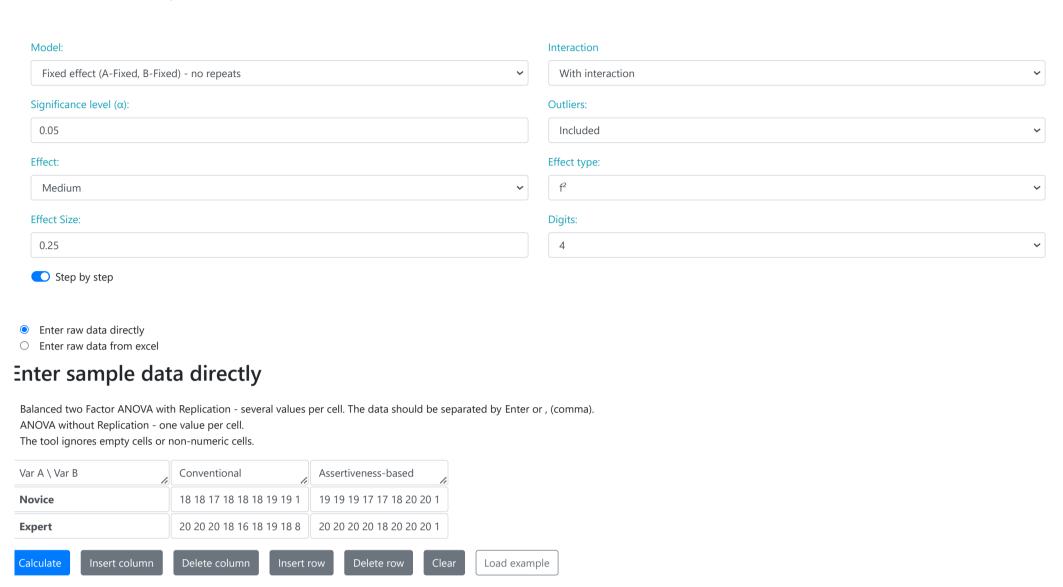
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# Two Way ANOVA Calculator

## Factorial ANOVA - Balanced design

Fixed effects, Mixed effects, Random effects and Mixed repeated measures

<u>Video</u> <u>Information</u> <u>One way ANOVA</u> <u>Levene's test</u>



Enter sample data from excel



ou may copy the data from Excel, Google sheets or any tool that separate the data with **Tab** and **Line Feed**. Copy the data, **one block of consecutive columns includes the header**, and paste. Click to see example: impty cells or non-numeric cells will be ignored

How to do with R?

### **ANOVA** table

Hover over the cells for formulas and calculation.

THOVEL OVER THE CONSTOLLION HOLLINGS OF	na carcalation.				
Source	DF	Sum of Square (SS)	Mean Square (MS)	F Statistic (df <sub>1</sub> ,df <sub>2</sub> )	P-value
Factor A - rows (A)	1	42.2729	42.2729	7.8523 (1,308)	0.005397
Factor B - columns (B)	1	4.6282	4.6282	0.8597 (1,308)	0.3545
Interaction AB	1	1.9315	1.9315	0.3588 (1,308)	0.5496
Error	308	1658.1289	5.3835		
Total	311	1706.9615	5.4886		



Two sample ANOVA - fixed test, using F distribution (right-tailed)

### Factor - A

1. H<sub>0</sub> hypothesis

#### Since the p-value $< \alpha$ , $H_0$ is rejected.

Some of the groups' averages consider to be not equal.

In other words, the difference between the averages of some groups is big enough to be statistically significant.

#### 2. P-value

The p-value equals 0.005397, ( $P(x \le 7.8523) = 0.9946$ ). It means that the chance of type I error (rejecting a correct  $H_0$ ) is small: 0.005397 (0.54%). The smaller the p-value the more it supports  $H_1$ .

#### 3. Test statistic

The test statistic  $\mathbf{F_A}$  equals 7.8523, which is not in the 95% region of acceptance: [- $\infty$ : 3.8718].

#### 4. Effect size

The observed effect size  $\eta^2$  is **small**, **0.025**. This indicates that the magnitude of the difference between the average is small.

#### Factor - B

### 1. H<sub>0</sub> hypothesis

Since the p-value >  $\alpha$ , H<sub>0</sub> can not be rejected.

The averages of all groups assume to be equal.

In other words, the difference between the averages of all groups is not big enough to be statistically significant.

A non-significance result can not prove that H<sub>0</sub> is correct, only that the null assumption can not be rejected.

#### 2. P-value

The p-value equals 0.3545, (  $P(x \le 0.8597) = 0.6455$  ). It means that the chance of type I error, rejecting a correct  $H_0$ , is too high: 0.3545 (35.45%). The larger the p-value the more it supports  $H_0$ .

#### 3. Test statistic

The test statistic  $\mathbf{F_A}$  equals 0.8597, which is in the 95% region of acceptance: [- $\infty$ : 3.8718].

#### A Effect size

The observed effect size  $\eta^2$  is **very small**, **0.0028**. This indicates that the magnitude of the difference between the average is very small.

### **Interaction AB**

#### 1. H<sub>0</sub> hypothesis

Since the p-value >  $\alpha$ , H<sub>0</sub> can not be rejected.

The averages of all groups assume to be equal.

In other words, the difference between the averages of all groups is not big enough to be statistically significant.

A non-significance result can not prove that H<sub>0</sub> is correct, only that the null assumption can not be rejected.

#### 2. P-value

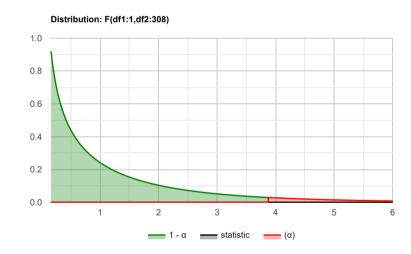
The p-value equals 0.5496, (  $P(x \le 0.3588) = 0.4504$  ). It means that the chance of type I error, rejecting a correct  $H_0$ , is too high: 0.5496 (54.96%). The larger the p-value the more it supports  $H_0$ .

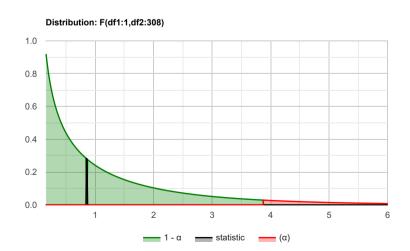
#### 3. Test statistic

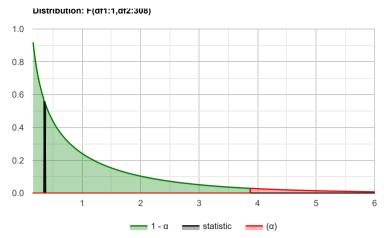
The test statistic  $\mathbf{F_A}$  equals 0.3588, which is in the 95% region of acceptance: [- $\infty$ : 3.8718].

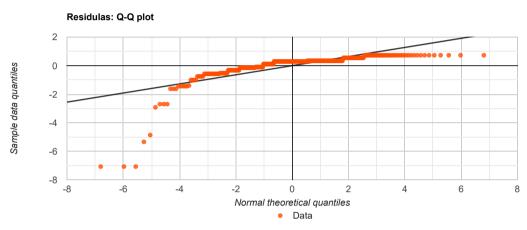
### 4. Effect size

The observed effect size  $\eta^2$  is **very small**, **0.0012**. This indicates that the magnitude of the difference between the average is very small.









Right click on: Save image, (please use 'save link as...' or 'open link in new tab').



Right click on: <u>Save image</u>, (please use 'save link as...' or 'open link in new tab').

### /alidation

## Outliers

 $\underline{\text{Outliers'}}_{\text{detection method: Tukey Fence, k=1.5.}}$ 

Residuals doesn't contain outliers. The **two way ANOVA** test is robust to the presence of outliers.

### Normality

The assumption was checked based on the <u>Shapiro-Wilk Test</u>. ( $\alpha$ =0.05)

It is assumed that **the residuals does not** follow a normal distribution (p-value is 0).

The test is considered robust for moderate violation of the normality assumption.

### Test power: Factor - A

The test priori power is strong 1

## Test power: Factor - B

The test priori power is strong 1

### Test power: Interaction

The test priori power is strong 1

### Balanced design

undefined

## **Tukey HSD / Tukey Kramer**

### Count

Var A \ Var B	undefined	undefined	Total
Novice	69	69	138

Expert	87	87	174
Total	156	156	312

#### <u>Average</u>

Var A \ Var B	undefined	undefined	Total
Novice	18.3188	18.7391	18.529
Expert	19.2184	19.3218	19.2701
Total	18.8205	19.0641	18.9423

### <u>Variance</u>

Var A \ Var B	undefined	undefined	Total
Novice	16.3086	2.2545	9.2583
Expert	3.5215	1.0813	2.2908
Total	9.3095	1.6733	5.4886

### Mean confidence interval (CL:0.95)

Var A \ Var B	undefined	undefined	Total
Novice	[10.4613,26.1764]	[15.8177,21.6606]	[12.587,24.471]
Expert	[15.5616,22.8752]	[17.2955,21.3481]	[16.3122,22.228]
Total	[12.8596,24.7815]	[16.5369,21.5913]	[14.3579,23.5267]

### <u>Differential effects</u>

Var A \ Var B	undefined	undefined	Total
Novice	-0.08835	0.08835	-0.4133
Expert	0.07007	-0.07007	0.3278
Total	-0.1218	0.1218	0

**Cells** - the differential effects of the interactions.

For example, the effect of the interactions of the categories **undefined** and **Novice** is **-0.08835**.

**Totals** - the differential effects of factor A (right column) and factor B (bottom row).

For example, the effect of factor B category **undefined** is **-0.1218**.

### Residuals

Residuals				
Α	В	$Y_{i,j,k}$	Formula: $Y_{i,j,k}$ - $\bar{Y}_{i,j}$	Residual
Novice	undefined	18	18 - 18.319	-0.3188
Novice	undefined	18	18 - 18.319	-0.3188
Novice	undefined	17	17 - 18.319	-1.3188
Novice	undefined	18	18 - 18.319	-0.3188
Novice	undefined	18	18 - 18.319	-0.3188
Novice	undefined	18	18 - 18.319	-0.3188
Novice	undefined	19	19 - 18.319	0.6812
Novice	undefined	19	19 - 18.319	0.6812
Novice	undefined	19	19 - 18.319	0.6812
Novice	undefined	18	18 - 18.319	-0.3188
Novice	undefined	18	18 - 18.319	-0.3188
Novice	undefined	18	18 - 18.319	-0.3188
Novice	undefined	20	20 - 18.319	1.6812
Novice	undefined	20	20 - 18.319	1.6812
Novice	undefined	20	20 - 18.319	1.6812
Novice	undefined	20	20 - 18.319	1.6812
Novice	undefined	20	20 - 18.319	1.6812
Novice	undefined	20	20 - 18.319	1.6812
Novice	undefined	20	20 - 18.319	1.6812
Novice	undefined	20	20 - 18.319	1.6812
Novice	undefined	20	20 - 18.319	1.6812
Novice	undefined	20	20 - 18.319	1.6812
Novice	undefined	20	20 - 18.319	1.6812
Novice	undefined	20	20 - 18.319	1.6812
Novice	undefined	19	19 - 18.319	0.6812
Novice	undefined	6	6 - 18.319	-12.3188
Novice	undefined	19	19 - 18.319	0.6812
Novice	undefined	18	18 - 18.319	-0.3188
Novice	undefined	18	18 - 18.319	-0.3188
Novice	undefined	18	18 - 18.319	-0.3188
Novice	undefined	2	2 - 18.319	-16.3188
Novice	undefined	2	2 - 18.319	-16.3188
Novice	undefined	2	2 - 18.319	-16.3188
Novice	undefined	20	20 - 18.319	1.6812
Novice	undefined	20	20 - 18.319	1.6812
Novice	undefined	20	20 - 18.319	1.6812
Novice	undefined	20	20 - 18.319	1.6812
Novice	undefined	20	20 - 18.319	1.6812
Novice	undefined	20	20 - 18.319	1.6812
Novice	undefined	20	20 - 18.319	1.6812

			Two Way ANOVA calculator	
Novice	undefined	20	20 - 18.319	1.6812
Novice	undefined	20	20 - 18.319	1.6812
Novice	undefined	20	20 - 18.319	1.6812
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Novice	undefined	19	19 - 18.319	0.6812
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Novice	undefined	20	20 - 18.319	1.6812
Novice	undefined	20	20 - 18.319	1.6812
Novice	undefined	15	15 - 18.319	-3.3188
Novice	undefined	15	15 - 18.319	-3.3188
Novice	undefined	15	15 - 18.319	-3.3188
Novice	undefined	20	20 - 18.319	1.6812
Novice	undefined	20	20 - 18.319	1.6812
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Novice	undefined	20	20 - 18.319	1.6812
Novice	undefined	20	20 - 18.319	1.6812
Novice	undefined	20	20 - 18.319	1.6812
Novice	undefined	19	19 - 18.739	0.2609
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Novice	undefined	17	17 - 18.739	-1.7391
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Novice	undefined	20 20 18 19 20 20 20 20 20 20 12 18 20 20 15 15 15 18 18 18 18	20 - 18.739  20 - 18.739  18 - 18.739  19 - 18.739  20 - 18.739  20 - 18.739  20 - 18.739  20 - 18.739  12 - 18.739  18 - 18.739  20 - 18.739  20 - 18.739  15 - 18.739  15 - 18.739  18 - 18.739  18 - 18.739  18 - 18.739  18 - 18.739  18 - 18.739  18 - 18.739  18 - 18.739  17 - 18.739	1.2609 1.2609 -0.7391 0.2609 1.2609 1.2609 1.2609 1.2609 -6.7391 -0.7391 1.2609 1.2609 -3.7391 -3.7391 -0.7391 -0.7391 -0.7391 -0.7391 -1.7391
Novice	undefined	20 20 18 19 20 20 20 20 20 20 12 18 20 20 15 15 15 15 18 18	20 - 18.739  20 - 18.739  18 - 18.739  19 - 18.739  20 - 18.739  20 - 18.739  20 - 18.739  20 - 18.739  12 - 18.739  18 - 18.739  20 - 18.739  15 - 18.739  15 - 18.739  18 - 18.739  18 - 18.739  18 - 18.739  18 - 18.739  18 - 18.739	1.2609 1.2609 -0.7391 0.2609 1.2609 1.2609 1.2609 1.2609 -6.7391 -0.7391 1.2609 1.2609 -3.7391 -3.7391 -0.7391 -0.7391 -0.7391
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5/4/22, 2.22 FIVI			Two way ANOVA calculator	
Novice	undefined	18	18 - 18.739	-0.7391
Novice	undefined	18	18 - 18.739	-0.7391
Novice	undefined	18	18 - 18.739	-0.7391
Novice	undefined	20	20 - 18.739	1.2609
Novice	undefined	20	20 - 18.739	1.2609
Novice	undefined	20	20 - 18.739	1.2609
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Novice	undefined	20	20 - 18.739	1.2609
Novice	undefined	18	18 - 18.739	-0.7391
Novice	undefined	18	18 - 18.739	-0.7391
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Novice	undefined	19	19 - 18.739	0.2609
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Novice	undefined	18	18 - 18.739	-0.7391
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Novice	undefined	19	19 - 18.739	0.2609
Novice	undefined	19	19 - 18.739	0.2609
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Novice	undefined	19	19 - 18.739	0.2609
Novice	undefined	19	19 - 18.739	0.2609
Novice	undefined	20	20 - 18.739	1.2609
Novice	undefined	20	20 - 18.739	1.2609
Novice	undefined	20	20 - 18.739	1.2609
Expert	undefined	20	20 - 19.218	0.7816
Expert	undefined	20	20 - 19.218	0.7816
Expert	undefined	20	20 - 19.218	0.7816
Expert	undefined	18	18 - 19.218	-1.2184
Expert	undefined	16	16 - 19.218	-3.2184
Expert	undefined	18	18 - 19.218	-1.2184
Expert	undefined	19	19 - 19.218	-0.2184
Expert	undefined	18	18 - 19.218	-1.2184
Expert	undefined	8	8 - 19.218	-11.2184
Expert	undefined	20	20 - 19.218	0.7816
	undefined	20	20 - 19.218	0.7816
Expert				
Expert	undefined	20	20 - 19.218	0.7816
Expert	undefined	19	19 - 19.218	-0.2184
Expert	undefined	19	19 - 19.218	-0.2184
	undefined	19	19 - 19.218	-0.2184
Expert				
Expert	undefined	18	18 - 19.218	-1.2184
Expert	undefined	18	18 - 19.218	-1.2184
Expert	undefined	18	18 - 19.218	-1.2184
Expert	undefined	20	20 - 19.218	0.7816
Expert	undefined	20	20 - 19.218	0.7816
Expert	undefined	20	20 - 19.218	0.7816
Expert	undefined	20	20 - 19.218	0.7816
Expert	undefined	20	20 - 19.218	0.7816
Expert	undefined	20	20 - 19.218	0.7816
Expert	undefined	20	20 - 19.218	0.7816
Expert	undefined	20	20 - 19.218	0.7816
Expert	undefined	20	20 - 19.218	0.7816
Expert	undefined	19	19 - 19.218	-0.2184
Expert	undefined	19	19 - 19.218	-0.2184
Expert	undefined	19	19 - 19.218	-0.2184
Expert	undefined	20	20 - 19.218	0.7816
Expert	undefined	20	20 - 19.218	0.7816
1		20	20 - 19.218	0.7816
Expert	undefined			
	undefined undefined	20	20 - 19.218	0.7816
Expert Expert	undefined	20		
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Expert Expert Expert Expert	undefined undefined	20 20 20	20 - 19.218 20 - 19.218	0.7816 0.7816
Expert Expert Expert	undefined undefined	20 20	20 - 19.218	0.7816
Expert Expert Expert Expert	undefined undefined	20 20 20	20 - 19.218 20 - 19.218	0.7816 0.7816

Open         celebration         10         10-70         control           Dect         celebration         3         0.703         celebration	0/4/22, 2.22 FIVI			Two way ANOVA calculator	
Bothmonifold200.00-2020.00-20Bothmonifold180.00-2020.00-20Bothmonifold180.00-2020.00-20Bothmonifold180.00-2020.00-20Bothmonifold180.00-2020.00-20Bothmonifold200.00-2020.00-20Bothmonifold200.00-2020.00-20Bothmonifold200.00-2020.00-20Bothmonifold200.00-2020.00-20Bothmonifold200.00-2020.00-20Bothmonifold200.00-2020.00-20Bothmonifold200.00-2020.00-20Bothmonifold200.00-2020.00-20Bothmonifold200.00-2020.00-20Bothmonifold200.00-2020.00-20Bothmonifold200.00-2020.00-20Bothmonifold200.00-2020.00-20Bothmonifold200.00-2020.00-20Bothmonifold200.00-2020.00-20Bothmonifold200.00-2020.00-20Bothmonifold200.00-2020.00-20Bothmonifold200.00-2020.00-20Bothmonifold200.00-2020.00-20Bothmonifold200.00-2020Bothmonifold200.0	Expert	undefined	20	20 - 19.218	0.7816
Bothmonifold200.00-2020.00-20Bothmonifold180.00-2020.00-20Bothmonifold180.00-2020.00-20Bothmonifold180.00-2020.00-20Bothmonifold180.00-2020.00-20Bothmonifold200.00-2020.00-20Bothmonifold200.00-2020.00-20Bothmonifold200.00-2020.00-20Bothmonifold200.00-2020.00-20Bothmonifold200.00-2020.00-20Bothmonifold200.00-2020.00-20Bothmonifold200.00-2020.00-20Bothmonifold200.00-2020.00-20Bothmonifold200.00-2020.00-20Bothmonifold200.00-2020.00-20Bothmonifold200.00-2020.00-20Bothmonifold200.00-2020.00-20Bothmonifold200.00-2020.00-20Bothmonifold200.00-2020.00-20Bothmonifold200.00-2020.00-20Bothmonifold200.00-2020.00-20Bothmonifold200.00-2020.00-20Bothmonifold200.00-2020.00-20Bothmonifold200.00-2020Bothmonifold200.0	Evport	undefined	20	20 - 19 218	0.7816
Speakunderlad300.92 %Negerunderlad120.742 %0.748 %Negerunderlad120.742 %0.748 %Decenunderlad120.742 %0.748 %Decenunderlad120.742 %0.748 %Econunderlad120.742 %0.742 %Econunderlad120.742 %0.742 %Econunderlad120.742 %0.742 %Eyerunderlad120.742 %0.742 %					
Speed         outsided         18         18-12/20         1.1	Expert	undefined	20	20 - 19.218	0.7816
Dece	Expert	undefined	20	20 - 19.218	0.7816
Dece	Expert	undefined	18	18 - 19.218	-1.2184
Interest         Interest         1.00 No. 1921 (1)         1.00 No. 19					_1 2184
Interest         Monthed         A 7- 100         Control					
speem         melfeld         20         A2-10-00         COMM           Flare         melfeld         20         A2-10-00         C704           Brant         melfeld         20         A2-10-00         C704           Inger         melfeld         20         A2-10-00         C704 <t< td=""><td>Expert</td><td>undefined</td><td>18</td><td>18 - 19.218</td><td>-1.2184</td></t<>	Expert	undefined	18	18 - 19.218	-1.2184
Symbol         one-field         50.00         3.19-18         0.004-16	Expert	undefined	20	20 - 19.218	0.7816
Symbol         one-field         50.00         3.19-18         0.004-16	Expert	undefined	20	20 - 19.218	0.7816
beet         Josephane         20         A.7.1973 (A)         Quelle           Deet         Josephane         20         A.7.1974 (A)         Quelle           Deet         Josephane         20         A.7.1976 (A)         Quelle           Deet         Josephane         20         A.7.1978 (A)         Quelle           Deet         Josephane <td></td> <td></td> <td></td> <td></td> <td></td>					
Open         undefined         23         A. 1973 (1)         October         Combined         20         A. 1974 (1)         October         Combined	Expert	undefined	20	20 - 19.218	0.7816
born         underlind         30         30-79/16         Q-019 b           Born         underlind         20         20-79/16         Q-019 b           Boyn         underlind         20         20-79/16         Q-019 b           Eyer         underlind         20         20-79/16         Q-019 b           Eyer         underlind         20         21-79/16	Expert	undefined	20	20 - 19.218	0.7816
Injury         Justiminal         26         26-97-85         C.0796           Desert         underlined         28         28-92-85         C.078-95           Desert         underlined         28         28-79-78         C.078-95           Dever         underlined         28         28-79-78         C.078-95           Dever         underlined         39         39-79-78         C.078-95           Dever         underl	Expert	undefined	20	20 - 19.218	0.7816
Essent         schaffined         26         20		undefined			0.7816
Figure         undefined         20         20-1928         Confe           Essert         underined         20         20-1928         Confe           Essert         undered         10         10-1928         Confe           Essert         undered         20         20-1928         Confe					
Figer	Expert	undefined	20	20 - 19.218	0.7816
Feerm         veloried         20         23 - 16216         C71 6           Ceper         veloried         20         22 - 16218         C71 6           Ceper         veloried         20         23 - 16218         C71 6           Ceper         veloried         20         23 - 16218         C71 6           Ceper         veloried         20         23 - 16218         C71 6           Equer         veloried         20         23 - 16218         C72 6           Equer         veloried         20         23 - 16218         C72 16           Exper         veloried         30         23 - 16218         C22 18           Exper         veloried         30         23 - 16218         C22 18           Exper         veloried         20         23 - 16218         C27 16           Exper         veloried         20	Expert	undefined	20	20 - 19.218	0.7816
Feerm         veloried         20         23 - 16216         C71 6           Ceper         veloried         20         22 - 16218         C71 6           Ceper         veloried         20         23 - 16218         C71 6           Ceper         veloried         20         23 - 16218         C71 6           Ceper         veloried         20         23 - 16218         C71 6           Equer         veloried         20         23 - 16218         C72 6           Equer         veloried         20         23 - 16218         C72 16           Exper         veloried         30         23 - 16218         C22 18           Exper         veloried         30         23 - 16218         C22 18           Exper         veloried         20         23 - 16218         C27 16           Exper         veloried         20	Expert	undefined	20	20 - 19.218	0.7816
Espert         sateffied         20         26 - 12/2 fs         20 16           Feyril         satefied         20         26 - 12/2 fs         20 76 fs           Feyril         satefield         20         26 - 12/2 fs         27 16 fs           Feyril         satefield         20         27 12/2 fs         377 16           Lepert         satefield         30         3 1-12/2 fs         20 21 14           Lepert         satefield         30         3 1-12/2 fs         20 21 14           Cepert         satefield         30         3 1-12/2 fs         20 21 16           Cepert         satefield         30         3 1-12/2 fs         20 21 16           Cepert         satefield         20         2 1-22/2 fs         20 21 16           Expert         satefield         20         2 1-22/2 fs         20 21 16           Expert         satefield         20         2 1-22/2 fs         20 21 16           Expert         satefield         20         2 1-22/2 fs         20 21 16           Expert         satefield         20         2 1-22/2 fs         20 21 16           Expert         satefield         20         2 1-22/2 fs         20 21 16           <					
Expert         unclaired         20         20 - 19.216         0.7816           Expert         unclaired         20         20 - 19.216         0.7816           Equat         unclaired         20         20 - 19.216         0.7816           Equat         unclaired         20         20 - 19.216         0.7816           Equat         unclaired         19         10 - 19.16         0.7184           Equat         unclaired         19         10 - 19.16         0.7184           Expert         unclaired         20         20 - 19.16         0.7218           Expert         unclaired         20         20 - 19.16         0.7216           Expert         unclaired         20         20 - 19.16         0.7216           Expert         unclaired         20         20 - 19.216         0.7216           Expert         unclai	Expert				
Epert         undéried         20         20-10-216         Command	Expert	undefined	20	20 - 19.218	0.7816
Epert         undéried         20         20-10-216         Command	Expert	undefined	20	20 - 19.218	0.7816
Patent		undefined		20 - 19.218	0.7816
Expert					
Expert	Expert				
Expert	Expert	undefined	20	20 - 19.218	0.7816
Pagent	Expert	undefined	19	19 - 19.218	-0.2184
Expert         Oxidened         18         9-19288         9-178         0-178           Expert         ucidened         28         30-19218         0-278           Expert         ucidened         28         30-19218         0-278           Expert         ucidened         28         20-19218         0-278           Expert         ucidened         28         20-19218         0-278           Expert         ucidened         28         20-19238         0-278           Expert         ucidened         29         30-19218         0-278           Expert         ucidened         19         19-1938         0-2184           Expert         ucidened         20         20-19218         0-2784           Expert         ucidened         20         20-19238         0-2784           Expert         ucidened         20         20-19238         0-2784           Expert         ucidened         20					
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Egent         Uniformed         20         20-18/21/8         0.781/6           Expert         Uniformed         20         20-18/21/8         0.7016           Expert         Uniformed         20         20-18/21/8         0.7014           Expert         Uniformed         30         31-18/21/8         0.7014           Expert         Uniformed         20         20-18/21/8         0.7016           Expert         Uniformed         20         20-18/21/8         0.7016           Expert         Uniformed         20         20-18/21/8         0.7016           Expert         Uniformed         31         31-19/21/8         0.7016           Expert         Uniformed </td <td>Expert</td> <td></td> <td></td> <td></td> <td>-0.2184</td>	Expert				-0.2184
Egypet         undefined         20         20-1218         0.7816         0.7816           Eypert         undefined         20         20-1218         0.7716         0.7716           Eypert         undefined         20         20-1218         0.7716         0.7716           Eypert         undefined         20         20-1238         0.7716         0.7816           Eypert         undefined         20         20-1238         0.7716         0.7716           Eypert         undefined         19         10-1218         0.7716         0.7716           Eypert         undefined         19         10-1218         0.7716         0.7716           Eypert         undefined         19         10-1238         0.7716         0.7716           Eypert         undefined         20         0.71238         0.7716         0.7716           Eypert         undefined         20	Expert	undefined	20	20 - 19.218	0.7816
Egypet         undefined         20         20-1218         0.7816         0.7816           Eypert         undefined         20         20-1218         0.7716         0.7716           Eypert         undefined         20         20-1218         0.7716         0.7716           Eypert         undefined         20         20-1238         0.7716         0.7816           Eypert         undefined         20         20-1238         0.7716         0.7716           Eypert         undefined         19         10-1218         0.7716         0.7716           Eypert         undefined         19         10-1218         0.7716         0.7716           Eypert         undefined         19         10-1238         0.7716         0.7716           Eypert         undefined         20         0.71238         0.7716         0.7716           Eypert         undefined         20	Expert	undefined	20	20 - 19.218	0.7816
Expert         undefined         20         20         19.218         0.7316           Expert         undefined         20         20         19.218         0.7616           Expert         undefined         13         19.19.218         0.7816           Expert         undefined         19         19.19.318         0.2184           Expert         undefined         19         19.19.318         0.2184           Expert         undefined         20         20         19.218         0.7616           Expert         undefined         20         20         19.218         0.7616           Expert         undefined         20         20         19.218         0.7616           Expert         undefined         13         13.19.318         4.2184           Expert         undefined         21         19.218         0.7616           Expert         undefined         20 <td></td> <td></td> <td></td> <td></td> <td></td>					
Spect         undefined         20         20-19-218         0.7816           Spect         undefined         20         20-19-318         0.7816           Spect         undefined         39         19-19-318         0.2134           Spect         undefined         39         19-19-318         0.2134           Spect         undefined         39         19-19-318         0.2134           Spect         undefined         39         19-19-318         0.27816           Spect         undefined         20         20-19-318         0.7816           Spect         undefined         20					
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Expert         undefined         20         20 - 19218         0.7816           Expert         undefined         20         20 - 19218         0.7816           Expert         undefined         20         20 - 19218         0.7816           Expert         undefined         19         19 - 19218         0.21164           Expert         undefined         19         19 - 19218         0.21164           Expert         undefined         20         20 - 19218         0.7816           Expert         undefined         13         13 - 19218         6.2114           Expert         undefined         13         13 - 19218         6.2114           Expert         undefined         20         0 - 19218         0.7816           Expert         undefined         20         0 - 19218         0.7816           Expert         undefined         20         0 - 19218         0.7816           Expert         undefined <td>Expert</td> <td>undefined</td> <td>20</td> <td>20 - 19.218</td> <td>0.7816</td>	Expert	undefined	20	20 - 19.218	0.7816
Expert         undefined         20         20 - 19218         0.7816           Expert         undefined         20         20 - 19218         0.7816           Expert         undefined         20         20 - 19218         0.7816           Expert         undefined         19         19 - 19218         0.21164           Expert         undefined         19         19 - 19218         0.21164           Expert         undefined         20         20 - 19218         0.7816           Expert         undefined         13         13 - 19218         6.2114           Expert         undefined         13         13 - 19218         6.2114           Expert         undefined         20         0 - 19218         0.7816           Expert         undefined         20         0 - 19218         0.7816           Expert         undefined         20         0 - 19218         0.7816           Expert         undefined <td>Expert</td> <td>undefined</td> <td>20</td> <td>20 - 19.218</td> <td>0.7816</td>	Expert	undefined	20	20 - 19.218	0.7816
Espert         undefined         20         20 - 19218         0.7816           Espert         undefined         20         20 - 19228         0.7816           Espert         undefined         19         19 - 19248         0.2144           Espert         undefined         19         19 - 19248         0.2144           Espert         undefined         20         10 - 19248         0.7816           Espert         undefined         20         20 - 19248         0.7816           Espert         undefined         20         20 - 19248         0.7816           Espert         undefined         13         13 - 19248         0.7816           Espert         undefined         13         13 - 19248         0.7816           Espert         undefined         13         13 - 19248         0.7816           Espert         undefined         20         20 - 19228         0.7812           Espert         undefined </td <td></td> <td></td> <td></td> <td></td> <td></td>					
Expert         undefined         20         20 - 19218         0.7816           Expert         undefined         19         19 - 19218         4.2184           Expert         undefined         19         19 - 19218         -0.2184           Expert         undefined         20         20 - 19218         0.7816           Expert         undefined         20         20 - 19218         0.7816           Expert         undefined         20         20 - 19218         0.7816           Expert         undefined         13         11 - 19218         4.2184           Expert         undefined         13         11 - 19218         4.2184           Expert         undefined         13         13 - 19218         4.2184           Expert         undefined         20         20 - 19218         0.7816           Expert         undefined<	Expert				
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Expert         undefined         19         19 - 19218         -0.2184           Expert         undefined         19         19 - 19218         -0.2184           Expert         undefined         20         20 - 19218         0.7816           Expert         undefined         20         20 - 19218         0.7816           Expert         undefined         20         20 - 19218         0.7816           Expert         undefined         13         13 - 19218         -6.2184           Expert         undefined         13         13 - 19218         -6.2184           Expert         undefined         13         13 - 19218         -6.2184           Expert         undefined         20         20 - 19218         0.7816           Expert         undefined         20         20 - 19228         0.7816           Expert         undefined         20         20 - 19322         0.6782           Expert         undefi	Expert	undefined	20	20 - 19.218	0.7816
Expert         undefined         19         19 - 19218         -0.2184           Expert         undefined         19         19 - 19218         -0.2184           Expert         undefined         20         20 - 19218         0.7816           Expert         undefined         20         20 - 19218         0.7816           Expert         undefined         20         20 - 19218         0.7816           Expert         undefined         13         13 - 19218         -6.2184           Expert         undefined         13         13 - 19218         -6.2184           Expert         undefined         13         13 - 19218         -6.2184           Expert         undefined         20         20 - 19218         0.7816           Expert         undefined         20         20 - 19228         0.7816           Expert         undefined         20         20 - 19322         0.6782           Expert         undefi	Fypert	undefined	19	19 - 19 218	-0.2184
Expert         Undefined         19         19-19-218         0-2184           Expert         Undefined         20         20-19-218         0.7816           Expert         Undefined         20         20-19-218         0.7816           Expert         Undefined         20         20-19-218         0.7816           Expert         Undefined         13         13-19-218         4.2184           Expert         Undefined         13         13-19-218         4.2184           Expert         Undefined         13         13-19-218         4.2184           Expert         Undefined         20         20-19-218         0.7816           Expert         Undefined         20         20-19-228         0.7822           Expert         Undefined         20         20-19-322         0.6782           Expert         Undefined <t< td=""><td></td><td></td><td></td><td></td><td></td></t<>					
Expert         undefined         20         20 - 19.218         0.7816           Expert         undefined         20         20 - 19.218         0.7816           Expert         undefined         20         20 - 19.218         0.7816           Expert         undefined         13         13 - 19.218         6.2184           Expert         undefined         13         13 - 19.218         6.2184           Expert         undefined         20         20 - 19.218         0.7816           Expert         undefined         20         20 - 19.322         0.6782           Expert         undefined         20         20 - 19.322         0.6782           Expert         <	Expert	undefined	19	19 - 19.218	-0.2184
Expert         undefined         20         20 - 19218         0.7816           Expert         undefined         20         20 - 19218         0.7816           Expert         undefined         13         13 - 19218         6-2184           Expert         undefined         13         13 - 19218         6-2184           Expert         undefined         20         20 - 19218         0.7816           Expert         undefined         20         20 - 19228         0.7826           Expert         undefined         20         20 - 19322         0.6782           Expert         undefined         20         20 - 19322         0.6782           Expert         undefined </td <td>Expert</td> <td>undefined</td> <td>19</td> <td>19 - 19.218</td> <td>-0.2184</td>	Expert	undefined	19	19 - 19.218	-0.2184
Expert         undefined         20         20 - 19218         0.7816           Expert         undefined         20         20 - 19218         0.7816           Expert         undefined         13         13 - 19218         6-2184           Expert         undefined         13         13 - 19218         6-2184           Expert         undefined         20         20 - 19218         0.7816           Expert         undefined         20         20 - 19228         0.7826           Expert         undefined         20         20 - 19322         0.6782           Expert         undefined         20         20 - 19322         0.6782           Expert         undefined </td <td>Expert</td> <td>undefined</td> <td>20</td> <td>20 - 19.218</td> <td>0.7816</td>	Expert	undefined	20	20 - 19.218	0.7816
Expert         undefined         20         20 - 19218         0.7816           Expert         undefined         13         13 - 19218         -62184           Expert         undefined         13         13 - 19218         -62184           Expert         undefined         13         13 - 19218         -62184           Expert         undefined         20         20 - 19218         0.7816           Expert         undefined         20         20 - 19228         0.782           Expert         undefined         20         20 - 19322         0.6782           Expert         undefined         20         20 - 19322         0.6782           Expert         undefined         20         20 - 19322         0.6782           Expert         undefined <td></td> <td></td> <td></td> <td></td> <td></td>					
Expert         undefined         13         13 - 19218         -6.2184           Expert         undefined         13         13 - 19218         -6.2184           Expert         undefined         20         20 - 19218         0.7816           Expert         undefined         20         20 - 19322         0.6782           Expert         undefined					
Expert         undefined         13         13-19218         6-2184           Expert         undefined         13         13-19218         6-2184           Expert         undefined         20         20-19218         0.7816           Expert         undefined         20         20-19322         0.6782           Expert         undefined         16	Expert	undefined	20	20 - 19.218	0.7816
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### Information

#### **Models**

There are many possible models, this calculator deal currently only with the following balanced models:

- Fixed effect model (A-<u>Fixed</u>, B-<u>Fixed</u>), no repeats both factors are fixed.
- Mixed effect model (A-Random, B-Fixed), no repeats factor A is random, factor B is fixed, each subject is measured only once.
- Mixed effect model (A-Fixed, B-Random), no repeats factor A is fixed, factor B is random, each subject is measured only once.
- Random effect model (A-Random, B-Random), no repeats
- Mixed repeated measures (A-Fixed, B-Repeated) factor A is fixed, factor B uses the same subject for all the categories.

You may use data with replications, or data without replications.

#### What is balanced model?

The balanced design has the same number of observations in each cell - each combination of factor.

#### Currently this calculator supports only the balanced design.

When the model is unbalanced, it causes correlation between the factors and the interaction if it is proportional, and also between the factors if it is unbalance but not proportional.

hence you don't know how to divide the shared sum of squares between the two factors.

There are several methods how to deal with the shared sum of squares.

Type I - sequenceial, the first some of squares (SS) you calculate get the shared some of squares, in this case the order is matter!

Type II - conservative, it assumes there is no interaction between the factors, it ignores the shared SS between the factors. Type III - it assumes there is interaction between the factors, it ignores all the shared SS between the factors and between the factors and the intercation.

#### **Targets**

The two way ANOVA test checks the following targets using sample data.

- Checks if the difference between **Factor A** averages of two or more categories is significant
- Checks if the difference between **Factor B** averages of two or more categories is significant
- Checks if there is an interaction between Factor A and Factor B

When performing ANOVA test, we try to determine if the difference between the averages reflects a real difference between the groups, or is due to the random noise inside each group.

The F statistic represents the ratio of the variance between the groups and the variance inside the groups. Unlike many other statistic tests, the smaller the F statistic the more likely the averages are equal.

Right-tailed F test, for ANOVA test you can use only the right tail. Why?

Hypotheses

Factor A: 
$$H_0$$
:  $\mu_1 = ... = \mu_a$ 

There is no difference in the means of variable A categories.

Factor B: 
$$H_0$$
:  $\mu_1 = ... = \mu_b$ 

There is no difference in the means of variable B categories.

$$H_0$$
: Interaction( $A_iB_i$ ) = 0 ( $\forall$  i = 1 to a, j = 1 to b)

There is no interaction between variable A and variable B, i.e., for all the cells, the effect of variable A on the cells' means is not depend on the effect of variable B, and vice versa.

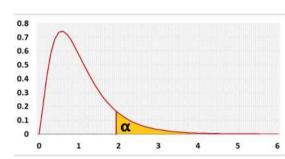
## **Assumptions**

- The dependent variable is continuous (ratio or interval)
- Two categorical independent variables
- Independent observations (no repeated measure)
- The residuals distribution is normal
- Homogeneity of variances, a similar variance for each cell

#### Test statistic

#### 

#### F distribution



### **Required Sample Data**

Sample data from all compared groups

### **Parameters**

- **a** the number of categories in variable A, number of rows.
- **b** the number of categories in variable B, number of columns.
- $\mathbf{n_i}$  sample side of category i of variable A (row i).
- $\mathbf{n_{j}}$  sample side of category j of variable B (column j).
- $\mathbf{n_{i,j}}$  sample side of cell i,j (row i, column j). In the balance  $\mathbf{n_{i,j}} = \mathbf{n}/(\mathbf{a}^*\mathbf{b})$
- ${f n}$  overall sample side, includes all the groups ( $\Sigma n_{i,j}$ , i=1 to a, j=1 to b).
- $ar{\mathbf{Y}}_{\mathbf{i}}$  average of all the observations of category i of variable A (row i).
- $\boldsymbol{\tilde{Y}_{j}}$  average of all the observations of category j of variable B (column j).
- $\boldsymbol{\bar{Y}}$  overall average (SY  $_{i,j,k}$  / n, i=1 to a, j=1 to b, k=1 to  $n_{i,j}).$

### Repeated measures ANOVA

 ${f s}$  - represent the order of subject in category i (subject 1 in category 1 is different than subject 1 in category 2)

**sub** - number of subjects per cell, cell is one combination of variable A and variable B. For the balance design: N=a\*b\*sub.

 $\mathbf{\tilde{Y}_{i,s}}$  - subject's average,  $\Sigma Y_{i,j,s}$  for subject i,s ,the average of all the observations of subject s of category j of variable B (column j).

 $\boldsymbol{\bar{Y}}$  - overall average ( $\Sigma Y_{i,j,s}$  / n

## **Results calculations**

## Sum of squares

The sum of squares accumulates the squared differences related to the effect we try to estimate.

SS<sub>A</sub> - the squared differences related to the effect of variable A. You compare the average of every category to the total average. The same value as the sum of squares between groups in one way ANOVA.

 $SS_B$  - the same as  $SS_A$ , for variable B.

**SS**<sub>AB</sub> - the squared differences related to the effect of the combination of variable A and variable B in each cell, Since we try to understand the influence of the interaction AB, the interaction of the specific value of variable A and the specific value of variable B, we take the average of each cell, remove the influence of variable B, and compare to the total average.

A effect =  $\bar{Y}_i - \bar{Y}$ 

**B** effect =  $\bar{Y}_i - \bar{Y}$ 

**AB effect** = Cell average - A effect - B effect - Total average.

 $= \bar{Y}_{i,j} - (\bar{Y}_i - \bar{Y}) - (\bar{Y}_j - \bar{Y}) - \bar{Y}.$ 

 $= \bar{Y}_{i,j} - \bar{Y}_i - \bar{Y}_j + \bar{Y}.$ 

Take the square of each difference

 $\bar{Y}_{i,j} - \bar{Y}_i - \bar{Y}_j + \bar{Y})^2$ .

Count the square differences of each value in the cell, hence multiply by the sample size of each cell (n<sub>i,i</sub>).

 $SS_{AB} = \Sigma_i^a \Sigma_j^b n_{i,j} (\bar{Y}_{i,j} - \bar{Y}_i - \bar{Y}_j + \bar{Y})^2$ 

### **Fixed and Random Effects**

The fixed and random effects are related to the independent variables ().

#### Fixed Effect

The effect is constant across individuals.

- The categories of the variable contains the entire categories' list
- The effect of this variable is interesting. The difference between the categories is important
- There is no know pattern on the difference between the categories

#### Random Effect

The effect vary across individuals, the individuals may be people, products.

- The categories' list is only a sample from the entire categories' list
- The effect of this variable is not interesting by itself. The difference between the categories is not important.
- There is no know pattern on the difference between the categories

Example: collecting data from several schools.

A sample from the entire groups' population.

There is no pattern about the difference between the schools, and if there will be a pattern, it will be another factor, like school's size.

Each school is not important by itself.

When you change the interaction field or the model, the following ANOVA table and diagram will be adjusted!

### ANOVA table - with interaction

Source	Degrees of Freedom (DF)	Sum of Squares (SS)	Mean Square (MS)	F statistic	p-value
Factor A (rows) Between the categories of factor A	DF <sub>A</sub> = a - 1	$SS_A = \Sigma_i^a n_i (\bar{Y}_{i^-} \bar{Y})^2$	$MS_A = SS_A / DF_A$	$F_A = MS_A / MS_E$	$P(x > F_A)$
Factor B (Columns) Between the categories of factor B	DF <sub>B</sub> = b - 1	$SS_B = \Sigma_j^{\ b} n_j (\bar{Y}_j \text{-} \bar{Y})^2$	$MS_B = SS_B / DF_B$	$F_B = MS_B / MS_E$	$P(x > F_B)$
<b>Interaction AB</b> Between the cells after reducing factor A and factor B effects	$DF_{AB} = (a - 1)(b - 1)$	$SS_{AB} \! = \! \Sigma_{i}^{a} \Sigma_{j}^{b} n_{i,j} (\bar{Y}_{i,j} - \bar{Y}_{i} - \bar{Y}_{j} + \bar{Y})^{2}$	$MS_{AB} = SS_{AB} / DF_{AB}$	$F_{AB} = MS_{AB} / MS_{E}$	$P(x > F_{AB})$
<b>Error</b> Within the cells	DF <sub>E</sub> = n - a*b	$SS_{E} \!\!=\!\! \Sigma_{i}{}^{a} \! \Sigma_{j}{}^{b} \! \Sigma_{k}{}^{n_{i,j}} (Y_{i,j,k} - \bar{Y}_{i,j})^{2}$	$MS_E = SS_E / DF_E$		
<b>Total</b> All the deviations from the average	DF <sub>T</sub> = n - 1	$\begin{aligned} &SS_{T} = \Sigma_i{}^{a} \Sigma_j{}^{b} \Sigma_k{}^{n_{i,j}} (Y_{i,j,k} - \bar{Y})^2 \\ &SS_{T} = Sample \ Variance*(n-1) \\ &SS_{T} = SS_{A} + SS_{B} + SS_{AB} + SS_{E} \end{aligned}$	$MS_E = S^2 = SS_T / (n - 1)$		

### Sum of squares diagram - with interaction

In the following diagram you may see the differences per each observation  $Y_{i,j,k}$  that used to calculate the sum of squares.

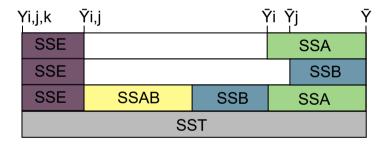
A effect:  $\bar{Y}_i - \bar{Y}$ .

B effect:  $\bar{Y}_j - \bar{Y}$ .

Interaction effect (AB):  $Y_{i,j} - \bar{Y}_i - \bar{Y}_j + \bar{Y}$ .

Error: Y<sub>i,j,k</sub> -  $\bar{Y}_{i,j}$ .

Total effect:  $Y_{i,j,k}$  -  $\bar{Y}$ .



## R Code

The following R code should produce the same results

A0 =

c("Novice","

A1 = c("Expert","Expert,"Expert,","E

A = c(A0,A1)

c("undefined","und

B = c(B0,B1)

 $\mathsf{DV} = \mathsf{c}(\mathsf{DV0}, \mathsf{DV1})$ 

ID0 =

ID = c(ID0,ID1)

 $df1 <- \ data.frame(A,B,DV,ID)$ 

Model1 <- aov(DV  $\sim$  A + B + A:B, data=df1)

summary(Model1)

res=residuals(object = Model1)