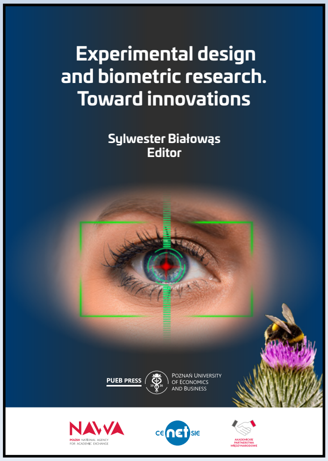

Experimental design and biometric research. Toward innovations

Sylwester Białowąs
Editor

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2.

INDEPENDENT SAMPLES— MORE HYPOTHESES TESTING

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Abstract: Two-way analysis of variance (ANOVA) without replication is called a factorial ANOVA with two factors. It is used to test if there is a significant difference between means of several sets of data (groups) dependable on two independent factors. It is applied when we have one measurement variable and two nominal variables (usually called 'factors' or 'main effects'). In this chapter hypotheses and assumptions of the method are given. Then the example of the procedure of two-way analysis of variance (ANOVA) without replication is described in details. The two-way analysis of variance (ANOVA) with replication is utilized to simultaneously test the effects of varying two variables for a sample which consists of more than one respondent per a certain combination of variables. The example of the procedure of two-way analysis of variance (ANOVA) with replication is described in details in this chapter. For both procedures the easy to follow examples shows the procedure step-by-step. The practical part includes the guidance for SPSS and for Excel.

Keywords: analysis of variance, ANOVA, two-way analysis of variance without replication, two-way analysis of variance with replication.

2.1. Two-way analysis of variance (ANOVA) without replication

General information

Two-way analysis of variance (ANOVA) without replication is used to determine if there is a significant difference between means of several subpopulations (groups) dependable on two independent factors (Balakirshnan, Render, & Stair, 2007; Fraser, 2016; Randolph & Myers, 2013). In other words, a two-way ANOVA (also called factorial ANOVA, with two factors) is applied when we have one measurement variable and two nominal variables (usually called 'factors' or 'main effects'). For instance, we could apply ANOVA with two factors without replication when explaining differences of revenue generation in different stores for different seasons where store would be one factor and particular season other factor by which we test differences in revenue generation. Or we can apply ANOVA without replication when we want to test in-field results of promotional activities of various sales representatives and various location where activities are applied (in this case representatives are one factor, locations are second factor and results or effect of promotion is variable which is tested for differences according to those two factors).

Hypothesis

In two-way ANOVA without replication, there is a single observation for each combination of the nominal variables, therefore we have only two null hypotheses:

H0(1): There is no difference between means of observations grouped by one factor.

H0(2): There is no difference between means of observations grouped by other factor.

In two-way ANOVA without replication we assume that there is no interaction between factors.

Assumptions

There are the following assumptions associated with the two-way ANOVA without replication (Dean & Ilowsky, 2013; Field, 2013; Winston, 2016):

- dependent variable—should be continuous;
- two independent variables (factors)—should be in two or more categorical, independent groups;
- each sample has to be drawn independently of the other samples (the samples are disjoint);
- the variance of data in the different groups should homogenous;

– each sample should be taken from a normally distributed population;
– there is no dependence or interaction between factors;
– there are no significant outliers.

Example
Dataset: In Retail Company Tradex we collected data on value of expired or spoiled merchandize in EUR per week. Now we want to analyze if this value varies according to sales region and according to product categories.

Data info:
– variable 1: product category—nominal (1—Fruits and vegetables, 2—Diaries, 3—Meat);
– variable 2: sales region – nominal (1—East, 2—West, 3—North, 4—South);
– variable 3: value of expired or spoiled merchandize in EUR per week—numeric.

Hypotheses:
H0(1): There is no difference between means of value of expired or spoiled merchandize grouped by product category.
H1(1): There is a difference between means of value of expired or spoiled merchandize grouped by product category.

H0(2): There is no difference between means of value of expired or spoiled merchandize grouped by sales region.
H1(2): There is a difference between means of value of expired or spoiled merchandize grouped by sales region.

Testing the hypotheses in SPSS
In our example, we observed value of expired or spoiled merchandize in EUR per week in a particular sales region and in particular product categories. In Table 1, dataset is shown.

Table 1. Dataset for two-way ANOVA without replication

	1—Region East	2—Region West	3—Region North	4—Region South
1—Fruits and vegetables	130	150	280	140
2—Diaries	250	320	330	230
3—Meat	120	130	250	180

Source: The authors' own elaboration.

For analysis in SPSS we will form three variables "Type", "Region" and "FW", then we will proceed to enter data. In the first row (see Figure 1, Row 1) we will enter 1, 1, 130 (meaning: 1—Fruit and vegetables, 1—Region East, 130 EUR of expired and spoiled merchandize per week). Then we will proceed to enter 1, 2, 150 (see Figure 1, row 2) for Fruits and vegetables in Region West—value 150 EUR.

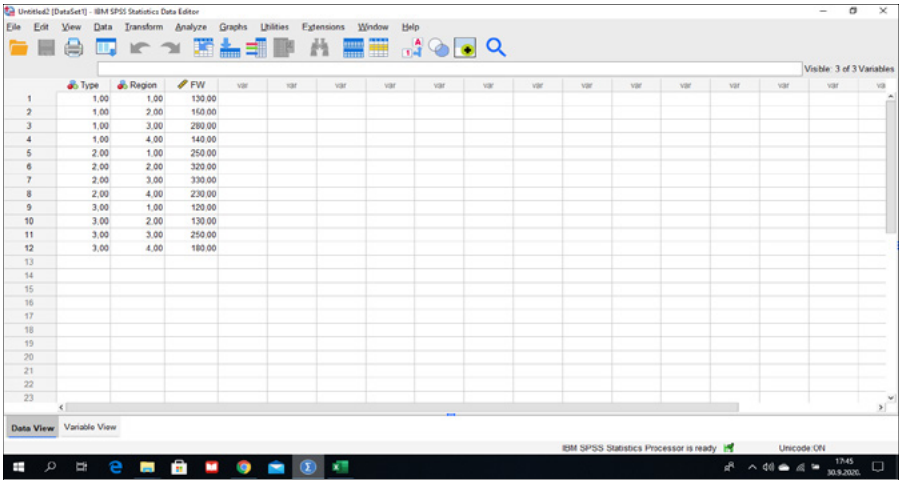


Figure 1. Dataset prepared for two-way ANOVA without replication analysis in SPSS

Source: The authors' own elaboration.

When all data is entered, we will choose type of analysis (see Figure 2). For two-way ANOVA without replication, we will select General Linear Model, Univariate option and then we will specify further options.

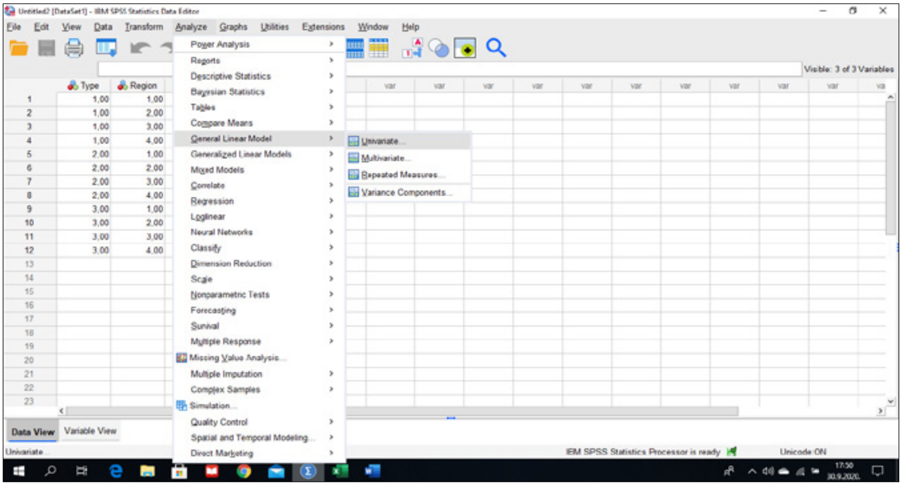


Figure 2. Choosing type of analysis—General Linear Model—Univariate

Source: The authors' own elaboration.

Firstly, we will have to set variables as shown in Figure 3. Our dependent variable is "FW" and our Fixed Factors are "Type" and "Region".

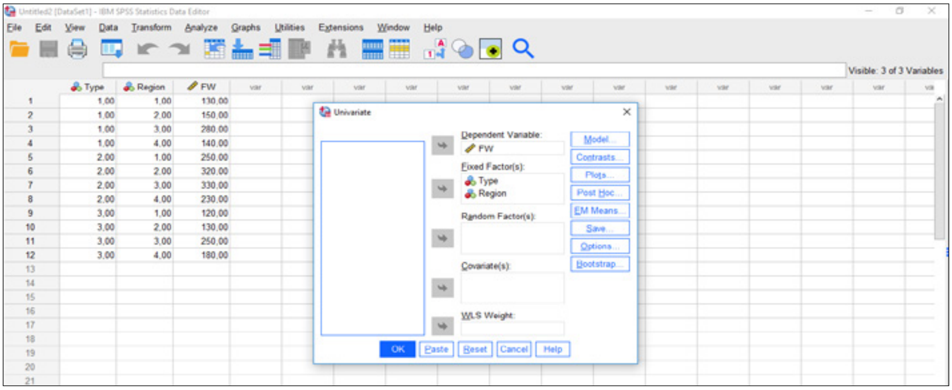


Figure 3. Setting options for analysis—variable specification

Source: The authors' own elaboration.

Secondly, we have to customize type of analysis. Therefore, we will have to specify our model. Therefore we select option "Model". We will use option "Build terms" and we will observe "Main effects" (see the central part of the screen at Figure 4). Moreover, by using arrow at the middle of the screen we have to transfer our factors from column "Factors & Covariates" to column "Model" (see right part of Figure 4). Then we will click to "Continue" and by clicking on "OK" at the previous screen, we will perform our analysis.

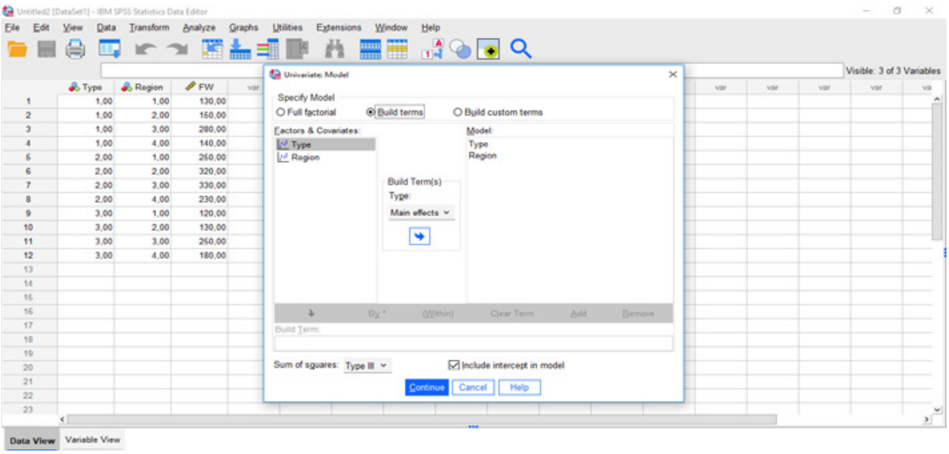
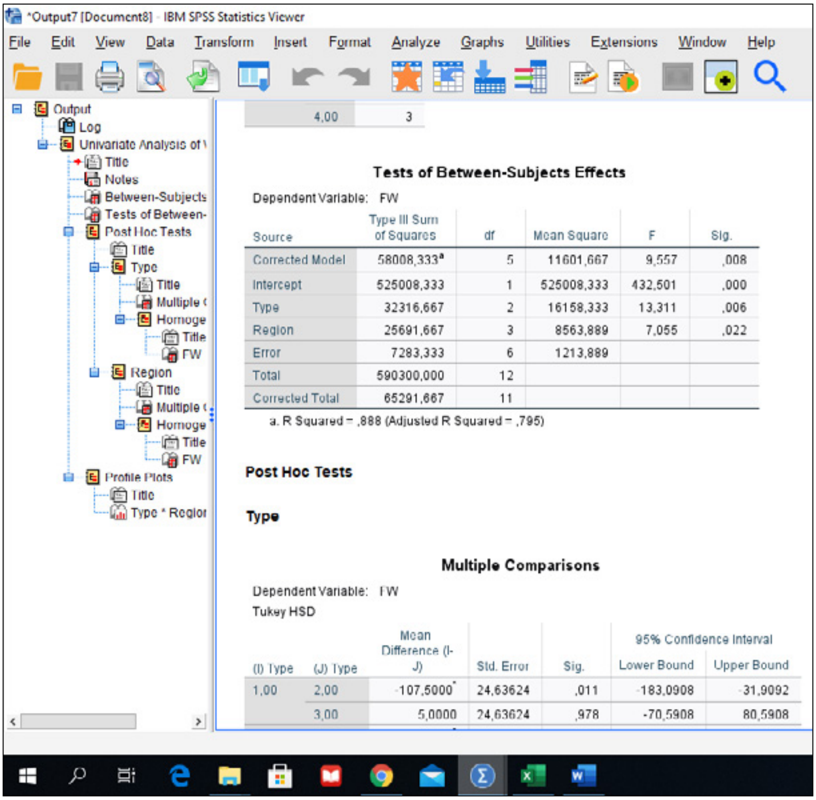


Figure 4. Setting options—Specify Model—customization of analysis

Source: The authors' own elaboration.

In Figure 5 results of analysis are shown. For quick interpretation, we will pay attention to the column "Sig." and we will search for value lower than .05 in order to not reject or reject our hypotheses. At the factor Type the significance value is .006 whereas at the factor Region the significance value is .022. Because both significance values are lower than .05, we can reject H0 hypotheses for both factors (Type and Region).



Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	58008,333a	5	11601,667	9,557	,008
Intercept	525008,333	1	525008,333	432,501	,000
Type	32316,667	2	16158,333	13,311	,006
Region	25691,667	3	8563,889	7,055	,022
Error	7283,333	6	1213,889		
Total	590300,000	12			
Corrected Total	65291,667	11			

(I) Type	(J) Type	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
1,00	2,00	-107,5000*	24,63624	,011	-183,0908	-31,9092
	3,00	5,0000	24,63624	,978	-70,5908	80,5908

Figure 5. Result of two-way ANOVA without replication analysis in SPSS

Source: The authors' own elaboration.

Based on this we conclude that we can conclude that there is the difference between means of value of expired or spoiled merchandize grouped by product category and that there is difference between means of value of expired or spoiled merchandize grouped by sales region.

Testing the hypotheses in Excel

Same dataset is entered to Excel. In Figure 6 collected data is shown in format suitable for analysis in Excel.

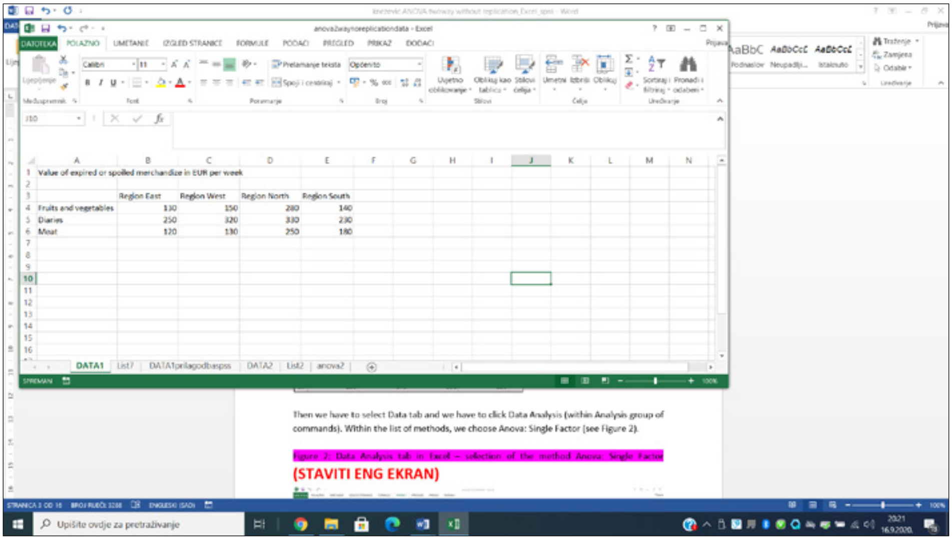


Figure 6. Dataset for two-way ANOVA (without replication) analysis in Excel

Source: The authors' own elaboration.

Then we have to select Data tab and we have to click Data Analysis (within Analysis group of commands). Within the list of methods, we choose ANOVA: two factor without replication (see Figure 7).

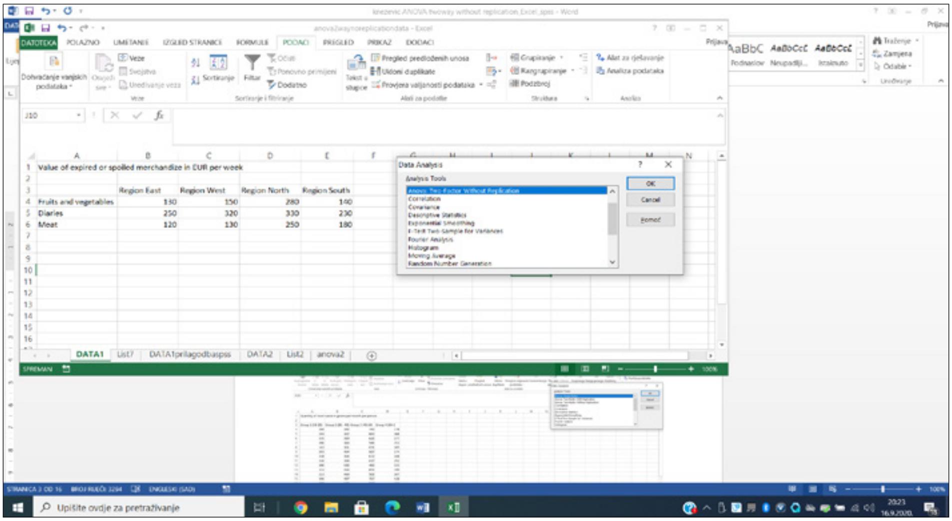


Figure 7. Data Analysis tab in Excel—selection of the method ANOVA: two-factor without replication

Source: The authors' own elaboration.

In the dialog box of ANOVA: two-factor without replication we have to configure as follows (see Figure 8):

– input range of the dataset including labels, in our example it is A3:E6;
– check existence of data labels (see Labels);
– output range, we can choose to show data at some position at the active Worksheet, then we have to specify exact cell from which our results are going to be presented (such as F3); but in our case we rather specified New Worksheet as the location of our results, also we can specify a name for our output (in our example "ANOVA");
– the last thing is the level of significance, i.e. alpha value. There we can use default value as it is already set to .05.

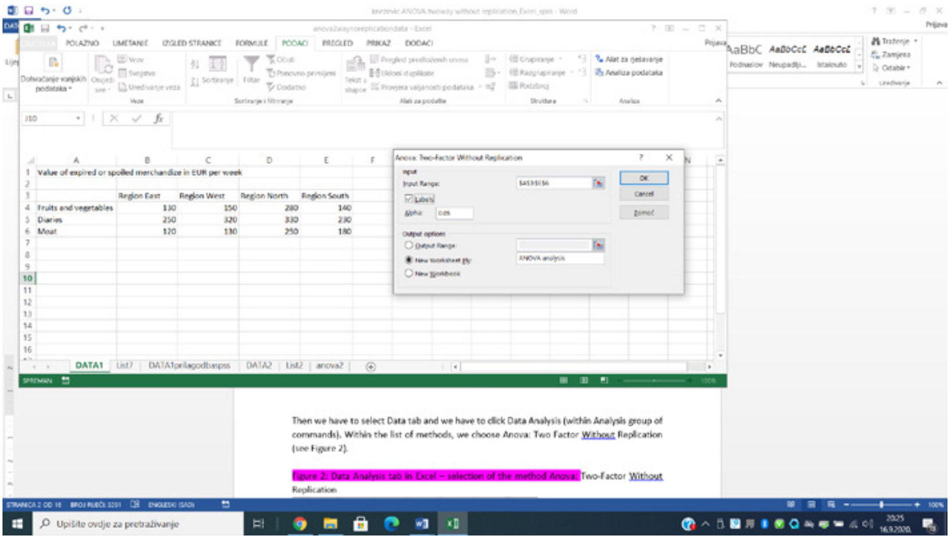


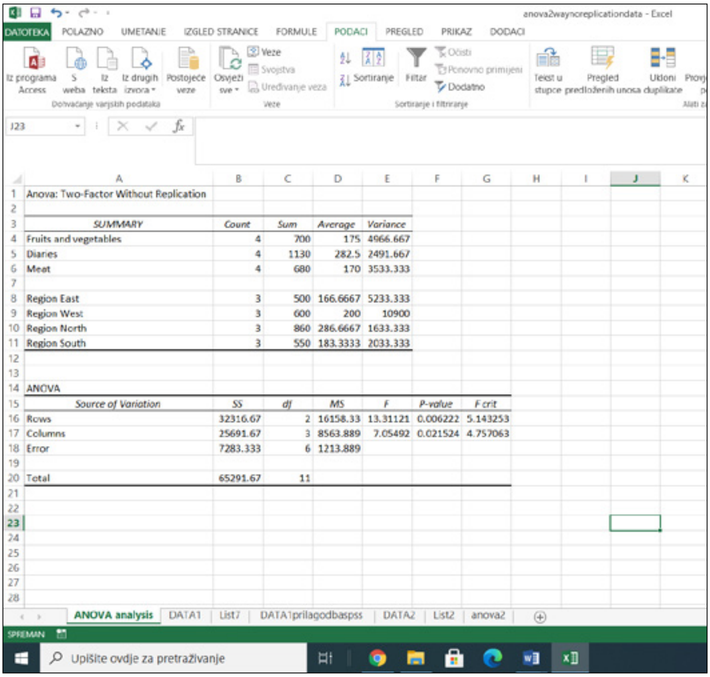
Figure 8. Dialog box ANOVA: two-factor without replication

Source: The authors' own elaboration.

In Figure 9 results of data analysis is shown and we can interpret our results. First of all, we have basic descriptive statistical data grouped by both factors. From this part we can read how many observations we had in which group (see column Number), then we can see what the average value of expired or spoiled merchandize in EUR per week in each group is, and what the variance within each group is. For instance, when we observe product categories, the lowest average of 170 EUR is expired or spoiled in Meat category and if we observe regions, the lowest average value of spoiled or expired merchandize is in region East and it is 166.6667 EUR.

In addition, ANOVA results are shown. In this table, the most important reading is p-value because by it we can decide not to reject or to reject the null hypothesis. In our case the *p*-value for rows .006222 (remember, in our dataset product categories are entered to Excel, see Figure 1). In this case *p*-value is lower than *alpha* value of .05 and it means that we can reject the null hypothesis H0(1) and we can conclude that there is difference between means of value of expired or spoiled merchandize grouped by product category. So, this difference is statistically significant at the level of .05.

In addition, we can observe that in our case the *p*-value for columns (in our case, Regions) is .021524 which is lower than .05. Therefore, we can reject the null hypothesis H0(2), and we can conclude that there is difference between means of value of expired or spoiled merchandize grouped by sales region. So, the test results have shown that this difference is statistically significant at the level of .05.



Anova: Two-Factor Without Replication

SUMMARY	Count	Sum	Average	Variance
Fruits and vegetables	4	700	175	4966.667
Diaries	4	1130	282.5	2491.667
Meat	4	680	170	3533.333
Region East	3	500	166.6667	5233.333
Region West	3	600	200	10900
Region North	3	860	286.6667	1633.333
Region South	3	550	183.3333	2033.333

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	32316.67	2	16158.33	13.31121	0.006222	5.143253
Columns	25691.67	3	8563.889	7.05492	0.021524	4.757063
Error	7283.333	6	1213.889			
Total	65291.67	11				

Figure 9. Two-way ANOVA without replication results

Source: The authors' own elaboration.

If ANOVA shows us that there is a statistically significant difference between observed groups, we have to do post hoc analysis by comparing pair of groups in order to explain which group differs in comparison to other group. For this purpose in Excel we can perform several *t*-tests. Procedure of *t*-tests is already explained in details in chapter about one-way ANOVA.

Summary of the example

Dataset: The value of expired or spoiled merchandize in EUR per week in different sales regions is observed. In addition, the value of expired or spoiled merchandize in EUR per week is observed according to the product category as well. For the purpose of the analysis four sales regions and three product categories are defined. For each combination of a sales region and a product category the value of expired or spoiled merchandize in EUR per week is collected. On that way, 12 data values of expired or spoiled merchandize in EUR per week were on disposal for our analysis needs.

Data info:
- variable 1: product category—nominal (1—Fruits and vegetables, 2—Diaries, 3—Meat);
- variable 2: sales region—nominal (1—East, 2—West, 3—North, 4—South);
- variable 3: value of expired or spoiled merchandize in EUR per week—numeric.

The two-way ANOVA approach was used to inspect whether the average value of expired or spoiled merchandize grouped by product category can be considered the same across all three product categories. Also, in the same time, the two-way ANOVA approach was used to inspect whether the average value of expired or spoiled merchandize grouped by sales categories can be considered the same across all four sales categories. The results of the two-way ANOVA have shown that there was a statistically significant difference between product categories groups ($F(2,6) = 13.311$, $p = .0062$). On the other side, the results of the two-way ANOVA have also shown that there was a statistically significant difference between sales region groups ($F(3,6) = 7.055$, $p = .0215$).

More info about two-way ANOVA without replication

The two-way ANOVA without replication can be observed as an extension of the one-way ANOVA. Whereas at the one-way analysis just one factor is observed, here at two-way ANOVA without replication two factors are inspected in the same time. Despite the fact that the two-way ANOVA without replication analysis is more complex than the one-way ANOVA they are sharing the same assumptions with additional assumption that there is no dependence or interaction between factors (Barrow, 2017; Randolph & Myers, 2013).

In the analysis, at both observed factors statistically significant differences are found. However, we do not know whether all means between all three product categories or all means between all four sales regions are different or the difference is statistically significant just between some groups. In order to find out that, in the following step in the analysis Tukey post hoc tests can be conducted to observe differences between pairs of categories at given factors. The Tukey post hoc tests procedure and interpretations are analogous to those explained at the one-way ANOVA.

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2.2. Two-way analysis of variance (ANOVA) with replication

General information

The two-way analysis of variance (ANOVA) with replication simultaneously tests the effects of varying two variables (such as gender and age or wealth and geographic area, and their interaction) for a sample which consists of more than one respondent per a certain combination of variables. While in two-factor ANOVA without replication there was only one sample item (observation) for each combination of factors.

Replication refers to the number of cases observed within the same combination of factors (Field, 2013; Fraser, 2016; Winston, 2016). Usually, we use this method in a case of a balanced research design when the size of each subgroup according to two factor is equal. Because then, we can calculate the mean square for each of the two factors, for their interaction, and for each combination of factors.

Hypotheses

In two-way ANOVA with replication, there are more than one observation for each combination of the nominal variables, therefore it is possible to examine interaction between factors as well. So, we will have three null-hypotheses:

H0(1): There is no difference between means of observations grouped by one factor.

H0(2): There is no difference between means of observations grouped by other factor.

H0(3): There is no interaction between factors.

The alternative hypothesis to every above stated is its negation.

The interaction test shows us if the effects of one factor depend on the other factor (Balakirshnan et al., 2007; Dean & Illowsky, 2013).

Assumptions

There are the following assumptions associated with the two-way ANOVA with replication (Barrow, 2017; Field, 2013; Randolph & Myers, 2016):

- dependent variable is continuous;
- two independent variables should consist of at least two or more categorical, independent groups;
- dependent variable should be approximately normally distributed for each combination of independent variables;
- independence of observations, i.e. no relationship between the observations in each group or between the groups;
- no significant outliers because they can have a negative effect on the two-way ANOVA results;
- homogeneity of variances for each combination of the groups of the two independent variables.

Example

Situation: Recently we finished our series of seminars in area of Sustainable consumption and Social responsibility in our local community center. So, we want to test effects of this education in real-life environment. We had 3 educations on various topics which included topics on Eco-friendly products and Fair trade. Therefore, together with the owner of the local supermarket we are collecting data on consumer will to purchase sustainable products in everyday life. We want to test is our education effective or not.

Dataset: observed number of products in a shopping cart at the checkout in a local supermarket according to product labels, number of educations taken (no education, one education, two educations or three educations). For each out of 4 levels of education we collect same number of observations (5), i.e. we have same number of respondents (5). Sample consisted of 20 respondents. For each respondent we count number of products in a shopping cart according to 3 types of product labels.

Data info:
- variable 1: number of educations taken—nominal (1—No education, 2—One education, 3—Two educations, 4—Three educations);
- variable 2: label of product—nominal (1—Eco-friendly, 2—Fair trade, 3—No label);
- variable 3: number of items (products) in the shopping cart—numerical.

Hypotheses:

H0(1): There is no difference between means of number of items in shopping cart grouped by number of educations taken.

H1(1): There is a difference between means of number of items in shopping cart grouped by number of educations taken.

H0(2): There is no difference between means of number of items in shopping cart grouped by label of products.

H1(2): There is a difference between means of means of number of items in shopping cart grouped by label of product.

H0(3): There is no interaction between factors.
H1(3): There is interaction between factors.

Testing the hypotheses in SPSS

In our example we observed how many items (product) labeled with labels in field of sustainable business some customer had and we observed how many educations in our local community this person attended in the field of sustainability and social responsibility, then we entered data into SPSS (see Figure 10). For instance, in the first row we have recorded data for respondent who did not attended seminars (see column "Education" where 1 means No education), and this person had only 2 items (see "Numberofitems" column where we recorded quantity 2) labeled as Eco-friendly products (see column "Label" where 1 meaning Eco-friendly is entered). For the same respondent we recorded 1, 2, 3—see row 6 at Figure 10 (as he/she did not attend education (1), and had 3 items labeled as 2—Fair trade) and we concluded entering data on contents of his/her shopping cart by entering 1, 3, 7—see row 11 at Figure 10 (as he/she did not attend education (1), and had 7 items without any label in field of sustainability, 3 is entered for No label in column "Label"). Then we entered data for all other respondents and items in their shopping carts.

As there were five respondents from each group according to 4 education levels, and for each respondent we counted number of items in their shopping carts for 3 labels, our dataset in SPSS at the end had 60 rows.

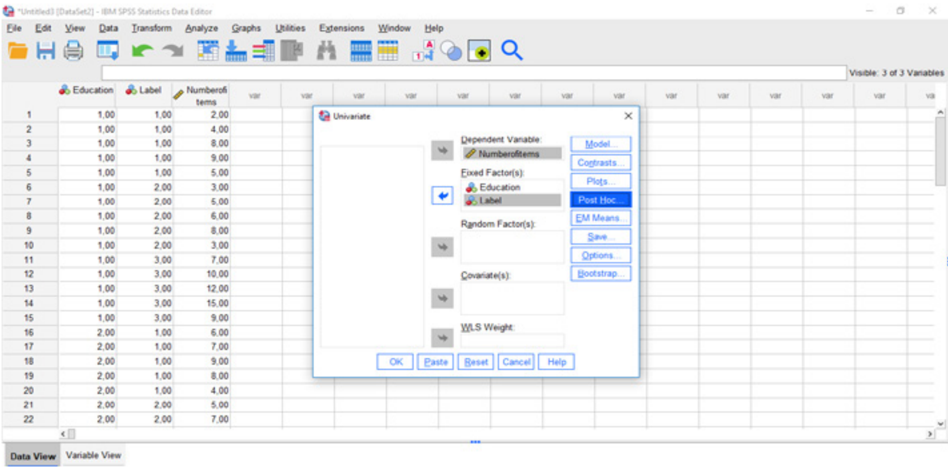

Figure 10. Excerpt of the dataset suitable for two-way ANOVA with replication

Source: The authors' own elaboration.

When data is entered, we proceed to Method selection (see Figure 11). For two-way ANOVA with replication as a method we will choose Analyze—General Linear Model and select Univariate.

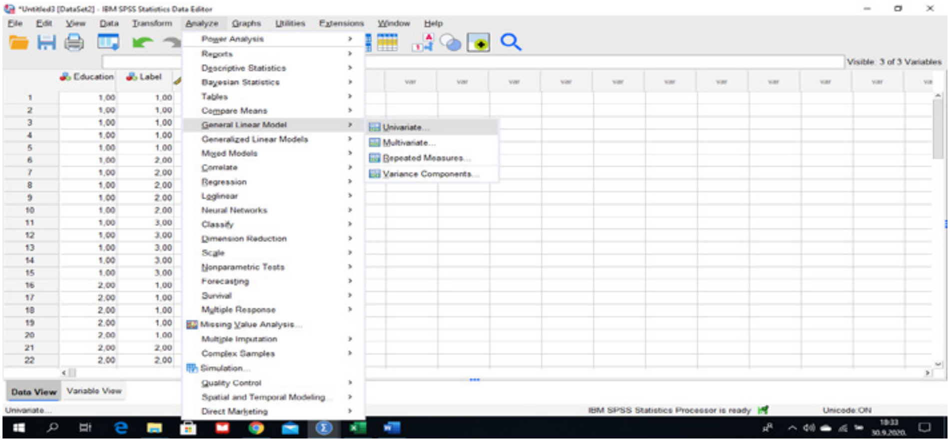

Figure 11. Choosing method—General Linear Model—Univariate

Source: The authors' own elaboration.

After that, we will define variables as shown at Figure 12. Dependent variable is "Numberofitems", while fixed factors are "Education" and "Label". Now we can specify several options which will enable us to interpret results of the analysis. In this chapter we will set options for Plot diagram and Post hoc analysis.

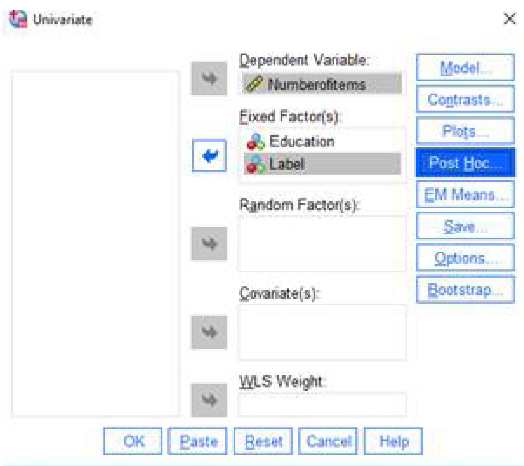

Figure 12. Setting basics options for the analysis—variables

Source: The authors' own elaboration.

Plot diagram settings are shown at Figure 13. Plot diagram will enable us to visualize results of ANOVA in quick and intuitive manner. It will show us interrelation between factors in a graphic mode. We will set Education to be shown at horizontal axis and Label as a separate lines, then we will click Add and we will just check if in the text box under word "Plots" "Education*Label" is shown and if the checkbox is selected for "Line Chart". If everything is correct, we can confirm everything by clicking the button "Continue".

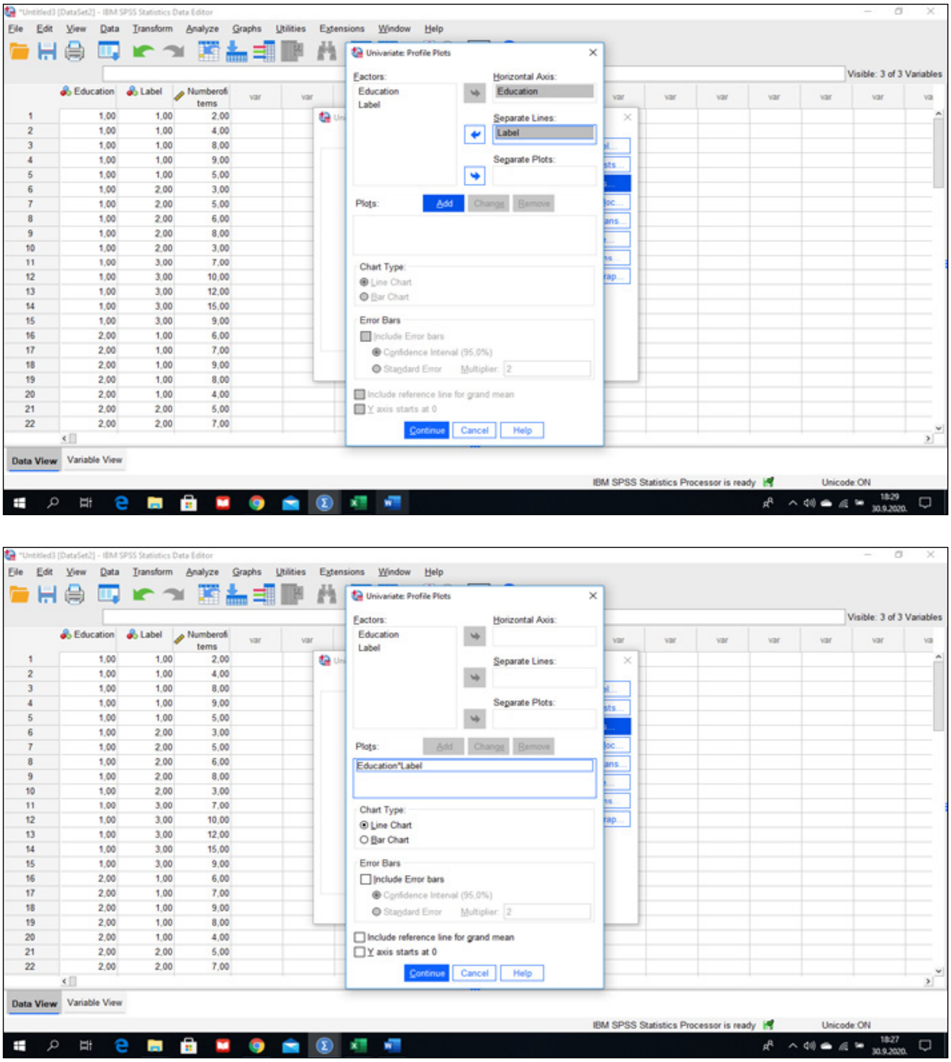

Figure 13. Settings for Plot diagram

Source: The authors' own elaboration.

Finally, we will define options for the post hoc analysis. We will perform post hoc tests for Education and Label and we will mark Tukey post hoc analysis (see Figure 14). Again, we will click button "Continue" and then at previous screen confirm analysis by clicking to "OK" button.

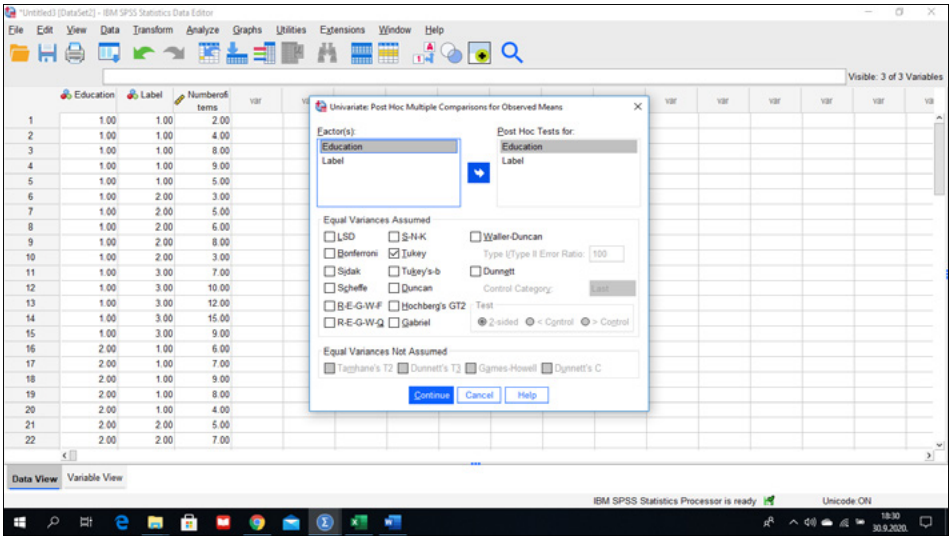

Figure 14. Setting post hoc analysis options

Source: The authors' own elaboration.

When analysis is finished, we will get results separated in several segments. Firstly, we will have two-way ANOVA general results (see Figure 15). On the basis of this table we will be able not to reject or reject our starting null hypotheses.

Tests of Between-Subjects Effects

Dependent Variable: Numberofitems

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	611.783[a]	11	55.617	9.715	.000
Intercept	4950.417	1	4950.417	864.702	.000
Education	144.850	3	48.283	8.434	.000
Label	39.033	2	19.517	3.409	.041
Education * Label	427.900	6	71.317	12.457	.000
Error	274.800	48	5.725		
Total	5837.000	60			
Corrected Total	886.583	59			

a. R Squared = .690 (Adjusted R Squared = .619)

Figure 15. Two-way ANOVA with replication results

Source: The authors' own elaboration.

We will pay attention to column "Sig." where *p*-values are shown. In this column we will observe which values are less than .05. In our case all significance values are lower than .05 (Education $p < .001$, Label $p = .041$, Education * Label $p < .001$). Therefore, we can reject all three H0 hypotheses. Therefore, at significance level .05 we can conclude that:

- there is a difference between means of number of items in shopping cart grouped by number of educations taken;
- there is a difference between means of means of number of items in shopping cart grouped by label of product;
- there is interaction between factors.

In Figure 16 the plot diagram is shown. We can observe that Education and Label curve intersect which means that those variables are in interaction and that we have to take this fact into account when interpret our post hoc data.

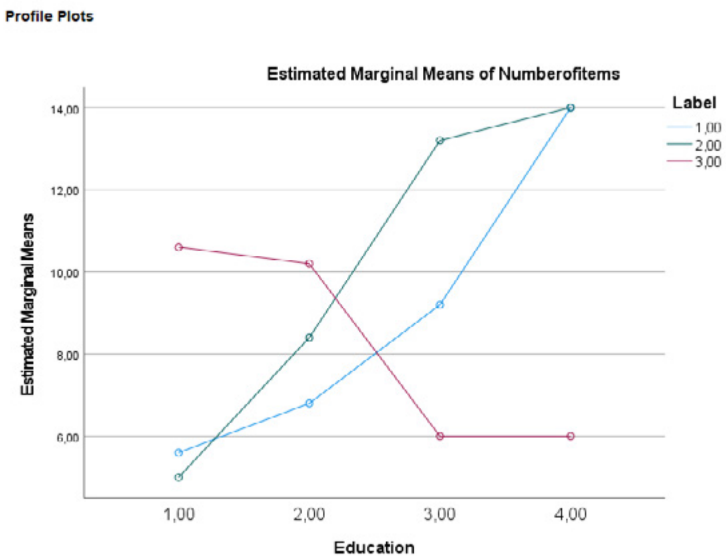

Figure 16. Plot diagram

Source: The authors' own elaboration.

As the two-way ANOVA results have shown that there are differences between groups (factors), it is recommended to do post hoc analysis to get better insight into the results. Results of the post hoc analysis help us to observe between which groups are strongest differences and are there some groups which do not differ from each other.

In Figure 17 Post hoc analysis results are shown based on Label. We can observe that between those who did not attend any education (1) and those who attended two educations (3), then between those who did not attend any education (1) and those who attended three educations (4), and between those who attended one education (2) and those who attended three educations (4) at level of .05, there is statistically significant difference between means of number of items in shopping cart. While other pairs of groups did not show statistically significant difference (*p*-values in column "Sig." are higher than .05).

Multiple Comparisons

Dependent Variable: Numberofitems
Tukey HSD

(I) Education	(J) Education	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1.00	2.00	-1.4000	.87369	.387	-3.7252	.9252
	3.00	-2.4000*	.87369	.041	-4.7252	-.0748
	4.00	-4.2667*	.87369	.000	-6.5919	-1.9415
2.00	1.00	1.4000	.87369	.387	-.9252	3.7252
	3.00	-1.0000	.87369	.664	-3.3252	1.3252
	4.00	-2.8667*	.87369	.010	-5.1919	-.5415
3.00	1.00	2.4000*	.87369	.041	.0748	4.7252
	2.00	1.0000	.87369	.664	-1.3252	3.3252
	4.00	-1.8667	.87369	.156	-4.1919	.4585
4.00	1.00	4.2667*	.87369	.000	1.9415	6.5919
	2.00	2.8667*	.87369	.010	.5415	5.1919
	3.00	1.8667	.87369	.156	-.4585	4.1919

Based on observed means.
The error term is Mean Square(Error) = 5.725.
*. The mean difference is significant at the 0.05 level.

Figure 17. Post hoc analysis results—Education

Source: The authors' own elaboration.

Multiple Comparisons

Dependent Variable: Numberofitems
Tukey HSD

(I) Label	(J) Label	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1.00	2.00	-1.2500	.75664	.234	-3.0799	.5799
	3.00	.7000	.75664	.627	1.1299	2.5299
2.00	1.00	1.2500	.75664	.234	-.5799	3.0799
	3.00	1.9500*	.75664	.034	.1201	3.7799
3.00	1.00	-.7000	.75664	.627	-2.5299	1.1299
	2.00	-1.9500*	.75664	.034	-3.7799	-.1201

Based on observed means.
The error term is Mean Square(Error) = 5.725.
*. The mean difference is significant at the 0.05 level.

Figure 18. Post hoc analysis results—Label

Source: The authors' own elaboration.

In Figure 18 Post hoc analysis results are shown based on Education. We can observe that between products with label Fair trade (2) and products with no label (3) at level of .05, there is a statistically significant difference between means of number of items in shopping cart. While other pairs of groups did not show statistically significant difference (*p*-values in column "Sig." are higher than .05).

Testing the hypotheses in Excel

To perform two-way ANOVA with replication in Excel, it is extremely important to have the same number of observations for one factor, in our case—education level. Therefore, we made and entered 5 observations for each level of education (see rows in Figure 19).

	A	B	C	D	E	F
1	Number of items in shopping cart					
2						
3			Eco-friendly	Fair trade	No label	
4	Number of educations	No education	2	3	7	
5			4	5	10	
6			8	6	12	
7			9	8	15	
8			5	3	9	
9		One education	6	5	7	
10			7	7	12	
11			9	10	13	
12			8	11	9	
13			4	9	10	
14		Two educations	8	15	7	
15			9	12	4	
16			10	13	8	
17			12	16	6	
18			7	10	5	
19		Three education	12	16	4	
20			17	14	5	
21			19	15	6	
22			12	13	8	
23			10	12	7	
24						

Figure 19. Dataset for two-way ANOVA (with replication) analysis in Excel

Source: The authors' own elaboration.

Data is entered into Excel in format suitable for data analysis grouped by number of educations as we have same number of respondents for each level of education, then in columns we enter another grouping variable, i.e. product labels (see Figure 19). In each row we enter data on one survey participant. For instance, we enter data for participants which did not attend any seminar (no education) in five rows, each row for one participant. First participant without education put 2 eco-friendly items, 3 fair-trade items and 7 no label items to his/her shopping cart, while second participant without education put 4 eco-friendly items, 5 fair trade items and 10 items without labels into his/her shopping cart.

To perform two-way ANOVA with replication, we have to click Data tab and we have to choose Data Analysis tab (within Analysis group of commands). Within the list of methods, we choose ANOVA: two factor with replication (see Figure 20).

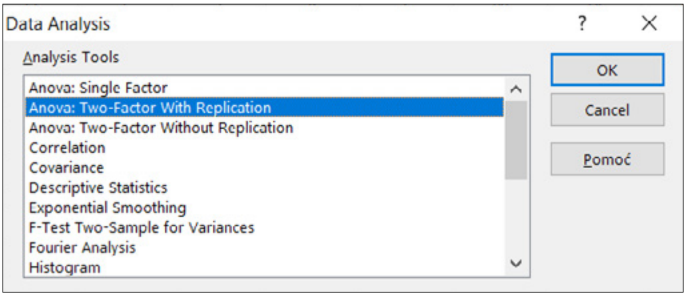

Figure 20. Data Analysis tab in Excel—selection of the method ANOVA: two-factor with replication

Source: The authors' own elaboration.

In the dialog box of ANOVA: two-factor with replication we have to configure as follows (see Figure 21):

– input range of the dataset including labels, in our example it is B3:E23;
– input number of rows per sample (i.e. number of observations), in our case 5;
– output range, we can choose to show data at some position at the active Worksheet, then we have to specify exact cell from which our results are going to be presented (such as F3); but in our case we rather specified New Worksheet as the location of our results, also we can specify a name for our output (in our example ANOVA);
– the last thing is the level of significance, i.e. alpha value. There we can use default value as it is already set to .05.

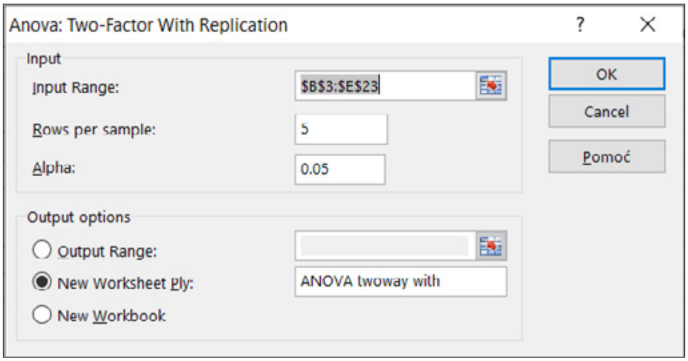

Figure 21. Dialog box ANOVA: two-factor with replication

Source: The authors' own elaboration.

	A	B	C	D	E	F
1	Anova: Two-Factor With Replication					
2						
3	SUMMARY	Eco-friend	Fair trade	No label	Total	
4	*No education*					
5	Count	5	5	5	15	
6	Sum	28	25	53	106	
7	Average	5.6	5	10.6	7.066667	
8	Variance	8.3	4.5	9.3	13.06667	
9						
10	*One education*					
11	Count	5	5	5	15	
12	Sum	34	42	51	127	
13	Average	6.8	8.4	10.2	8.466667	
14	Variance	3.7	5.8	5.7	6.409524	
15						
16	*Two educations*					
17	Count	5	5	5	15	
18	Sum	46	66	30	142	
19	Average	9.2	13.2	6	9.466667	
20	Variance	3.7	5.7	2.5	12.69524	
21						
22	*Three educations*					
23	Count	5	5	5	15	
24	Sum	70	70	30	170	
25	Average	14	14	6	11.33333	
26	Variance	14.5	2.5	2.5	20.80952	
27						
28	*Total*					

	A	B	C	D	E	F	G
34							
35	ANOVA						
36	*Source of Variation*	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
37	Sample	144.85	3	48.28333	8.43377	0.000132	2.798061
38	Columns	39.03333	2	19.51667	3.409025	0.041269	3.190727
39	Interaction	427.9	6	71.31667	12.45706	2.08E-08	2.294601
40	Within	274.8	48	5.725			
41							
42	Total	886.5833	59				
43							

Figure 22. Two-way ANOVA with replication results

Source: The authors' own elaboration.

In Figure 22 there are results of two-way ANOVA with replication analysis. First of all, in Excel we have basic descriptive statistical data grouped by factor in rows (number of educations) systemized by factor in columns (in our case product labels). From this part we can read how many observations we had in which combination of factors (see rows Count in each sub table), then we can see what the average number of items for each combination of factors, together with data on variance. For instance, when we observe sub table "No education", we will see that there are on average 5.5 items labeled as Eco-friendly in the shopping cart, 5 items labeled as Free trade, and 10.6 items with no label. On the other hand, in sub table "Three educations" there are on average 14 items labeled as Eco-friendly, 14 labeled as Fair-trade and 6 with no label.

In addition, ANOVA results are shown. In this table, the most important reading is *p*-value because by it we can decide not to reject or to reject the null hypothesis. In our case the *p*-value for Sample (in our case this data refers to number of education) is .000132 and it is less than significance level of .05 which means that we can reject the null hypothesis H0(1), and we can conclude that there is a difference between means of number of items in shopping cart grouped by number of educations taken. So, this difference is statistically significant at the level of .05.

In addition, we can observe that in our case the *p*-value for columns (in this case, product labels) is .041269 which is lower than .05. Therefore, we can reject the null hypothesis H0(2), and we can conclude that there is difference between means of means of number of items in shopping cart grouped by label of product. In other words, this difference is statistically significant at the level of .05.

Moreover, the *p*-value for testing interaction between our two factors (number of education and label of products) is 2.08E-08 which is lower than .05 and means that we can reject H0(3) and consequently conclude that there is an interaction between factors and we have to take it into account when we interpret our data. Because if an interaction effect is present, the impact of one factor depends on the level of the other factor.

Summary of the example

Dataset: The number of products in a shopping cart at the checkout in a local supermarket according to product labels is observed. Three product labels have been defined. Overall, 20 respondents have been selected to participate in the study according to their number of taken educations. Four levels of educations taken are recognized. In the study participated equal number of respondents according to the number of educations taken. Consequently, at each level of educations taken we had 5 respondents for which we measured the number of products with different product labels. On that way, three measurement for each respondent have been conducted.

Data info:

- variable 1: number of educations taken—nominal (1—No education, 2—One education, 3—Two educations, 4—Three educations);
- variable 2: label of product—nominal (1—Eco-friendly, 2—Fair trade, 3—No label);
- variable 3: number of items (products) in the shopping cart—numerical.

The two-way ANOVA with replication approach was used to inspect whether our education is effective in changing consumer habits to purchase sustainable products in everyday life. The results have shown that there was a statistically significant interaction between the number of educations taken and label of product ($F(6, 48) = 12.457$, $p < .001$).

More info about two-way ANOVA with replication

All previously mentioned additional information about two-way ANOVA without replication apply to two-way ANOVA with replication.

The main difference between two-way ANOVA without replication and two-way ANOVA with replication is the sample structure. In the ANOVA without replication we have only a single observation for each combination of nominal variables while in two-way ANOVA with replication we have more than one observation. In other words, in two-way ANOVA without replication design there is only 1 experimental unit for each combination of the factors. While in two-way ANOVA with replication "there are more than one experimental unit per combination of the factors. In such design we have enough degrees of freedom and the interaction between factors can be estimated" (Field, 2013; Fraser, 2016). It is recommended that in two-way ANOVA with replication we should use balanced data or sample with uniform size to get results in efficient manner".

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