Fall 2019

CS6501: Topics in Human-Computer Interaction

http://seongkookheo.com/cs6501_fall2019

Lecture 7: Statistical Analysis

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September 17, 2019

UNIVERSITY of VIRGINIA | SCHOOL of ENGINEERING & APPLIED SCIENCE

What You Learned Last Class

- Process of conducting an experiment
- Research Hypothesis
- Null Hypothesis Significance Testing

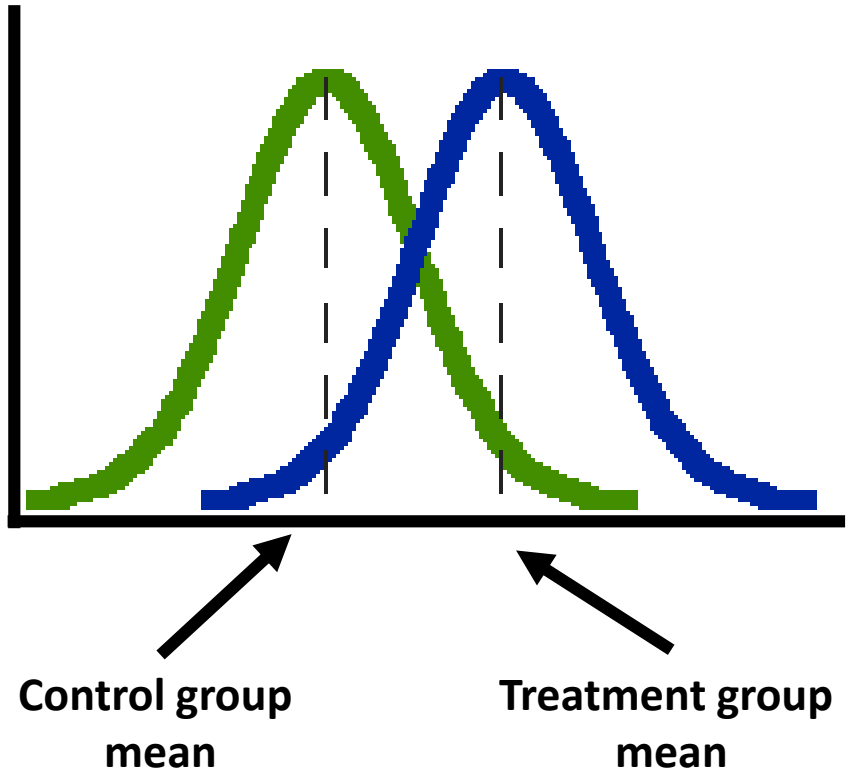
Conducting an Experiment

Preparing Data for Analysis

- Record the data
  - Be thorough (if possible: be able to recreate the study)
    - Small file that summarizes each trial + Large log that records everything with time stamp
  - **Check for bugs!**
- Clean the data
  - Detect errors
  - Formatting
- Remove the outliers
  - Follow guidelines
  - Be consistent

Descriptive Statistics

- Measures of central tendency
  - Mean
  - Median
  - Mode
- Measures of spread
  - Min/Max
  - Range
  - Variance
  - Standard deviations



Descriptive Statistics

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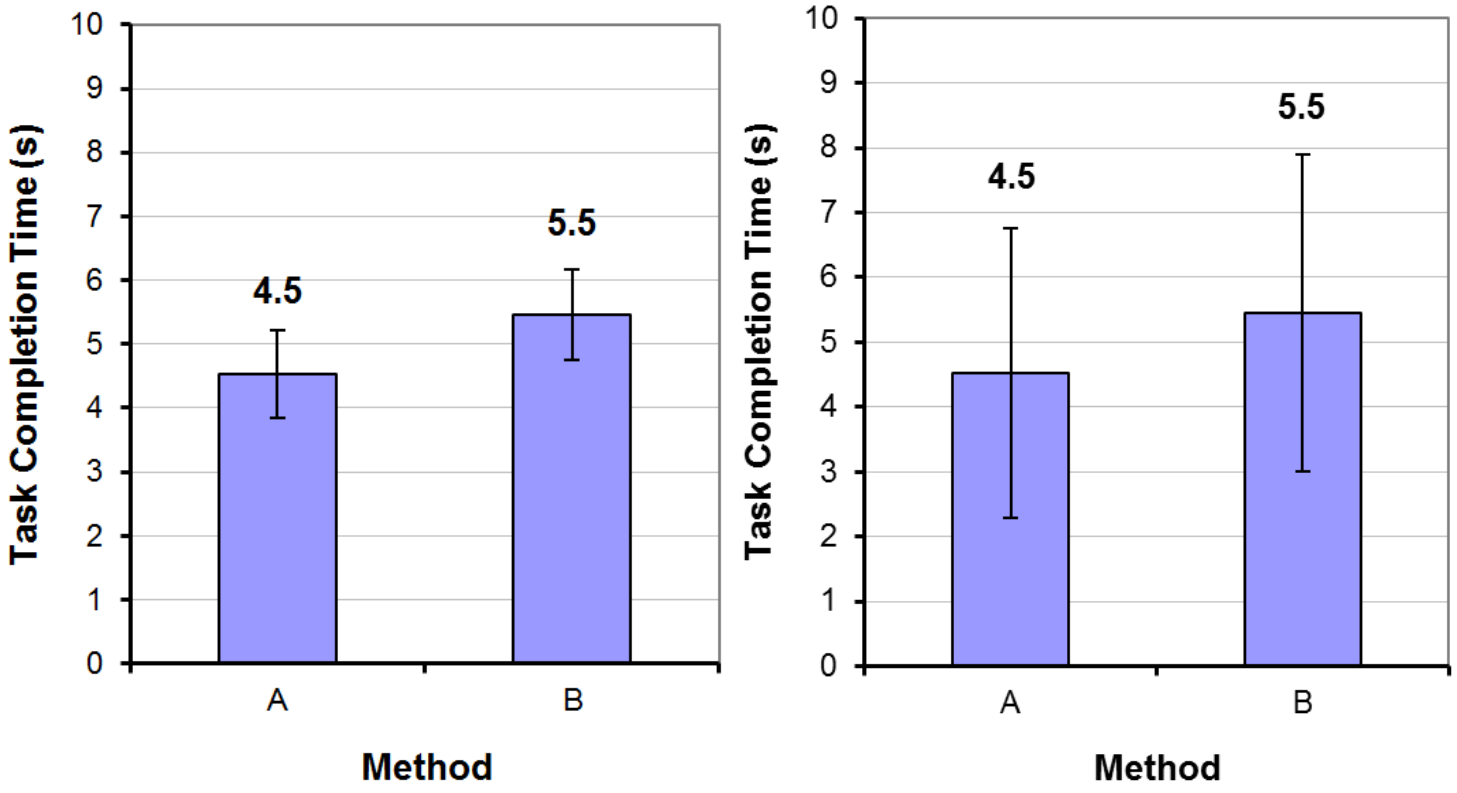


Statistical Significance

- Null Hypothesis:
  - IV x has no effect on DV y
- “P-Value”:
  - Probability of obtaining your results, assuming the null hypothesis is true
- When $p < .05$
  - Reject the null hypothesis
  - IV x have an effect on DV y

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

  - A reasonable basis for deciding on the most appropriate test is to match the type of test with the measurement scale of the data

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	

Which Statistical Test to Use?

- Parametric
  - Analysis of variance (ANOVA)
    - Used for ratio data and interval data
    - Most common statistical procedure in HCI research
- Non-parametric
  - Chi-square test
    - Used for nominal data
  - Mann-Whitney U, Wilcoxon Signed-Rank, Kruskal-Wallis, and Friedman tests
    - Used for ordinal data

Which Statistical Test to Use?

	Interval/Ratio (Normality assumed)	Interval/Ratio (Normality not assumed), Ordinal	Dichotomy (Binomial)
Compare two unpaired groups	Unpaired t test	Mann-Whitney test	Fisher's test
Compare two paired groups	Paired t test	Wilcoxon test	McNemar's test
Compare more than two unmatched groups	ANOVA	Kruskal-Wallis test	Chi-square test
Compare more than two matched groups	Repeated-measures ANOVA	Friedman test	Cochran's Q test
Find relationship between two variables	Pearson correlation	Spearman correlation	Cramer's V
Predict a value with one independent variable	Linear/Non-linear regression	Non-parametric regression	Logistic regression
Predict a value with multiple independent variables or binomial variables	Multiple linear/non-linear regression		Multiple logistic regression

http://yatani.jp/teaching/doku.php?id=hcistats:start

Analysis of Variance

- The *analysis of variance* (ANOVA) is the most widely used statistical test for hypothesis testing in factorial experiments
- Determine if an IV has a significant effect on a DV
  - e.g., one of the test conditions is faster/slower than the other
- Remember, an IV has at least two levels

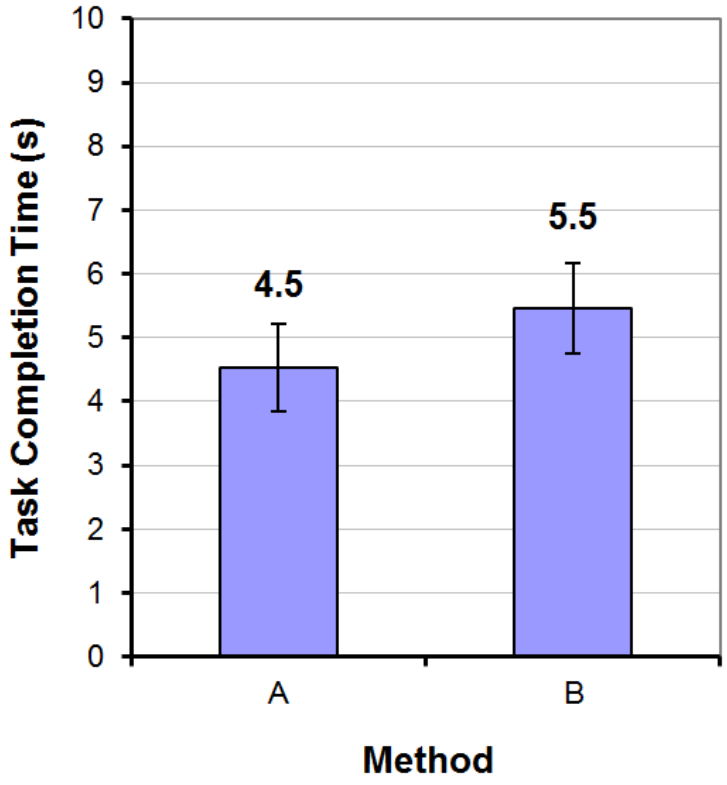
Why Analyze the Variance?

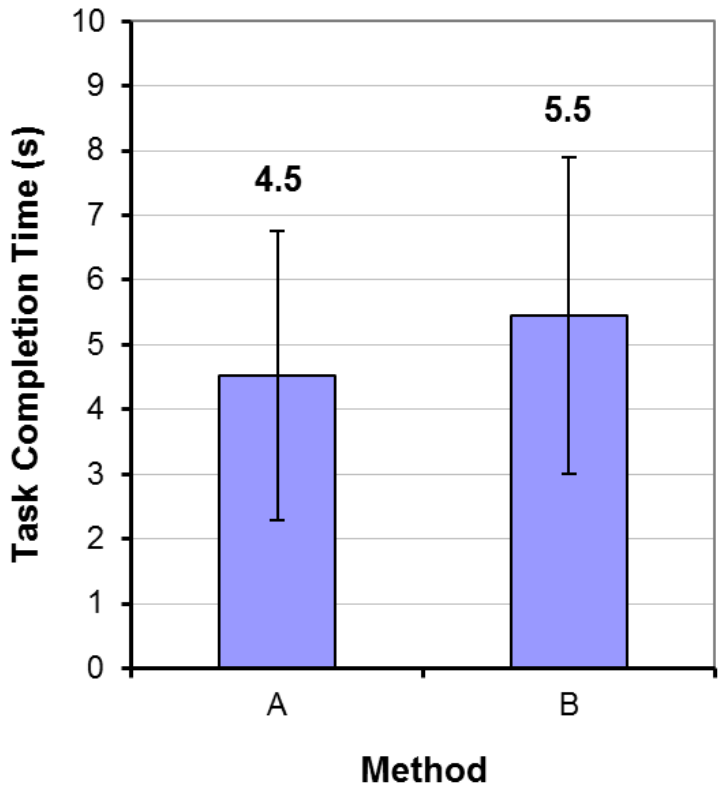
- Seems odd that we analyze the variance, when the research question is concerned with the overall means:

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

Why Analyze the Variance?

- Two examples:

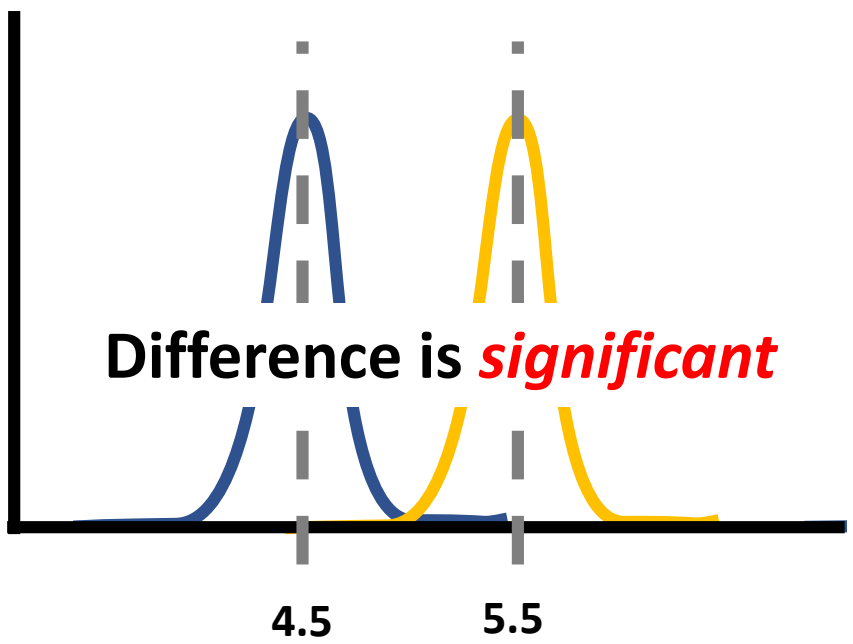


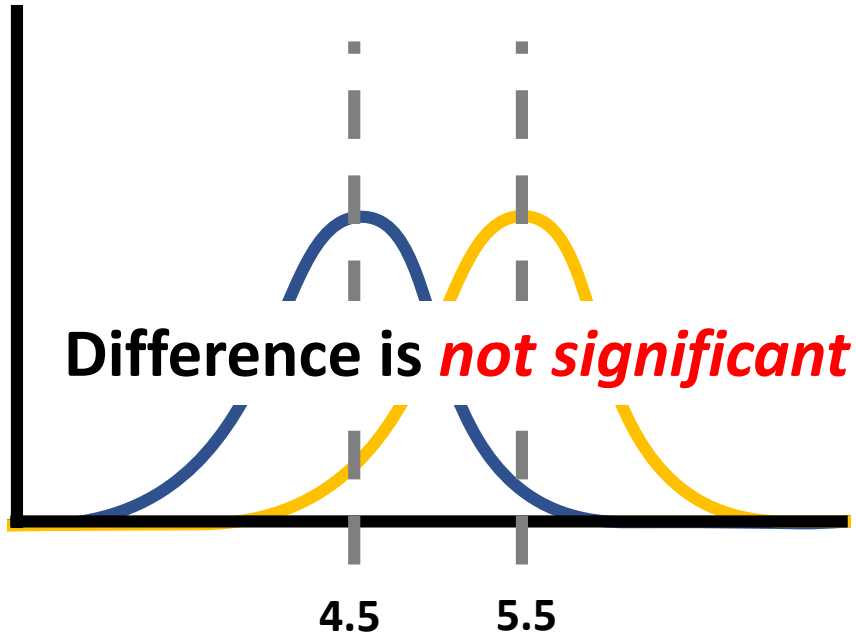


Error bars show ±1 standard deviation

Why Analyze the Variance?

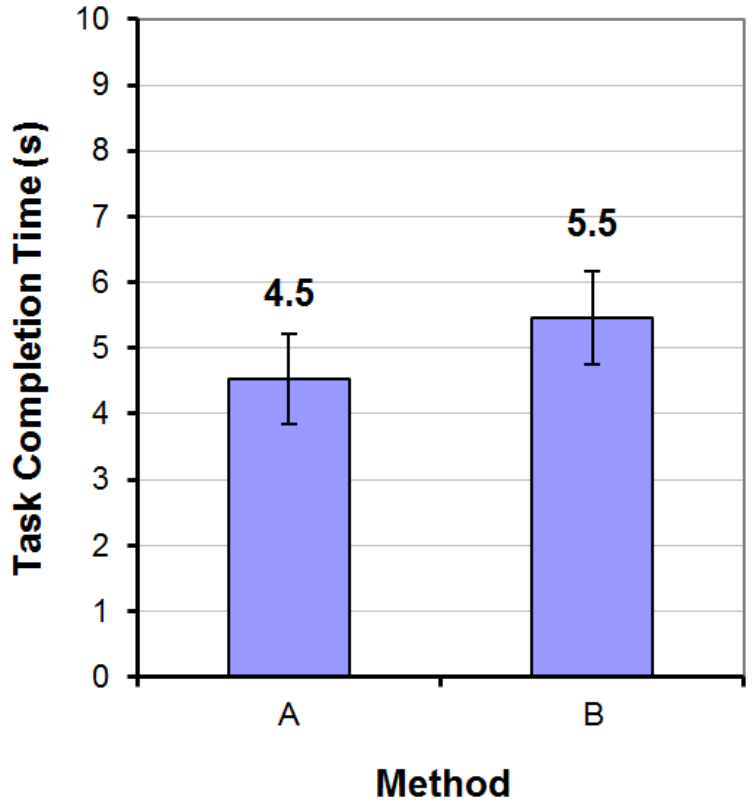
- Two examples:





$$F = \frac{\text{between-group variability}}{\text{within-group variability}}$$

Example #1: ANOVA Analysis



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

Example #1: ANOVA Analysis

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 observed data if the null hypothesis is true

Reported as…

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

Thresholds for "p"

- .05
- .01
- .005
- .001
- .0005
- .0001

Example #1: ANOVA Analysis

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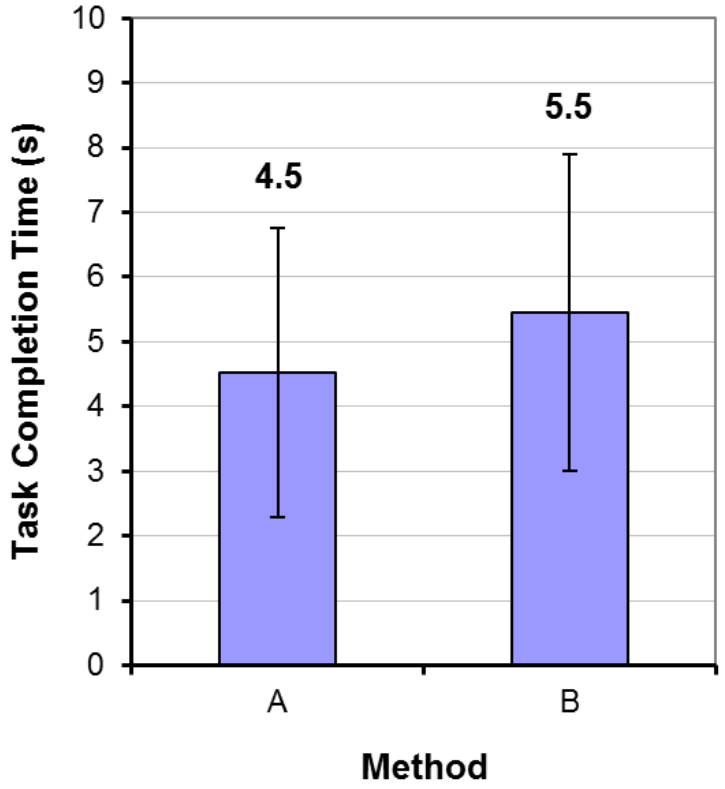
Method * Subject	9	3.888	.432				

Probability of obtaining the observed data if the null hypothesis is true

The mean task completion time for Method A was 4.5s. This was 20.1% less than the mean of 5.5s observed for Method B. The difference was statistically significant ($F_{1,9} = 9.80$, $p < 0.05$)

Example #2: ANOVA Analysis



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 Analysis

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 observed data 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: ANOVA Analysis

ANOVA Table for Task Completion Time (s)

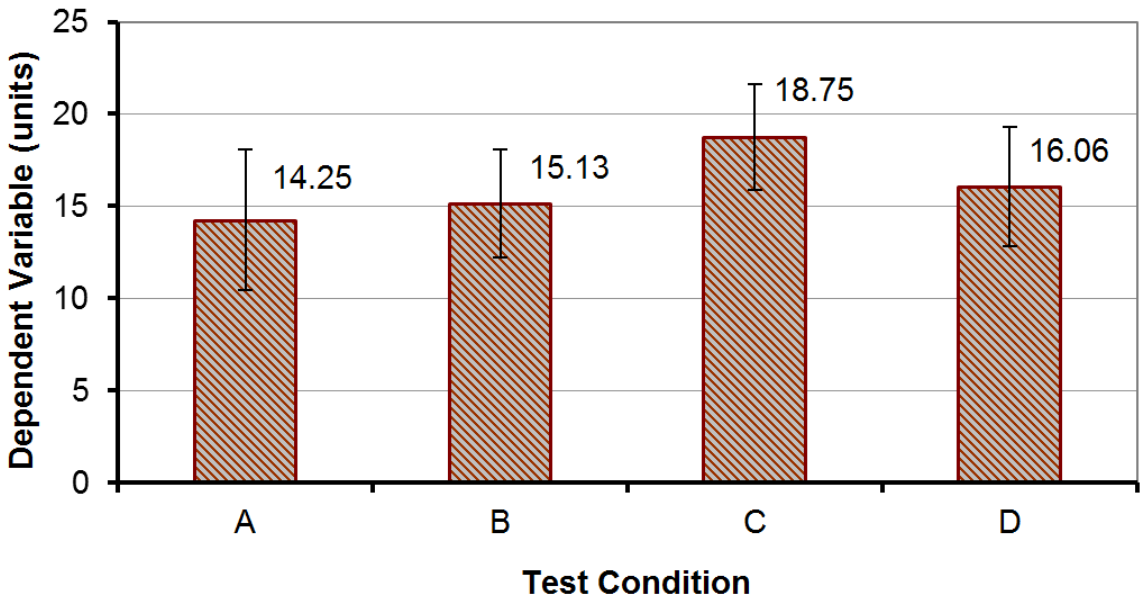
	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
Subject	9	37.372	4.152				
Method	1	4.324	4.324	.626	.4491	.626	.107
Method * Subject	9	62.140	6.904				

Probability of obtaining the observed data if the null hypothesis is true

The mean task completion times were 4.5s for Method A and 5.5s 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).

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



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

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
- Many post hoc tests exist: Fisher PLSD, Bonferroni/Dunn, Dunnett, Tukey/Kramer, Games/Howell, Student-Newman-Keuls, orthogonal contrasts, Scheffé, etc.

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

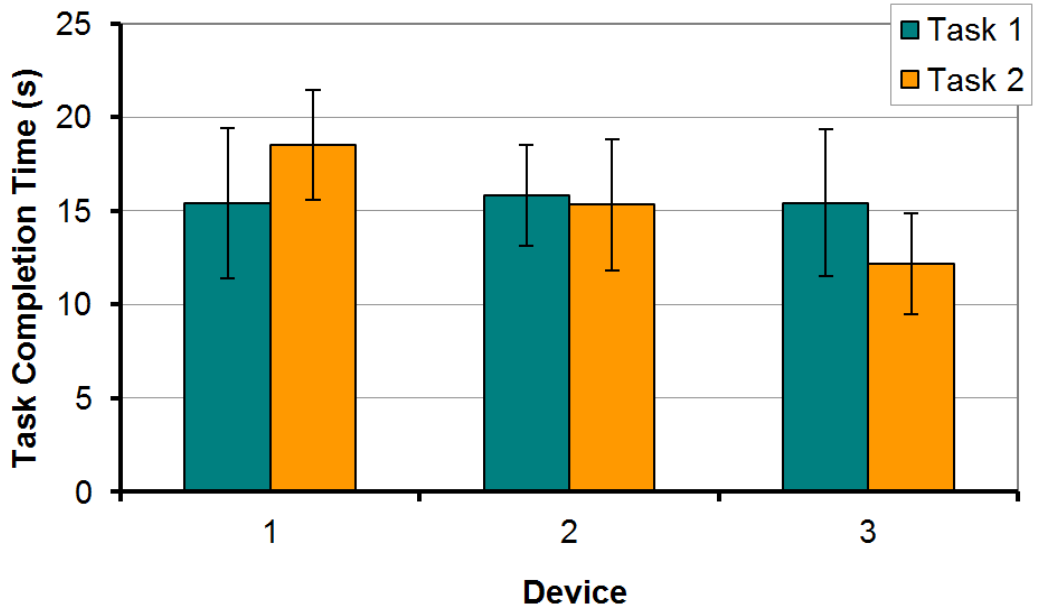
Two-way ANOVA

- 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
  - Both IVs assigned within-subjects
  - Participants: 12

Two-way ANOVA Example

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

	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



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				

ANOVA

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 $\times$ 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.

How to run Statistical Tests?

- Use statistical analysis software
  - Microsoft Excel (Not recommend)
  - IBM SPSS
  - SAS JMP
  - R
  - Matlab
  - Python
  - GoStats (http://www.yorku.ca/mack/GoStats/)

Same Stats, Different Graphs:

Generating Datasets with Varied Appearance and Identical Statistics through Simulated Annealing

Justin Matejka
George Fitzmaurice

AUTODESK RESEARCH

https://www.autodeskresearch.com/publications/samestats

Assignment #1: Quantitative Evaluation

- Use GoFitts software (http://www.yorku.ca/mack/FittsLawSoftware/doc/index.html?GoFitts.html)
- Choose two pointing devices of your choice: e.g., Touchpad and Mouse
- Run an experiment with four participants
- Measure the throughput for each device
- Report should include:
  - Experiment design
  - Experiment results
  - Your reflections on the study

Due Sep 23 (Mon) 23:59 pm

Assignment instruction will be on the course webpage

Design Project Proposal

- On Oct 1
- Each team will present for 15 minutes + 5-minute discussion
- You're presenting
  - Refined problem + research question
  - Related work
  - Suggested solution
  - Plans for evaluation

Acknowledgements

- Some of the materials are based on materials by
  - Tovi Grossman, Univ. of Toronto
  - Juho Kim, KAIST
  - Scott MacKenzie, Human-Computer Interaction: An Empirical Research Perspective

Thank you!