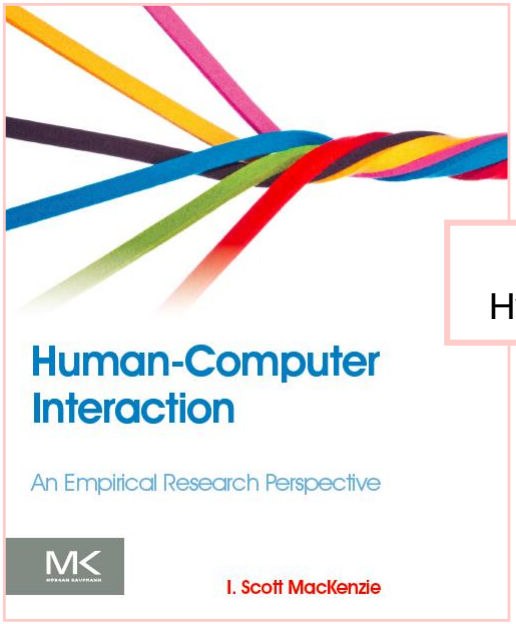


Chapter 6
Hypothesis Testing

Objectives

- Main objective: know enough of statistics to analyze your project's experiment data
  - Use simple tools to run statistical tests to determine whether your results were significant
- You will not learn theoretical foundations of statistics
- We will treat statistic tools as “black boxes”. You will learn how to…
  - …give input and interpret output
  - …write results in your report

2

What is Hypothesis Testing?

- … the use of statistical procedures to answer research questions
- Typical research question (generic):

> Is the time to complete a task less using Method A than using Method B?

- For hypothesis testing, research questions are statements:

> There is no difference in the mean time to complete a task using Method A vs. Method B.

- This is the *null hypothesis* (assumption of "no difference")
- Statistical procedures seek to reject or accept the null hypothesis (details to follow)

3

Statistical Procedures

- Two types:
  - Parametric
    - Data are assumed to come from a distribution, such as the normal distribution, *t*-distribution, etc.
  - Non-parametric
    - Data are not assumed to come from a distribution
- Lots of debate on assumptions testing and what to do if assumptions are not met (avoided here, for the most part)
- A reasonable basis for deciding on the most appropriate test is to match the type of test with the measurement scale of the data (next slide)

4

Measurement Scales vs. Statistical Tests

Measurement Scale	Defining Relations	Examples of Appropriate Statistics	Appropriate Statistical Tests
Nominal	• Equivalence	• Mode • Frequency	• Non-parametric tests
Ordinal	• Equivalence • Order	• Median • Percentile	
Interval	• Equivalence • Order • Ratio of intervals	• Mean • Standard deviation	• Parametric tests • Non-parametric tests
Ratio	• Equivalence • Order • Ratio of intervals • Ratio of values	• Geometric mean • Coefficient of variation	

- Parametric tests most appropriate for…
  - Ratio data, interval data
- Non-parametric tests most appropriate for…
  - Ordinal data, nominal data (although limited use for ratio and interval data)

5

Tests Presented Here

- Parametric
  - Analysis of variance (ANOVA)
    - Used for ratio data and interval data
    - Most common statistical procedure in HCI research
  - Post hoc tests
    - Useful in case we have more than two test conditions
    - To know between which pair of test conditions thare was a significant difference
- We will see…
  - One-Way ANOVA (single factor)
    - 2 Test conditions
    - >2 Test conditions (post-hoc test needed)
    - 2 Test conditions with Between-subject design
  - Two-way ANOVA (two factors)

6

Analysis of Variance

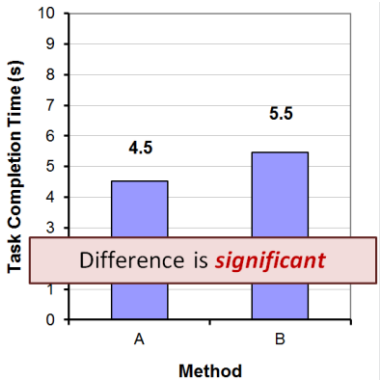
- The *analysis of variance* (ANOVA) is the most widely used statistical test for hypothesis testing in factorial experiments
- Goal → determine if an independent variable has a significant effect on a dependent variable
- Consider the following research question

> Is the time to complete a task less using Method A than using Method B?

- Let's explain through two simple examples (next slide)

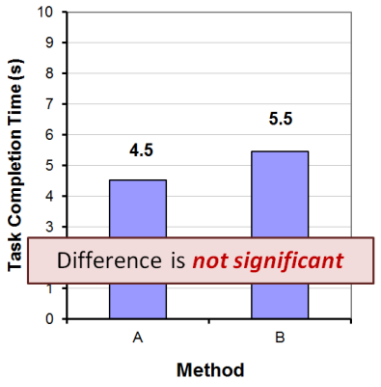
7

Example #1



"Significant" implies that in all likelihood the difference observed is due to the test conditions (Method A vs. Method B).

Example #2

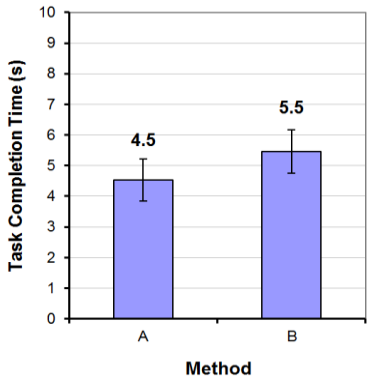


"Not significant" implies that the difference observed is likely due to chance.

File: `06-AnovaDemo.xlsx`

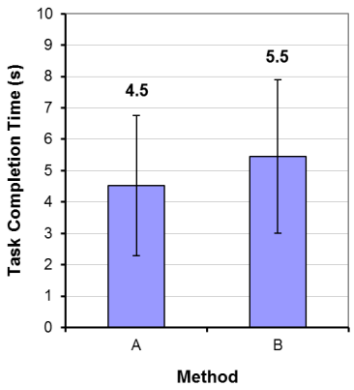
8

Example #1



"Significant" implies that in all likelihood the difference observed is due to the test conditions (Method A vs. Method B).

Example #2

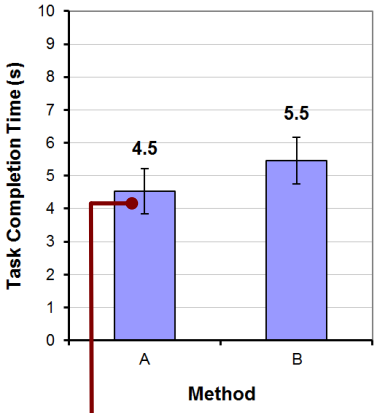


"Not significant" implies that the difference observed is likely due to chance.

File: `06-AnovaDemo.xlsx`

9

Example #1 - Details



Error bars show ±1 standard deviation

Note: Within-subjects design

Participant	Method	
	A	B
1	5.3	5.7
2	3.6	4.8
3	5.2	5.1
4	3.6	4.5
5	4.6	6.0
6	4.1	6.8
7	4.0	6.0
8	4.8	4.6
9	5.2	5.5
10	5.1	5.6
Mean	4.5	5.5
SD	0.68	0.72

Note: *SD* is the square root of the variance

10

Example #1 – ANOVA[1]

ANOVA Table for Task Completion Time (s)

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
Subject	9	5.080	.564				
Method	1	4.232	4.232	9.796	.0121	9.796	.804
Method * Subject	9	3.888	.432				

Probability of obtaining the same (or a more extreme) result if the null hypothesis is true

Reported as…

$F_{1,9} = 9.80, p < .05$

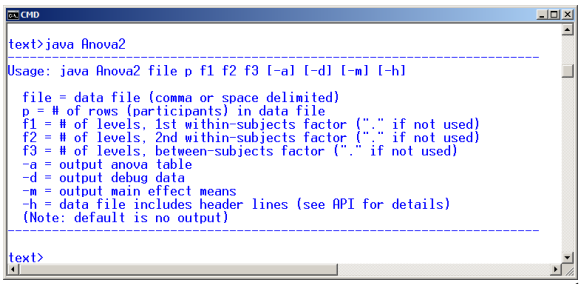
Thresholds for "p"
- .05
- .01
- .005
- .001
- .0005
- .0001

[1] ANOVA table created by *StatView* (now marketed as *JMP*, a product of SAS; www.sas.com)

Anova2 Software

- **HCI:ERP** web site includes analysis of variance Java software: Anova2
- Operates from command line on data in a text file
- Extensive API with demos, data files, discussions, etc.
- Download and demonstrate

Demo



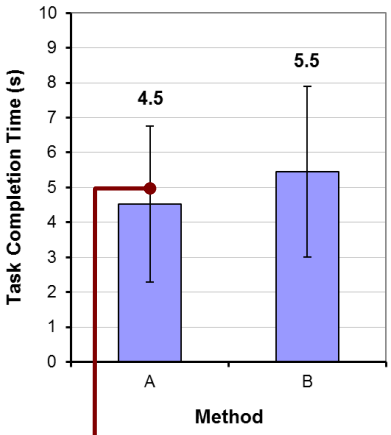
12

How to Report an *F*-statistic

The mean task completion time for Method A was 4.5 s. This was 20.1% less than the mean of 5.5 s observed for Method B. The difference was statistically significant ($F_{1,9} = 9.80$, $p < .05$).

- Notice in the parentheses
  - Uppercase for *F*
  - Lowercase for *p*
  - Italics for *F* and *p*
  - Space both sides of equal sign
  - Space after comma
  - Space on both sides of less-than sign
  - Degrees of freedom are subscript, plain, smaller font
  - Three significant figures for *F* statistic
  - No zero before the decimal point in the *p* statistic (except in Europe)

Example #2 - Details



Error bars show ±1 standard deviation

Participant	Method	
	A	B
1	2.4	6.9
2	2.7	7.2
3	3.4	2.6
4	6.1	1.8
5	6.4	7.8
6	5.4	9.2
7	7.9	4.4
8	1.2	6.6
9	3.0	4.8
10	6.6	3.1
Mean	4.5	5.5
SD	2.23	2.45

Example #2 – ANOVA

ANOVA Table for Task Completion Time (s)

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
Subject	9	37.372	4.152				
Method	1	4.324	4.324	.626	.4491	.626	.107
Method * Subject	9	62.140	6.904				

Probability of obtaining the same (or a more extreme) result if the null hypothesis is true

Reported as…

$F_{1,9} = 0.626$, ns

Note: For non-significant effects, use "ns" if $F < 1.0$, or "$p > .05$" if $F > 1.0$.

Example #2 - Reporting

The mean task completion times were 4.5 s for Method A and 5.5 s for Method B. As there was substantial variation in the observations across participants, the difference was not statistically significant as revealed in an analysis of variance ($F_{1,9} = 0.626$, ns).

16

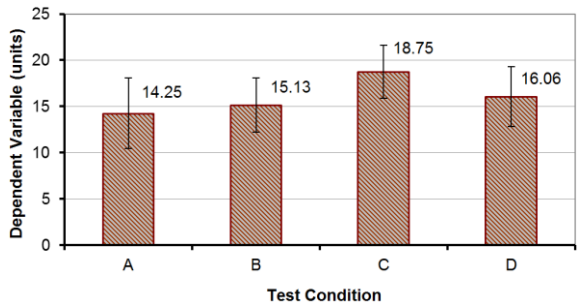
Challenge

- Run ANOVA on the data of the experiment Tapping VS Gesturing
- For each Dependent Variable
  - Which is the null hypothesis?
  - Appropriately format input file
  - Run ANOVA and write the phrase to report the result

17

More Than Two Test Conditions

Participant	Test Condition			
	A	B	C	D
1	11	11	21	16
2	18	11	22	15
3	17	10	18	13
4	19	15	21	20
5	13	17	23	10
6	10	15	15	20
7	14	14	15	13
8	13	14	19	18
9	19	18	16	12
10	10	17	21	18
11	10	19	22	13
12	16	14	18	20
13	10	20	17	19
14	10	13	21	18
15	20	17	14	18
16	18	17	17	14
Mean	14.25	15.13	18.75	16.06
SD	3.84	2.94	2.89	3.23



18

ANOVA

ANOVA Table for Dependent Variable (units)

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
Subject	15	81.109	5.407				
Test Condition	3	182.172	60.724	4.954	.0047	14.862	.896
Test Condition * Subject	45	551.578	12.257				

- There was a significant effect of Test Condition on the dependent variable ($F_{3,45} = 4.95$, $p < .005$)
- Degrees of freedom
  - If n is the number of test conditions and m is the number of participants, the degrees of freedom are…
  - Effect → $(n - 1)$
  - Residual → $(n - 1)(m - 1)$
  - Note: single-factor, within-subjects design

19

Post Hoc Comparisons Tests

- A significant F-test means that at least one of the test conditions differed significantly from one other test condition
- Does not indicate which test conditions differed significantly from one another
- To determine which pairs differ significantly, a post hoc comparisons tests is used
- Examples:
  - Fisher PLSD, Bonferroni/Dunn, Dunnett, Tukey/Kramer, Games/Howell, Student-Newman-Keuls, orthogonal contrasts, Scheffé
- Scheffé test on next slide

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Scheffé Post Hoc Comparisons

Scheffe for Dependent Variable (units)
Effect: Test Condition
Significance Level: 5 %

	Mean Diff.	Crit. Diff.	P-Value	
A, B	-.875	3.302	.9003	
A, C	-4.500	3.302	.0032	S
A, D	-1.813	3.302	.4822	
B, C	-3.625	3.302	.0256	S
B, D	-.938	3.302	.8806	
C, D	2.688	3.302	.1520	

- Test conditions A:C and B:C differ significantly (see chart three slides back)

21

Between-subjects Designs

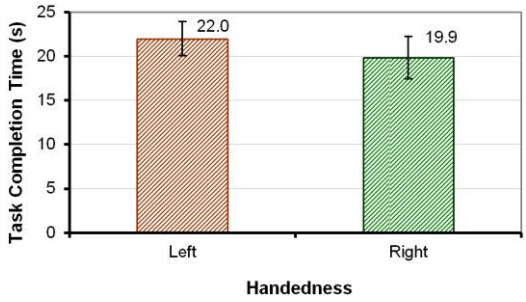
- Research question:
  - *Do left-handed users and right-handed users differ in the time to complete an interaction task?*
- The independent variable (handedness) must be assigned between-subjects
- Example data set →

Participant	Task Completion Time (s)	Handedness
1	23	L
2	19	L
3	22	L
4	21	L
5	23	L
6	20	L
7	25	L
8	23	L
9	17	R
10	19	R
11	16	R
12	21	R
13	23	R
14	20	R
15	22	R
16	21	R
Mean	20.9	
SD	2.38	

22

Summary Data and Chart

Handedness	Task Completion Time (s)	
	Mean	*SD*
Left	22.0	1.93
Right	19.9	2.42



23

ANOVA

ANOVA Table for Task Completion Time (s)

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
Handedness	1	18.063	18.063	3.781	.0722	3.781	.429
Residual	14	66.875	4.777				

- The difference was not statistically significant ($F_{1,14}$ = 3.78, $p > .05$)
- Degrees of freedom:
  - Effect → $(n - 1)$
  - Residual → $(m - n)$
  - Note: single-factor, between-subjects design

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Two-way ANOVA

- An experiment with two independent variables is a *two-way design*
- ANOVA tests for
  - Two main effects + one interaction effect
- Example
  - Independent variables
    - Device → D1, D2, D3 (e.g., mouse, stylus, touchpad)
    - Task → T1, T2 (e.g., point-select, drag-select)
  - Dependent variable
    - Task completion time (or something, this isn't important here)
  - Both IVs assigned within-subjects
  - Participants: 12
  - Data set (next slide)

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Data Set

Participant	Device 1		Device 2		Device 3	
	Task 1	Task 2	Task 1	Task 2	Task 1	Task 2
1	11	18	15	13	20	14
2	10	14	17	15	11	13
3	10	23	13	20	20	16
4	18	18	11	12	11	10
5	20	21	19	14	19	8
6	14	21	20	11	17	13
7	14	16	15	20	16	12
8	20	21	18	20	14	12
9	14	15	13	17	16	14
10	20	15	18	10	11	16
11	14	20	15	16	10	9
12	20	20	16	16	20	9
Mean	15.4	18.5	15.8	15.3	15.4	12.2
SD	4.01	2.94	2.69	3.50	3.92	2.69

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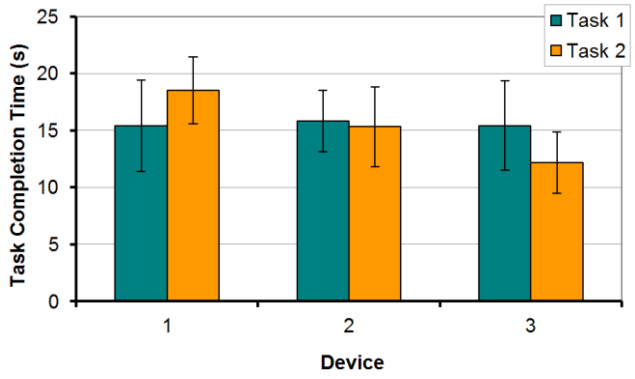
Summary Data and Chart

	Task 1	Task 2	*Mean*
Device 1	15.4	18.5	17.0
Device 2	15.8	15.3	15.6
Device 3	15.4	12.2	13.8
Mean	15.6	15.3	15.4



27

ANOVA

ANOVA Table for Task Completion Time (s)

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
Subject	11	134.778	12.253				
Device	2	121.028	60.514	5.865	.0091	11.731	.831
Device * Subject	22	226.972	10.317				
Task	1	.889	.889	.076	.7875	.076	.057
Task * Subject	11	128.111	11.646				
Device * Task	2	121.028	60.514	5.435	.0121	10.869	.798
Device * Task * Subject	22	244.972	11.135				

Can you pull the relevant statistics from this chart and craft statements indicating the outcome of the ANOVA?

28

ANOVA - Reporting

The grand mean for task completion time was 15.4 seconds. Device 3 was the fastest at 13.8 seconds, while device 1 was the slowest at 17.0 seconds. The main effect of device on task completion time was statistically significant ($F_{2,22} = 5.865$, $p < .01$). The task effect was modest, however. Task completion time was 15.6 seconds for task 1. Task 2 was slightly faster at 15.3 seconds; however, the difference was not statistically significant ($F_{1,11} = 0.076$, ns). The results by device and task are shown in Figure x. There was a significant Device × Task interaction effect ($F_{2,22} = 5.435$, $p < .05$), which was due solely to the difference between device 1 task 2 and device 3 task 2, as determined by a Scheffé post hoc analysis.

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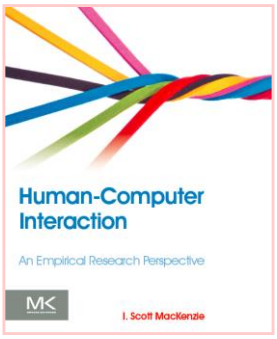
Thank You



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