Why regressing out confounds from a nested design will often fall short

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Introduction & Conclusion

- Researchers often regress out confounds by including regressors that code only for the main effects of confounds.
- This leaves unmodeled interactions involving confounds.
- If a regressor of interest is correlated with such unmodeled interactions, it may “steal” variance due to those interactions.
- This could lead to a significant beta value that reflects confounds, rather than (or in addition to) the effect of interest.
  - Thus, it’s best to avoid confounds in the experimental design if possible!

Two intuitive examples from a hypothetical sleep-deprivation study

1. A confound that DOESN'T interact with an effect of interest

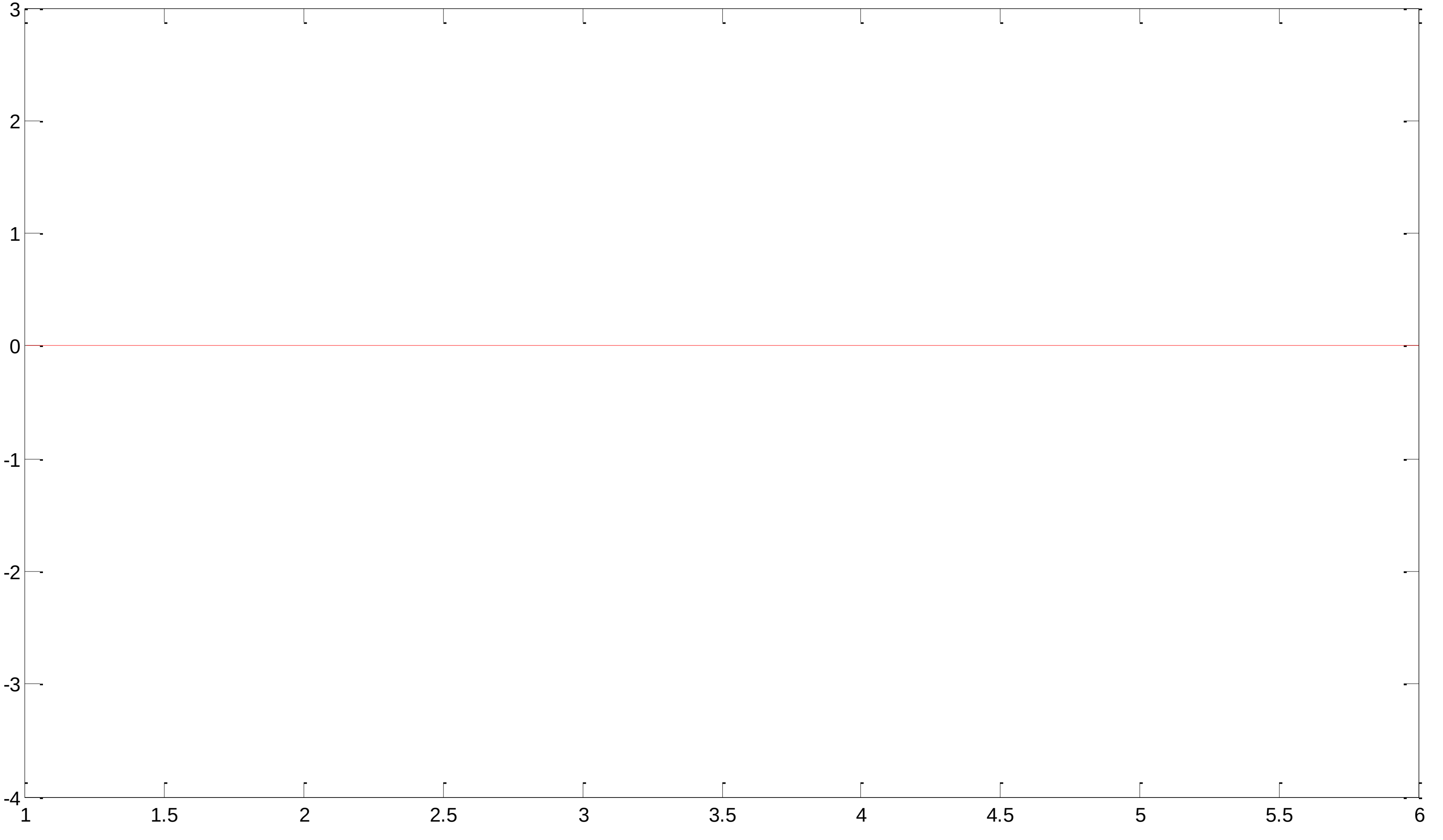
2. A confound that DOES interact with an effect of interest

Ex. 1: A confound that doesn't interact

$$
\begin{array}{c}
\textbf{WM score} \\
\begin{bmatrix} 62 \\ 64 \\ 66 \\ 72 \\ 74 \\ 76 \end{bmatrix}
\end{array}
=
\begin{array}{cccc}
\boxed{\textbf{Sleep}} & \boxed{\textbf{Caff}} & \boxed{\textbf{SleepXCaff}} & \boxed{\textbf{Y-int}} \\
\end{array}
\begin{bmatrix}
-1 & 1 & -1 & 1 \\
-1 & 2 & -2 & 1 \\
-1 & 3 & -3 & 1 \\
1 & 4 & 4 & 1 \\
1 & 5 & 5 & 1 \\
1 & 6 & 6 & 1
\end{bmatrix}
$$

	Sleep	Caff	SleepXCaff	Y-int
Reg1 ßetas:	5			69
Reg2 ßetas:	2	2		62
Reg3 ßetas:	2	2	0	62

Residuals from Regression Without Interaction term

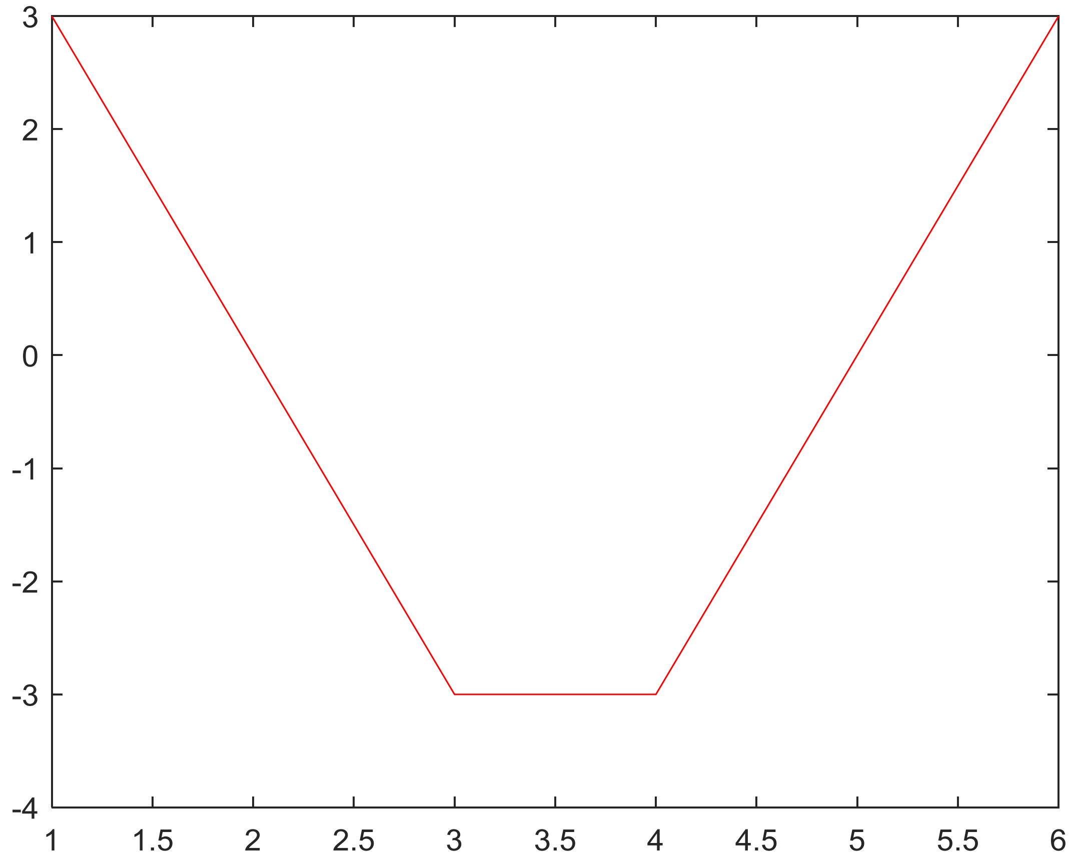


Ex. 2: A confound that DOES interact

$$\begin{array}{c} \textbf{WM score} \\ \begin{bmatrix} 62 \\ 64 \\ 66 \\ 72 \\ 80 \\ 88 \end{bmatrix} \end{array} = \begin{array}{cccc} \boxed{\textbf{Sleep}} & \boxed{\textbf{Caff}} & \boxed{\textbf{SleepXCaff}} & \boxed{\textbf{Y-int}} \\ \end{array} \begin{bmatrix} -1 & 1 & -1 & 1 \\ -1 & 2 & -2 & 1 \\ -1 & 3 & -3 & 1 \\ 1 & 4 & 4 & 1 \\ 1 & 5 & 5 & 1 \\ 1 & 6 & 6 & 1 \end{bmatrix}$$

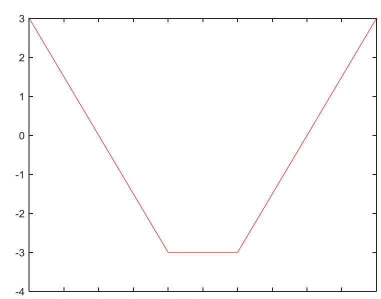
	Sleep	Caff	SleepXCaff	Y-int
Reg1 ßetas:	8			72
Reg2 ßetas:	.5	5		54.5
Reg3 ßetas:	-10	5	3	50

Residuals from Regression Without Interaction term



How do we know whether there is significant unmodeled variance?

- Conduct a Lack of Fit Test (Faraway, 2004)
  - Fit a regression model for each subject
  - Conduct a one-way (M)ANOVA on the group residuals
  - If the residuals deviate significantly from a flat line, then there is systematic, unmodeled variance.



What if there are more regressors?

$$
\begin{array}{c} \textbf{WM score} \\ \left[\begin{array}{c} 62 \\ 64 \\ 66 \\ 72 \\ 80 \\ 88 \end{array}\right] \end{array}
=
\begin{array}{c} \begin{array}{cccccc} \textbf{Sleep} & \textbf{Caff} & \textbf{SleepXCaff} & \textbf{Mood} & \textbf{TV} & \textbf{Y-int} \end{array} \\ \left[\begin{array}{cccccc} -1 & 1 & -1 & 1 & 2 & 1 \\ -1 & 2 & -2 & 3 & 5 & 1 \\ -1 & 3 & -3 & 2 & 3 & 1 \\ 1 & 4 & 4 & 6 & 1 & 1 \\ 1 & 5 & 5 & 5 & 4 & 1 \\ 1 & 6 & 6 & 4 & 3 & 1 \end{array}\right] \end{array}
$$

Now we need to model 14 additional effects to ensure no unmodeled variance: 3 main effects, 6 two-way interactions, 4 three-way interactions, and 1 four-way interaction!!!!!

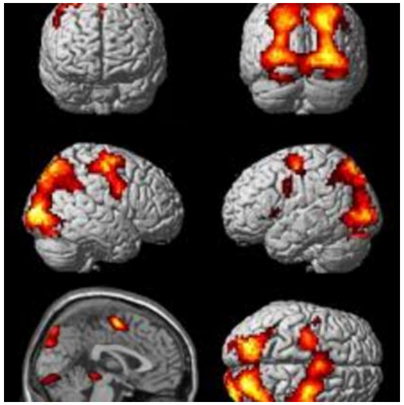
Two potential obstacles

1. Some of the interactions may not be observed in a study (e.g., our subject was never in a great mood when sleep-deprived).

2. The model may run out of degrees of freedom (i.e., become saturated) before we add all of the additional effects, especially if some interactions are not observed in the real data.

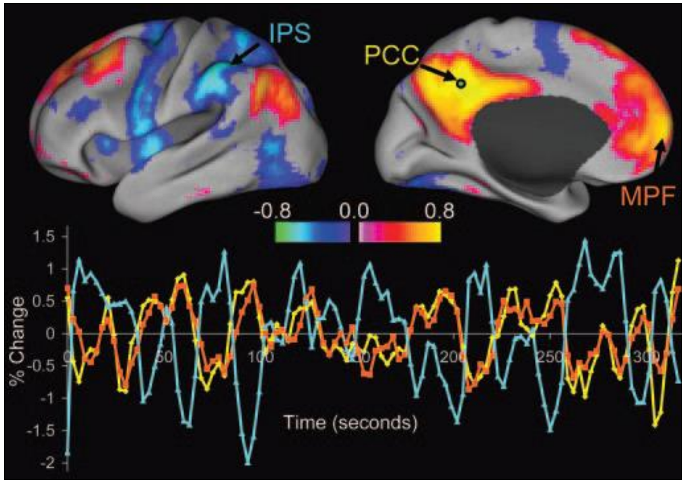
Real-world examples

1. Cognitive neuroscience



2. Cognitive Psychology

Cognitive Neuroscience

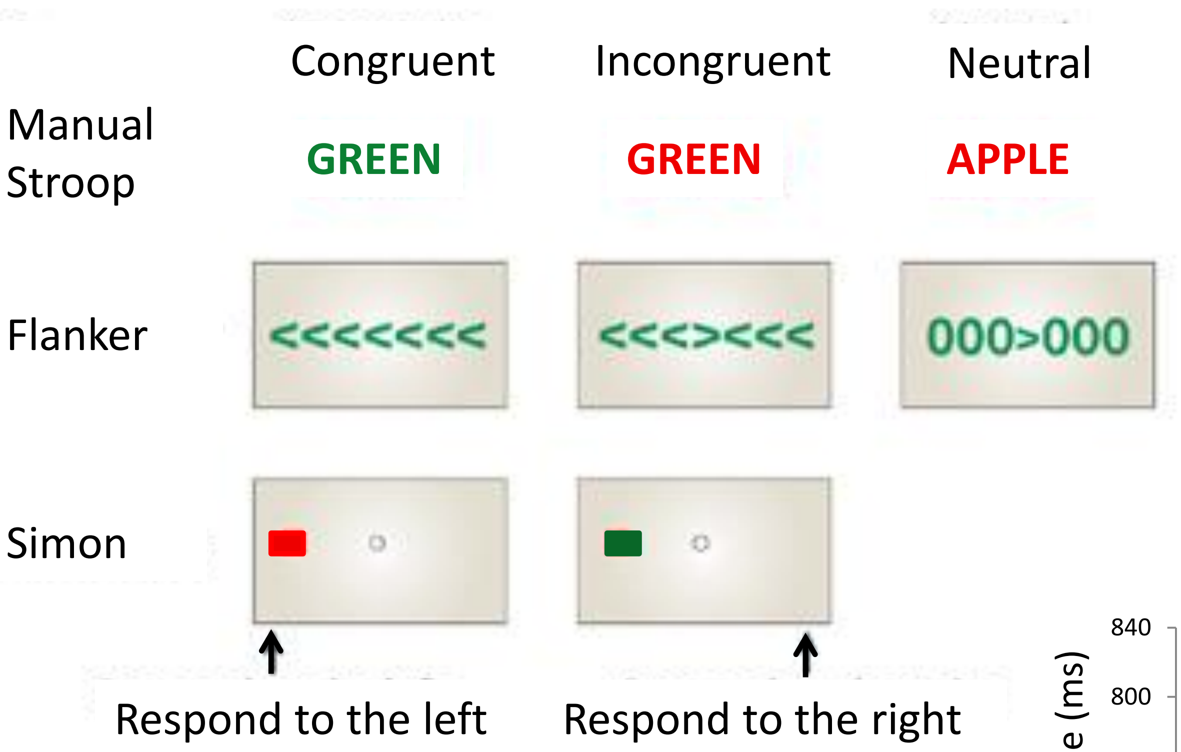


$$\begin{array}{c} \textbf{IPS} \\ \begin{bmatrix} 2 \\ 4 \\ 6 \\ 12 \\ 18 \\ 24 \end{bmatrix} \end{array} = \begin{array}{c} \textbf{PCC} \quad \textbf{Main Effects of Motion} \\ \begin{bmatrix} 1 & .17 & .26 \\ 2 & .63 & .11 \\ 3 & .21 & .02 \\ 1 & .46 & .18 \\ 2 & .23 & .63 \\ 3 & .39 & .54 \end{bmatrix} \end{array}$$

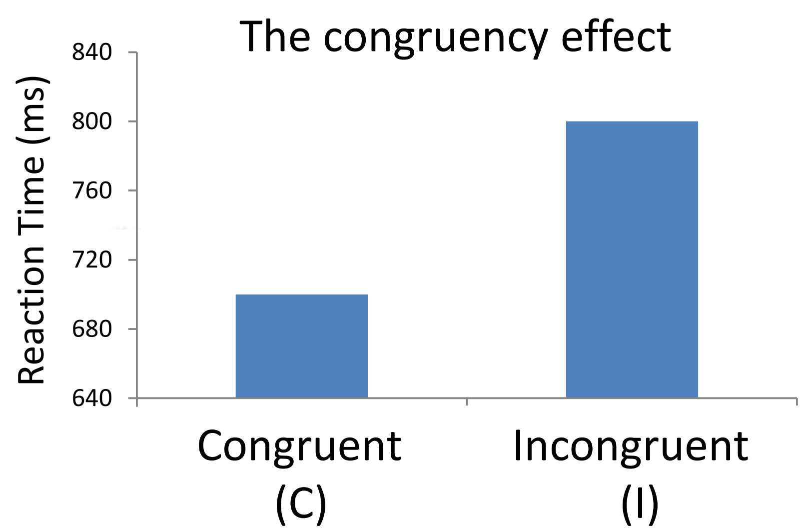
Limitations of Motion Regressors

- Some functional connectivity can be explained by unmodeled interactions involving motion and resting-state functional connectivity (Lemiuex et al., 2007; Satterhwaite et al., 2012).
- These interactions are not completely “regressed out” with linear “main effect” motion regressors (Power et al., 2014).
- In addition, the nature of such interactions is not always clear.
- Therefore, researchers now often delete time points at which motion occurs, rather than trying to model motion confounds.

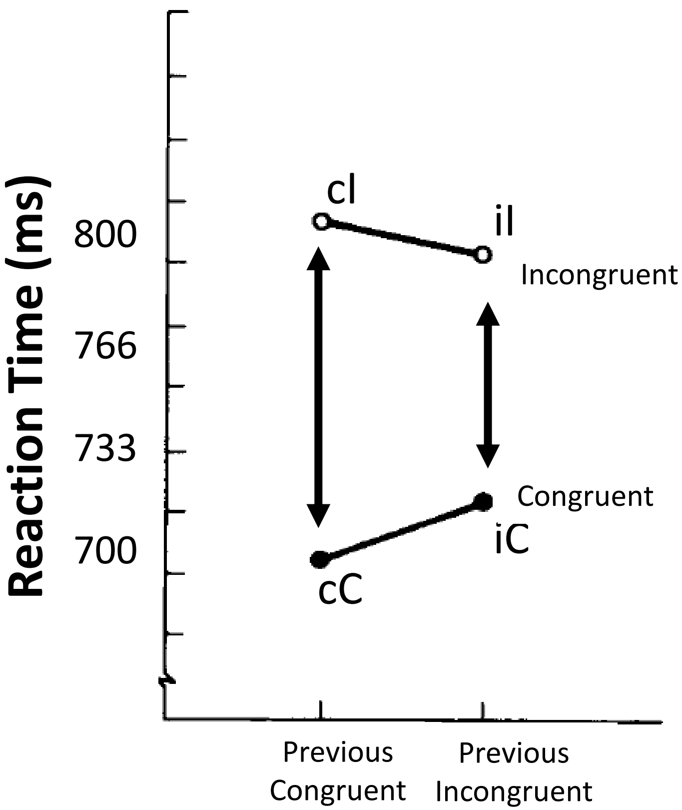
Cognitive Psychology



Adapted from Mansouri et al. (2009)



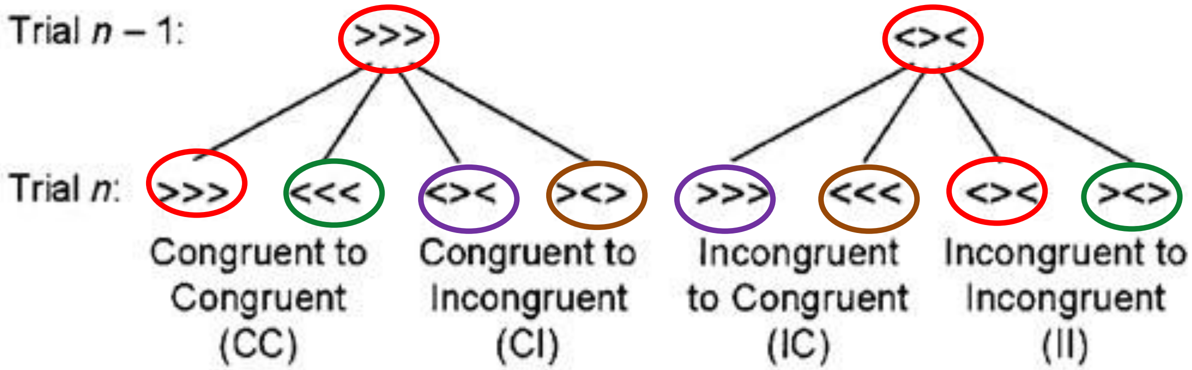
The congruency sequence effect (CSE)



Adapted from
Gratton et al. (1992)

- The CSE is thought to reflect cognitive mechanisms that cope with distraction (Botvinick et al., 2001; Gratton et al., 1992).

Feature repetition Confounds
(Mayr et al., 2003, Nature Neuroscience)



Notebaert & Verguts (2007) presented a method for "regressing out" feature repetition confounds

Table 1
The 15 Experimentally Observable Combinations of Current Congruency, Previous Congruency, and the Four Types of Feature Repetitions

Distractor–distractor:	Repetition (R)								Alternation (A)							
Target–target:	R				A				R				A			
Distractor–target:	R		A		R		A		R		A		R		A	
Target–distractor:	R	A	R	A	R	A	R	A	R	A	R	A	R	A	R	A
Congruent–congruent	✓															✓[a]
Congruent–incongruent							✓			✓						✓[a]
Incongruent–congruent						✓					✓					✓[a]
Incongruent–incongruent				✓				✓				✓	✓	✓	✓	✓[a]

[a] The four cells used in the repetition deletion analysis.

Table 2
Different Linear Combinations of Eight Regressors Were Employed to Predict Mean Reaction Time in 15 Unique Trial Types

Trial type	Congruency	Target–target	Distractor–distractor	Feature integration	Negative priming	Target–distractor	Previous congruency	CSE
Congruent–congruent								
1. $BLUE_{blue} \rightarrow RED_{red}$	0	0	0	1	0	0	0	1
2. $BLUE_{blue} \rightarrow BLUE_{blue}$	0	1	1	1	0	1	0	1
Congruent–Incongruent								
3. $BLUE_{blue} \rightarrow RED_{green}$	1	0	0	1	0	0	0	0
4. $BLUE_{blue} \rightarrow BLUE_{red}$	1	0	1	0	0	1	0	0
5. $BLUE_{blue} \rightarrow RED_{blue}$	1	1	0	0	0	0	0	0
Incongruent–congruent								
6. $RED_{blue} \rightarrow GREEN_{green}$	0	0	0	1	0	0	1	0
7. $RED_{blue} \rightarrow RED_{red}$	0	0	1	0	0	0	1	0
8. $RED_{blue} \rightarrow BLUE_{blue}$	0	1	0	0	0	1	1	0
Incongruent–incongruent								
9. $RED_{blue} \rightarrow GREEN_{yellow}$	1	0	0	1	0	0	1	1
10. $RED_{blue} \rightarrow RED_{green}$	1	0	1	0	0	0	1	1
11. $RED_{blue} \rightarrow GREEN_{blue}$	1	1	0	0	0	0	1	1
12. $RED_{blue} \rightarrow RED_{blue}$	1	1	1	1	0	0	1	1
13. $RED_{blue} \rightarrow GREEN_{red}$	1	0	0	1	1	0	1	1
14. $RED_{blue} \rightarrow BLUE_{green}$	1	0	0	1	0	1	1	1
15. $RED_{blue} \rightarrow BLUE_{red}$	1	0	0	1	1	1	1	1

Note. Although example Stroop trial types from Experiment 1 are provided in the Table, the same analysis was employed with analogous flanker and Simon trial types, respectively, in Experiments 2 and 3.

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COMMENTARY

Removing the Influence of Feature Repetitions on the Congruency Sequence Effect: Why Regressing Out Confounds From a Nested Design Will Often Fall Short

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This article illustrates a shortcoming of using regression to control for confounds in nested designs. As an example, we consider the congruency sequence effect, which is the observation that the congruency effect in distractor interference (e.g., Stroop) tasks is smaller following incongruent as compared with congruent trials. The congruency sequence effect is often interpreted as indexing conflict adaptation: a relative increase of attention to the target following incongruent trials. However, feature repetitions across consecutive trials can complicate this interpretation. To control for this confound, the standard procedure is to delete all trials with a stimulus or response repetition and analyze the remaining trials. Notebaert and Verguts (2007) present an alternative method that allows researchers to use all trials. Specifically, they employ multiple regression to model conflict adaptation independent of feature repetitions. We show here that this approach fails to account for certain feature repetition effects. Furthermore, modeling these additional effects is typically not possible because of an upper bound on the number of degrees of freedom in the experiment. These findings have important implications for future investigations of conflict adaptation and, more broadly, for all researchers who attempt to regress out confounds in nested designs.

Keywords: congruency sequence effects, conflict adaptation, feature repetitions, regression, nesting

Schmidt, De Schryver, & Weissman (2014)

Table 3
Regression Model Results

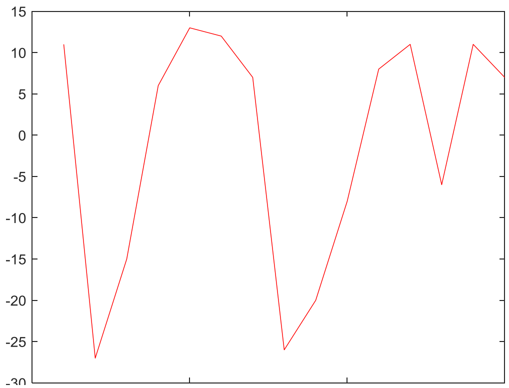
Regressor	Estimate	t	p
Experiment 1			
Intercept	506	27.149	<.001
Current congruency	−57	−14.393	<.001
Target–target	209	53.651	<.001
Distractor–distractor	31	7.960	<.001
Feature integration	15	3.648	<.001
Negative priming	1	0.141	.888
Target–distractor	−2	−0.453	.651
Previous congruency	9	2.327	.020
CSE	7	1.700	.089
Experiment 2			
Intercept	543	36.448	<.001
Current congruency	−36	−13.126	<.001
Target–target	101	37.301	<.001
Distractor–distractor	14	5.355	<.001
Feature integration	17	5.949	<.001
Negative priming	−3	−0.973	.331
Target–distractor	−4	−1.885	.059
Previous congruency	−1	−0.504	.614
CSE	2	0.692	.489
Experiment 3			
Intercept	515	30.990	<.001
Current congruency	−57	−14.480	<.001
Target–target	100	23.166	<.001
Distractor–distractor	18	4.090	<.001
Feature integration	18	4.053	<.001
Negative priming	−13	−2.606	.009
Target–distractor	−2	−0.617	.537
Previous congruency	−4	−0.995	.320
CSE	9	2.163	.031

Note. CSE = congruency sequence effect.

Schmidt, De Schryver, & Weissman (2014)

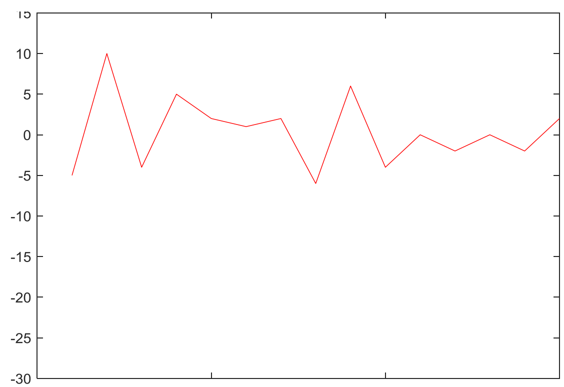
Systematic unmodeled variance in a lack of fit test (One-Way MANOVA)

Experiment 1



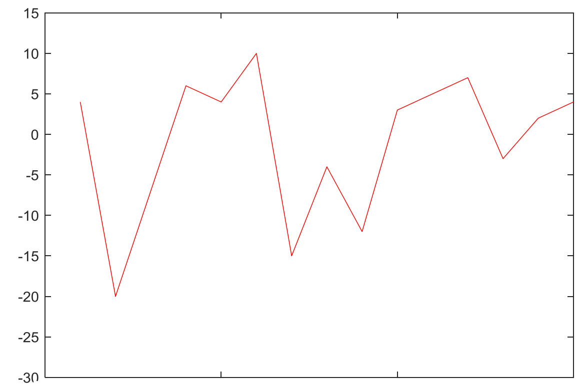
$F(6, 9) = 34.846$, $p < 0.001$

Experiment 2



$F(6, 9) = 2.982$, $p = 0.069$

Experiment 3



$F(6, 9) = 6.613$, $p < 0.01$

<u>Solution:</u> Create selective attention tasks wherein no features repeat across consecutive trials (Schmidt & Weissman, 2014; Weissman, Jiang, & Egner, 2014).

Empirical evidence that unmodeled higher-order interactions exist

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Different Levels of Learning Interact to Shape the Congruency Sequence Effect

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The congruency effect in distracter interference tasks is often reduced after incongruent relative to congruent trials. Moreover, this *congruency sequence effect* (CSE) is influenced by learning related to concrete stimulus and response features as well as by learning related to abstract cognitive control processes. There is an ongoing debate, however, over whether interactions between these learning processes are best explained by an episodic retrieval account, an adaptation by binding account, or a cognitive efficiency account of the CSE. To make this distinction, we orthogonally manipulated the expression of these learning processes in a novel factorial design involving the prime-probe arrow task. In Experiment 1, these processes interacted in an over-additive fashion to influence CSE magnitude. In Experiment 2, we replicated this interaction while showing it was not driven by conditional differences in the size of the congruency effect. In Experiment 3, we ruled out an alternative account of this interaction as reflecting conditional differences in learning related to concrete stimulus and response features. These findings support an episodic retrieval account of the CSE, in which repeating a stimulus feature from the previous trial facilitates the retrieval and use of previous-trial control parameters, thereby boosting control in the current trial. In contrast, they do not fit with (a) an adaptation by binding account, in which CSE magnitude is directly related to the size of the congruency effect, or (b) a cognitive efficiency account, in which costly control processes are recruited only when behavioral adjustments cannot be mediated by low-level associative mechanisms.

Keywords: conflict adaptation, feature integration, cognitive control

Conclusion

- Researchers often regress out confounds by including regressors that code only for the main effects of confounds.
- This leaves unmodeled interactions involving confounds.
- If a regressor of interest is correlated with such unmodeled interactions, it may "steal" variance due to those interactions.
- This could lead to a significant beta value that reflects confounds, rather than (or in addition to) the effect of interest.
  - Thus, it's best to avoid confounds in the experimental design if possible!