n}}$$

and test hypotheses using $z^* = \dfrac{\bar{d} - \mu_{0d}}{\sigma_d / \sqrt{n}}$.

Figure from Johnson & Kuby, 2012.

10: Inferences Involving Two Populations

10.2 Inference for Mean Difference Two Dependent Samples

However, as in Inferences for One Population, we never know the true value of σ_d . So we estimate it with sample standard deviation s_d. This changes $z=\dfrac{\bar{d}-\mu_d}{\sigma_d/\sqrt{n}}$ to $t=\dfrac{\bar{d}-\mu_d}{s_d/\sqrt{n}}$ and the distribution from standard normal to Student t with $df=n-1$ where $s_d^2=\dfrac{1}{n-1}\sum_{i=1}^{n}(d_i-\bar{d})^2$.

10: Inferences Involving Two Populations

10.2 Inference for Mean Difference Two Dependent Samples

Confidence Interval Procedure

With σ_d unknown, a 1-α confidence interval for μ_d is:

Confidence Interval for Mean Difference (Dependent Samples)

$$\bar{d} - t(df,\alpha/2)\frac{s_d}{\sqrt{n}} \quad \text{to} \quad \bar{d} + t(df,\alpha/2)\frac{s_d}{\sqrt{n}} \quad \text{where } df=n-1 \qquad (10.2)$$

$$\bar{d} = \frac{1}{n}\sum_{i=1}^{n} d_i \qquad (10.3)$$

$$s_d^2 = \frac{1}{n-1}\sum_{i=1}^{n}(d_i - \bar{d})^2 \qquad (10.4)$$

10: Inferences Involving Two Populations

10.2 Inference for Mean Difference Two Dependent Samples

Car	1	2	3	4	5	6
Brand A	125	64	94	38	90	106
Brand B	133	65	103	37	102	115

Example:

Construct a 95% CI for mean difference in Brand B – A tire wear.

d_i's: $8,\ 1,\ 9,\ -1,\ 12,\ 9$

$$\bar{d} = \frac{1}{n}\sum_{i=1}^{n} d_i$$

$n = 6$ $\quad df = 5$ $\quad t(df, \alpha/2) = 2.57$

$\bar{d} = 6.3$ $\quad \alpha = 0.05$

$$s_d^2 = \frac{1}{n-1}\sum_{i=1}^{n}(d_i - \bar{d})^2$$

$s_d = 5.1$

$$\bar{d} \pm t(df, \alpha/2)\frac{s_d}{\sqrt{n}} \longrightarrow (0.090, 11.7)$$

Figure from Johnson & Kuby, 2012.

10: Inferences Involving Two Populations

10.2 Inference for Mean Difference Two Dependent Samples

Hypothesis Testing Procedure

We can test for differences in the population means:

H_0: $\mu_1 \geq \mu_2$ vs. H_a: $\mu_1 < \mu_2$ → H_0: $\mu_1 - \mu_2 \geq 0$ vs. H_a: $\mu_1 - \mu_2 < 0$

H_0: $\mu_1 \leq \mu_2$ vs. H_a: $\mu_1 > \mu_2$ → H_0: $\mu_1 - \mu_2 \leq 0$ vs. H_a: $\mu_1 - \mu_2 > 0$

H_0: $\mu_1 = \mu_2$ vs. H_a: $\mu_1 \neq \mu_2$ → H_0: $\mu_1 - \mu_2 = 0$ vs. H_a: $\mu_1 - \mu_2 \neq 0$

$\mu_d = \mu_1 - \mu_2$ → H_0: $\mu_d \geq 0$ vs. H_a: $\mu_d < 0$

$(\mu_d = \mu_{before} - \mu_{after})$ H_0: $\mu_d \leq 0$ vs. H_a: $\mu_d > 0$

H_0: $\mu_d = 0$ vs. H_a: $\mu_d \neq 0$

10: Inferences Involving Two Populations

10.2 Inference for Mean Difference Two Dependent Samples

Hypothesis Testing Procedure

With σ_d unknown, the test statistic for μ_d is:

Test Statistic for Mean Difference (Dependent Samples)

$$t^* = \frac{\bar{d} - \mu_{d0}}{s_d / \sqrt{n}}$$

where $df=n-1$

(10.5)

Go through the same five hypothesis testing steps.

9: Inferences Involving One Population

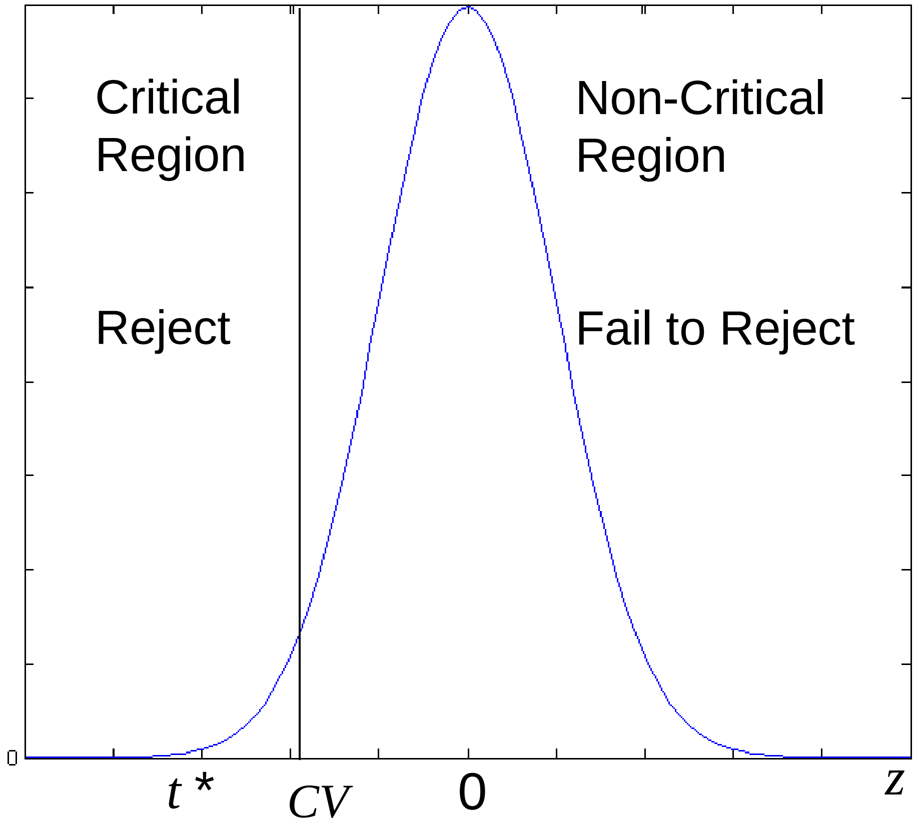
9.2 Inference about the Binomial Probability of Success

There are three possible hypothesis pairs for the difference in means.

H_0: $\mu_d \geq \mu_{d0}$ vs. H_a: $\mu_d < \mu_{d0}$

Reject H_0 if $t^* = \dfrac{\bar{d} - \mu_{d0}}{s_d / \sqrt{n}}$ less than $-t(df, \alpha)$

data indicates $\mu_d < \mu_{d0}$ because $\bar{d}$ is "a lot" smaller than μ_{d0}



9: Inferences Involving One Population

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There are three possible hypothesis pairs for the difference in means.

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Reject H_0 if $t^* = \frac{\bar{d} - \mu_{d0}}{s_d / \sqrt{n}}$ greater then $t(df, \alpha)$

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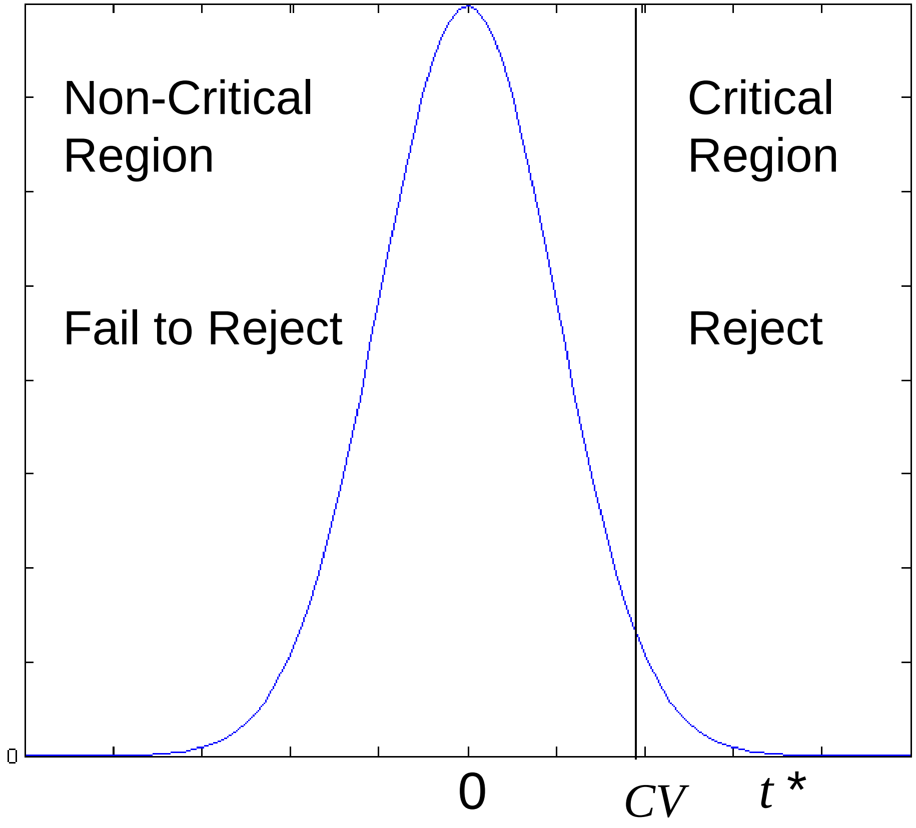


9: Inferences Involving One Population

9.2 Inference about the Binomial Probability of Success

There are three possible hypothesis pairs for the difference in means.

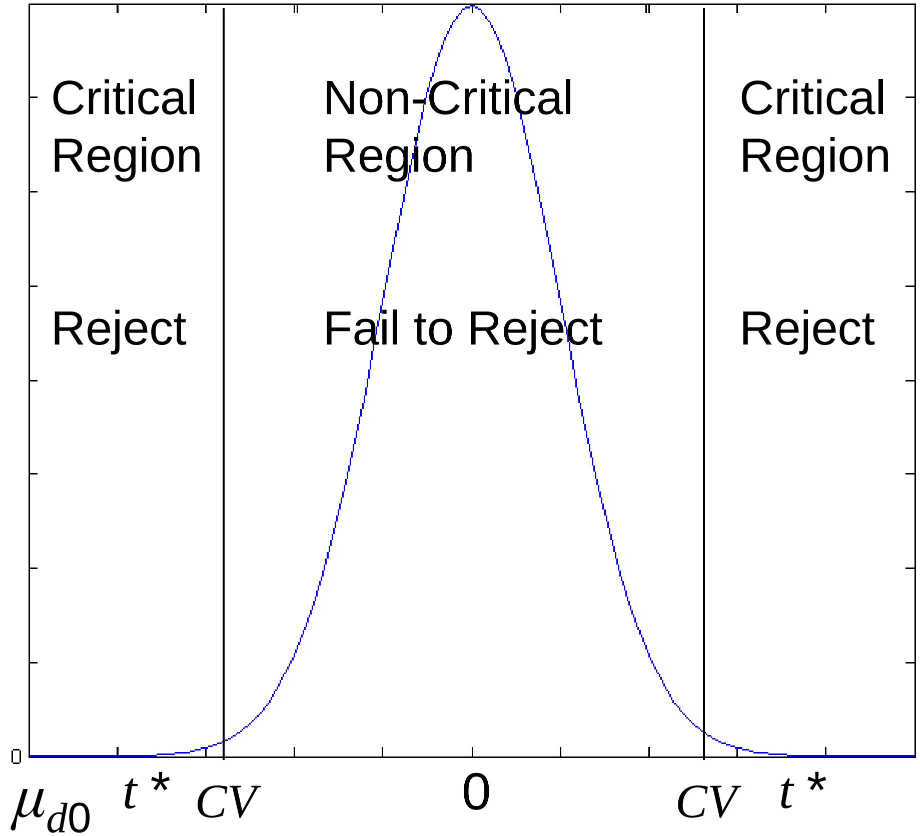
H_0: $\mu_d = \mu_{d0}$ vs. H_a: $\mu_d \neq \mu_{d0}$

Reject H_0 if less than

$$t^* = \frac{\bar{d} - \mu_{d0}}{s_d / \sqrt{n}} \qquad -t(df, \alpha/2)$$

or if is greater than

$$t^* = \frac{\bar{d} - \mu_{d0}}{s_d / \sqrt{n}} \qquad t(df, \alpha/2)$$



data indicates $\mu_d \neq \mu_{d0}$, $\bar{d}$ far from μ_{d0}

10: Inferences Involving Two Populations

10.2 Inference for Mean Difference Two Dependent Samples

$n = 6 \quad 8,\ 1,\ 9,\ -1,\ 12,\ 9$

Example:

Car	1	2	3	4	5	6
Brand A	125	64	94	38	90	106
Brand B	133	65	103	37	102	115

Test mean difference of Brand B minus Brand A is zero.

Step 1 $H_0: \mu_d = 0$ vs. $H_a: \mu_d \neq 0$

Step 2

$df = 5$

$\alpha = .05$

$$t^* = \frac{\bar{d} - \mu_{d0}}{s_d / \sqrt{n}}$$

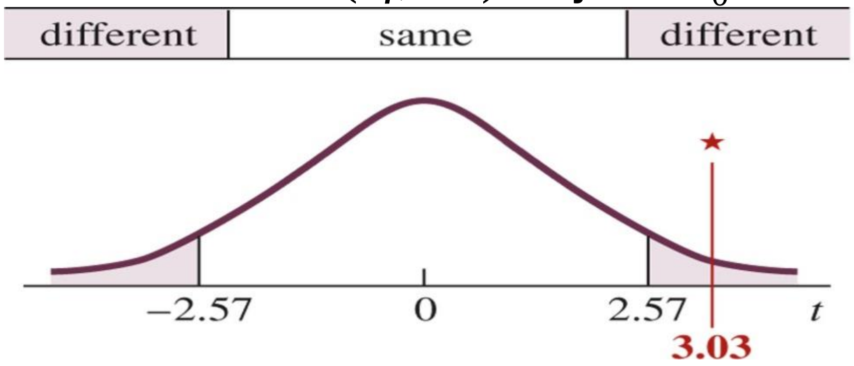
Step 3 $\bar{d} = 6.3$

$s_d = 5.1$

$$t^* = \frac{6.3 - 0}{5.1 / \sqrt{6}} = 3.03$$

Step 4 $t(df, \alpha / 2) = 2.57$

Step 5 Since $t^* > t(df, \alpha/2)$, reject H_0



Conclusion: Significant difference in tread wear at .05 level.

Figures from Johnson & Kuby, 2012.

Chapter 10: Inferences Involving Two Populations

Questions?

Homework: Read Chapter 10.1-10.2
WebAssign
Chapter 10 #13, 15, 23, 25, 29, 31, 35

Chapter 10: Inference Involving Two Populations

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Department of Mathematical and Statistical Sciences

10: Inferences Involving Two Populations

10.3 Inference for Mean Difference Two Independent Samples

Background

We said from SDSM that $\text{mean}(\bar{x}) = \mu$ and $\text{variance}(\bar{x}) = \dfrac{\sigma^2}{n}$.

We are often interested in comparisons between means $\bar{x}_1 - \bar{x}_2$.

There's a rule that says that if $\bar{x}_1$ and $\bar{x}_2$ have means μ_1 and μ_2 ,

and variances σ_1^2 and σ_2^2 ,

then $\text{mean}(\bar{x}_1 - \bar{x}_2) = \mu_1 - \mu_2$

and variance $\left(\bar{x}_1 - \bar{x}_2\right) = \dfrac{\sigma_1^2}{n_1} + \dfrac{\sigma_2^2}{n_2} \longrightarrow \sigma_{\bar{x}_1 - \bar{x}_2} = \sqrt{\dfrac{\sigma_1^2}{n_1} + \dfrac{\sigma_2^2}{n_2}}$.

if x_1 & x_2 independent

Variances add not standard deviations.

10: Inferences Involving Two Populations

10.3 Inference for Mean Difference Two Independent Samples Means Using Two Independent Samples

If two populations are independent we can construct confidence intervals and test hypotheses for the difference in their means.

If independent samples of sizes n_1 and n_2 are drawn … with means μ_1 and μ_2 and variances σ_1^2 and σ_2^2 , then the sampling distribution of $\bar{x}_1 - \bar{x}_2$ … has

1. mean $\mu_{\bar{x}_1 - \bar{x}_2} = \mu_1 - \mu_2$ and
2. standard error $\sigma_{\bar{x}_1 - \bar{x}_2} = \sqrt{\left(\frac{\sigma_1^2}{n_1}\right) + \left(\frac{\sigma_2^2}{n_2}\right)}$

If both pops. are normal, then $\bar{x}_1 - \bar{x}_2$ is normal . (10.6)

Actually the CLT works here for $\bar{x}$'s.

10: Inferences Involving Two Populations

10.3 Inference for Mean Difference Two Independent Samples

However, the true population variances are never truly known

so we estimate σ_1^2 and σ_2^2 by s_1^2 and s_2^2 and the

standard error

$$\sigma_{\bar{x}_1-\bar{x}_2} = \sqrt{\left(\frac{\sigma_1^2}{n_1}\right)+\left(\frac{\sigma_2^2}{n_2}\right)} \qquad (10.6)$$

by

$$s_{\bar{x}_1-\bar{x}_2} = \sqrt{\left(\frac{s_1^2}{n_1}\right)+\left(\frac{s_2^2}{n_2}\right)} \quad . \qquad (10.7)$$

10: Inferences Involving Two Populations

10.3 Inference for Mean Difference Two Independent Samples

Confidence Interval Procedure

With σ_1 and σ_2 unknown, a 1-α confidence interval for $\mu_1 - \mu_2$ is:

Confidence Interval for Mean Difference (Independent Samples)

$$(\bar{x}_1 - \bar{x}_2) - t(df, \alpha/2)\sqrt{\left(\frac{s_1^2}{n_1}\right) + \left(\frac{s_2^2}{n_2}\right)} \text{ to } (\bar{x}_1 - \bar{x}_2) + t(df, \alpha/2)\sqrt{\left(\frac{s_1^2}{n_1}\right) + \left(\frac{s_2^2}{n_2}\right)}$$

where df is either calculated or smaller of df_1, or df_2 (10.8)

Actually, this is for $\sigma_1 \neq \sigma_2$.

Next larger number than

$$df = \left(\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}\right)^2 \Bigg/ \left(\frac{\left(s_1^2/n_1\right)^2}{n_1 - 1} + \frac{\left(s_2^2/n_2\right)^2}{n_2 - 1}\right)$$

If using a computer program.

If not using a computer program.

Need normal populations to use t critical values.

10: Inferences Involving Two Populations

10.3 Inference Mean Difference Confidence Interval

Sample	Number	Mean	Standard Deviation
Female (f)	$n_1 = 20$	$\bar{x}_f = 63.8$	$s_f = 2.18$
Male (m)	$n_2 = 30$	$\bar{x}_m = 69.8$	$s_m = 1.92$

Example:

Interested in difference in mean heights between men and women. The heights of 20 females and 30 males is measured. Construct a 95% confidence interval for $\mu_m - \mu_f$, σ_m & σ_f unknown

$$(\bar{x}_m - \bar{x}_f) \pm t(df, \alpha/2) \sqrt{\left(\frac{s_m^2}{n_m}\right) + \left(\frac{s_f^2}{n_f}\right)}$$

$$\alpha = 0.05$$

$$t(19, .025) =$$

Figure from Johnson & Kuby, 2012.

10: Inferences Involving Two Populations

10.3 Inference Mean Difference Confidence Interval

Sample	Number	Mean	Standard Deviation
Female (f)	$n_1 = 20$	$\bar{x}_f = 63.8$	$s_f = 2.18$
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Example:

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$$(\bar{x}_m - \bar{x}_f) \pm t(df, \alpha/2)\sqrt{\left(\frac{s_m^2}{n_m}\right) + \left(\frac{s_f^2}{n_f}\right)}$$

$$\alpha = 0.05$$

$$t(19, .025) = 2.09$$

$$(69.8 - 63.8) \pm 2.09\sqrt{\left(\frac{(1.92)^2}{30}\right) + \left(\frac{(2.18)^2}{20}\right)}$$

therefore 4.75 to 7.25

Figure from Johnson & Kuby, 2012.

10: Inferences Involving Two Populations

10.3 Inference for Mean Difference Two Independent Samples

Hypothesis Testing Procedure

We can test for differences in the population means:

H_0: $\mu_1 \geq \mu_2$ vs. H_a: $\mu_1 < \mu_2$ $\rightarrow$ H_0: $\mu_1 - \mu_2 \geq 0$ vs. H_a: $\mu_1 - \mu_2 < 0$

H_0: $\mu_1 \leq \mu_2$ vs. H_a: $\mu_1 > \mu_2$ $\rightarrow$ H_0: $\mu_1 - \mu_2 \leq 0$ vs. H_a: $\mu_1 - \mu_2 > 0$

H_0: $\mu_1 = \mu_2$ vs. H_a: $\mu_1 \neq \mu_2$ $\rightarrow$ H_0: $\mu_1 - \mu_2 = 0$ vs. H_a: $\mu_1 - \mu_2 \neq 0$

10: Inferences Involving Two Populations

10.3 Inference for Mean Difference Two Independent Samples

Hypothesis Testing Procedure

With σ_1 and σ_2 unknown, the test statistic for $\mu_1 - \mu_2$ is:

Test Statistic for Mean Difference (Independent Samples)

$$t^* = \frac{(\bar{x}_1 - \bar{x}_2) - (\mu_{0,1} - \mu_{0,2})}{\sqrt{\left(\frac{s_1^2}{n_1}\right) + \left(\frac{s_2^2}{n_2}\right)}}$$

Next larger number than

$$df = \left(\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}\right)^2 \Bigg/ \left(\frac{\left(s_1^2/n_1\right)^2}{n_1 - 1} + \frac{\left(s_2^2/n_2\right)^2}{n_2 - 1}\right)$$

If not using a computer program.

where df is either calculated or smaller of df_1, or df_2 (10.9)

Actually, this is for $\sigma_1 \neq \sigma_2$.

If using a computer program.

Go through the same five hypothesis testing steps.

Need normal populations to use t critical values.

9: Inferences Involving One Population

9.2 Inference about the Binomial Probability of Success

There are three possible hypothesis pairs for the difference in means.

H_0: μ_1-μ_2 ≥ 0 vs. H_a: μ_1-μ_2 < 0

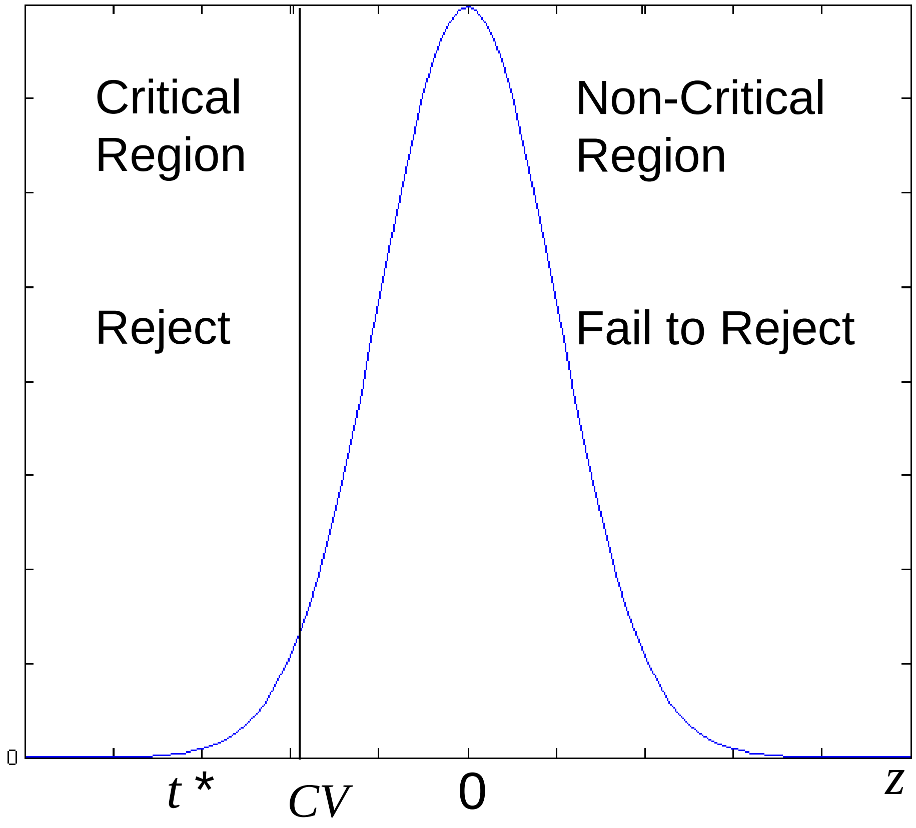
Reject H_0 if

$$t^* = \frac{(\bar{x}_1 - \bar{x}_2) - 0}{\sqrt{\left(s_1^2/n_1\right) + \left(s_2^2/n_2\right)}}$$

less than

$$-t(df,\alpha)$$

data indicates μ_1-μ_2 < 0 because $\bar{x}_1 - \bar{x}_2$ is "a lot" smaller than 0.



9: Inferences Involving One Population

9.2 Inference about the Binomial Probability of Success

There are three possible hypothesis pairs for the difference in means.

H_0: μ_1-μ_2 ≤ 0 vs. H_a: μ_1-μ_2 > 0

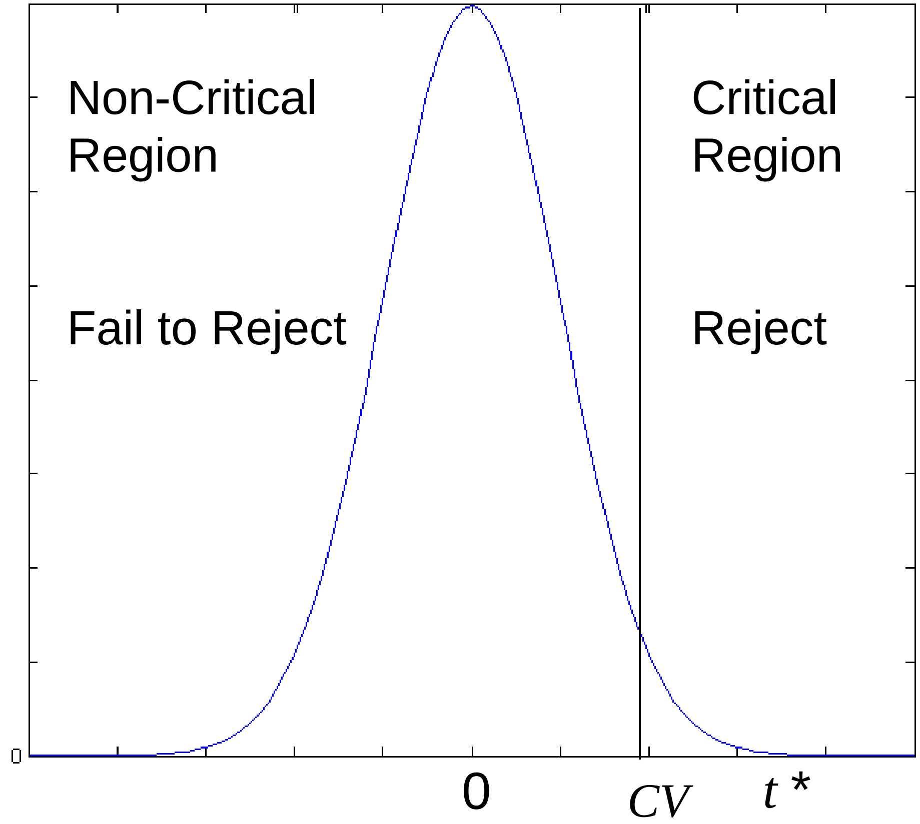
Reject H_0 if

$$t^* = \frac{(\bar{x}_1 - \bar{x}_2) - 0}{\sqrt{(s_1^2/n_1) + (s_2^2/n_2)}}$$

greater then

$$t(df, \alpha)$$

data indicates μ_1-μ_2 > 0 because $\bar{x}_1 - \bar{x}_2$ is "a lot" smaller than 0.



9: Inferences Involving One Population

9.2 Inference about the Binomial Probability of Success

There are three possible hypothesis pairs for the difference in means.

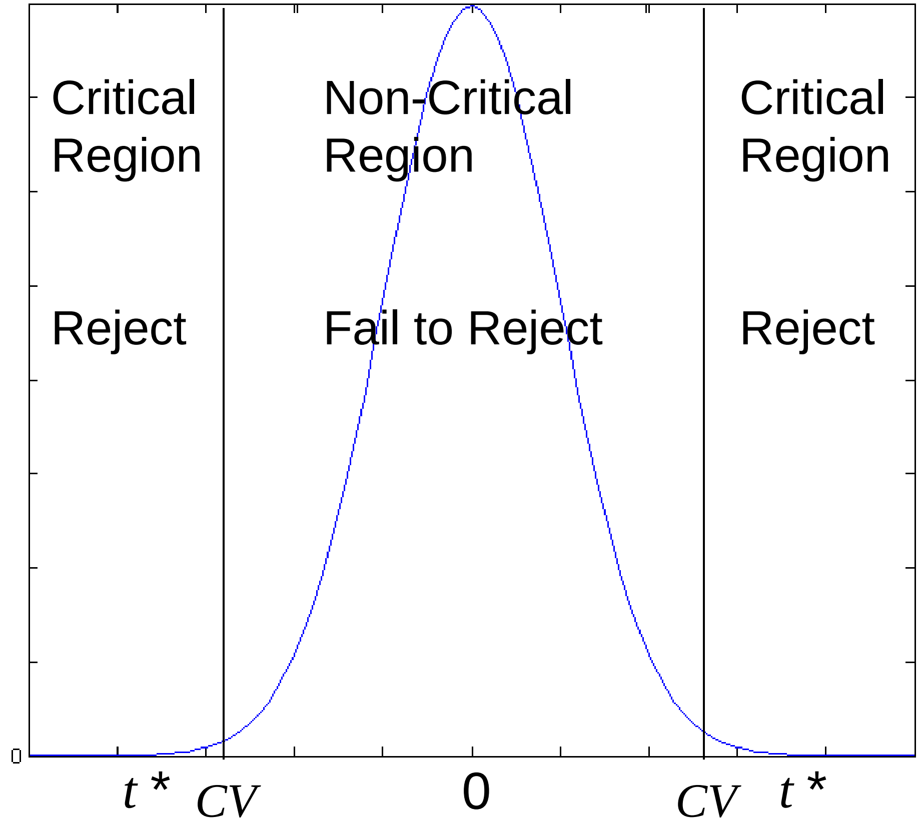
H_0: μ_1-μ_2 = 0 vs. H_a: μ_1-$\mu_2 \neq 0$

Reject H_0 if less than

$$t^* = \frac{(\bar{x}_1 - \bar{x}_2) - 0}{\sqrt{\left(s_1^2/n_1\right) + \left(s_2^2/n_2\right)}} \quad -t(df, \alpha/2)$$

or if is greater than

$$t^* = \frac{(\bar{x}_1 - \bar{x}_2) - 0}{\sqrt{\left(s_1^2/n_1\right) + \left(s_2^2/n_2\right)}} \quad t(df, \alpha/2)$$



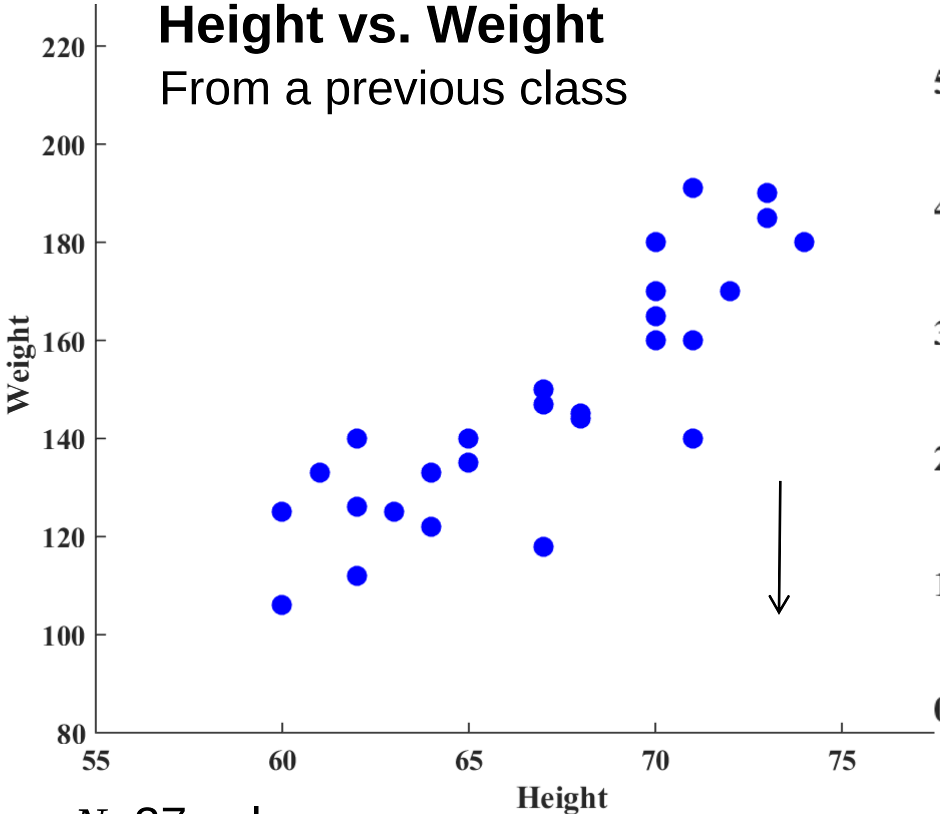
data indicates μ_1-$\mu_2 \neq 0$, $\bar{x}_1 - \bar{x}_2$ far from 0.

10: Inferences Involving Two Populations

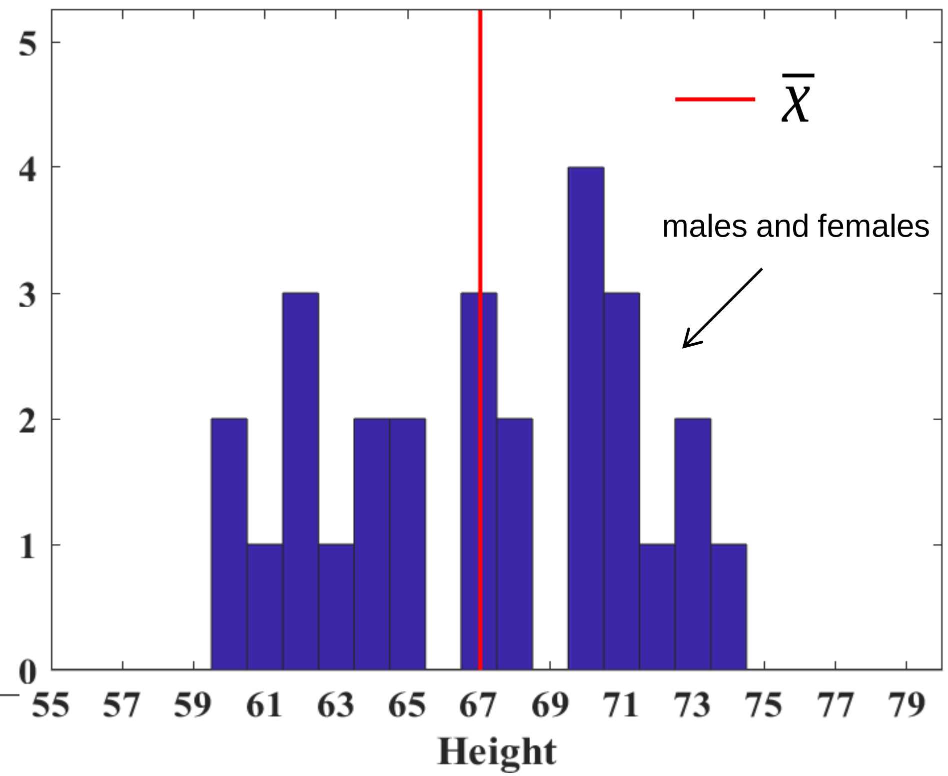
10.3 Inference for Mean Difference Two Independent Samples

Hypothesis Testing Procedure

27 values



N=27 values



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Hypothesis Testing Procedure

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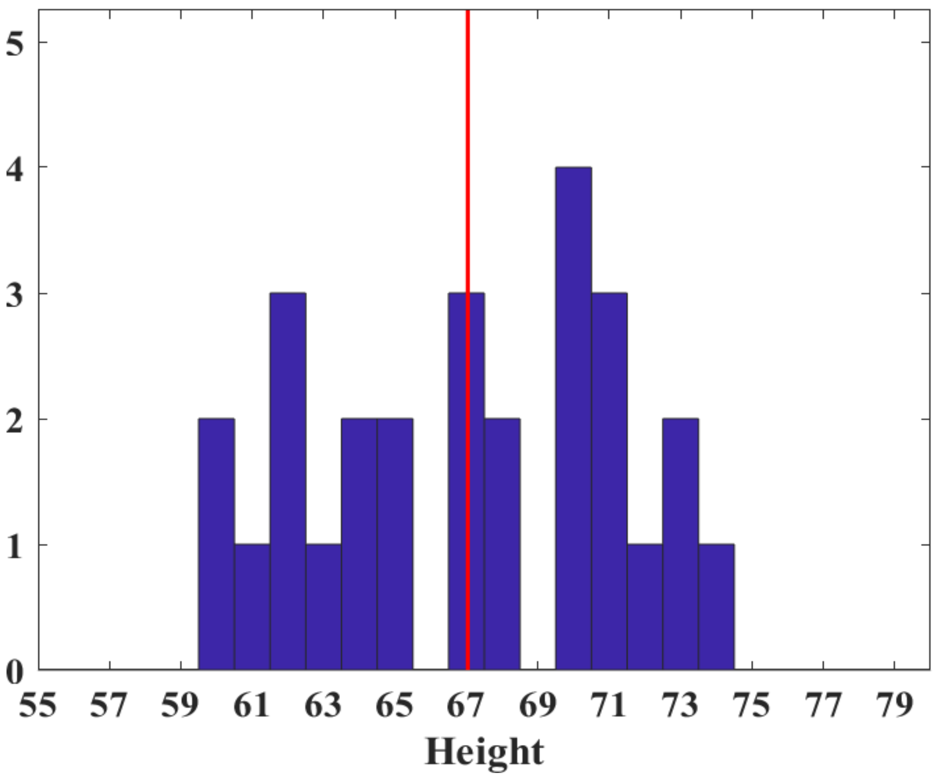
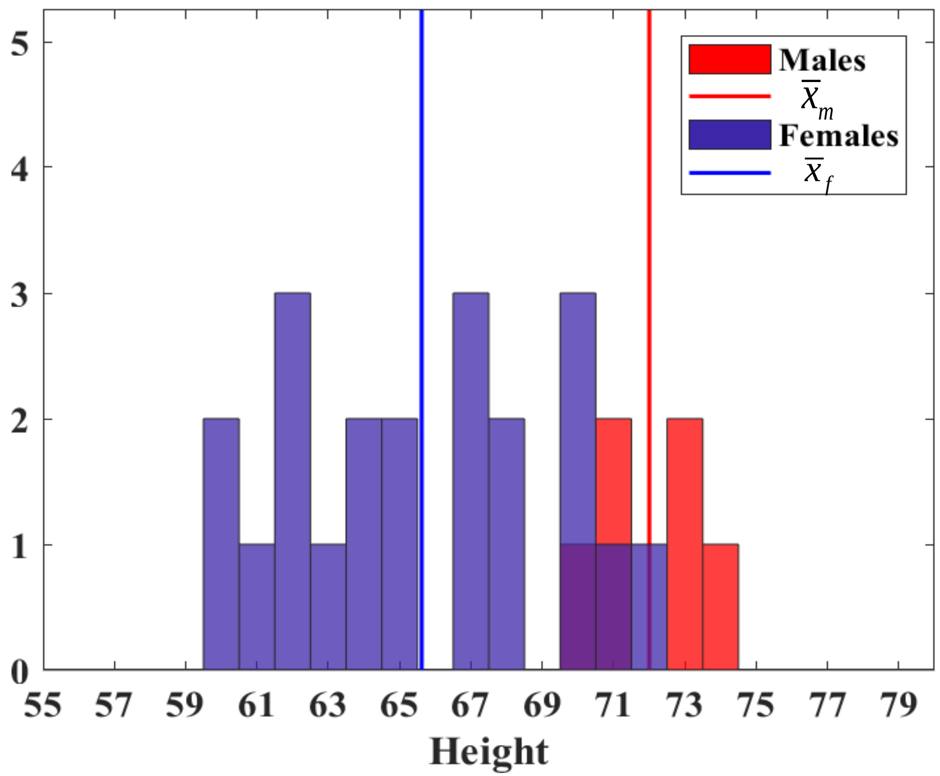




Is the height of males = height of females at α=.05?

10: Inferences Involving Two Populations

10.3 Inference for Mean Difference Two Independent Samples

Hypothesis Testing Procedure

27 values

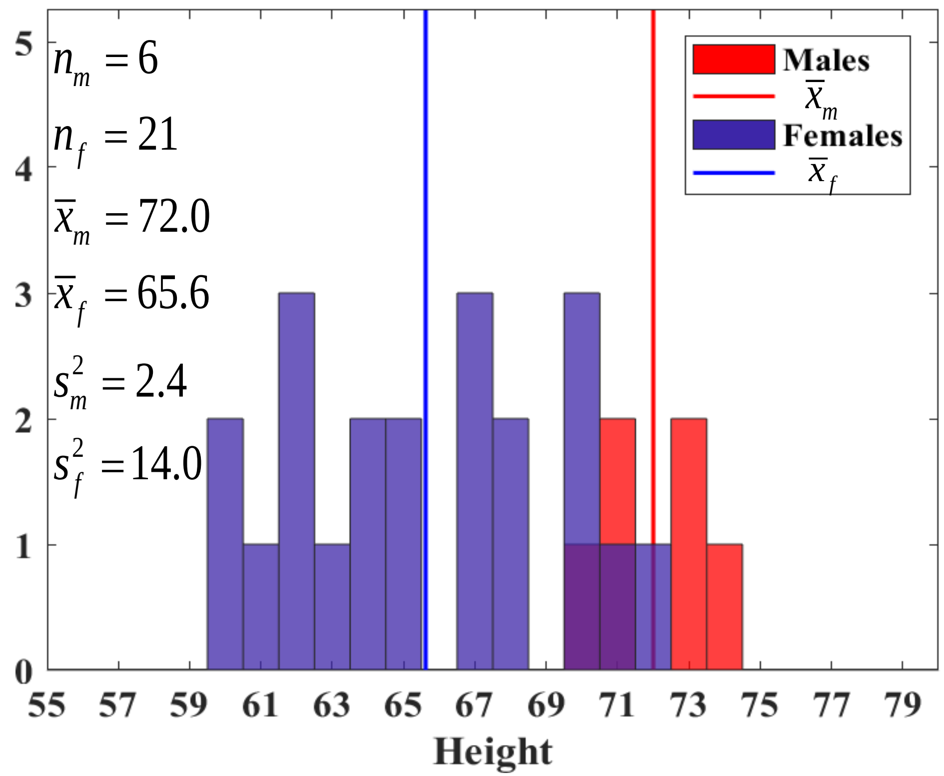
Step 1

Step 2

Step 3

Step 4

Step 5



10: Inferences Involving Two Populations

10.3 Inference for Mean Difference Two Independent Samples

Hypothesis Testing Procedure

27 values

Step 1

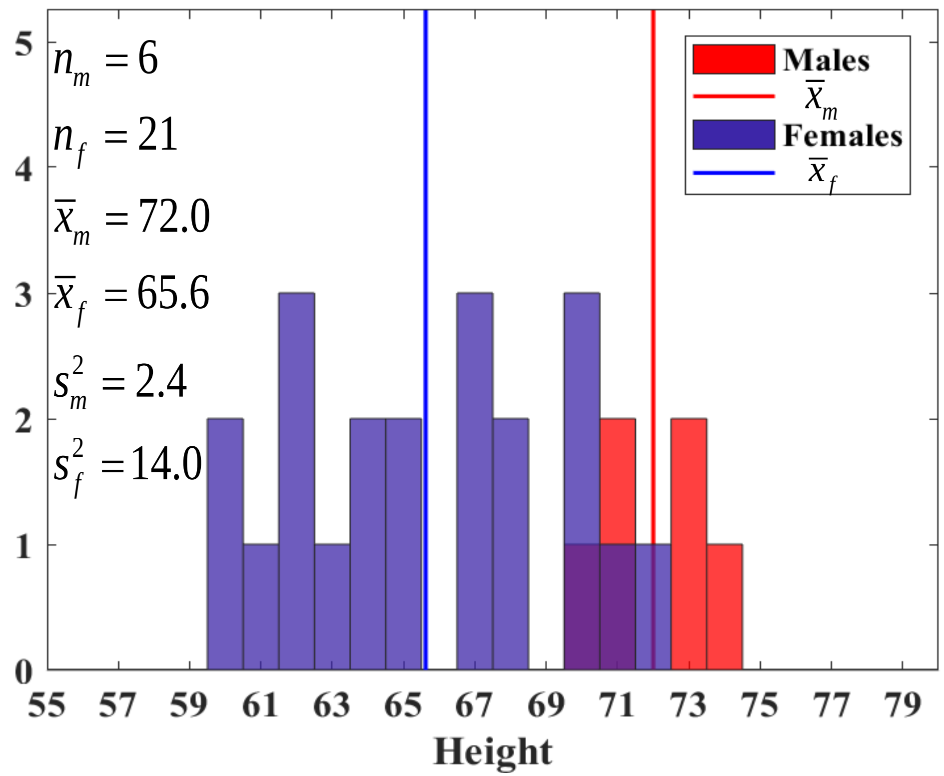
H_0: $\mu_f = \mu_m$ vs. H_a: $\mu_f \neq \mu_m$

Step 2

Step 3

Step 4

Step 5



10: Inferences Involving Two Populations

10.3 Inference for Mean Difference Two Independent Samples

Hypothesis Testing Procedure

27 values

Step 1

H_0: $\mu_f = \mu_m$ vs. H_a: $\mu_f \neq \mu_m$

Step 2

$$t^* = \frac{(\bar{x}_m - \bar{x}_f) - (\mu_m - \mu_f)}{\sqrt{\left(\frac{s_m^2}{n_m}\right) + \left(\frac{s_f^2}{n_f}\right)}}$$

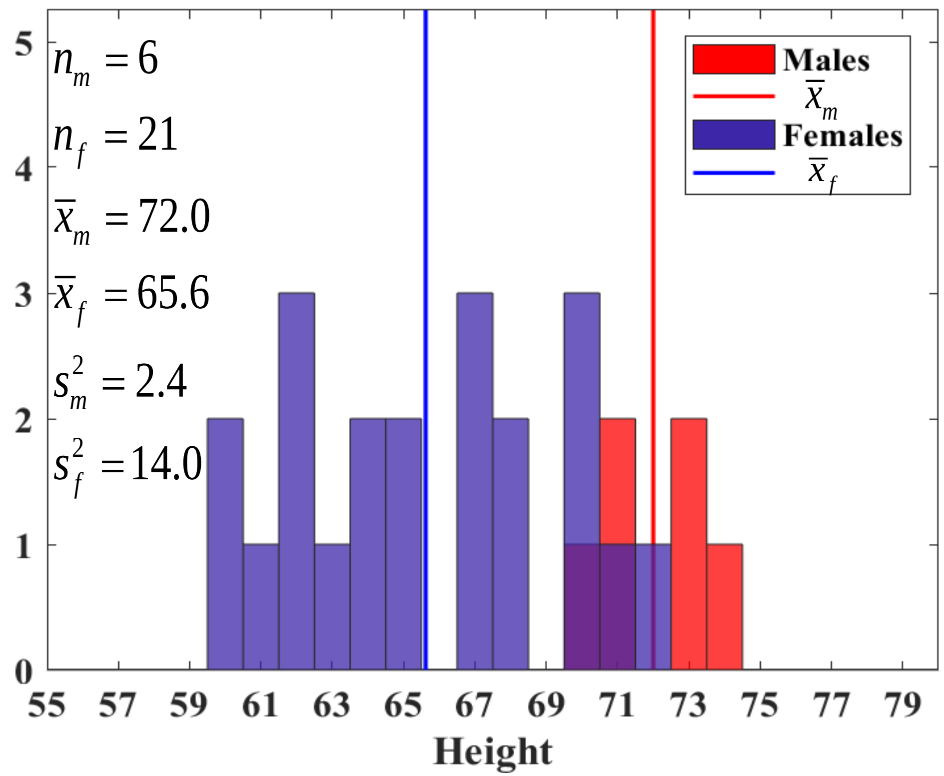
$df = 5$

$\alpha = .05$

Step 3

Step 4

Step 5



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$df = 5$

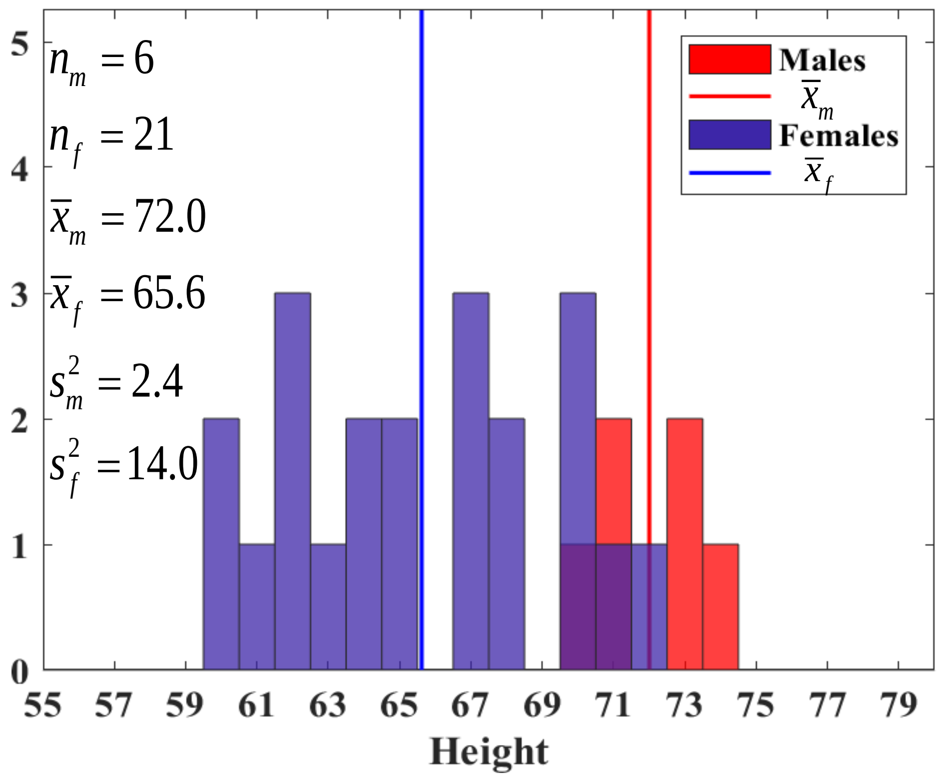
$\alpha = .05$

Step 3

$$t^* = \frac{(72.0 - 65.6) - (0)}{\sqrt{\left(\frac{2.4}{6}\right) + \left(\frac{14.0}{21}\right)}} = 6.17$$

Step 4

Step 5



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27 values

Step 1

H_0: $\mu_f = \mu_m$ vs. H_a: $\mu_f \neq \mu_m$

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$df = 5$

$\alpha = .05$

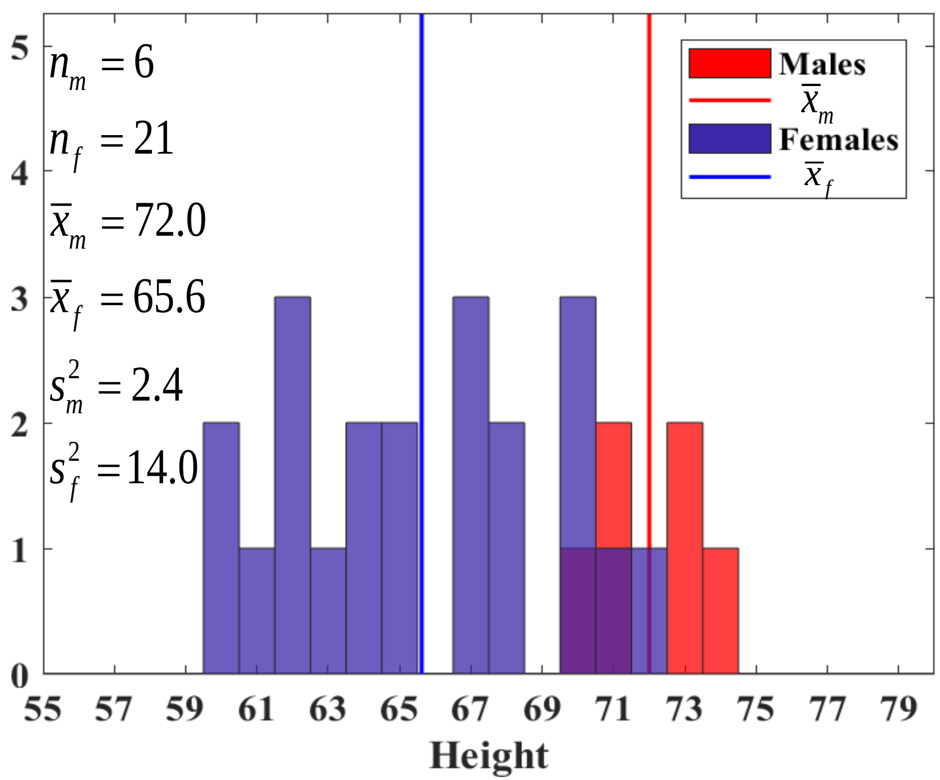
Step 3

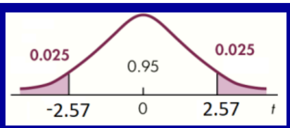
$$t^* = \frac{(72.0 - 65.6) - (0)}{\sqrt{\left(\frac{2.4}{6}\right) + \left(\frac{14.0}{21}\right)}} = 6.17$$

Classical
Step 4

$t(df, \alpha/2) = 2.57$

Classical
Step 5





10: Inferences Involving Two Populations

10.3 Inference for Mean Difference Two Independent Samples

Hypothesis Testing Procedure

27 values

Step 1

H_0: $\mu_f = \mu_m$ vs. H_a: $\mu_f \neq \mu_m$

Step 2

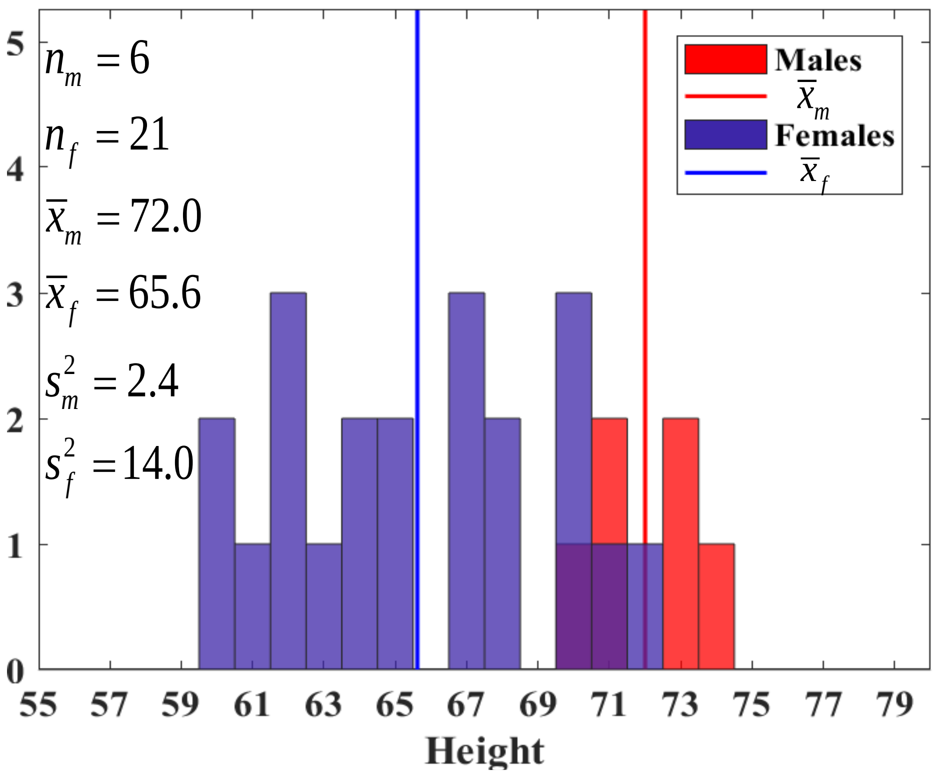
$$t^* = \frac{(\bar{x}_m - \bar{x}_f) - (\mu_m - \mu_f)}{\sqrt{\left(\frac{s_m^2}{n_m}\right) + \left(\frac{s_f^2}{n_f}\right)}}$$

$df = 5$

$\alpha = .05$

Step 3

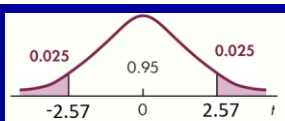
$$t^* = \frac{(72.0 - 65.6) - (0)}{\sqrt{\left(\frac{2.4}{6}\right) + \left(\frac{14.0}{21}\right)}} = 6.17$$



Classical
Step 4

$t(df, \alpha/2) = 2.57$

Classical
Step 5 Reject H_0 $6.17 > 2.57$, height males≠height females



10: Inferences Involving Two Populations

10.3 Inference for Mean Difference Two Independent Samples

Hypothesis Testing Procedure

27 values

Step 1

H_0: $\mu_f = \mu_m$ vs. H_a: $\mu_f \neq \mu_m$

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$$t^* = \frac{(\bar{x}_m - \bar{x}_f) - (\mu_m - \mu_f)}{\sqrt{\left(\frac{s_m^2}{n_m}\right) + \left(\frac{s_f^2}{n_f}\right)}}$$

$df = 5$

$\alpha = .05$

Step 3

$$t^* = \frac{(72.0 - 65.6) - (0)}{\sqrt{\left(\frac{2.4}{6}\right) + \left(\frac{14.0}{21}\right)}} = 6.17$$

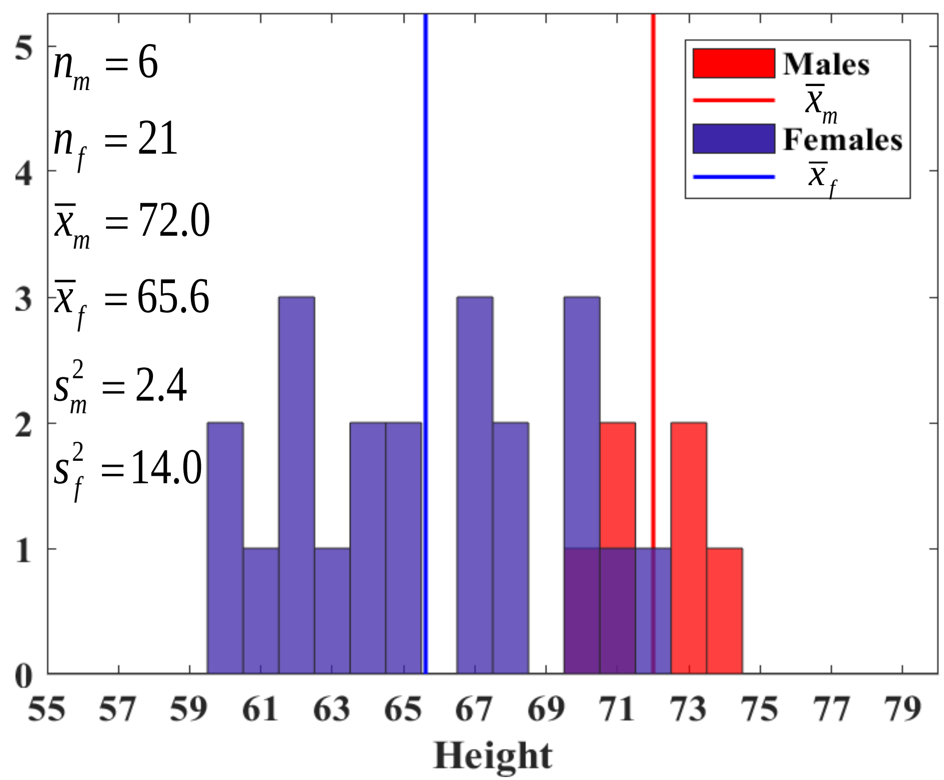
p-value

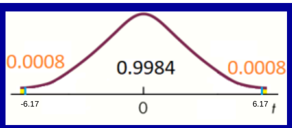
Step 4

$P(|t^*| > 6.17) = .0016$

p-value

Step 5





10: Inferences Involving Two Populations

10.3 Inference for Mean Difference Two Independent Samples

Hypothesis Testing Procedure

27 values

Step 1

H_0: $\mu_f = \mu_m$ vs. H_a: $\mu_f \neq \mu_m$

Step 2

$$t^* = \frac{(\bar{x}_m - \bar{x}_f) - (\mu_m - \mu_f)}{\sqrt{\left(\frac{s_m^2}{n_m}\right) + \left(\frac{s_f^2}{n_f}\right)}}$$

$df = 5$

$\alpha = .05$

Step 3

$$t^* = \frac{(72.0 - 65.6) - (0)}{\sqrt{\left(\frac{2.4}{6}\right) + \left(\frac{14.0}{21}\right)}} = 6.17$$

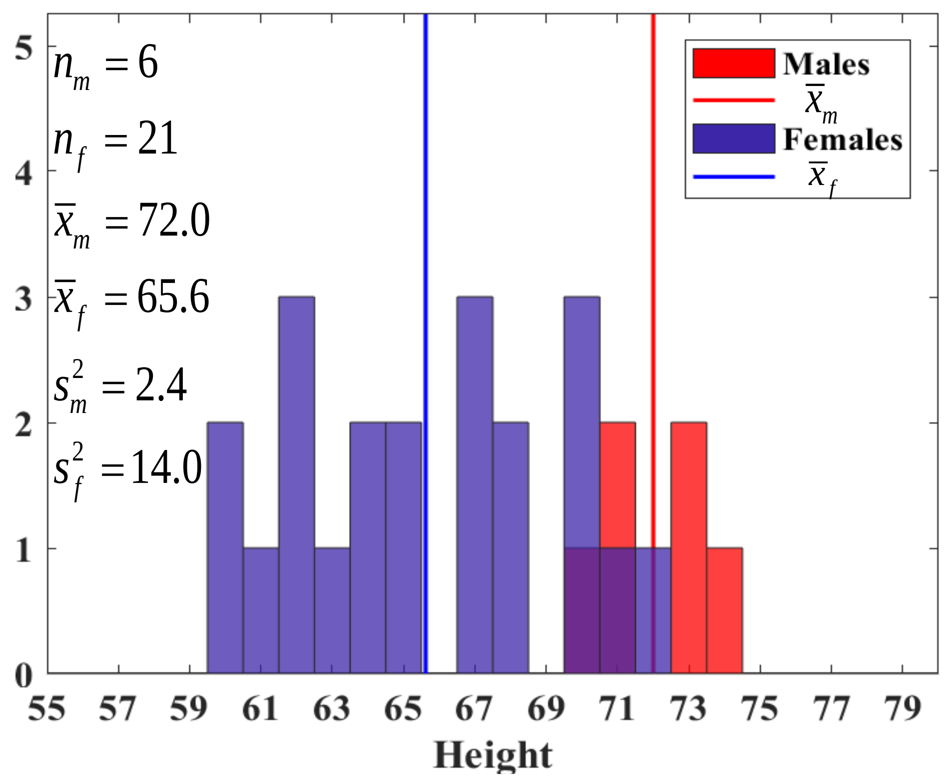
p-value

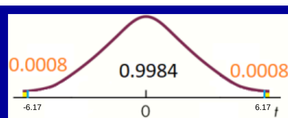
Step 4

$P(|t^*| > 6.17) = .0016$

p-value

Step 5 Reject H_0 $.002 < .05$, height males≠height females





Chapter 10: Inferences Involving Two Populations

Questions?

Homework: Read Chapter 10.3
WebAssign
Chapter 10 # 41, 45, 53, 57, 58, 59, 63