

### Factorial ANOVA for Mixed Designs

#### Notation

In the following hypothetical example, I examine the effects of the educational context on vocabulary in 5<sup>th</sup> grade students. Vocabulary (number of words correct on a vocabulary test) before and after the lecture (Pre and Post) is compared for three lecture types (physical science, social science, history). Thus, the design is a 3 X 2 factorial design where Lecture Types is a between-subjects factor and Pre/Post is a within-subjects factor. In the following table, I represent the between-subjects factor, Lecture Type, as Factor A, and the within-subjects factor, Pre/Post, as Factor B to illustrate the design and notation.

#### Notation: Data Matrix

Physical science (a1)

	Pre ( $b_1$ )	Post ( $b_2$ )	
s1	$Y_{ijk}$	$Y_{ijk}$	$\bar{Y}_{.1.}$
s2	$Y_{ijk}$	$Y_{ijk}$	$\bar{Y}_{.2.}$
s3	$Y_{ijk}$	$Y_{ijk}$	$\bar{Y}_{.3.}$
s4	$Y_{ijk}$	$Y_{ijk}$	$\bar{Y}_{.4.}$
s5	$Y_{ijk}$	$Y_{ijk}$	$\bar{Y}_{.5.}$
s6	$Y_{ijk}$	$Y_{ijk}$	$\bar{Y}_{.6.}$
	$\bar{Y}_{.11}$	$\bar{Y}_{.12}$	$\bar{Y}_{.1.}$

Social science (a2)

	Pre ( $b_1$ )	Post ( $b_2$ )	
s7	$Y_{ijk}$	$Y_{ijk}$	$\bar{Y}_{.7.}$
s8	$Y_{ijk}$	$Y_{ijk}$	$\bar{Y}_{.8.}$
s9	$Y_{ijk}$	$Y_{ijk}$	$\bar{Y}_{.9.}$
s10	$Y_{ijk}$	$Y_{ijk}$	$\bar{Y}_{.10.2.}$
s11	$Y_{ijk}$	$Y_{ijk}$	$\bar{Y}_{.11.2.}$
s12	$Y_{ijk}$	$Y_{ijk}$	$\bar{Y}_{.12.2.}$
	$\bar{Y}_{.21}$	$\bar{Y}_{.22}$	$\bar{Y}_{.2.}$

History (a3)

	Pre ( $b_1$ )	Post ( $b_2$ )	
s13	$Y_{ijk}$	$Y_{ijk}$	$\bar{Y}_{.13.3.}$
s14	$Y_{ijk}$	$Y_{ijk}$	$\bar{Y}_{.14.3.}$
s15	$Y_{ijk}$	$Y_{ijk}$	$\bar{Y}_{.15.3.}$
s16	$Y_{ijk}$	$Y_{ijk}$	$\bar{Y}_{.16.3.}$
s17	$Y_{ijk}$	$Y_{ijk}$	$\bar{Y}_{.17.3.}$
s18	$Y_{ijk}$	$Y_{ijk}$	$\bar{Y}_{.18.3.}$
	$\bar{Y}_{.3.1}$	$\bar{Y}_{.3.2}$	$\bar{Y}_{.3.}$

#### Notation: Summary of Means

		B		
		Pre ( $b_1$ )	Post ( $b_2$ )	
A	Physical science ( $a_1$ )	$\bar{Y}_{.11}$	$\bar{Y}_{.12}$	$\bar{Y}_{.1.}$
	Social science ( $a_2$ )	$\bar{Y}_{.21}$	$\bar{Y}_{.22}$	$\bar{Y}_{.2.}$
	History ( $a_3$ )	$\bar{Y}_{.31}$	$\bar{Y}_{.32}$	$\bar{Y}_{.3.}$
		$\bar{Y}_{.1.}$	$\bar{Y}_{.2.}$	$\bar{Y}_{.3.}$

### Factorial ANOVA--Test of Main Effects and Interaction

The interpretation and general procedures for testing the main effects and the interaction are the same in the mixed factorial as they are in the between-subjects factorial ANOVA. Different error terms, however, are used for the test of the between-subjects main effect and the within-subjects main effect. *Note that the error term used to test the interaction is the same as the error term used to test the within-subjects main effect.* The table below summarizes the overall analysis.  $Y_{ijk}$  is an individual vocabulary score,  $\bar{Y}_{.jk}$  is a cell mean,  $\bar{Y}_{.j.}$  is a marginal mean for a level of the lecture factor,  $\bar{Y}_{..k}$  is a marginal mean for pre or post test,  $\bar{Y}_{i..}$  is the mean for an individual student, and  $\bar{Y}_{...}$  is the grand mean.

Description	SS (definitional formula)	df	MS	F
A main effect (between-subjects)	$SS_A = (b)(n) \sum (\bar{Y}_{.j.} - \bar{Y}_{...})^2$	$a - 1$	$\frac{SS_A}{df_A}$	$\frac{MS_A}{MS_{S/A}}$
Error term for A main effect	$SS_{S/A} = b \sum \sum (\bar{Y}_{.jk} - \bar{Y}_{.j.})^2$	$a(n - 1)$	$\frac{SS_{S/A}}{df_{S/A}}$	
B main effect (within-subjects)	$SS_B = (a)(n) \sum \sum (\bar{Y}_{..k} - \bar{Y}_{...})^2$	$b - 1$	$\frac{SS_B}{df_B}$	$\frac{MS_B}{MS_{BxS/A}}$
Interaction	$SS_{AxB} = n \sum \sum \sum (\bar{Y}_{.jk} - \bar{Y}_{.j.} - \bar{Y}_{..k} + \bar{Y}_{...})^2$	$(a - 1)(b - 1)$	$\frac{SS_{AxB}}{df_{AxB}}$	$\frac{MS_{AxB}}{MS_{BxS/A}}$
Error term for B main effect and interaction	$SS_{BxS/A} = \sum \sum \sum (Y_{ijk} - \bar{Y}_{.jk} - \bar{Y}_{i..} - \bar{Y}_{.j.})^2$	$a(b - 1)(n - 1)$	$\frac{SS_{BxS/A}}{df_{BxS/A}}$	
Total	$SS_T = \sum \sum \sum (Y_{ijk} - \bar{Y}_{...})^2$	$(a)(b)(n) - 1$		

If the interaction is not significant, the main effects are examined. If the interaction is significant, the simple effects should be examined using overall simple effects tests or simple contrasts (i.e., single df-contrasts). When examining simple effects, however, there are a few complications, because the within-subjects factor requires different error terms for different situations.

### Between-Subjects Main Effects

Assuming there is no significant interaction, one can examine the between-subjects main effect (i.e., differences in lecture types). In the above example, we would be examining the variation of the mean for each level of A ( $\bar{Y}_{.1.}, \bar{Y}_{.2.}, \bar{Y}_{.3.}$ ) around the total mean ( $\bar{Y}_{...}$ ). This is exactly the same as the procedure for the between-subjects one-way ANOVA.

	B		
	Pre ( $b_1$ )	Post ( $b_2$ )	
Physical science ( $a_1$ )	$\bar{Y}_{.11}$	$\bar{Y}_{.12}$	$\bar{Y}_{.1.}$
A Social science ( $a_2$ )	$\bar{Y}_{.21}$	$\bar{Y}_{.22}$	$\bar{Y}_{.2.}$
History ( $a_3$ )	$\bar{Y}_{.31}$	$\bar{Y}_{.32}$	$\bar{Y}_{.3.}$
	$\bar{Y}_{..1}$	$\bar{Y}_{..2}$	$\bar{Y}_{...}$

If there are more than two levels of A, as there are in this example, one could follow the main effect analysis with a single-df contrast to compare particular marginal means for lecture types. For example, one might compare the marginal means for social science and history. These analyses examine the overall effect of A, collapsing or averaging across the levels of B. In this example, we average the Pre and Post measures. Note that averaging the Pre and Post may not always be very meaningful or useful.

		B		
		Pre ( $b_1$ )	Post ( $b_2$ )	
A	Physical science ( $a_1$ )	$\bar{Y}_{.11}$	$\bar{Y}_{.12}$	$\bar{Y}_{.1}$
	Social science ( $a_2$ )	$\bar{Y}_{.21}$	$\bar{Y}_{.22}$	$\bar{Y}_{.2}$
	History ( $a_3$ )	$\bar{Y}_{.31}$	$\bar{Y}_{.32}$	$\bar{Y}_{.3}$
		$\bar{Y}_{.1}$	$\bar{Y}_{.2}$	$\bar{Y}_{..}$

### Within-Subjects Main Effects

Assuming there is no significant interaction, one can examine the main effect for B, a within-subjects factor. Here, we average all three of the Lecture types conditions to see if there is an overall increase in the number of words correct from the Pretest to the Posttest.

		B		
		Pre ( $b_1$ )	Post ( $b_2$ )	
A	Physical science ( $a_1$ )	$\bar{Y}_{.11}$	$\bar{Y}_{.12}$	$\bar{Y}_{.1}$
	Social science ( $a_2$ )	$\bar{Y}_{.21}$	$\bar{Y}_{.22}$	$\bar{Y}_{.2}$
	History ( $a_3$ )	$\bar{Y}_{.31}$	$\bar{Y}_{.32}$	$\bar{Y}_{.3}$
		$\bar{Y}_{.1}$	$\bar{Y}_{.2}$	$\bar{Y}_{..}$

There are only two levels of Factor B in this example, so the single-df contrast is the same as the main effect. If there were more than two levels of Factor B, however, we could compare just two of the conditions in a single-df contrast. This proceeds just as it does in the within-subjects one-way ANOVA, in which only two of the conditions are compared using the error term for two conditions only (i.e., a paired t-test or within-subjects F-test for two repeated measures).

### Follow-up Analyses to a Significant Interaction

Assuming the interaction is significant, one would want to examine the simple effects. There are two approaches, the overall simple effect which compares all means within a level of one of the independent variables, and the simple contrast (or “comparison”).

**Simple effect for the between-subjects factor.** To compute the simple effects within each level of the within-subjects factor, we are comparing groups between-subjects. In this example, we might compare all three of the lecture conditions (Physical Science, Social Science, and History) for the Pretest. To do this, we just pretend that we have a one-way design with the number of vocabulary words before the lecture (Pretest) as the dependent variable. We forget about the Posttest for that analysis. Thus, using SPSS, *we would just run a one-way between-subjects ANOVA to test A at  $b_1$  or A at  $b_2$ .*

**Simple contrast for the between-subjects factor.** In this analysis, we would be interested in comparing two means (e.g.,  $a_2$  vs.  $a_3$ ) within one level of the B factor. For example, we might compare Social Science ( $\bar{Y}_{.22}$ ) with History ( $\bar{Y}_{.23}$ ) for the Posttest only. This contrast is conducted just as it is with the one-way between-subjects contrasts (using contrast weights ( $w_i$ ) and  $\psi$ ). The error term used is the one used with the overall simple effect for between subjects (e.g.,  $MS_{S/A}$  at  $b_2$ )—*the error term from the one-way ANOVA analyzing Posttest.*

**Simple effect for the within-subjects factor.** In this analysis, we would be interested in comparing the means of the within-subjects factor for one of the levels of the between subjects factor (e.g. B at  $a_1$ ). For example, we would compare pretest and posttest scores for Physical Sciences only. The error term used is the B x S term *only for cases in level  $a_1$ .* In SPSS, one would just run a within-subjects ANOVA after selecting the students in Physical Sciences lecture.

		B		
		Pre ( $b_1$ )	Post ( $b_2$ )	
A	Physical science ( $a_1$ )	$\bar{Y}_{.11}$	$\bar{Y}_{.12}$	$\bar{Y}_{.1}$
	Social science ( $a_2$ )	$\bar{Y}_{.21}$	$\bar{Y}_{.22}$	$\bar{Y}_{.2}$
	History ( $a_3$ )	$\bar{Y}_{.31}$	$\bar{Y}_{.32}$	$\bar{Y}_{.3}$
		$\bar{Y}_{.1}$	$\bar{Y}_{.2}$	$\bar{Y}_{..}$

**Simple contrast for the within-subjects factor.** In this analysis, we would compare two means of the within-subjects factor (here, the B factor) within one level of the between-subjects factor (the A factor in this example). For example, we would compare pretest and posttest for the Physical Science group. In our present example, there are just two levels of the B factor, so the simple contrast is equal to the test of the overall simple effect. (Table illustration is the same as above simple effect for B within  $a_1$  for the two group case).

If there were more than two levels of the B factor, we could conduct several single-df contrasts, comparing two means of the within-subjects factor (e.g.,  $b_2$  vs.  $b_3$  at  $a_2$ ). This analysis follows the same procedure as the contrasts with the one-way within-subjects ANOVA, *but it is done only with subjects in one of the A groups (e.g., only  $a_2$ )*. To do this, we just select out the cases for that level of the between subjects factor (select all cases in  $a_2$ ), and then conduct a within-subjects ANOVA for our two cells or a paired t-test.

		B			
		Pre ( $b_1$ )	Post ( $b_2$ )	Follow-up ( $b_3$ )	
A	Physical science ( $a_1$ )	$\bar{Y}_{.11}$	$\bar{Y}_{.12}$	$\bar{Y}_{.13}$	$\bar{Y}_{.1}$
	Social science ( $a_2$ )	$\bar{Y}_{.21}$	$\bar{Y}_{.22}$	$\bar{Y}_{.23}$	$\bar{Y}_{.2}$
	History ( $a_3$ )	$\bar{Y}_{.31}$	$\bar{Y}_{.32}$	$\bar{Y}_{.33}$	$\bar{Y}_{.3}$
		$\bar{Y}_{.1}$	$\bar{Y}_{.2}$	$\bar{Y}_{.3}$	$\bar{Y}_{..}$

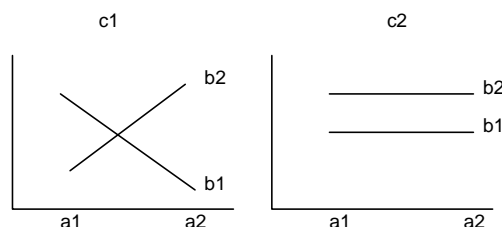
**General Comments**

Naturally, we could have any combination of within-subjects factors and between-subjects factors in a factorial ANOVA. A design with two or more within-subjects factors and no between-subjects factors is a "pure" within-subjects factorial. As you can imagine, the analyses for these designs become increasingly complex, but "pure" within-subjects factorials are not used too much in applied social science literature. They do occur quite frequently in laboratory studies of memory, communication, or exercise science, because researchers have more complete control over the independent variables.

When describing a mixed factorial design, researchers will often state that they have a 2 X 3 design with the first factor between-subjects and the second factor within-subjects, for example. A three-factor design might be described like this: "our design was a 2 X 2 X 4 design with the first two factors as between-subjects factors and the last factor a within-subjects factor." Such a design has two between-subjects factors with two levels each and a four-level within-subjects factor.

With 3-way factorial designs, things become much more complex. We might call the third factor "C", so that a 3-way design is an A X B X C design. For example, we might examine whether two-way interaction between Lecture Type and Pre/Post is different for boys and girls (i.e., Factor C would be gender). A three-way interaction would indicate that the 2-way interaction between A and B is not the same at different levels of C. This means that if C has 2 levels, there might be a significant interaction between A and B at  $C_1$  but not at  $C_2$ . Or it might mean that the A X B interaction takes a different form at  $C_1$  than it does at  $C_2$ . Of course, we also have three possible 2-way interactions to deal with: A X B, A X C, and B X C. Plus, there are possible main effects for A, B, or C.

Just for kicks, here is a graphical representation of a three-way interaction for a 2 X 2 X 2 design:



In the above example, there is a 2-way interaction between A and B at  $c_1$ , but not at  $c_2$ . At  $c_2$ , there seems to be just a main effect for B.

**Further Reading**

A good source for details on complex ANOVA designs is Keppel, G., & Wickens, T.D. (2004). *Design and analysis: A researcher's handbook* (4<sup>th</sup> Edition). Upper Saddle River, NJ: Prentice Hall.

A good source for testing complex ANOVA designs and conducting follow-up tests in SPSS is Braver, S.L., & MacKinnon, D.P., (2003). *Levine's guide to SPSS for analysis of variance* (2<sup>nd</sup> Edition). Mahwah, NJ: Erlbaum.