Cautions with ANCOVA in SPSS

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Dear colleagues,

Today a caution about the use of covariates in (repeated measures) ANOVA. To illustrate this caution I attached examples of a fictitious analysis. In this study, researchers investigate the effect of a therapy (categorical: placebo versus physio) in conjunction with a drug treatment (continuous: 0.1 g to 1 g dosage), on a health index (response). The scatter plot (FIG1) indicates that the drug dosage strongly interacts with the therapy, such that those who receive physio respond better for higher drug dosages. Interactions in ANCOVA are the focus of this mailing.
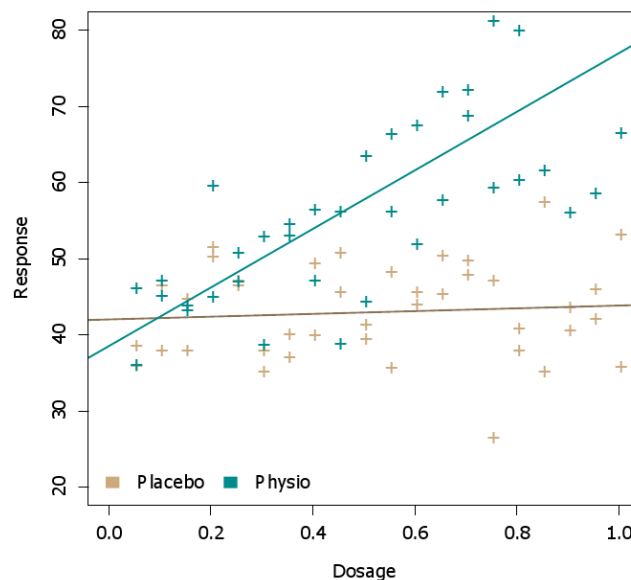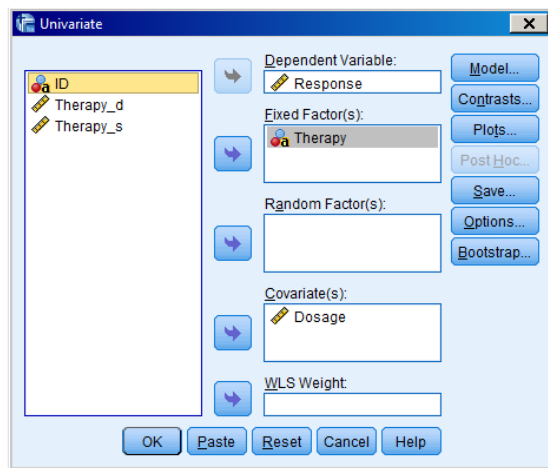

Figure 1. Fictitious clinical data scatter plot

The problem

When you conduct a general linear model analysis in SPSS, the software makes a distinction between "factors" and "covariates" among the between-subjects variables (FIG2). The first thing to note is that this distinction is technically artificial. A factor is nothing more than a covariate with binary values. For example, the factor gender (male, female) could be recoded numerically to -1 for males and 1 for females. This would be an example of so-called effect/sum coding (-1/1).

However, the default coding scheme in SPSS---and almost all statistics packages---is so-called **dummy/treatment coding**, where one level of the factor is assigned 0 (e.g., placebo) and the other level is assigned 1 (e.g., physio). When you enter a between-subjects factor into a model, SPSS will perform the dummy conversion automatically. As an alternative, you could also create the dummy variable manually and add it as a between covariate (FIG2). These approaches should give identical results in the ANOVA. Unfortunately, this is not always true in SPSS!

"therapy" as explicit factor   "therapy" as implicit factor with dummy covariate
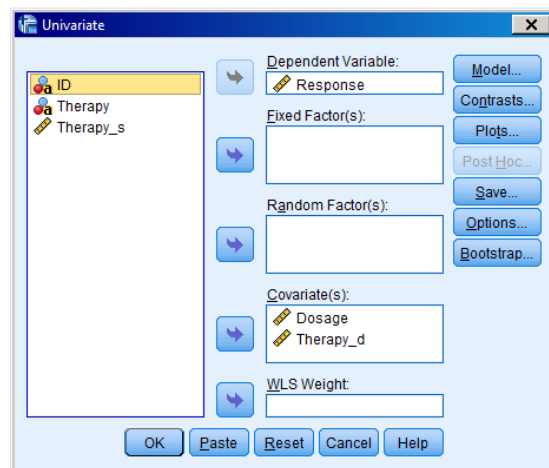
Figure 2. Factors entered as qualitative versus quantitative

FIG3 and FIG4 contrast the output of the factor and the covariate approaches. SPSS will print an ANOVA table by default and parameter estimates by request (options menu). When "therapy" is specified as a covariate (with a manually added dummy), these two tables are identical (FIG4). When "therapy" is specified as a factor, the tables differ! The "main" effect of dosage is suddenly very significant in the ANOVA table (FIG3).

The cause

Many researchers are not aware that there are different **types of ANOVA** (I, II, III, and IV). Distinctions between these types merit their own mailing. Here I note that the default in most software is **type III ANOVA.** When used in conjunction with dummy-coded factors (the default in most software), this has important consequences for models that contain interactions. That is, conventional main effects parameters do not exist in these models!

To understand this, it is useful to interpret the parameter estimates given in FIG3. For example:

- **Intercept:** the average health response when dosage is at 0 and therapy is at 0. For therapy 0=placebo. In other words, this parameter codes for the average health response at 0 dosage in the placebo group.
- **Dosage:** the regression slope of dosage on health response, when therapy is at 0 (=placebo). In other words, this parameter codes only for the slope of the placebo group!
- **[Therapy=physio]:** the difference in average health response between the placebo group and the physio group, when dosage is at 0. In other words, this parameter codes only for the therapy effect at 0 dosage!
- **[Therapy=physio]*Dosage:** the difference in dosage slope between the placebo and the physio group.
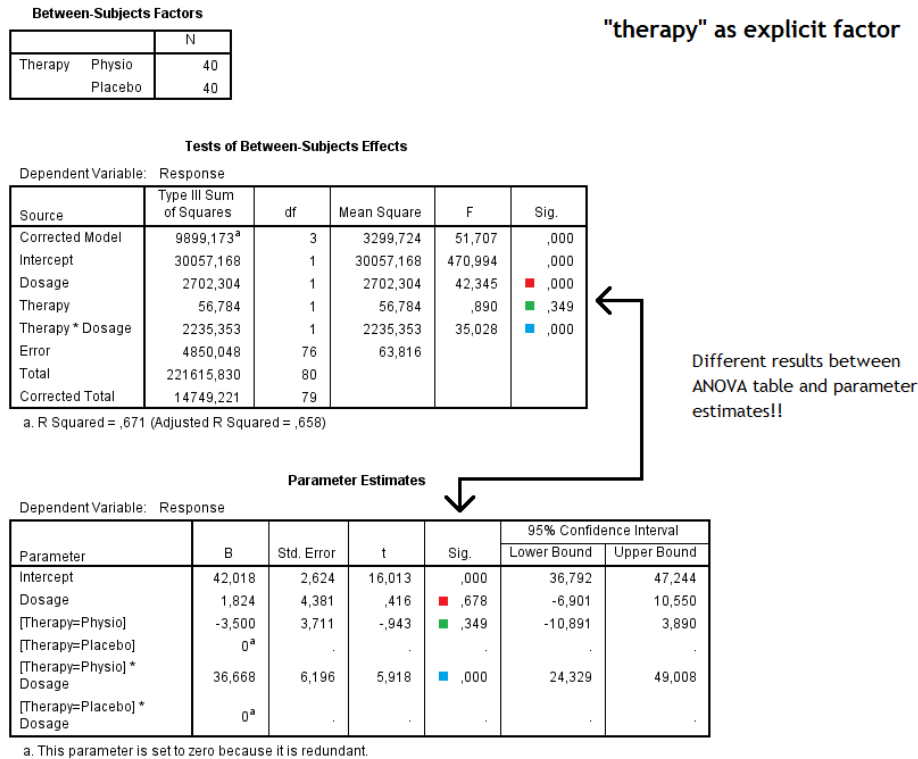
Between-Subjects Factors

		N
Therapy	Physio	40
	Placebo	40

Tests of Between-Subjects Effects

Dependent Variable: Response

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	9899,173a	3	3299,724	51,707	,000
Intercept	30057,168	1	30057,168	470,994	,000
Dosage	2702,304	1	2702,304	42,345	■ ,000
Therapy	56,784	1	56,784	,890	■ ,349
Therapy * Dosage	2235,353	1	2235,353	35,028	■ ,000
Error	4850,048	76	63,816		
Total	221615,830	80			
Corrected Total	14749,221	79			

a. R Squared = ,671 (Adjusted R Squared = ,658)

Different results between ANOVA table and parameter estimates!!

Parameter Estimates

Dependent Variable: Response

Parameter	B	Std. Error	t	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Intercept	42,018	2,624	16,013	,000	36,792	47,244
Dosage	1,824	4,381	,416	■ ,678	-6,901	10,550
[Therapy=Physio]	-3,500	3,711	-,943	■ ,349	-10,891	3,890
[Therapy=Placebo]	0a	.	.	.	.	.
[Therapy=Physio] * Dosage	36,668	6,196	5,918	■ ,000	24,329	49,008
[Therapy=Placebo] * Dosage	0a	.	.	.	.	.

a. This parameter is set to zero because it is redundant.

Figure 3. Therapy entered as qualitative factor. Comparison with parameter estimates.

The last parameter codes the genuine interaction between dosage and therapy, in that it expresses the differences in dosage-response slopes for the two therapy conditions. However, the "main" effects are clearly not main effects at all! They do not average across levels of the other variables but look at specific conditional contrasts. For example, the dosage parameter only expresses the regression slope for the placebo therapy (which is insignificant; see also FIG1).

These conditional contrasts might not seem helpful if you are interested in testing genuine main effects but it should be noted that the parameter estimates output (and the ANOVA output of the covariate analysis) is the "correct" one, statistically speaking. Marginal main effects should not appear in type III ANOVA with dummy coded factors and interactions in the design!

So what is going on in the ANOVA table of the factor output then (FIG3)? Why is there a significant "main" effect for dosage here? It turns out that SPSS changes the coding of factors for the ANOVA table. Instead of dummy coding (0/1), the software switches to sum coding (-1/1). As a consequence, the main effect of dosage now represents a genuine marginal main effect of dosage. SPSS does not do this when the same variable is manually entered as a covariate. For covariates, the ANOVA table returns Type III ANOVA that is consistent with dummy coding.

Presumably, the factor output is more interesting for most researchers because you get genuine main effects for the factors. However, this output is not consistent with the parametrization that SPSS uses for the underlying model, so in my opinion this is extremely misleading. As well, it might lead researchers to conclude that the ANOVA table also returns genuine main effects for continuous between covariates in an ANCOVA, which is typically not true!
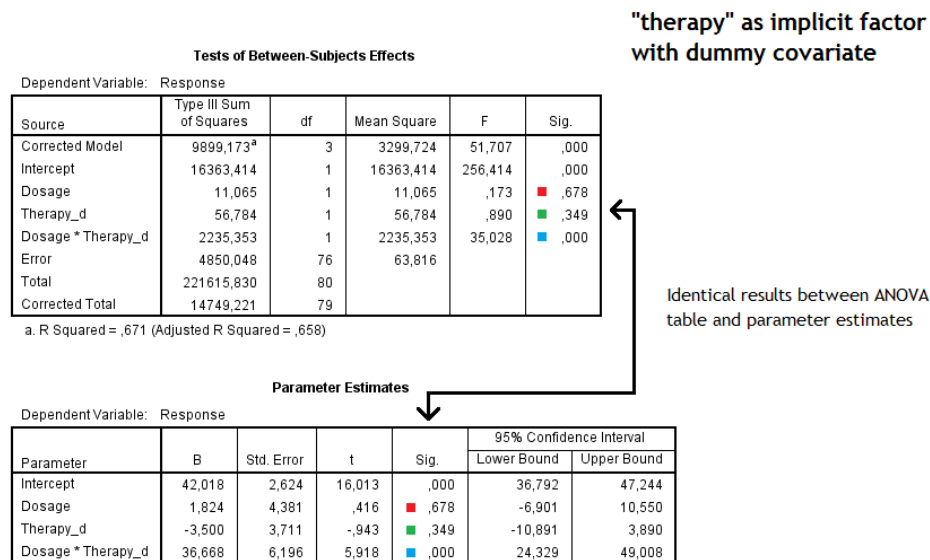
"therapy" as implicit factor with dummy covariate

Tests of Between-Subjects Effects

Dependent Variable: Response

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	9899,173a	3	3299,724	51,707	,000
Intercept	16363,414	1	16363,414	256,414	,000
Dosage	11,065	1	11,065	,173	,678
Therapy_d	56,784	1	56,784	,890	,349
Dosage * Therapy_d	2235,353	1	2235,353	35,028	,000
Error	4850,048	76	63,816		
Total	221615,830	80			
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a. R Squared = ,671 (Adjusted R Squared = ,658)

Identical results between ANOVA table and parameter estimates

Parameter Estimates

Dependent Variable: Response

Parameter	B	Std. Error	t	Sig.	95% Confidence Interval Lower Bound	Upper Bound
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Therapy_d	-3,500	3,711	-,943	,349	-10,891	3,890
Dosage * Therapy_d	36,668	6,196	5,918	,000	24,329	49,008

Figure 4. Therapy entered as quantitative dummy variable. Comparison with parameter estimates.

In general, I would also add that main effects are actually irrelevant in the presence of significant interactions. An interaction states by definition that the effect of one variable depends on levels of another variable. This is evident in FIG1.

Conclusions and advice

As a take-home message, here is a summary of guidelines for interpreting an ANCOVA where the covariate interacts with the other variables of interest:

- As a general rule, You should not interpret/report main effects for variables that are involved in significant interactions. In a factorial analysis, you should always start with testing the highest-order effects, and work your way down from there. If an interaction with a covariate is insignificant, the safest thing might be to drop the interaction from your model and re-estimate
- Type III AN(C)OVA with interactions and dummy-coded factors should not return marginal main effects in the ANOVA output. SPSS is an exception to do this, but still only does it when the factors are explicitly identified as factors. In R you would never get marginal main effects for this type of analysis.
- Be very careful with repeated measures ANCOVA. Again, if you specified your between variable as a factor, you will also get marginal main effects for the within variables. If you specified your between variable as a covariate, you will not get marginal main effects for the within variables! This case is particularly important since adding a covariate to a repeated measures analysis automatically adds interactions with that covariate too!

If your output looks suspicious or inconsistent (especially for main effects), it is always worthwhile to plot your data and see whether main effects or interactions should be expected.

Best,
Ben

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