9.63 Laboratory in Visual Cognition

Fall 2008

ANOVA:
Analysis of Variance

Statistics analysis for factor design

- When an experiment has:
- \- a single factor with 3 or more levels
- \- 2 or more factors
- Statistical test: <u>Analysis of Variance</u>

- ANOVA means Analysis of Variance
- The heart of the ANOVA is a comparison of variance estimates between your conditions (groups)

ANOVA

- In the ANOVA, <u>two independent estimates of variance</u> are obtained:
- <u>(1) Between groups variance:</u> based on the variability between the different experimental groups – **how much the means of the different group differ from one another.** Actually, the variance is computed as to how much the individual group means differ from the overall mean of all scores in the experiment.
- <u>(2) Within groups variance:</u> give an estimate of **how much the participants in a group differ from one another** (or the mean of the group)

ANOVA

- <u>Basic idea</u>: are the scores of the different groups or conditions different from each other?
- <u>Null hypothesis:</u> all the participants in the various conditions are drawn from the same population: the experimental variable has no effect.
- Consequence of the null hypothesis on the between and within variance?

ANOVA

- Basic idea: are the scores of the different groups or conditions different from each other?
- Null hypothesis: all the participants in the various conditions are drawn from the same population: the experimental variable has no effect.
- Consequence of the null hypothesis: the between group variance should be the same as the between group variance

ANOVA

- To reject the null hypothesis, the means of the different groups must vary from one another more than the scores vary within the groups
- The greater the variance (differences) between the groups of the experiment, the more likely the independent variable is to have had an effect, especially if the within group variance is low
- The *F* test is simply a ratio of the between groups variance estimate to the within-groups variance estimate

$$F = \frac{\text{Between-groups variance}}{\text{Within-groups variance}}$$

ANOVA

- Under the null hypothesis, the F ratio should be ?

$$F = \frac{\text{Between-groups variance}}{\text{Within-groups variance}}$$

ANOVA

- Under the null hypothesis, the F ratio should be 1
- The greater the between groups variance is than the within group variance and consequently, the greater the F ratio is than 1.00, the more confident we can be in rejecting the null hypothesis.

$$F = \frac{\text{Between-groups variance}}{\text{Within-groups variance}}$$

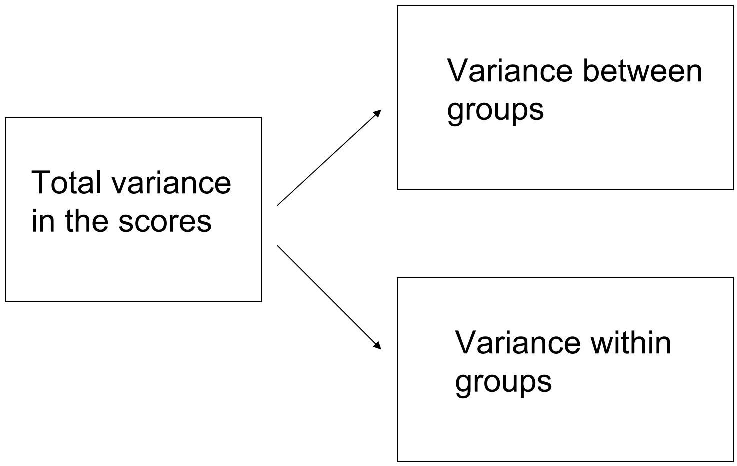
Sources of Variability

- Some of the variability comes from **variability among subjects**: how people differ from one another regardless of the experimental conditions (e.g. some subjects are slow, some subjects are faster)
- Other **variability is caused by the independent variables**, which cause subjects to behave differently.

ANOVA

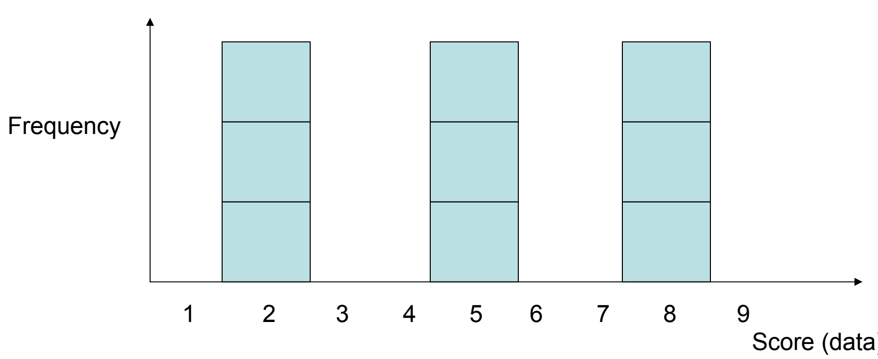
- Variance is simply a way to measure the *differences* between the scores (data)
- ANOVA involves partitioning the variances: we take the **total variability of the scores** in an experiment and we **break it up** in terms of its sources

Sources of variance



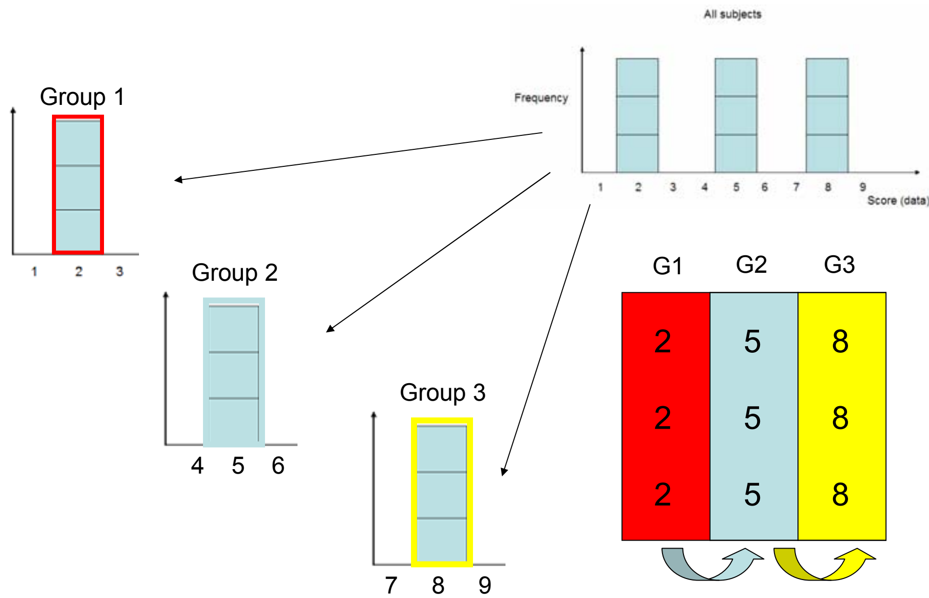
A toy case: Partitioning the variance

e.g. an experiment with 9 subjects



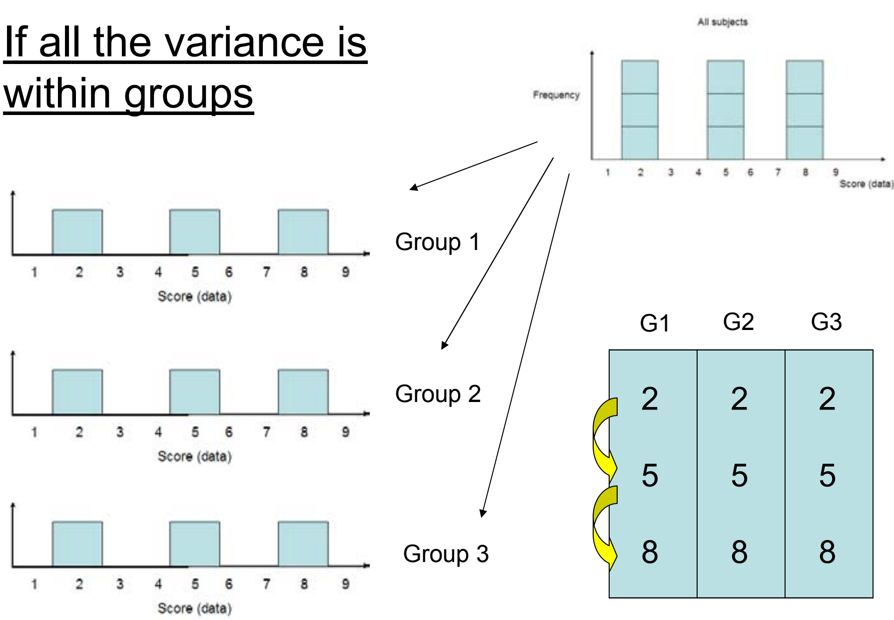
We see a certain amount of variability among the subjects, but we do not know how much is between groups variance and how much is within groups variance

If all the variance is between groups



G1	G2	G3
2	5	8
2	5	8
2	5	8

If all the variance is within groups



G1	G2	G3
2	2	2
5	5	5
8	8	8

Step : Heart of ANOVA

Total variance In the scores

Variance between Groups: mean square deviation between groups

Variance within Groups: mean square deviation within groups

Sources of variances

Total variance In the scores

Variance between Groups: mean square deviation between groups

Variance within Groups: mean square deviation within groups

Total variance
In the scores

→

Variance between
Groups: mean square
deviation between
groups

The mean square between groups is an estimate of the difference in scores that occur between the levels in a factor (or independent variable A)

Here, we find the
difference between
the mean of
each condition
and the overall mean
of the study

	Level A1	Level A2	
	X	X	
	X	X	
	X	X	
	X	X	
	X	X	
(mean)	$\bar{X}1$	$\bar{X}2$	Overall X

Total variance
In the scores

→

Variance within
Groups: mean square
deviation within
groups

The mean square within groups is an estimate of the variability in scores as measured by differences within the conditions of an experiment

Here, we find the difference
between each score in a condition
and the mean of that condition

1) find the variance in level 1
2) find the variance in level 2

3) “pool” – average together – the variances
-> We have the average variability
of the scores in each condition around
the mean of that condition

Level A1	Level A2
X	X
X	X
X	X
X	X
X	X
$\bar{X}1$	$\bar{X}2$
(mean)	(mean)

ANOVA

The *F* test is a ratio of the between groups variance estimate to the within-groups variance estimate

$$F = \frac{\text{Between-groups variance estimate}}{\text{Within-groups variance estimate}}$$

The greater the between groups variance is than the within groups variance
the greater F ratio is than 1.00
the more confident we can be in rejecting null hypothesis

Effect of color on scene recognition

- Question: does color help fast scene recognition?
- Dependant variable: Reaction time to *name* the category of a scene
- Factor 1: presence of color (color vs. gray)
- Factor 2: Type of scenes
- (man-made vs. natural)

	Man-made scenes	Natural landscape scenes
color		
gray		

Figures removed due to copyright restrictions.

Man-made & Natural Scenes

- *Man-made* categories
- *City, Road, Room, Shop*
- Chrominance histograms => no specific colour mode

- *Natural* categories
- *Coast, Canyon, Desert, Forest*
- Chrominance histograms => specific and distinctive colour modes

Figures removed due to copyright restrictions.

Organize the Reaction Time Means

Main effect of factor “color”

	Man-made scenes	Natural landscape scenes	Mean
color	743 msec	750 msec	746 msec
gray	742 msec	800 msec	771 msec
Mean	742 msec	775 msec	

Main effect of factor “image type”

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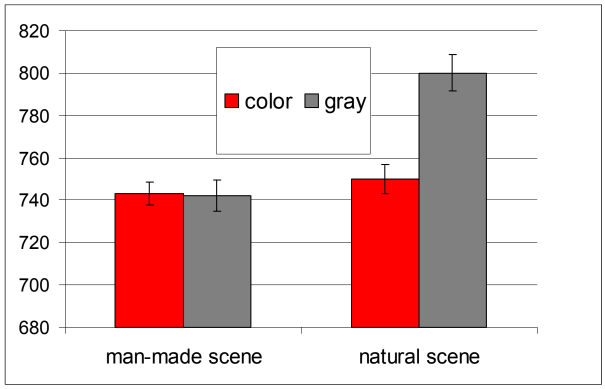
Graph the data

Reaction time (msec)



Error bars show 1 s.e.m (standard error mean)

Experiment design

- Three possible experimental designs:

- Within group (repeated measures)
- Between group
- Mixte design

Case 1: All factors are within: 10 participants (<u>a participant did all the conditions</u>)

Repeated-measures ANOVA

	Natural Color	Natural Gray	Man-made Color	Man-made Gray
Participant 1	752	835	750	748
	721	802	719	710
	768	780	754	762
	765	798	760	750
	712	805	716	699
	748	815	740	745
	781	821	765	761
	753	798	748	752
	754	802	741	760
Participant 10	742	740	735	730

Within-Subject or Repeated Measure ANOVA

- Either the same participants are measured repeatedly
- Either different participants are matched under all levels of one factor
- Other assumptions of ANOVA:
- 1) dependent variable is a ratio or interval factor
- 2) populations data are normally distributed
- 3) population variances are homogeneous

Case 2: All factors and conditions are between (a participant only do 1 condition):
40 participants (10 / conditions)

Between-measures ANOVA

Factor: scene type	Factor: Color status	Dep. Variable RT	
Natural	color	752	Participant 1
Natural	color	721	
Natural	color	768	
Natural	gray	835	
Natural	gray	802	
Natural	gray	780	
Manmade	color	750	
Manmade	color	719	
Manmade	color	754	
Manmade	gray	748	
Manmade	gray	710	
Manmade	gray	762	Participant N (e.g. 40)

Case 3: A factor is between, a factor is repeated (one participant participates in all the conditions of one factor, but not in the conditions of the other factor).
20 participants

Mixte-measures ANOVA

	Natural scenes	Man-made scenes	
color	752	750	Participant 1
color	721	719	
color	768	754	
color	765	760	
color	712	716	
color	748	740	
color	781	765	
color	753	748	
color	754	741	
color	742	735	
gray	835	748	
gray	802	710	
gray	780	762	
gray	798	750	
gray	805	699	
gray	815	745	
gray	821	761	
gray	798	752	
gray	802	760	
gray	740	730	Participant 20

Factorial design: 2 x 2
Scene types and color status

- Main effect of Factor 1 (scene type: natural or man made): Is there a difference between the RT for recognizing “natural scene pictures” and RT for recognizing “man-made scenes pictures”?

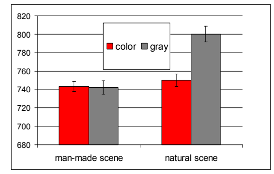
- A *F* and a *p* value for Factor 1

Factorial design: 2 x 2
Scene types and color status

- Main effect of Factor 2 (color status: color or gray): Is there a difference between RT of naming “color pictures” and RT of naming “gray level pictures”?

- A *F* and a p value for Factor 2

Factorial design: 2 x 2
Scene types and color status



- Interaction between scene type and color status: e.g. would the presence or absence of color only have an effect in the natural landscape condition?

- A *F* and a p value for the interaction between factor 1 and factor 2

ANOVA TABLE
FOR BETWEEN GROUPS

Factor: scene type	Factor: Color status	Dep. Variable RT	
Natural	color	752	Participant 1
Natural	color	721	
Natural	color	768	
Natural	gray	835	
Natural	gray	802	
Natural	gray	780	
Manmade	color	750	
Manmade	color	719	
Manmade	color	754	
Manmade	gray	748	
Manmade	gray	710	
Manmade	gray	762	Participant N (n=40)

ANOVA TABLE FOR BETWEEN GROUPS

Statistical analysis of factor 1: scene type

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Scene	1	10465.225	10465.225	22.860	<.0001
Color	1	5978.025	5978.025	13.058	.0009
Scene * Color	1	6528.025	6528.025	14.260	.0006
Residual	36	16480.500	457.792		

ANOVA TABLE FOR BETWEEN GROUPS

Statistical analysis of factor 2: color status

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Scene	1	10465.225	10465.225	22.860	<.0001
Color	1	5978.025	5978.025	13.058	.0009
Scene * Color	1	6528.025	6528.025	14.260	.0006
Residual	36	16480.500	457.792		

ANOVA TABLE FOR BETWEEN GROUPS

Statistical analysis of interaction

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Scene	1	10465.225	10465.225	22.860	<.0001
Color	1	5978.025	5978.025	13.058	.0009
Scene * Color	1	6528.025	6528.025	14.260	.0006
Residual	36	16480.500	457.792		

ANOVA TABLE FOR BETWEEN GROUPS

Statistical analysis of factor 1: scene type

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Scene	1	10465.225	10465.225	22.860	<.0001
Residual	36	16480.500	457.792		

$$F = \frac{\text{Between-groups variance estimate = "Mean square" between groups}}{\text{Within-groups variance estimate = "mean square" within all the conditions (4) "residual"}} = \frac{10465.225}{457.792} = 22.860$$

ANOVA TABLE FOR BETWEEN GROUPS

Statistical analysis of factor 1: scene type

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Scene	1	10465.225	10465.225	22.860	<.0001
Residual	36	16480.500	457.792		

DF = Degree of freedom of factor 1 (scene):
number of levels – 1

DF = Degree of freedom of within score variance (scene):
(Nb measures -1) – df factor 1 – df factor 2 – df interaction

Degree of freedom: the number of score in a sample that are free to vary, and the number that is used to calculate an estimate of the population variability

ANOVA TABLE FOR BETWEEN GROUPS

Statistical analysis of factor 1: scene type

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Scene	1	10465.225	10465.225	22.860	<.0001
Residual	36	16480.500	457.792		

$F(1, 36) = 22{,}86,\ p < .0001$

Scene type factor is significant: there is a difference between naming "natural landscape scenes " pictures and naming "man-made scene pictures"

ANOVA TABLE FOR BETWEEN GROUPS

Statistical analysis of factor 2: color status

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Scene	1	10465.225	10465.225	22.860	<.0001
Color	1	5978.025	5978.025	13.058	.0009
Scene * Color	1	6528.025	6528.025	14.260	.0006
Residual	36	16480.500	457.792		

ANOVA TABLE FOR BETWEEN GROUPS

Statistical analysis of factor 2: color status

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Scene	1	10465.225	10465.225	22.860	<.0001
Color	1	5978.025	5978.025	13.058	.0009
Scene * Color	1	6528.025	6528.025	14.260	.0006
Residual	36	16480.500	457.792		

$F(1, 36) = 13.058, p < .001$

Scene color status is significant: there is a difference between naming “colorful pictures” vs. “gray level” pictures

ANOVA TABLE FOR BETWEEN GROUPS

Statistical analysis of interaction

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Scene	1	10465.225	10465.225	22.860	<.0001
Color	1	5978.025	5978.025	13.058	.0009
Scene * Color	1	6528.025	6528.025	14.260	.0006
Residual	36	16480.500	457.792		

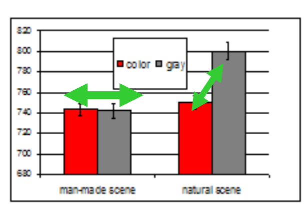
ANOVA TABLE FOR BETWEEN GROUPS

Statistical analysis of interaction

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Scene	1	10465.225	10465.225	22.860	<.0001
Color	1	5978.025	5978.025	13.058	.0009
Scene * Color	1	6528.025	6528.025	14.260	.0006
Residual	36	16480.500	457.792		

$F(1, 36) = 14.25, p < .001$

There is an interaction



Repeated measures ANOVA (Within groups)

Case 1: All factors are within (a participant is doing all the conditions)

	Natural Color	Natural Gray	Man-made Color	Man-made Gray
Participant 1	752	835	750	748
	721	802	719	710
	768	780	754	762
	765	798	760	750
	712	805	716	699
	748	815	740	745
	781	821	765	761
	753	798	748	752
	754	802	741	760
Participant 10	742	740	735	730

Repeated measures ANOVA (Within groups)

Number of level - 1

Number of subjects - 1

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Subject	9	9892.025	1099.114		
Scenes Types	1	10465.225	10465.225	54.537	<.0001
Scenes Types * Subject	9	1727.025	191.892		
Color status	1	5978.025	5978.025	27.047	.0006
Color status * Subject	9	1989.225	221.025		
Scenes Types * Color ...	1	6528.025	6528.025	20.455	.0014
Scenes Types * Color ...	9	2872.225	319.136		

Interaction DF = DF factor 1 * DF factor 2

Repeated measures ANOVA (Within groups)

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Subject	9	9892.025	1099.114		
Scenes Types	1	10465.225	10465.225	54.537	<.0001
Scenes Types * Subject	9	1727.025	191.892		
Color status	1	5978.025	5978.025	27.047	.0006
Color status * Subject	9	1989.225	221.025		
Scenes Types * Color ...	1	6528.025	6528.025	20.455	.0014
Scenes Types * Color ...	9	2872.225	319.136		

Effect of scene types ? F(1,9) = 54, p <. 0001

Effect of Color ? F(1,9) = 27, p <. 001

Interaction ? F(1,9) = 20, p <. 01

Mixte design

Scenes type is a within factor

Color is a between factor

	Natural scenes	Man-made scenes
color	752	750
color	721	719
color	768	754
color	765	760
color	712	716
color	748	740
color	781	765
color	753	748
color	754	741
color	742	735
gray	835	748
gray	802	710
gray	780	762
gray	798	750
gray	805	699
gray	815	745
gray	821	761
gray	798	752
gray	802	760
gray	740	730

Participant 1

Participant 20

Mixte design

	DF	Sum of Squares	Mean Square	F-Value	P-Value
color	1	5978.025	5978.025	9.057	.0075
Subject(Group)	18	11881.250	660.069		
Scenes Types	1	10465.225	10465.225	40.958	<.0001
Scenes Types * color	1	6528.025	6528.025	25.549	<.0001
Scenes Types * Subject(Group)	18	4599.250	255.514		

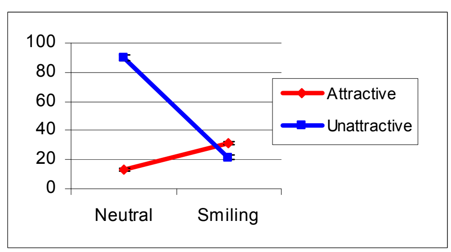
Effect of color (between groups) ? F(1,18) = 9.06, p <. 01

Effect of scene types (within factor) ? F(1,18) = 40.96, p <. 0001

Interaction between color and scene types?
F(1,18) = 25.55, p <. 0001

Exercise : How guilty is that face

	Beauty			
	Attractive		Unattractive	
	Neutral	Smiling	Neutral	Smiling
S1	15	30	92	22
S2	16	32	88	15
S3	8	36	75	30
S4	10	28	95	28
S5	11	26	89	18
S6	12	32	84	26
S7	16	33	100	24
S8	15	28	92	15
S9	17	34	95	15
S10	16	35	90	22
Mean	13.6	31.4	90	21.5
s.e.m	0.98	1.05	2.17	1.77



In the ANOVA, we want to know:
(1) If there is an effect of the first factor (attractive-unattractive)
(2) If there is an effect of the second factor (neutral-smiling)
(3) If the interaction between the two factors is significant.

How guilty is that face: Two-within factors: A within (or repeated measures) ANOVA - Each subject does all the conditions of the experiment -

Number of subjects -1

Degree of freedom

F is much higher than "1"

Significant if p < . 05

ANOVA Table for guiltiness

		DF	Sum of Squares	Mean Square	F-Value	P-Value
	Subject	9	163.125	18.125		
Factor 1	beauty (Nb condition - 1)	1	11055.625	11055.625	578.072	<.0001
	beauty * Subject	9	172.125	19.125		
Factor 2	Emotion (Nb condition - 1)	1	6426.225	6426.225	129.525	<.0001
	Emotion* Subject	9	446.525	49.614		
Interaction	beauty * Emotion	1	18619.225	18619.225	1558.456	<.0001
	beauty * Emotion* Subject	9	107.525	11.947		

Effect of beauty ? F(1,9) = 578, p <. 0001

Effect of Emotion ? F(1,9) = 129, p <. 0001

Interaction ? F(1,9) = 1558, p <. 0001

How guilty is that face: Two-between factors: A between (or unrepeated measures) ANOVA - Each subject does only 1 condition of the experiment -

Significant if p < . 05

Degree of freedom

ANOVA Table for guiltiness

		DF	Sum of Squares	Mean Square	F-Value	P-Value
Factor 1	beauty (Nb condition - 1)	1	11055.625	11055.625	447.546	<.0001
Factor 2	emotion (Nb condition - 1)	1	6426.225	6426.225	260.142	<.0001
Interaction	beauty * emotion	1	18619.225	18619.225	753.730	<.0001
	Residual	36	889.300	24.703		

DF factor 1 * DF factor 2

(Nb measures -1) – df factor 1 – df factor 2 – df interaction

Effect of beauty ? F(1,36) = 447, p <. 0001

Effect of Emotion ? F(1,36) = 260, p <. 0001

Interaction ? F(1,36) = 753, p <. 0001

How guilty is that face: one between – one within factors: A mixte ANOVA

- One factor has different groups of subject – within a group, all subjects run the conditions of the second factor

One group saw only neutral emotion (with attractive and unattractive faces)

Another group saw only smiling expression (with attractive and unattractive faces)

ANOVA Table for Beauty

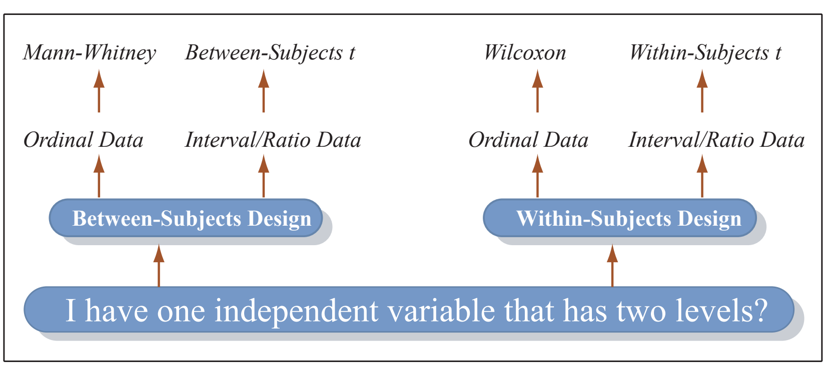
	DF	Sum of Squares	Mean Square	F-Value	P-Value
Emotion	1	6426.225	6426.225	189.735	<.0001
Subject(Group)	18	609.650	33.869		
Category for Beauty **Factor 2**	1	11055.625	11055.625	711.608	<.0001
Category for Beauty * Emotion **Interaction**	1	18619.225	18619.225	1198.448	<.0001
Category for Beauty * Subject(Group)	18	279.650	15.536		

Effect of Emotion? $F(1,18) = 189$, $p < .0001$

Effect of beauty ? $F(1,18) = 711$, $p < .0001$

Interaction ? $F(1,18) = 1198$, $p < .0001$

Statistics Test at a glance
One Factor with 2 levels

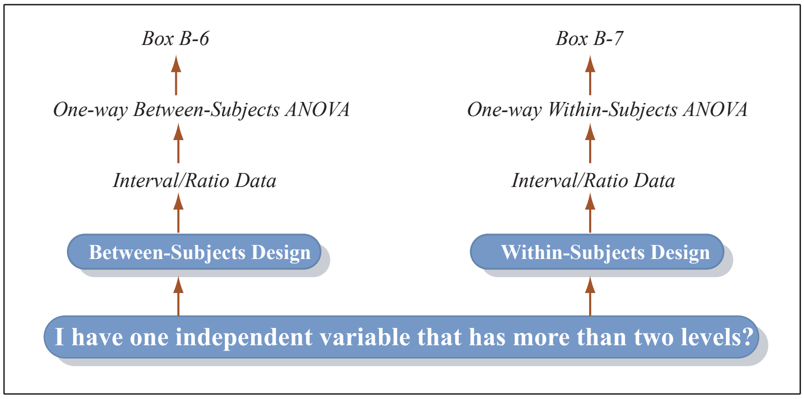


t-test

t-test

Figure by MIT OpenCourseWare.

Statistics Test at a glance
One Factor with more than 2 levels



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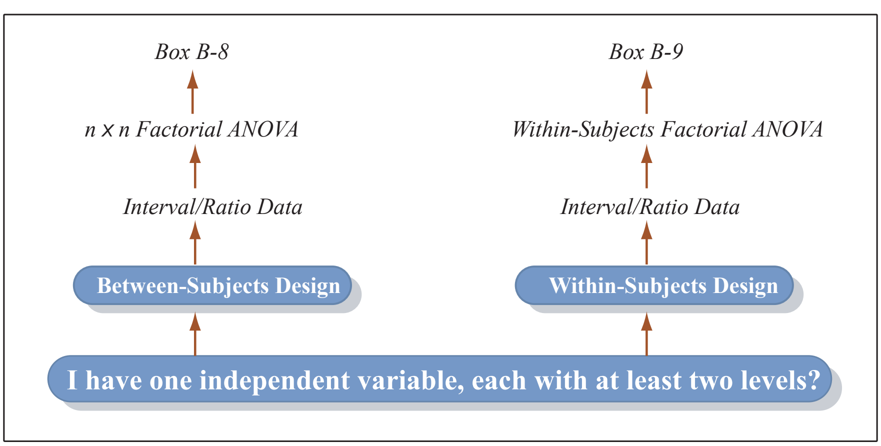
Statistics Test at a glance
Two Factors with at least 2 levels each



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