Three-Factor ANOVA

PSYC214: Statistics For Group Comparisons

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Week 9

Notes

Learning Objectives

- Procedures for analysing and interpreting three-factor ANOVA
- How to decompose a three-way interaction:
  - splitting the design and analysing it as a series of two-factor ANOVAs
- Examples:
  - $2 \times 2 \times 2$ fully within-participants ANOVA
  - $2 \times 2 \times 2$ mixed ANOVA
- General things to consider

Notes

Three-Factor ANOVA

- Three-factor ANOVAs are common in psychology
- In such designs, there are three possible two-way interactions:
  - A $\times$ B
  - A $\times$ C
  - B $\times$ C
- There is also the possibility of a three-way interaction:
  - A $\times$ B $\times$ C
- Complexity of interpreting these designs arises when the three-way interaction is significant

Notes

Three-Factor ANOVA

- Basic design principles of earlier lectures still apply
- A between-participants design is still relatively simple, with only a single error term for all effects
- However, a $2 \times 2 \times 2$ design would require at least 160 participants (obeying our maxim of $N = 20$ per cell)
- Problems with fully within-participants and mixed designs apply equally to three-factor designs
- Try to avoid exceeding two levels per factor where possible

Notes

Three-Factor ANOVA

- The most straightforward outcome is when the three-way interaction is not significant
- Where this occurs, one or more of the two-way interactions may be significant
- In which case, each significant two-way interaction should be investigated separately of the others
- The procedures for interpreting each interaction are the same as those discussed in previous lectures
- For example, if the A $\times$ B two-way interaction is significant, the simple main effects of factor A at B, and factor B at A can be investigated

Notes

Three-Factor ANOVA

- The simplest case arises when none of the interactions are significant
- In this case, the outcome must be interpreted in terms of the main effects, if any of these are significant
- If nothing is significant, then unless specific pairwise comparisons are planned, the analysis is complete

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Dealing With A Significant Three-Way Interaction

- A significant three-way interaction occurs when there are different two-way interactions between two of the factors according to the levels of the third factor
- The simplest way to analyse a significant three-way interaction is to reanalyse it as a series of two-factor ANOVAs, e.g. :
  1. a 2 (factor A: level A_1 vs. level A_2) $\times$ 2 (factor B: level B_1 vs. level B_2) ANOVA at level C_1 of factor C
  2. a 2 (factor A: level A_1 vs. level A_2) $\times$ 2 (factor B: level B_1 vs. level B_2) ANOVA at level C_2 of factor C
- Any significant interactions would be followed up with a simple main effects analysis

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Memory and Context: A 2 $\times$ 2 $\times$ 2 Fully Within-Participants Design

- A memory researcher wants to know if memory is better when material is tested in the same context it was learned in
- They also want to know whether recall and recognition memory are equally context dependent
- The researcher manipulates three factors in a 2 $\times$ 2 $\times$ 2 fully within-participants design:
  1. memory test (recall vs. recognition)
  2. learning context (learn under water vs. learn land)
  3. testing context (test under water vs. test land)
- Participants given words to remember in a learning context $\rightarrow$ memory for the words tested via recall or recognition
- Dependent measure is the number of words remembered correctly

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Raw Data For Memory and Context Study

Table: A 2 × 2 × 2 factorial design

Factor A: Task	Level A_1 recall				Level A_2 recognition			
Factor B: Learning	Level B_1 under		Level B_2 land		Level B_1 under		Level B_2 land	
Factor C: Testing	C_1 under	C_2 land	C_1 under	C_2 land	C_1 under	C_2 land	C_1 under	C_2 land
P_1	8	5	3	7	5	5	7	6
P_2	9	6	3	8	7	6	5	8
P_3	7	5	4	6	6	7	5	6
P_4	8	4	4	5	7	5	6	5
P_5	6	3	3	8	5	4	6	4

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Aggregate Data For Memory and Context Study

Table: A 2 × 2 × 2 factorial design

	Level A_1 recall task				Level A_2 recognition task		
	Level B_1 under	Level B_2 land	Overall		Level B_1 under	Level B_2 land	Overall
Level C_1 under water	**7.6**	**3.4**	5.5	Level C_1 under water	**6**	**5.8**	5.9
Level C_2 on land	**4.6**	**6.8**	5.7	Level C_2 on land	**5.4**	**5.8**	5.6
Overall	6.1	5.1	5.6		5.7	5.8	5.8

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ANOVA Table For Memory and Context Study

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	P
A (memory task)	0.225	1	0.225	1.000	0.374
Error A × P	0.900	4	0.225		
B (learning context)	2.025	1	2.025	1.588	0.276
Error B × P	5.100	4	1.275		
C (testing context)	0.025	1	0.025	0.014	0.911
Error C × P	7.100	4	1.775		
A × B	3.025	1	3.025	2.951	0.161
Error A × B × P	4.100	4	1.025		
A × C	0.625	1	0.625	0.714	0.446
Error A × C × P	3.500	4	0.875		
B × C	30.625	1	30.625	27.222	0.006
Error B × C × P	4.500	4	1.125		
A × B × C	21.025	1	21.025	27.129	0.006
Error A × B × C × P	3.10	4	0.775		
P (participants)	10.900	4	2.733		

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Interpreting The Significant Three-Way Interaction

- To decompose our significant three-way interaction, we first need to decide which factor to split our design by
- The obvious choice is factor A (memory task: recall vs. recognition)
- Next, we perform two two-factor ANOVAs:
  1. 2 (learning context: learn under water vs. learn land) × 2 (testing context: test under water vs. test land) ANOVA for the recall memory test condition only
  2. 2 (learning context: learn under water vs. learn land) × 2 (testing context: test under water vs. test land) ANOVA for the recognition memory test condition only

Notes

ANOVA Table For Recall Memory Task

Source	Sum of Squares	Degrees of Freedom	Mean Square	*F*	*P*
B (learning context)	5.000	1	5.000	3.636	0.129
Error B × P	5.500	4	1.375		
C (testing context)	0.200	1	0.200	0.186	0.688
Error C × P	4.300	4	1.075		
B × C	51.200	1	51.200	62.061	0.001
Error B × C × P	3.300	4	0.825		
P (participants)	5.300	4	1.333		

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Simple Main Effects Table For Recall Memory Task

Source	Sum of Squares	Degrees of Freedom	Mean Square	*F*	*P*
learning context at					
test under water	44.100	1	44.100	32.073	0.005
test land	12.100	1	12.100	8.800	0.041
Error term	5.50	4	1.375		
testing context at					
learn under water	22.500	1	22.500	20.930	0.010
learn land	28.900	1	28.900	26.884	0.007
Error term	4.300	4	1.075		

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ANOVA Table For Recognition Memory Task

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	P
B (learning context)	0.050	1	0.050	0.054	0.828
$Error\ B \times P$	3.700	4	0.925		
C (testing context)	0.450	1	0.450	0.286	0.621
$Error\ C \times P$	6.300	4	1.575		
$B \times C$	0.450	1	0.450	0.419	0.553
$Error\ B \times C \times P$	4.300	4	1.075		
P (participants)	6.500	4	1.633		

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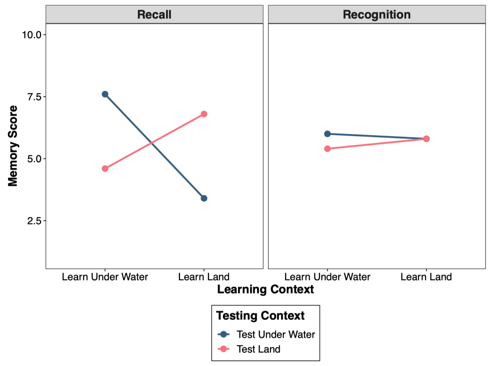
Interaction Plots For Memory and Context Study



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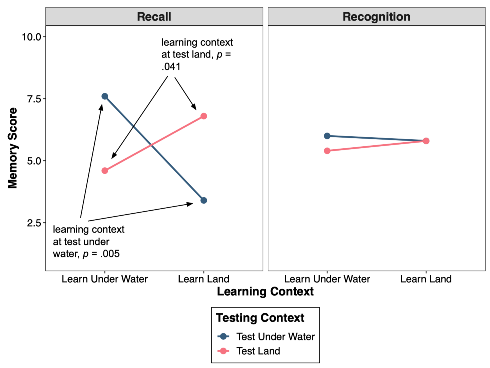

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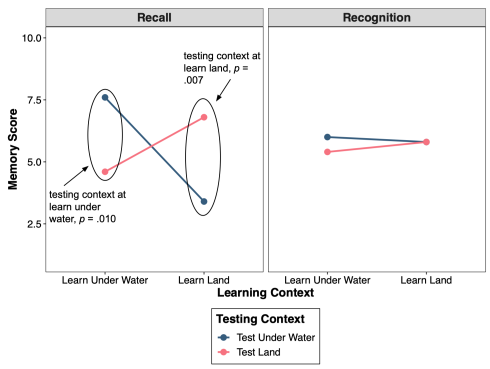

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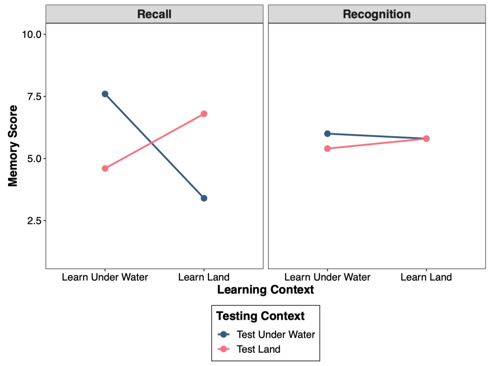

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Learning To Pronounce Irregular Words: A 2 $\times$ 2 $\times$ 2 Mixed Design

- A researcher wants to investigate the development in children's ability to pronounce regular and irregular words
- The researcher adopts a 2 $\times$ 2 $\times$ 2 mixed design:
  1. age (7 years old vs. 9 years old) is between-participants
  2. word frequency (low vs. high) is within-participants
  3. word type (regular vs. irregular) is within-participants
- Participants are given 10 words to pronounce in each category (40 words in total)
- Dependent measure is the number of pronunciation errors

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Raw Data For Word Pronunciation Study

Table: A 2 $\times$ 2 $\times$ 2 factorial design

Factor A: Age	*Level A_1 7-years-old*					*Level A_2 9-years-old*			
Factor B: Frequency	*Level B_1 high*		*Level B_2 low*			*Level B_1 high*		*Level B_2 low*	
Factor C: Word type	*C_1 reg*	*C_2 irr*	*C_1 reg*	*C_2 irr*		*C_1 reg*	*C_2 irr*	*C_1 reg*	*C_2 irr*
P_1	6	7	5	6	P_6	4	4	3	6
P_2	7	5	6	7	P_7	3	4	4	7
P_3	5	6	7	6	P_8	4	3	5	9
P_4	6	7	5	7	P_9	5	5	3	8
P_5	6	6	5	7	P_{10}	3	4	3	7

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Aggregate Data For Word Pronunciation Study

Table: A 2 $\times$ 2 $\times$ 2 factorial design

	Level A_1 7-years-old				*Level A_2 9-years-old*		
	Level B_1 high	*Level B_2 low*	*Overall*		*Level B_1 high*	*Level B_2 low*	*Overall*
Level *C_1 regular*	6.0	5.6	5.8	Level *C_1 regular*	3.8	3.6	3.7
Level *C_2 irregular*	6.2	6.6	6.4	Level *C_2 irregular*	4.0	7.4	5.7
Overall	6.1	6.1	6.1		3.9	5.5	4.7

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ANOVA Table For Word Pronunciation Study

Source	Sum of Squares	Degrees of Freedom	Mean Square	*F*	*P*
A (age)	19.600	1	19.600	34.844	< .001
Between error S/A	4.500	8	0.562		
B (frequency)	6.400	1	6.400	5.885	0.042
Error B × S/A	8.700	8	1.087		
C (word type)	16.900	1	16.900	36.541	< .001
Error C × S/A	3.700	8	0.462		
A × B	6.400	1	6.400	5.885	0.042
Error B × S/A	8.700	8	1.087		
A × C	4.900	1	4.900	10.595	0.012
Error C × S/A	3.700	8	0.462		
B × C	12.100	1	12.100	17.600	0.003
Error B × C × S/A	5.500	8	0.688		
A × B × C	4.900	1	4.900	7.127	0.028
Error B × C × S/A	5.500	8	0.688		

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Interpreting The Significant Three-Way Interaction

- To decompose our significant three-way interaction, we first need to decide which factor to split our design by
- The obvious choice is our between-participants factor A (age: 7 year olds vs. 9 year olds)
- Next, we perform two two-factor ANOVAs:
  1. 2 (frequency: low vs. high) × 2 (word type: regular vs. irregular) ANOVA for the 7 year olds only
  2. 2 (frequency: low vs. high) × 2 (word type: regular vs. irregular) ANOVA for the 9 year olds only

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ANOVA Table For 7 Year Olds

Source	Sum of Squares	Degrees of Freedom	Mean Square	*F*	*P*
B (frequency)	0.000	1	0.000	0.000	1.000
Error B × P	2.500	4	0.625		
C (word type)	1.800	1	1.800	5.885	0.178
Error C × P	2.700	4	0.675		
B × C	0.800	1	0.800	5.885	0.405
Error B × C × P	3.700	4	0.925		
P (participants)	0.300	4	0.075		

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ANOVA Table For 9 Year Olds

Source	Sum of Squares	Degrees of Freedom	Mean Square	*F*	*P*
B (frequency)	12.800	1	12.800	8.258	0.045
Error B × *P*	6.200	4	1.550		
C (word type)	20.000	1	20.000	80.000	< .001
Error C × *P*	1.000	4	0.250		
B × *C*	16.200	1	16.200	36.000	0.004
Error B × *C* × *P*	1.800	4	0.450		
P (participants)	4.200	4	1.050		

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B × *C*	16.200	1	16.200	36.000	0.004
Error B × *C* × *P*	1.800	4	0.450		
P (participants)	4.200	4	1.050		

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Simple Main Effects Table For 9 Year Olds

Source	Sum of Squares	Degrees of Freedom	Mean Square	*F*	*P*
word frequency at					
regular words	0.100	1	0.100	0.065	0.812
irregular words	28.900	1	28.900	18.645	0.013
Error term	6.200	4	1.550		
word type at					
low frequency	36.100	1	36.100	144.400	< .001
high frequency	0.100	1	0.100	0.400	0.561
Error term	1.000	4	0.250		

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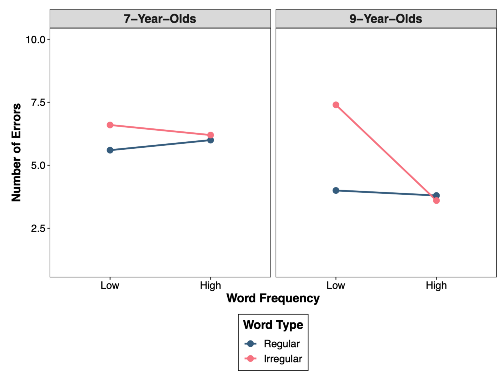

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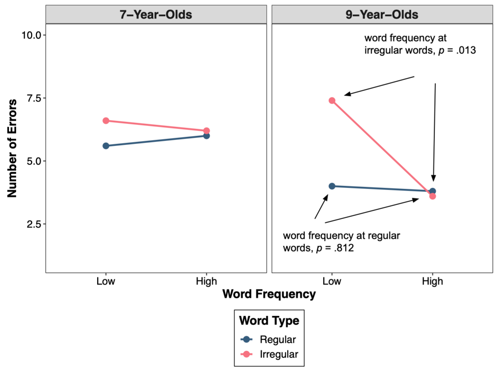

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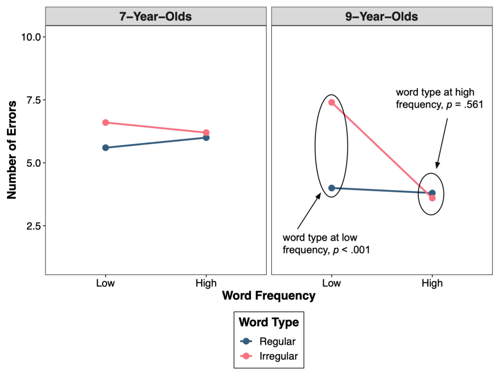
Interaction Plots For Word Pronunciation Study



PSYC214: Statistics for Group Comparisons
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Three-Factor ANOVA
Memory and Context
Data
ANOVA Table
Recall ANOVA Table
Recall Simple Main Effects Table
Recognition ANOVA Table
Interaction Plots
Pronouncing Words
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ANOVA Table
7 Year Old ANOVA Table
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Concluding Remarks
Three-Way Interactions
General Points

Notes

A Final Note On Interpreting Three-Way Interactions

- In both of these examples, one of the two-factor ANOVAs returned a significant interaction, whereas the other returned a non-significant interaction
- This will **not** always be the case
- Sometimes the interaction for each two-factor ANOVA will be significant and both will need to be followed up with a simple main effects analysis
- Under these conditions, the simple main effects for the two interactions will differ in direction and/or size of their trends

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General Points

- As always, start at the bottom of the ANOVA table and work your way up
- If the three-way interaction is significant, then this must be analysed
- If not, then each of the significant two-way interactions should be analysed independently
- If none of the two-way interactions is significant, the ANOVA results may be described in terms of the main effects, with follow-up tests for any factors with three or more levels

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In Next Week's Lab ...

- Running a three-factor (fully within-participants and mixed) ANOVA in R

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Roberts, M. J., & Russo, R. (1999, Chapter 12). *A student's guide to Analysis of Variance*. Routledge: London.

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