Quick calculation of TWO-WAY and ONE-WAY ANOVA (Experiment finding paper)

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Quick calculation for TWO-WAY and ONE-WAY ANOVA

(Experiment finding paper)

Experiment finding paper about calculation of one-way and two-way ANOVA in fast and effective way using a scientific calculator. The paper starts explaining from two-way ANOVA because it may difficult or complex to study one-way ANOVA without knowing two-way first. But if the researcher knows clearly about two-way, one-way is also clearly known and no need to add any new knowledge to study one-way.

The two-way ANOVA compares the mean differences between groups that have been split on two independent variables (called factors). The primary purpose of a two-way ANOVA is to understand if there is an interaction between the two independent variables on the dependent variable. It is very easy to calculate ANOVA using computer, but it is incredibly complex with number by hand. If some numerical calculation is wrong in complex steps like finding variance, the whole calculation answer will go wrong. However, ANOVA calculation needs to use scientific calculator and this method is an effective and good also for time consuming.

One-way ANOVA is to determine whether there are any statistically significant differences between the means of two or more independent groups. This method is used when there is a minimum of three or rather than two groups.

Key ideas

ANOVA is a statistical procedure for analyzing the results of an experiment with multiple groups. It is the extension of similar procedures for A/B test, used to access whether the overall variation among groups is within the range of chance variation. A useful outcome of an ANOVA is the identification of variance components associated with group treatments, interaction effects and errors.

All calculator instructions are made using **Canon F-789SGA** scientific calculator.

Canon F-789SGA scientific calculator

Shop here: http://tiny.cc/348h8y

Please note that all calculator calculation instructions made in this paper are done with above illustrated calculator brand. Button and instructions may vary with other brands but generally all scientific calculator has similar instructions.

Contents

TWO-WAY ANOVA

Assumptions

1. The populations from which the samples were obtained must be normally or approximately normally distributed.
2. The samples must be independent.
3. The variances of the populations must be equal.
4. The groups must have the same sample size.

Two-way ANOVA calculation steps

- Step 1: Define hypothesis
- Step 2: Find the means for Row and Column
- Step 3: Frame the ANOVA summary table
- Step 4: Calculate DF (Degree of freedom)
- Step 5: Calculate SS (Sum of squares)
- Step 6: Calculate MS (Mean squares)
- Step 7: Calculate F (F value)
- Step 8: Calculate F-critical values
- Step 10: Compare F and F-critical for each effect and conclusion

Hypothesis

- There are three sets of hypotheses with the two-way ANOVA.
- The null hypotheses for each of the sets are given below.
- The population means of the first factor are equal.
- The population means of the second factor are equal.
- There is no interaction between the two factors.

F > F-critical = H1
F < F-critical = H0

Formula

SS = A Variance$^{2 \times N}$

SS total = Standard deviation$^{2 \times (N - 1)}$

MS = SS ÷ DF

F = MS ÷ MS residual

Two-way ANOVA summary table

	DF	**SS**	**MS**	**F**	**F-critical**
Main effect A	A – 1	A Variance$^{2 \times N}$	$SS_A \div DF_A$	$MS_A \div MS_r$	DF_A, DF_r
Main effect B	B – 1	B Variance$^{2 \times N}$	$SS_B \div DF_B$	$MS_B \div MS_r$	DF_B, DF_r
Residual (Error)	Total – (A + B)	$SS_{total} - (SS_A + SS_B)$	$SS_r \div DF_r$	N/A	N/A
Total	N – 1	Standard deviation$^{2 \times (N - 1)}$	N/A	N/A	N/A

Where:

- DF = Degree of freedom
- SS = Sum of squares
- MS = Mean square
- F = F values
- F-critical = Critical statistics F

Example Question

Three variety of potatoes are being compared for yield. The experiment was carried out by assigning each variety at random to four different plots. One variety of potato in each of the 4 locations. Potato type (3 levels) and location (4 levels). The plot is as follows.

		Potato type		
		P-1	P-2	P-3
Yield	Y-1	18	13	12
	Y-2	20	23	21
	Y-3	14	12	9
	Y-4	11	17	10

Answer

Step 1: Define hypothesis

Set 1

H0: $\mu 1 = \mu 2 = \mu 3$ (The population means of the yields are equal.)

H1: $\mu 1 \neq \mu 2 \neq \mu 3$ (At least one mean is different.)

Set 2

H0: $\mu 1 = \mu 2 = \mu 3 = \mu 4$ (The population means of the potato types are equal.)

H1: $\mu 1 \neq \mu 2 \neq \mu 3 \neq \mu 4$ (At least one mean is different.)

Step 2: Find the means for Row and Column

Calculator setup

1. Enter Mode and select STAT to enter statistical calculation mode.
2. Choose SD and put Row data (for each yield type). Click AC to go back main screen and data will be automatically saved inside.
3. Click APPS to enter statistics mode and select S-VAR.
4. Select $\bar{X}$ and press = to show mean result.
5. Repeat this process to find mean for each row and column of dataset. The answer will obtain as follows. G mean (grand mean) is the mean of overall dataset.

		Potato type (**B**)			
		P-1	P-2	P-3	**Mean ($\bar{X}$)**
Yield (**A**)	Y-1	**18**	**13**	**12**	**14.33**
	Y-2	**20**	**23**	**21**	**21.33**
	Y-3	**14**	**12**	**9**	**11.66**
	Y-4	**11**	**17**	**10**	**12.66**
Mean ($\bar{X}$)		**15.75**	**16.25**	**13**	**15 (G mean)**

Step 3: Frame the ANOVA summary table

	DF	**SS**	**MS**	**F**	**F-critical**
Yield (A)					
Potato (B)					
Residual					
Total					

Step 4: Calculate DF (Degree of freedom)

DF for yield	**Number of rows – 1 = 4 – 1 = 3**
DF for potato	**Number of columns – 1 = 3 – 1 = 2**
DF total	**Total number of observations in dataset – 1 = 12 – 1 = 11**
DF residual	**DF total – (DF yield + DF potato) = 11 – 5 = 6**

Step 5: Calculate SS (Sum of squares)

Calculator setup

1. Enter Mode and select STAT to enter statistical calculation mode.
2. Choose SD and put row **mean** data (**calculated in step 2**). Click AC to go back main screen and data will be automatically saved inside.
3. Click APPS to enter statistics mode and select S-VAR.
4. Select **xσn** for variance.
5. Put square and multiply with total number of observations in dataset. This will produce SS for Yield. Final formula on calculator screen will like this.

$\mathbf{x\sigma n^{2\times 12}}$

Therefore, SS for yield is like

SS yield = Variance (14.33, 21.33, 11.66, 12.66)$^{2\times 12}$ = 171.44

Repeat same process of Potato and result is like

SS potato = Variance (15.75, 16.25, 13)$^{2\times 12}$ = 24.5

After these two SSs for main effects are complete, the next process is to calculate SS total.

Calculator setup

1. Enter Mode and select STAT to enter statistical calculation mode.
2. Choose SD and put **ALL** observation values in dataset. Click AC to go back main screen and data will be automatically saved inside.

3. Click APPS to enter statistics mode and select S-VAR.
4. Select **xσn-1** for standard deviation of dataset.
5. Put square and multiply with DF total which is already calculated in **Step 4**. This will produce SS total. Final formula on calculator screen will like this.

xσn-1$^{2 \text{ x } (12\text{-}1)}$

Therefore, SS total result is like

SS total = Standard deviation$^{2 \text{ x } 11}$ = 238

After 3 SS values are complete, calculation is simple to find SS residual values by

SS residual = SS total – (SS yield + SS potato) = 238 – (171.44 + 24.5) = 42.39

After these DF and SS processes are complete, put the values in ANOVA frame.

	DF	SS	MS	F	F-critical
Yield (A)	**3**	**171.44**			
Potato (B)	**2**	**24.5**			
Residual	**6**	**42.17**			
Total	**11**	**238**			

Step 6: Calculate MS (Mean squares)

The formula of MS is as follows

MS = SS ÷ DF

Therefore, MS for each row is calculated as follows.

MS yield = SS yield ÷ DF yield = 171.44 ÷ 3 = 57.14

MS potato = SS potato ÷ DF potato = 24.5 ÷ 2 = 12.25

MS residual = SS residual ÷ DF residual = 42.17 ÷ 6 = 7.03

Note: There is no need to find MS total.

Place the MS values in frame.

	DF	SS	MS	F	F-critical
Yield (A)	3	171.44	**57.14**		
Potato (B)	2	24.5	**12.25**		
Residual	6	42.17	**7.03**		
Total	11	238	-		

Step 7: Calculate F (F value)

F values for yield and potato are calculated as follows.

F yield = MS yield ÷ MS residual = 57.14 ÷ 7.03 = 8.12

F potato = MS potato ÷ MS residual = 12.55 ÷ 7.03 = 1.74

Update the table with F values

	DF	SS	MS	F	F-critical
Yield (A)	3	171.44	57.14	**8.12**	
Potato (B)	2	24.5	12.25	**1.74**	
Residual	6	42.17	7.03	-	
Total	11	238	-	-	

Step 8: Calculate F-critical values

Check the critical F values in F table (p=0.05) with calculated **DFs**.

F-critical = F 0.05, DF effect (F table column), DF residual (F table row)

Therefore,

F-critical yield = $F_{0.05, 3, 6}$ = 4.76

F-critical potato = $F_{0.05, 2, 6}$ = 5.14

Update the table (Final table)

	DF	SS	MS	F	F-critical
Yield (A)	3	171.44	57.14	8.12	**4.76**
Potato (B)	2	24.5	12.25	1.74	**5.14**
Residual	6	42.17	7.03	-	**-**
Total	11	238	-	-	-

Step 10: Compare F and F-critical for each effect and conclusion

F yield > F-critical yield (H1)

Reject null hypothesis and accept alternative hypothesis. Yield has significant effect on the dependent variable. The result is significant at $p < .05$

F potato < F-critical potato (H0)

Accept null hypothesis and reject alternative hypothesis. Potato has no significant effect on the dependent variable. The result is not significant at $p < .05$

More investigation

We can convert F-critical to P values from following link.

https://www.socscistatistics.com/pvalues/fdistribution.aspx

The result is as follows.

	DF	**SS**	**MS**	**F**	**F-critical**	**P value**
Yield	3	171.44	57.14	8.12	4.76 (3,6)	.049938
Potato	2	24.5	12.25	1.74	5.14 (2,6)	.05006
Residual	6	42.17	7.03	7.03	-	-
Total	11	238	-	-	-	-

ONE-WAY ANOVA

Assumptions

1. The populations from which the samples were obtained must be normally or approximately normally distributed.
2. The samples must be independent.
3. The variances of the populations must be equal.

One-way ANOVA calculation steps

- Step 1: Define hypothesis
- Step 2: Find the means of each group
- Step 3: Frame the ANOVA summary table
- Step 4: Calculate DF (Degree of freedom)
- Step 5: Calculate SS (Sum of squares)
- Step 6: Calculate MS (Mean squares)
- Step 7: Calculate F (F value)
- Step 8: Calculate F-critical values
- Step 10: Compare F and F-critical then conclusion

Hypothesis

The null hypothesis will be that all population means are equal, the alternative hypothesis is that at least one mean is different.

F > F-critical = H1
F < F-critical = H0

Formula

SS = Variance$^{2 \times N}$

SS total = Standard deviation$^{2 \times (N-1)}$

MS = SS ÷ DF

F = MS ÷ MS residual

Two-way ANOVA summary table

	DF	**SS**	**MS**	**F**	**F-critical**
Main effect A	A – 1	A Variance$^{2 \times N}$	$SS_A \div DF_A$	$MS_A \div MS_r$	DF_A, DF_r
Residual (Error)	Total – A	$SS_{total} - SS_A$	$SS_r \div DF_r$	N/A	N/A
Total	N – 1	Standard deviation$^{2 \times (N-1)}$	N/A	N/A	N/A

Where:

- DF = Degree of freedom
- SS = Sum of squares
- MS = Mean square
- F = F values
- F-critical = Critical statistics F

Example Question

Students of different countries were randomly selected and their height (in meter) were recorder as below:

African 1.7, 1.5, 1.6, 1.6, 1.8

Asian 1.5, 1.5, 1.7, 1.7, 1.6

European 1.6, 1.8, 1.6, 1.7, 1.8

Use one-way ANOVA to test at 0.05 level of significant whether there is difference among the mean of heights for the three nationalities. The heights for all nationalities follow normal distribution.

Answer

Dataset in clear format

African	1.7	1.5	1.6	1.6	1.8
Asian	1.5	1.5	1.7	1.7	1.6
European	1.6	1.8	1.6	1.7	1.8

Step 1: Define hypothesis

H0: All mean heights are equal

H1: Not all mean heights are equal

Step 2: Find the means of each group

Calculator setup

1. Enter Mode and select STAT to enter statistical calculation mode.
2. Choose SD and put data (for each ethnicity type). Click AC to go back main screen and data will be automatically saved inside.

3. Click APPS to enter statistics mode and select S-VAR.
4. Select $\bar{X}$ and press = to show mean result.
5. You need to repeat this process **3 times** for each ethnicity.

The result will be obtained as follows;

						Mean ($\bar{X}$)
African	1.7	1.5	1.6	1.6	1.8	**1.64**
Asian	1.5	1.5	1.7	1.7	1.6	**1.6**
European	1.6	1.8	1.6	1.7	1.8	**1.7**
					Grand mean = 1.64	

Grand mean is the mean of all observations in dataset.

Step 3: Frame the ANOVA summary table

	DF	SS	MS	F	F-critical
Main effect					
Residual					
Total					

Step 4: Calculate DF (Degree of freedom)

DF for main effect **Number of columns – 1 = 3 – 1 = 2**

DF total **Total number of observations in dataset – 1 = 15 – 1 = 14**

DF residual **DF total – DF main effect = 14 – 2 = 12**

Arrange the values in ANOVA frame.

	DF	SS	MS	F	F-critical
Main effect	**2**				
Residual	**12**				
Total	**14**				

Step 5: Calculate SS (Sum of squares)

Calculator setup

1. Enter Mode and select STAT to enter statistical calculation mode.
2. Choose SD and put row **mean** data (**calculated in step 2**). Click AC to go back main screen and data will be automatically saved inside.
3. Click APPS to enter statistics mode and select S-VAR.
4. Select **xσn** for variance.
5. Put square and multiply with total number of observations in dataset. This will produce SS for main effect (Ethnicity). Final formula on calculator screen will like this.

xσn$^{2 \text{ x } 15}$

Therefore, SS for main effect (ethnicity) is like

SS main = Variance (16.4, 1.6, 1.7)$^{2 \text{ x } 15}$ = 0.0253

After SS for main effects is complete, the next process is to calculate SS total.

Calculator setup

1. Enter Mode and select STAT to enter statistical calculation mode.
2. Choose SD and put **ALL** observation values in dataset. Click AC to go back main screen and data will be automatically saved inside.
3. Click APPS to enter statistics mode and select S-VAR.
4. Select **xσn-1** for standard deviation of dataset.
5. Put square and multiply with DF total which is already calculated in **Step 4**. This will produce SS total. Final formula on calculator screen will like this.

xσn-1$^{2 \text{ x } (15-1)}$

Therefore, SS total result is like

SS total = Standard deviation$^{2 \times 14}$ = 0.1573

After SS main and total are calculated, SS residual is easy to find by

SS residual = SS total – SS residual = 0.1573 – 0.0253 = 0.132

After SS calculations are complete, update the ANOVA frame.

	DF	SS	MS	F	F-critical
Main effect	2	**0.0253**			
Residual	12	**0.132**			
Total	14	**0.1573**			

Step 6: Calculate MS (Mean squares)

The formula of MS is as follows

MS = SS ÷ DF

Therefore, MS for each row is calculated as follows.

MS main = SS main ÷ DF main = 0.0253 ÷ 2 = 0.0126

MS residual = SS residual ÷ DF residual = 0.132 ÷ 12 = 0.011

Note: There is no need to find MS total.

Place the MS values in frame.

	DF	SS	MS	F	F-critical
Main effect	2	0.0253	**0.0126**		
Residual	12	0.132	**0.011**		
Total	14	0.1573			

Step 7: Calculate F (F value)

Using the formula, F values for main effect is calculated as follows.

F main = MS main ÷ MS main = 0.0126 ÷ 0.011 = 1.145

Update the table with F values

	DF	SS	MS	F	F-critical
Main effect	2	0.0253	0.0126	**1.145**	
Residual	12	0.132	0.011		
Total	14	0.1573			

Step 8: Calculate F-critical values

Check the critical F values in F table (p=0.05) with calculated **DF**.

F-critical = F 0.05, DF main (F table column), DF residual (F table row)

Therefore,

F-critical main = $F_{0.05,\,2,\,12}$ = 3.89

Update the table (Final table)

	DF	SS	MS	F	F-critical
Main effect	2	0.0253	0.0126	1.145	**3.89**
Residual	12	0.132	0.011		
Total	14	0.1573			

Step 10: Compare F and F-critical then conclusion

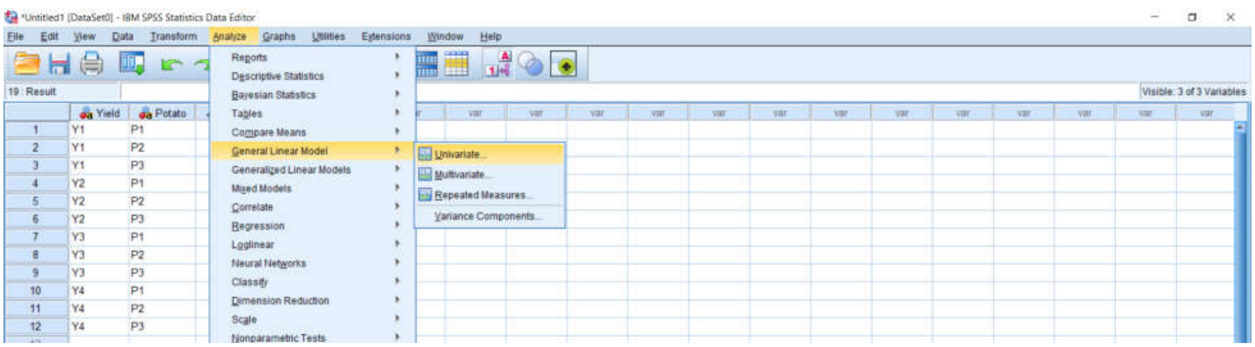
F main < F-critical (H0)

Null hypothesis cannot be rejected. The difference among the mean heights are not significant. The result is not significant at $p < .05$

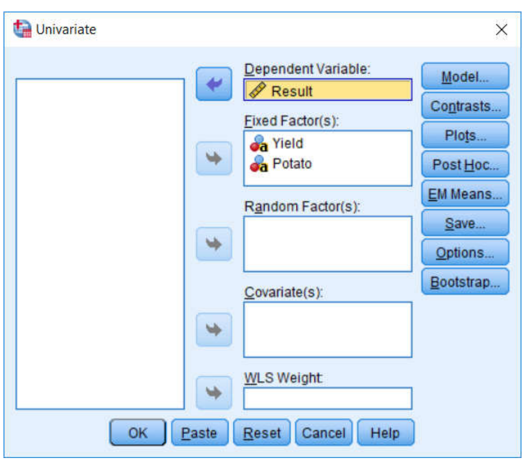
Two-way ANOVA in SPSS

	Yield	Potato	Result
1	Y1	P1	18.00
2	Y1	P2	13.00
3	Y1	P3	12.00
4	Y2	P1	20.00
5	Y2	P2	23.00
6	Y2	P3	21.00
7	Y3	P1	14.00
8	Y3	P2	12.00
9	Y3	P3	9.00
10	Y4	P1	11.00
11	Y4	P2	17.00
12	Y4	P3	10.00

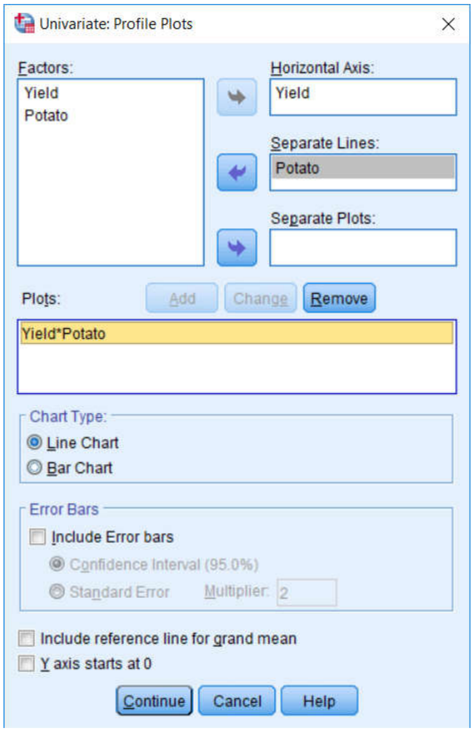
Step 1: Insert data into SPSS data frame



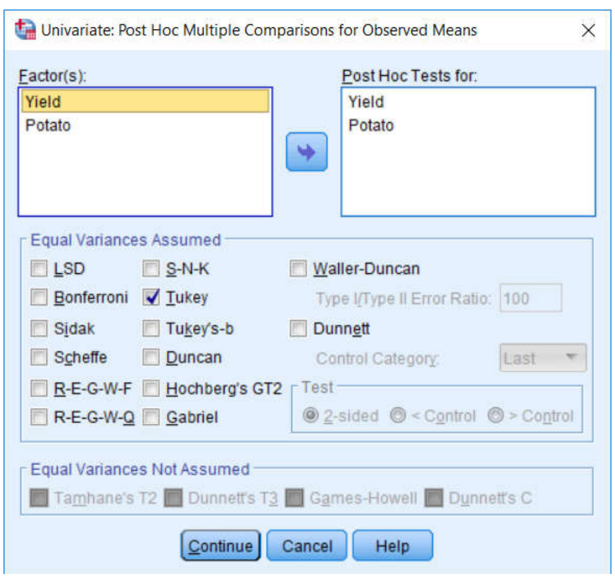
Step 2: Select Analyze → General Linear Model → Univariate



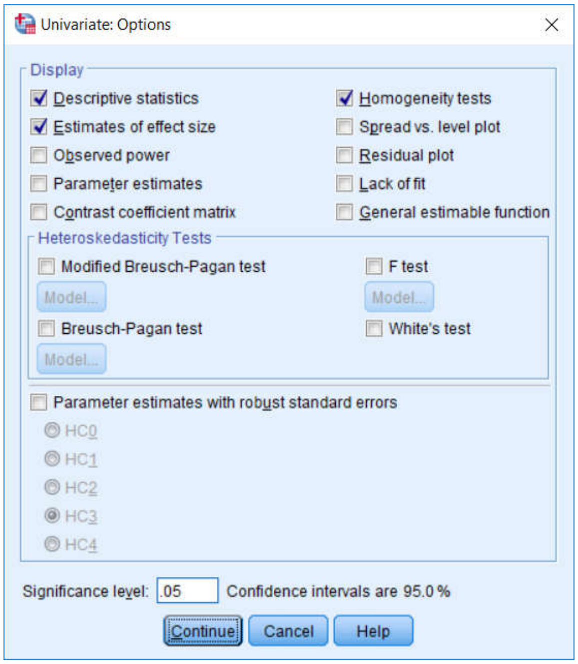
Step 3: Arrange variables into their correct order. Next 3 steps to configure are “Plots”, “Post Hoc”, and “Options” buttons.



Step 4: Click “Plots” button and configure above settings. Click “Add” button and select chart type. Then click “Continue”. This will lead to previous screen.



Step 5: Click “Post Hoc” button and configure above settings. Click “Continue” for next step.

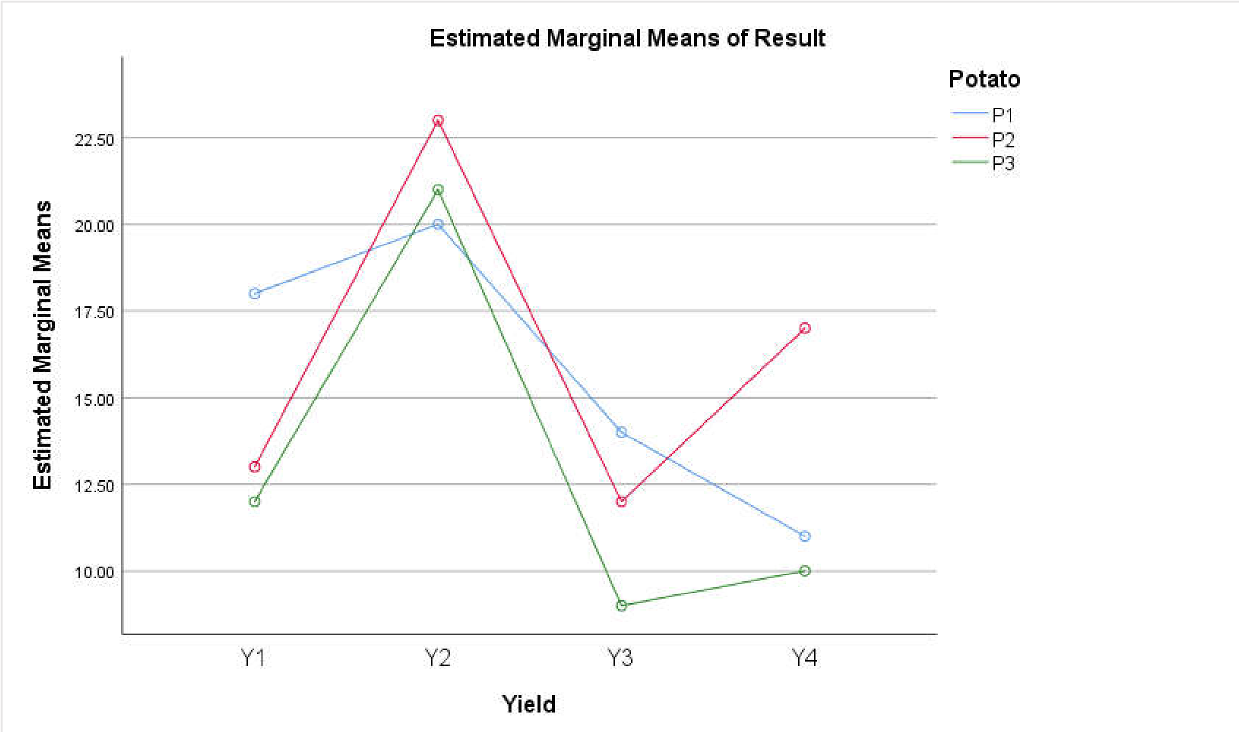


Step 6: Click "Options" and check for above values. Click "Continue" and this will close that form. ANOVA setup is completed and click "OK" to start analysis.

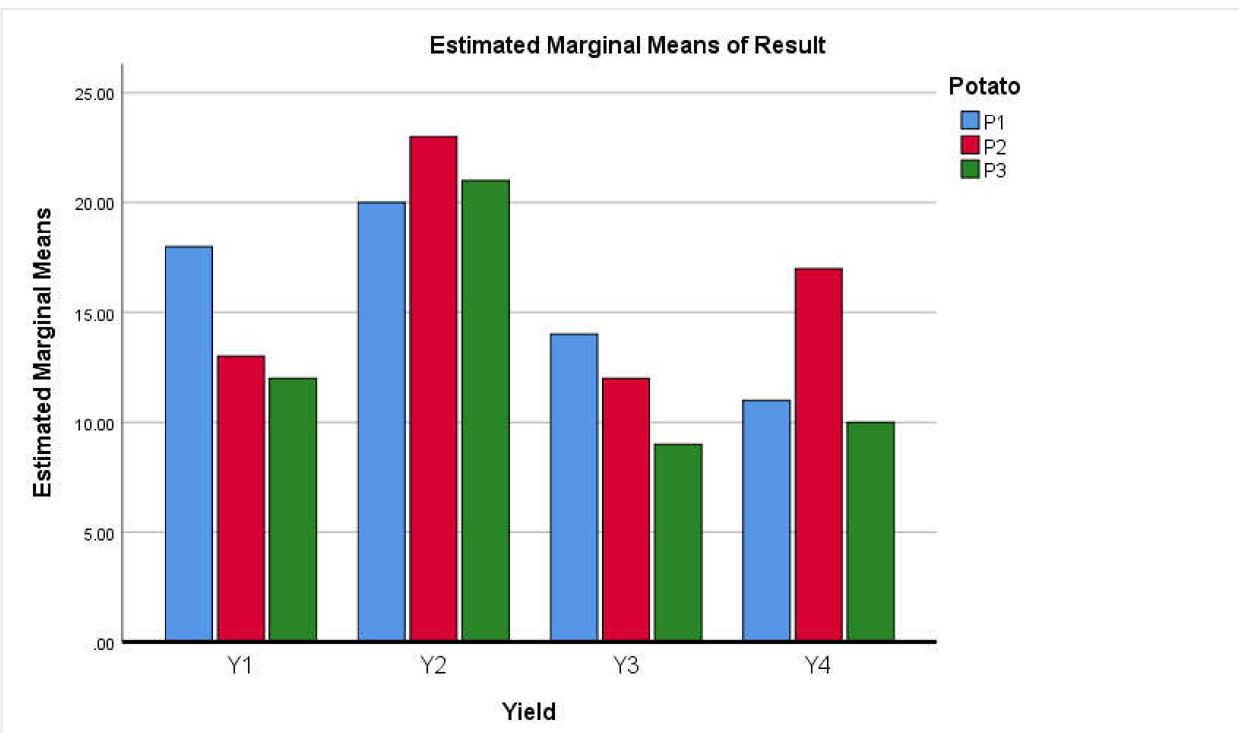
Result

Tests of Between-Subjects Effects						
Dependent Variable:						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	238.000[a]	11	21.636			1.000
Intercept	2700.000	1	2700.000			1.000
Yield	171.333	3	57.111			1.000
Potato	24.500	2	12.250			1.000
Yield * Potato	42.167	6	7.028			1.000
Error	0.000	0				
Total	2938.000	12				
Corrected Total	238.000	11				

a. R Squared = 1.000 (Adjusted R Squared = .)



If you select “Bar Chart” in step 4, the plot will produce like this.

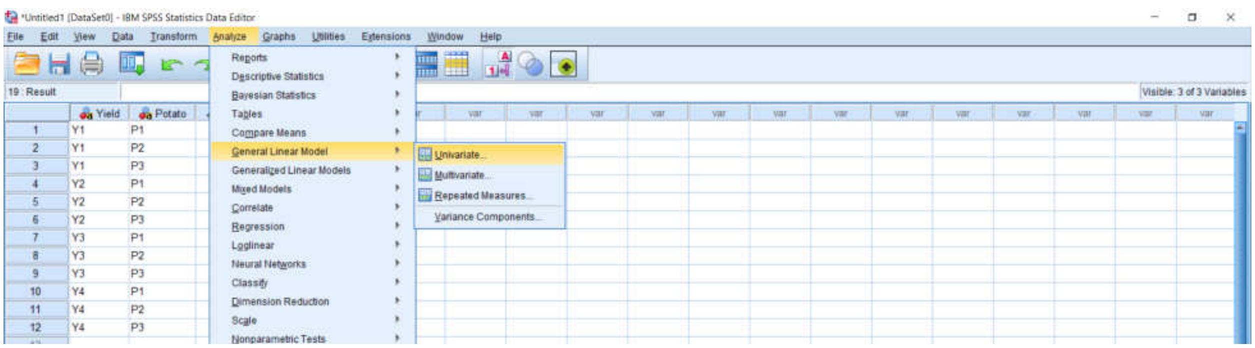


One-way ANOVA in SPSS

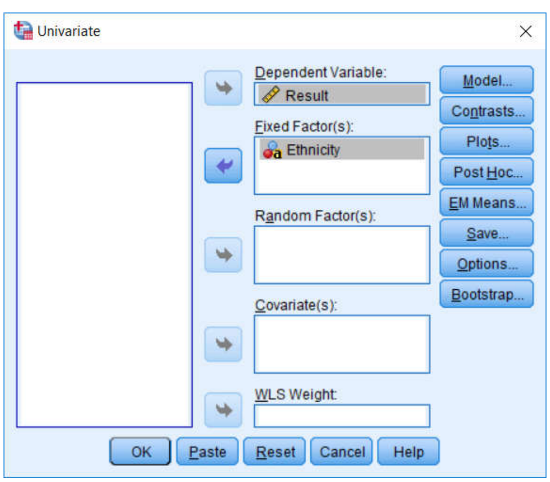
On-way process is same with two-way.

	Ethnicity	Result
1	African	1.7
2	African	1.5
3	African	1.6
4	African	1.6
5	African	1.8
6	Asian	1.5
7	Asian	1.5
8	Asian	1.7
9	Asian	1.7
10	Asian	1.6
11	European	1.6
12	European	1.8
13	European	1.6
14	European	1.7
15	European	1.8

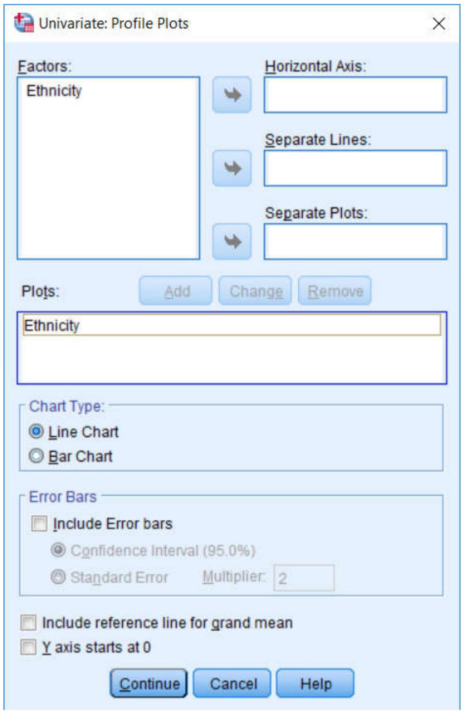
Step 1: Insert data into SPSS data frame



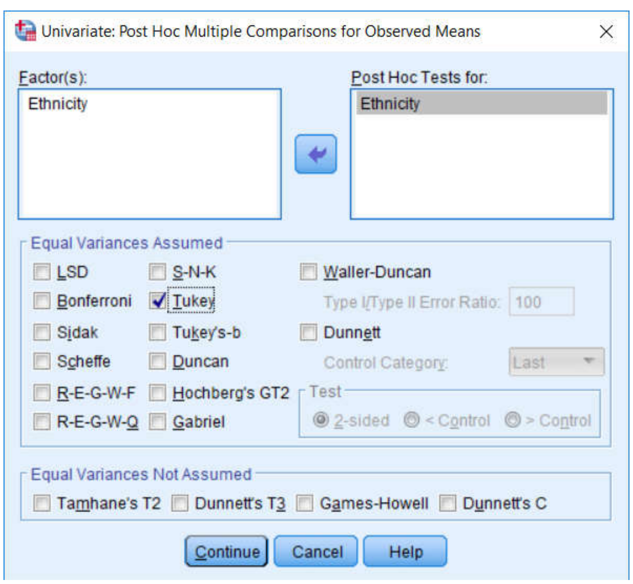
Step 2: Select Analyze → General Linear Model → Univariate



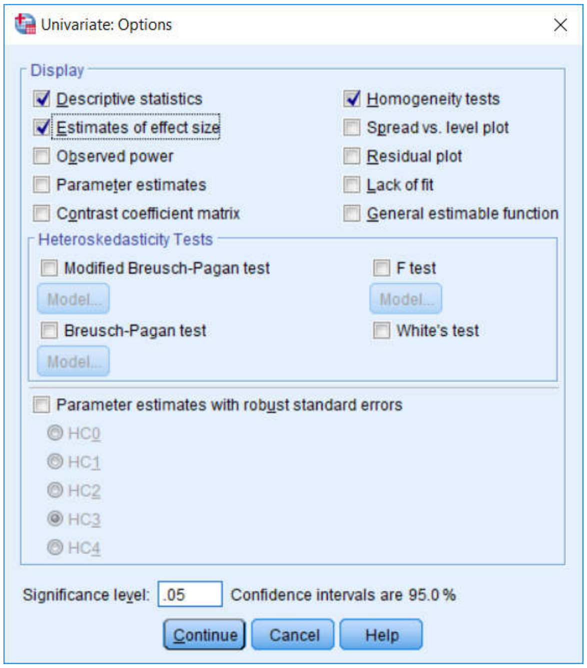
Step 3: Arrange variables into their correct order. Next 3 steps to configure are “Plots”, “Post Hoc”, and “Options” buttons.



Step 4: Click "Plots" button. Drag Ethnicity to Horizontal Axis and click Add. Select chart type then click "Continue". This will lead to previous screen.



Step 5: Click "Post Hoc" button and configure above settings. Click "Continue" for next step.



Step 6: Click "Options" and check for above values. Click "Continue" and this will close that form. ANOVA setup is completed and click "OK" to start analysis.

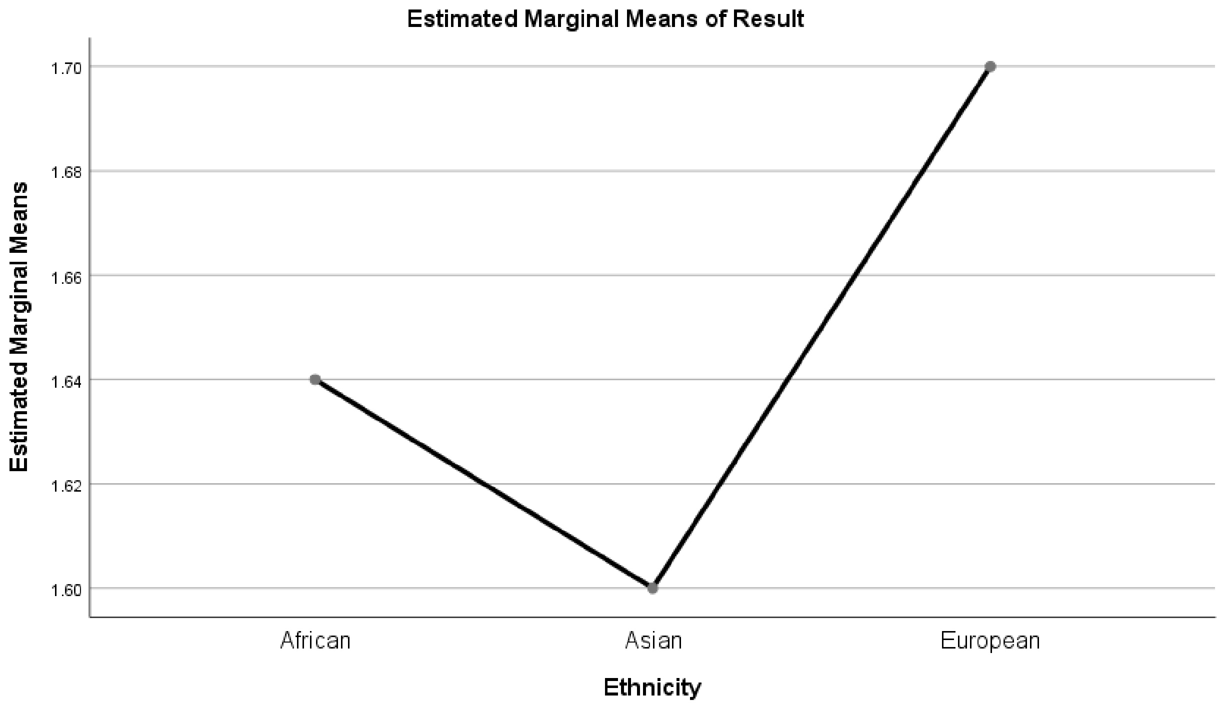
Result

Tests of Between-Subjects Effects

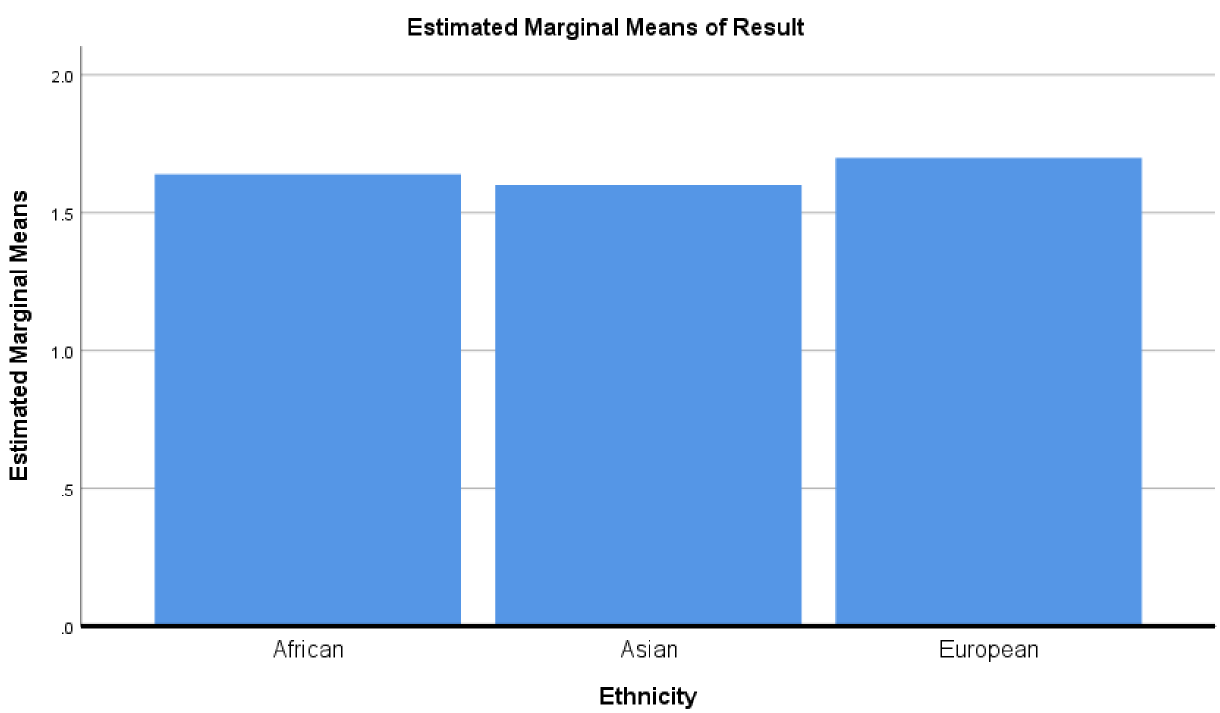
Dependent Variable:

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	.025[a]	2	0.013	1.152	0.349	0.161
Intercept	40.673	1	40.673	3697.515	0.000	0.997
Ethnicity	0.025	2	0.013	1.152	0.349	0.161
Error	0.132	12	0.011			
Total	40.830	15				
Corrected Total	0.157	14				

a. R Squared = .161 (Adjusted R Squared = .021)


Estimated Marginal Means of Result
Estimated Marginal Means
1.70
1.68
1.66
1.64
1.62
1.60
African
Asian
European
Ethnicity

Bar chart


Estimated Marginal Means of Result
Estimated Marginal Means
2.0
1.5
1.0
.5
.0
African
Asian
European
Ethnicity

Two-way ANOVA in SAS

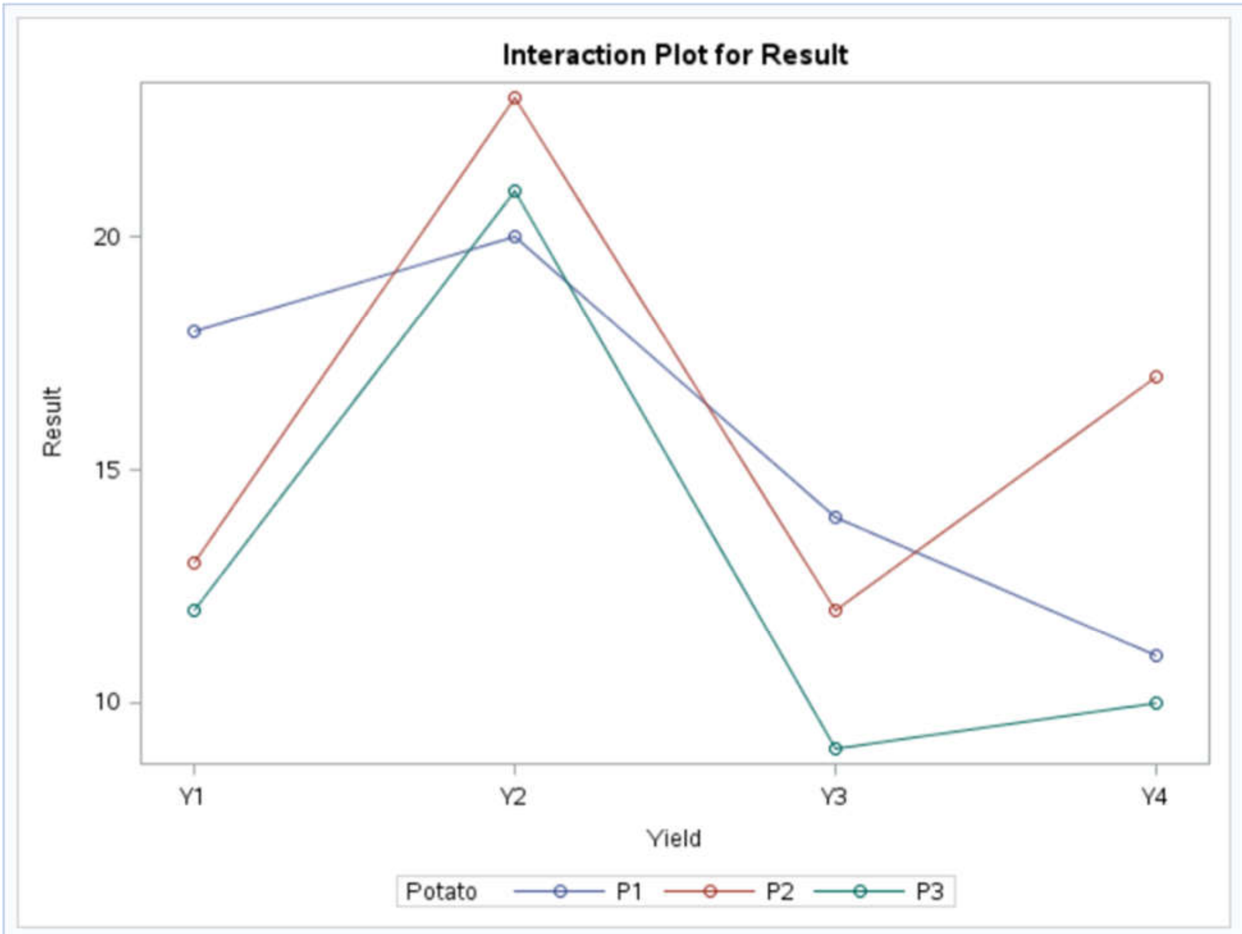
SAS supports GUI setup for two-way ANOVA. Example codes are shown below.

```
DATA Potato;
INPUT Yield$ Potato$ Result;
DATALINES;
Y1 P1 18
Y1 P2 13
Y1 P3 12
Y2 P1 20
Y2 P2 23
Y2 P3 21
Y3 P1 14
Y3 P2 12
Y3 P3 9
Y4 P1 11
Y4 P2 17
Y4 P3 10
;
RUN;
PROC PRINT DATA=Potato;
RUN;
```

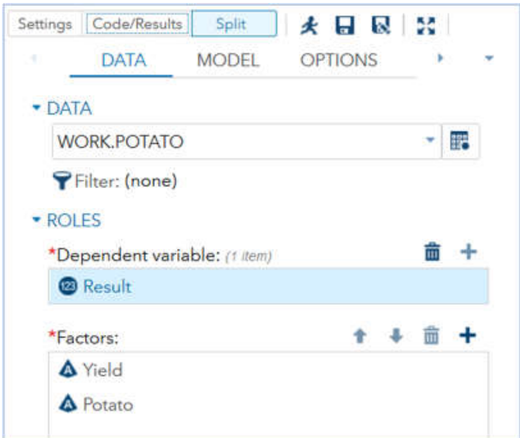
Obs	Yield	Potato	Result
1	Y1	P1	18
2	Y1	P2	13
3	Y1	P3	12
4	Y2	P1	20
5	Y2	P2	23
6	Y2	P3	21
7	Y3	P1	14
8	Y3	P2	12
9	Y3	P3	9
10	Y4	P1	11
11	Y4	P2	17
12	Y4	P3	10

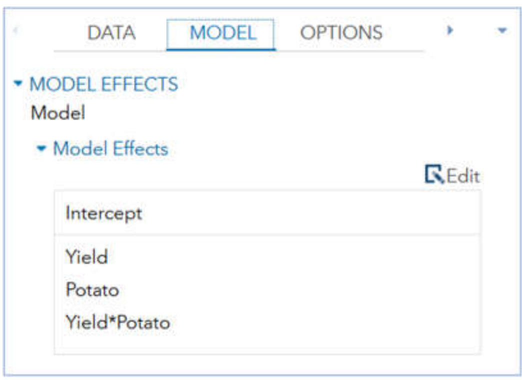
```
proc glm data=WORK.POTATO plot(only)=(intplot);
    class Yield Potato;
    model Result=Yield Potato Yield*Potato / ss3;
    lsmeans Yield Potato / adjust=tukey pdiff=all alpha=0.05 cl plots=();
quit;
```

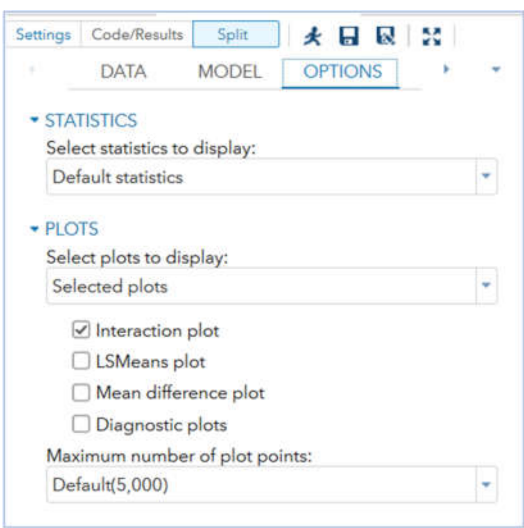
Source	DF	Type III SS	Mean Square	F Value	Pr > F
Yield	3	171.3333333	57.1111111	.	.
Potato	2	24.5000000	12.2500000	.	.
Yield*Potato	6	42.1666667	7.0277778	.	.


Interaction Plot for Result
Result
20
15
10
Y1
Y2
Y3
Y4
Yield
Potato
P1
P2
P3

SAS setup


Settings
Code/Results
Split
DATA
MODEL
OPTIONS
DATA
WORK.POTATO
Filter: (none)
ROLES
*Dependent variable: (1 item)
Result
*Factors:
Yield
Potato


DATA
MODEL
OPTIONS
MODEL EFFECTS
Model
Model Effects
Edit
Intercept
Yield
Potato
Yield*Potato


Settings
Code/Results
Split
DATA
MODEL
OPTIONS
STATISTICS
Select statistics to display:
Default statistics
PLOTS
Select plots to display:
Selected plots
Interaction plot
LSMeans plot
Mean difference plot
Diagnostic plots
Maximum number of plot points:
Default(5,000)

One-way ANOVA in SAS

SAS supports GUI setup for one-way ANOVA. Example codes are shown below.

```
data Ethnicity;
input Nationality$ Height;
datalines;
African 1.7
African 1.5
African 1.6
African 1.6
African 1.8
Asian 1.5
Asian 1.5
Asian 1.7
Asian 1.7
Asian 1.6
European 1.6
European 1.8
European 1.6
European 1.7
European 1.8
;
run;
proc print data=Ethnicity;
run;
```

Obs	Nationality	Height
1	African	1.7
2	African	1.5
3	African	1.6
4	African	1.6
5	African	1.8
6	Asian	1.5
7	Asian	1.5
8	Asian	1.7
9	Asian	1.7
10	Asian	1.6
11	European	1.6
12	European	1.8
13	European	1.6
14	European	1.7
15	European	1.8

```
Title 'ONE-WAY ANOVA';
ods noproctitle;
ods graphics / imagemap=on;

proc glm data=WORK.ETHNICITY plots(only);
    class Nationality;
    model Height=Nationality;
    means Nationality / welch plots=none;
    lsmeans Nationality / adjust=tukey pdiff alpha=.05 plots=(diffplot);
    run;
quit;
```

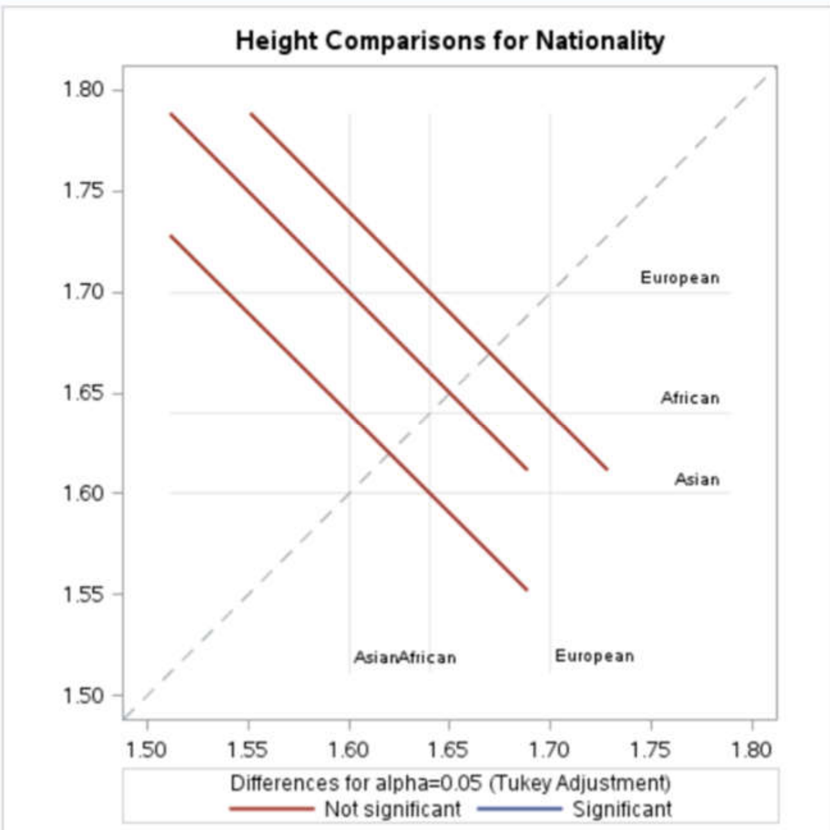
Dependent Variable: Height

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.02533333	0.01266667	1.15	0.3488
Error	12	0.13200000	0.01100000		
Corrected Total	14	0.15733333			

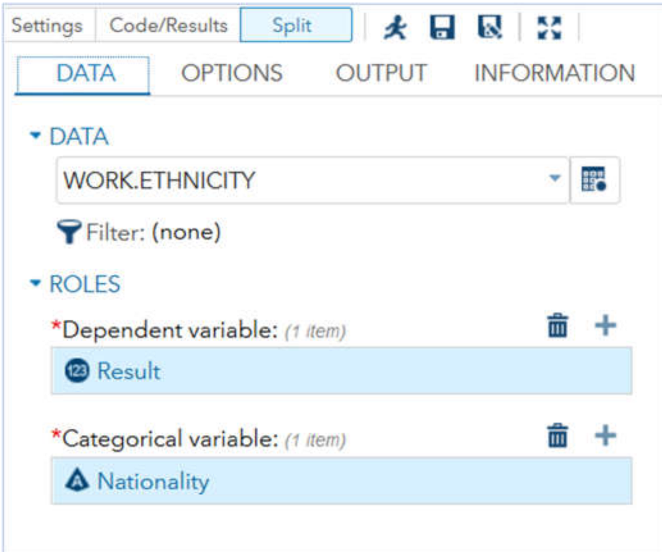
R-Square	Coeff Var	Root MSE	Height Mean
0.161017	6.369285	0.104881	1.646667

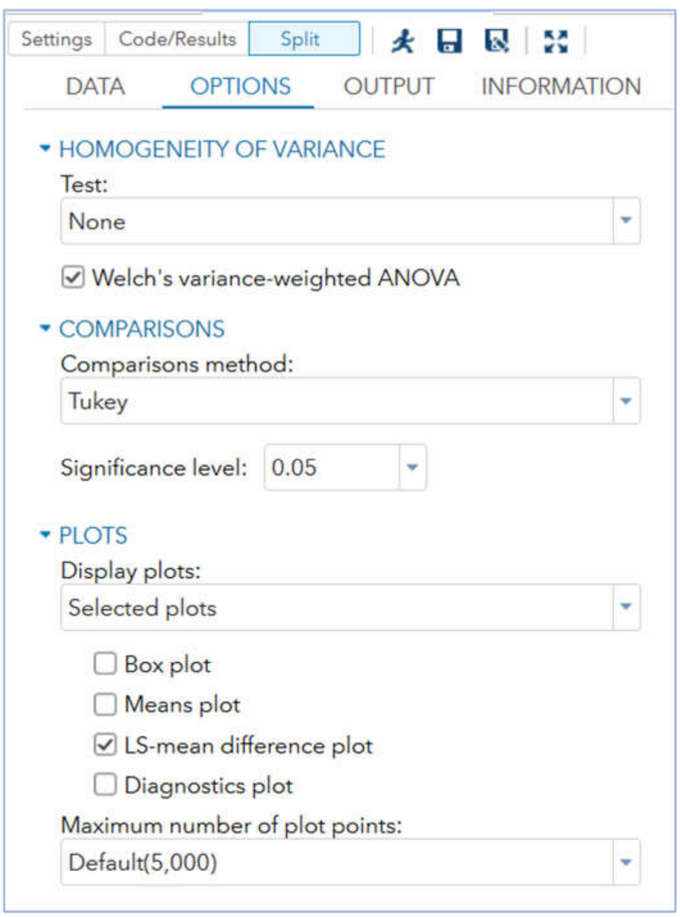
Source	DF	Type I SS	Mean Square	F Value	Pr > F
Nationality	2	0.02533333	0.01266667	1.15	0.3488

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Nationality	2	0.02533333	0.01266667	1.15	0.3488



SAS setup


Settings
Code/Results
Split
DATA
OPTIONS
OUTPUT
INFORMATION
DATA
WORK.ETHNICITY
Filter: (none)
ROLES
*Dependent variable: (1 item)
Result
*Categorical variable: (1 item)
Nationality


Settings
Code/Results
Split
DATA
OPTIONS
OUTPUT
INFORMATION
HOMOGENEITY OF VARIANCE
Test:
None
Welch's variance-weighted ANOVA
COMPARISONS
Comparisons method:
Tukey
Significance level:
0.05
PLOTS
Display plots:
Selected plots
Box plot
Means plot
LS-mean difference plot
Diagnostics plot
Maximum number of plot points:
Default(5,000)

Datasets

Data table for two-way ANOVA

Yield	Potato	Result
Y1	P1	18
Y1	P2	13
Y1	P3	12
Y2	P1	20
Y2	P2	23
Y2	P3	21
Y3	P1	14
Y3	P2	12
Y3	P3	9
Y4	P1	11
Y4	P2	17
Y4	P3	10

Data table for one-way ANOVA

Ethnicity	Height
African	1.7
African	1.5
African	1.6
African	1.6
African	1.8
Asian	1.5
Asian	1.5
Asian	1.7
Asian	1.7
Asian	1.6
European	1.6
European	1.8
European	1.6
European	1.7
European	1.8

Reference websites

[1]: https://statistics.laerd.com/spss-tutorials/two-way-anova-using-spss-statistics.php

[2]: https://people.richland.edu/james/lecture/m170/ch13-2wy.html

[3]: https://www.socscistatistics.com/pvalues/fdistribution.aspx

[4]: https://www.spss-tutorials.com/spss-two-way-anova-basics-tutorial/

[5]: http://vassarstats.net/anova1u.html

[6]: http://vassarstats.net/anova2u.html

[7]: https://people.richland.edu/james/lecture/m170/ch13-1wy.html

PROFILE

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