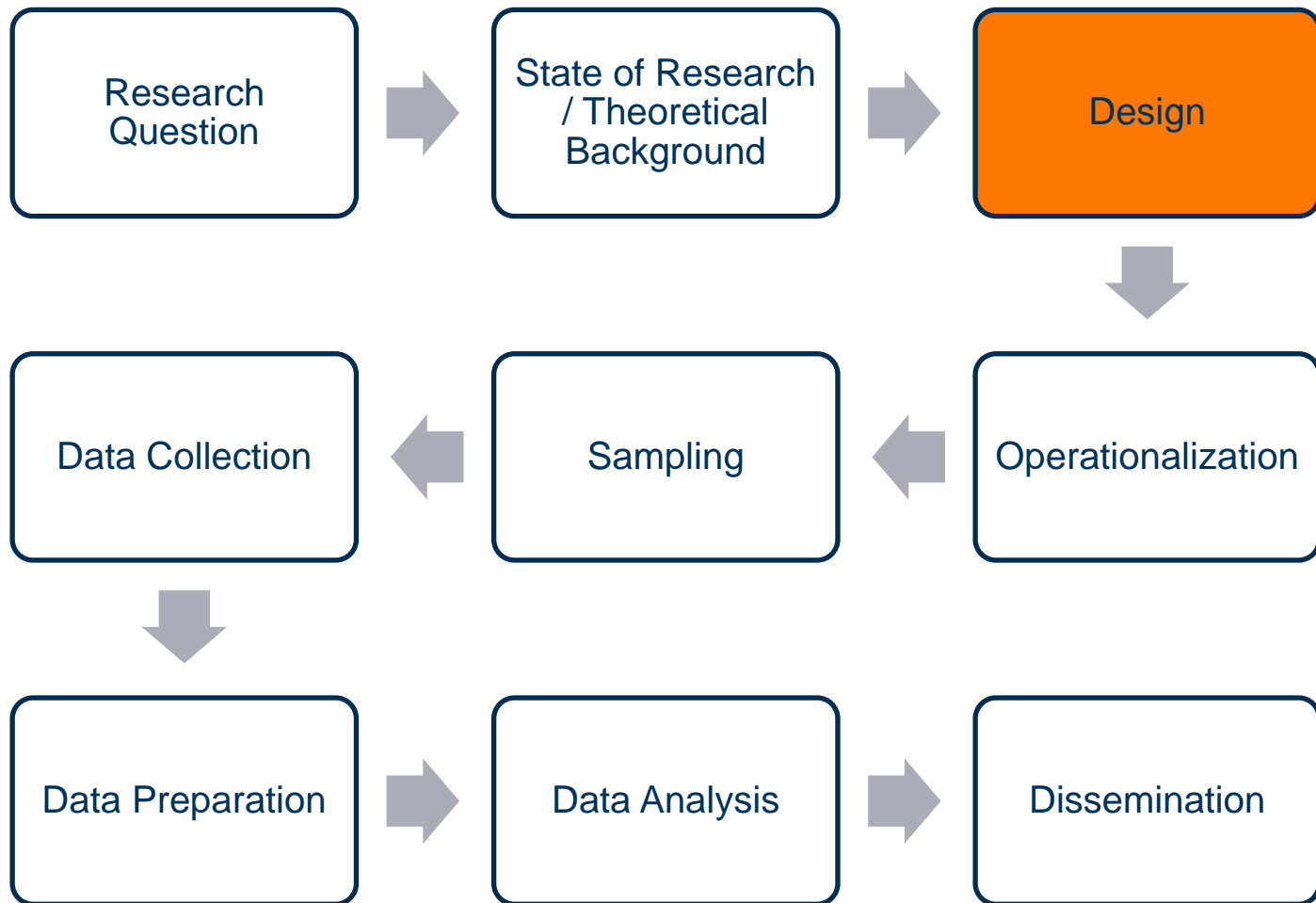


Workshop Research Methods and Statistical Analysis

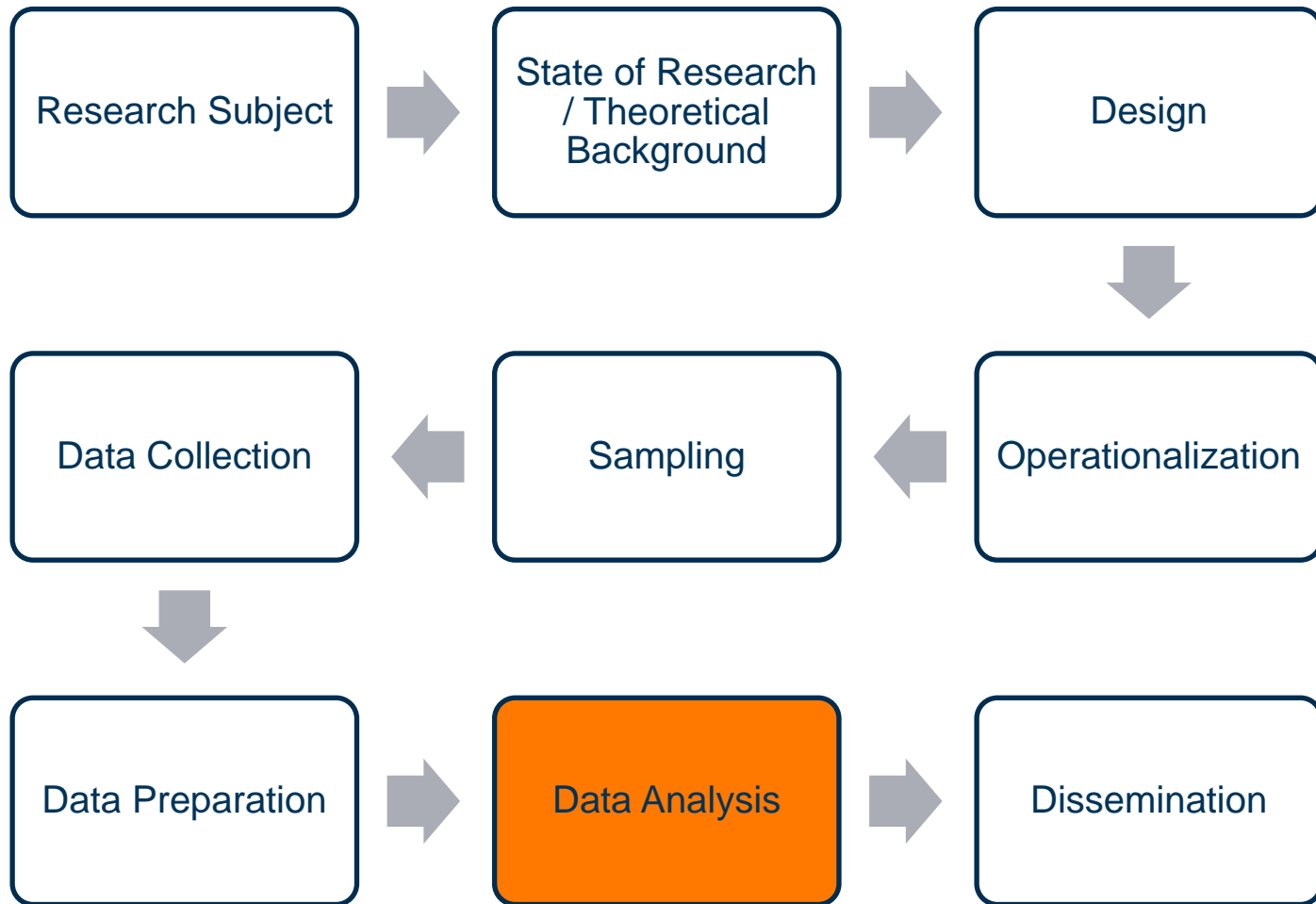
Session 2 – Data Analysis

Sandra Poeschl

Research process



Research process



Designs we will deal with

- Experimental designs
 - Quantitative
 - Empirical
 - Explanatory
 - Sample study
- Frequency of measurements as an effect on choice of statistical tests
 - Cross-sectional
 - Repeated measures

Agenda

- Descriptive and inferential statistics
- Indication (which test?)
- Two groups (experimental / control)
 - t-Test for independent and dependent samples
- One-way (1 factor)
 - One-way ANOVA
- Multi-factorial (several factors)
 - Two-way ANOVA, within-between subjects

DESCRIPTIVE AND INFERENCEAL STATISTICS

Descriptive vs. inferential

Descriptive statistics

- Reporting sample data
 - Measures of location (arithmetic mean, median, mode)
 - Measures of spread (range, variance, standard deviation)
 - Correlations
 - frequencies
- Reported in text, also tables, graphs

Inferential statistics

- Inference from sample data to population effects
- Parameter estimation
 - Point & interval estimation
- Testing hypotheses
- Significance tests

Descriptive vs. inferential in explanatory studies

Descriptive statistics

- Describing the sample
- Complementary presentation of sample statistics for tested hypotheses

Inferential statistics

- Testing hypotheses
- Significance tests

WHICH TEST?

How do I choose the appropriate test?

- Type of hypothesis
 - **Difference**, correlation, change
- Number of groups / treatments or variables
- Levels of measurement
 - nominal, ordinal, interval / ratio

Level of measurement

	Affiliation to Category	Rank order	Same differences between gradings	Absolute zero
Nominal	+			
Ordinal	+	+		
Interval	+	+	+	
Ratio	+	+	+	+

Nominal: eye color

Ordinal: level of education

Interval: opinion, date

Ratio: age

TWO GROUPS

2-Groups (Treatment / Control)

- 1 IV, dichotomous,
1 DV, metric
(univariate)
 - Cross-sectional or repeated measures
 - t-Test (independent / dependent samples)

No sound	Spatial sound

IV: sound (no sound/spatial sound)

DV: error rate in an orientation task

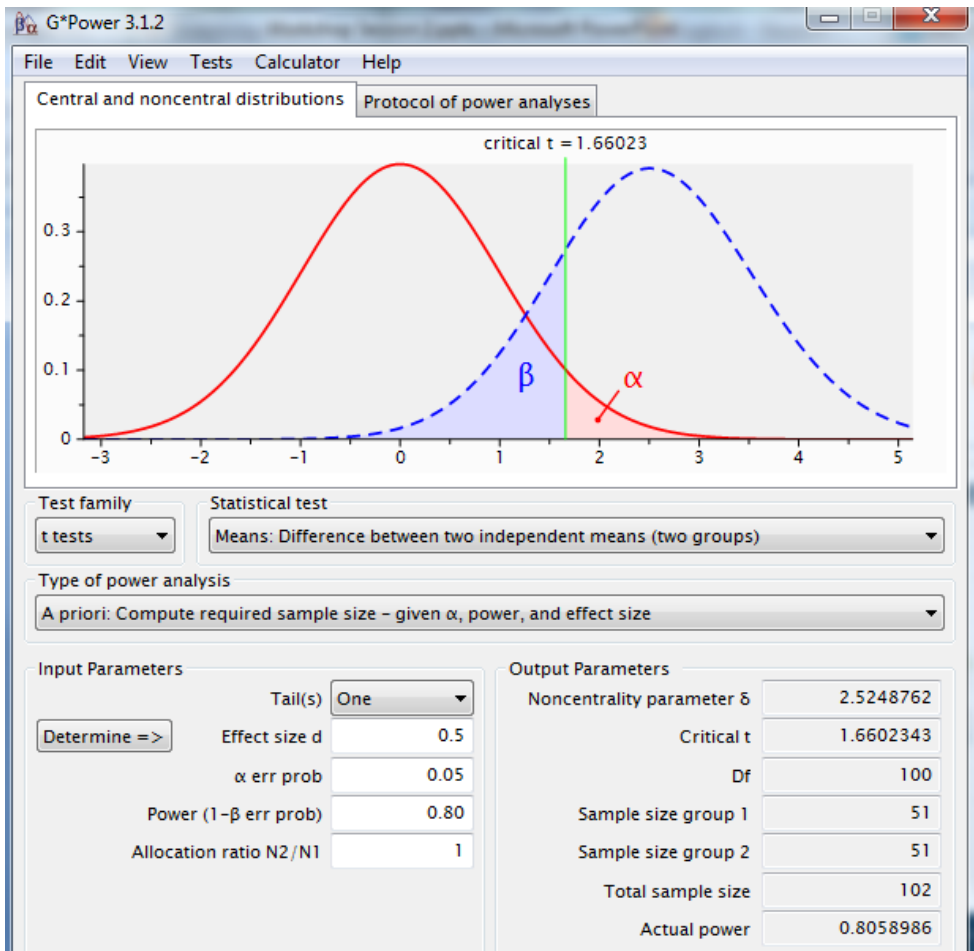
Which test?

- H1: Integrating spatial sound in a VE leads to lower error rates in an orientation task than a no-sound display.
- Hypothesis on a difference
- Independent samples
- 1 independent variable, 2 groups (no sound / spatial sound)
- 1 dependent variable (ratio)
- → Student's t-Test

Requirements Student's t-Test

- Level of measurement of DV at least interval
- Normal distribution of DV
- Variances σ_A and σ_B are equal
- Levene's Test for equality of variances, corrections of df.
- Sample within groups should be very similar, $n_A = n_B > 30$.
- Non-parametric alternative: Mann-Whitney U-Test

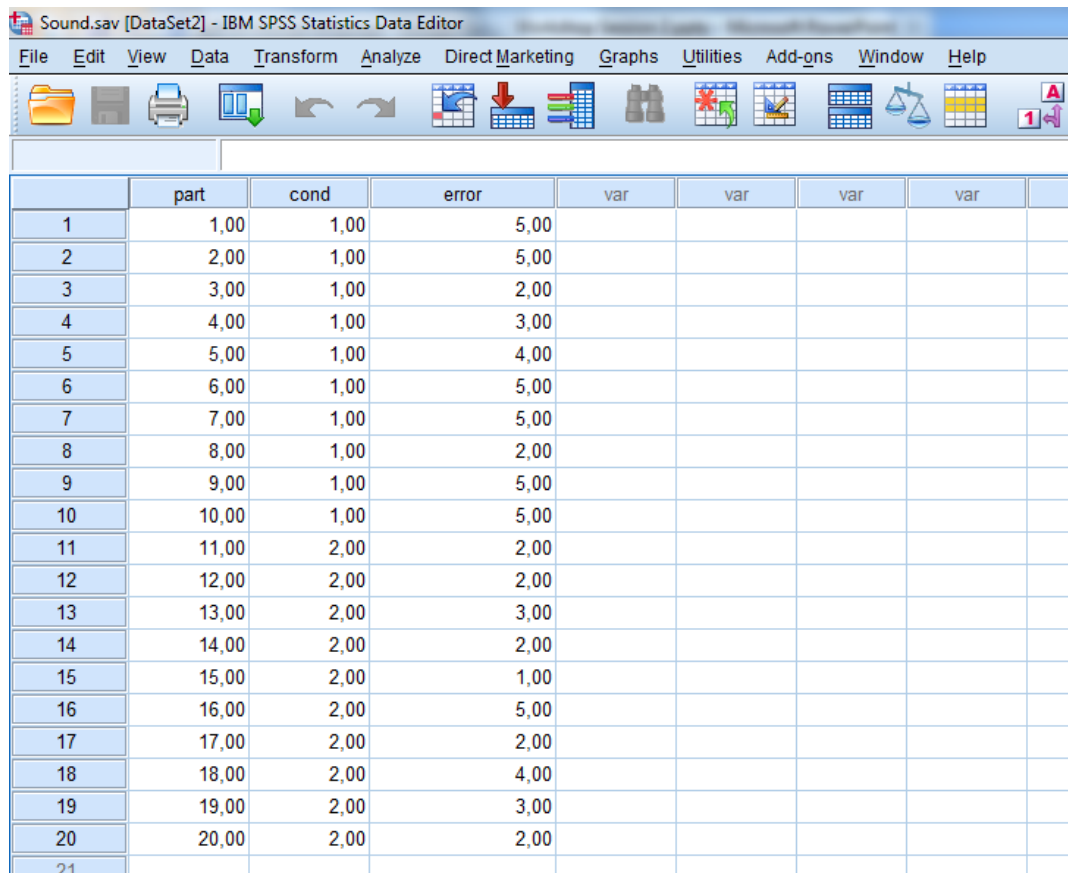
A priori power analysis



- Test family: t tests
- Statistical test: Means: Differences between two independent means
- Type of power analysis: A priori
- Medium effect size $d = .5$
- $\alpha = .05$
- $1 - \beta = .80$
- Allocation ratio = 1

- Sample size / group = 51
- Total sample size = 102

The data set



	part	cond	error	var	var	var	var	v
1	1,00	1,00	5,00					
2	2,00	1,00	5,00					
3	3,00	1,00	2,00					
4	4,00	1,00	3,00					
5	5,00	1,00	4,00					
6	6,00	1,00	5,00					
7	7,00	1,00	5,00					
8	8,00	1,00	2,00					
9	9,00	1,00	5,00					
10	10,00	1,00	5,00					
11	11,00	2,00	2,00					
12	12,00	2,00	2,00					
13	13,00	2,00	3,00					
14	14,00	2,00	2,00					
15	15,00	2,00	1,00					
16	16,00	2,00	5,00					
17	17,00	2,00	2,00					
18	18,00	2,00	4,00					
19	19,00	2,00	3,00					
20	20,00	2,00	2,00					
21								

- One case per row
- One variable per column
- Part = participant #
- Cond = condition
- Error = error rate

Independent Samples t-Test

The screenshot shows the IBM SPSS Statistics Data Editor interface. The 'Analyze' menu is open, and the path 'Analyze > Compare Means > Independent-Samples T Test...' is highlighted. The data table below shows two columns: 'part' and 'cond'.

	part	cond
1	1,00	1,0
2	2,00	1,0
3	3,00	1,0
4	4,00	1,0
5	5,00	1,0
6	6,00	1,0
7	7,00	1,0
8	8,00	1,0
9	9,00	1,0
10	10,00	1,0
11	11,00	2,0
12	12,00	2,0
13	13,00	2,0
14	14,00	2,0
15	15,00	2,0
16	16,00	2,0
17	17,00	2,0
18	18,00	2,0
19	19,00	2,0
20	20,00	2,0
21		

Analyze /
Compare Means /
Independent-Samples
T Test

Independent Samples t-Test

The screenshot shows the IBM SPSS Statistics Data Editor interface. The main window displays a dataset with the following data:

	part	cond	error	var	var	var	var	var	var	var	var	var
1	1,00	1,00	5,00									
2	2,00	1,00	5,00									
3	3,00	1,00	2,00									
4	4,00	1,00	3,00									
5	5,00	1,00	4,00									
6	6,00	1,00	5,00									
7	7,00	1,00	5,00									
8	8,00	1,00	2,00									
9	9,00	1,00	5,00									
10	10,00	1,00	5,00									
11	11,00	2,00	2,00									
12	12,00	2,00	2,00									
13	13,00	2,00	3,00									
14	14,00	2,00	2,00									
15	15,00	2,00	1,00									
16	16,00	2,00	5,00									
17	17,00	2,00	2,00									
18	18,00	2,00	4,00									
19	19,00	2,00	3,00									
20	20,00	2,00	2,00									
21												
22												
23												

Two dialog boxes are overlaid on the data editor:

- Independent-Samples T Test**: The "Test Variable(s)" list contains "Number of errors [er...". The "Grouping Variable:" list contains "cond(? ?)".
- Define Groups**: The "Use specified values" radio button is selected. "Group 1:" is set to 1 and "Group 2:" is set to 2.

Determine Grouping Variable → Condition

SPSS Output

Group Statistics ^a					
	condition ^a	N ^a	Mean ^a	Std. Deviation ^a	Std. Error Mean ^a
Number of errors	no sound ^a	10	4,1000	1,28668	,40689
	spatial sound ^a	10	2,6000	1,17379	,37118

Independent-Samples Test ^a										
		Levene's Test for Equality of Variances ^a		t-test for Equality of Means ^a						
		F ^a	Sig. ^a	t ^a	df ^a	Sig. (2-tailed) ^a	Mean Difference ^a	Std. Error Difference ^a	95% Confidence Interval of the Difference ^a	
									Lower ^a	Upper ^a
Number of errors	Equal variances assumed ^a	,321	,578	2,724	18	,014	,50000	,55076	,34290	2,65710
	Equal variances not assumed ^a			2,724	17,850	,014	1,50000	,55076	,34221	2,65779

Effect size

- Test family: t tests
- Statistical test: Means: Difference between 2 independent means
- Type of power analysis: post hoc
- Determine Effect Size (Means, SD)
- Sample Sizes

Central and noncentral distributions Protocol of power analyses

critical t = 1.73406

Test family: t tests
Statistical test: Means: Difference between two independent means (two groups)
Type of power analysis: Post hoc: Compute achieved power - given α , sample size, and effect size

Input Parameters: Tail(s) One, Effect size d 1.2180638, α err prob 0.05, Sample size group 1 10, Sample size group 2 10

Output Parameters: Noncentrality parameter δ 2.7236735, Critical t 1.7340636, Df 18, Power ($1 - \beta$ err prob) 0.8350296

Secondary window: n1 != n2, Mean group 1 0, Mean group 2 1, SD σ within each group 0.5
 n1 = n2, Mean group 1 4.1, Mean group 2 2.6, SD σ group 1 1.29, SD σ group 2 1.17
Calculate Effect size d 1.218064
Calculate and transfer to main window
Close

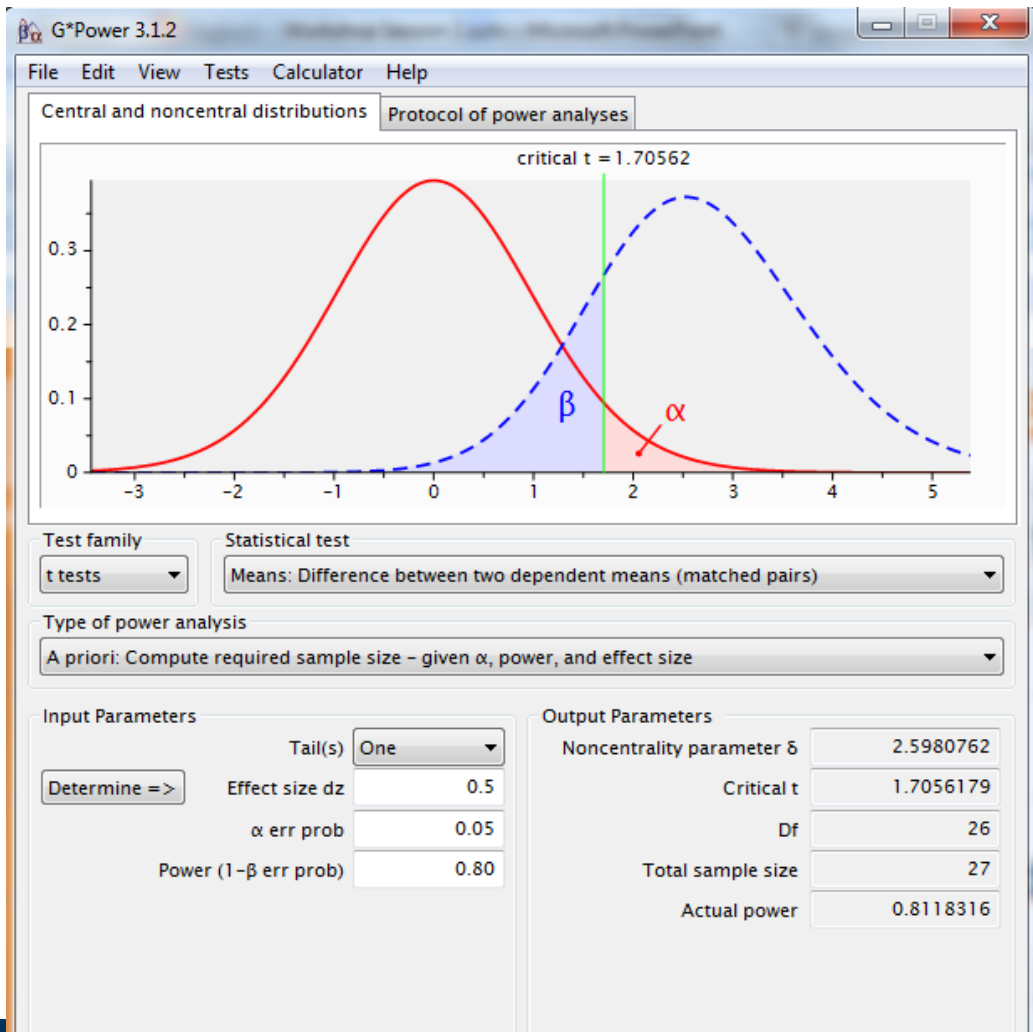
Results

- H1: Integrating spatial sound in a VE leads to lower error rates in an orientation task than a no-sound display.
- $M_{\text{no sound}} = 4.10$ (SD = 1.29; $n = 10$)
- $M_{\text{spatial sound}} = 2.6$ (SD = 1.17; $n = 10$)
- $d = 1.22$ (large)
- $t = 2.72$; $df = 18$; $p < .05$
- $\rightarrow H_0$ is rejected

Which test?

- H1: Integrating spatial sound in a VE leads to lower error rates in an orientation task than a no-sound display.
- Hypothesis on a difference
- Dependent samples
- 1 independent variable, 2 groups (no sound / spatial sound), within-subjects
- 1 dependent variable (ratio)
- → Student's t-Test for paired samples

A priori power analysis



- Test family: Means: Difference between two dependent means
- Type of power analysis: A priori
- Medium effect size $d = .5$
- $\alpha = .05$
- $1 - \beta = .80$

Total sample size = 27

Data Set

Sound_dependent.sav [DataSet2] - IBM SPSS Statistics Data Editor

File Edit View Data Transform Analyze Direct Marketing Graphs Utilities Add-ons Window Help

	u_teilnehmer_ref	error_nosound	error_sound	var	var	var	var	v
1	Proband01	3	3					
2	Proband02	6	7					
3	Proband03	3	3					
4	Proband04	3	2					
5	Proband06	5	4					
6	Proband07	5	4					
7	Proband08	4	2					
8	Proband10	2	3					
9	Proband11	4	2					
10	Proband14	3	4					
11	Proband16	6	3					
12	Proband17	3	2					
13	Proband18	6	2					
14	Proband19	5	4					
15	Proband20	6	4					
16	Proband21	4	5					
17	Proband23	4	3					
18	Proband24	3	4					
19	Proband25	5	3					
20	Proband26	4	5					
21	Proband27	4	3					
22	Proband28	3	4					
23	Proband29	3	3					

Data View Variable View

2 variables / participant:
dependent variable for
condition 1 and condition 2

Paired-Samples t-Test

The screenshot shows the IBM SPSS Statistics Data Editor interface. The 'Analyze' menu is open, and the path 'Analyze > Compare Means > Paired-Samples T Test...' is highlighted. The background shows a data table with columns 'u_teilnehmer_ref' and 'var'.

	u_teilnehmer_ref	var	var
1	Proband01		
2	Proband02		
3	Proband03		
4	Proband04		
5	Proband06		
6	Proband07		
7	Proband08		
8	Proband10		
9	Proband11		
10	Proband14		
11	Proband16		
12	Proband17		
13	Proband18		
14	Proband19		
15	Proband20		
16	Proband21		
17	Proband23		
18	Proband24		
19	Proband25		
20	Proband26		
21	Proband27	4	3
22	Proband28	3	4
23	Proband29	3	3

Analyze / Compare Means /
Paired-Samples T-Test

Paired-Samples t-Test

The screenshot shows the IBM SPSS Statistics Data Editor interface. The main window displays a dataset with the following data:

	u_teilnehmer_ref	error_nosound	error_sound	var	var	var	var
1	Proband01	3	3				
2	Proband02	6	7				
3	Proband03	3	3				
4	Proband04						
5	Proband06						
6	Proband07						
7	Proband08						
8	Proband10						
9	Proband11						
10	Proband14						
11	Proband16						
12	Proband17						
13	Proband18						
14	Proband19						
15	Proband20						
16	Proband21						
17	Proband23						
18	Proband24						
19	Proband25	5	3				
20	Proband26	4	5				
21	Proband27	4	3				
22	Proband28	3	4				
23	Proband29	3	3				

The Paired-Samples T Test dialog box is open, showing the following configuration:

- Paired Variables:

Pair	Variable1	Variable2
1	error rat...	error rat...
2		
- Buttons: Options..., Bootstrap..., OK, Paste, Reset, Cancel, Help

Determine paired variables

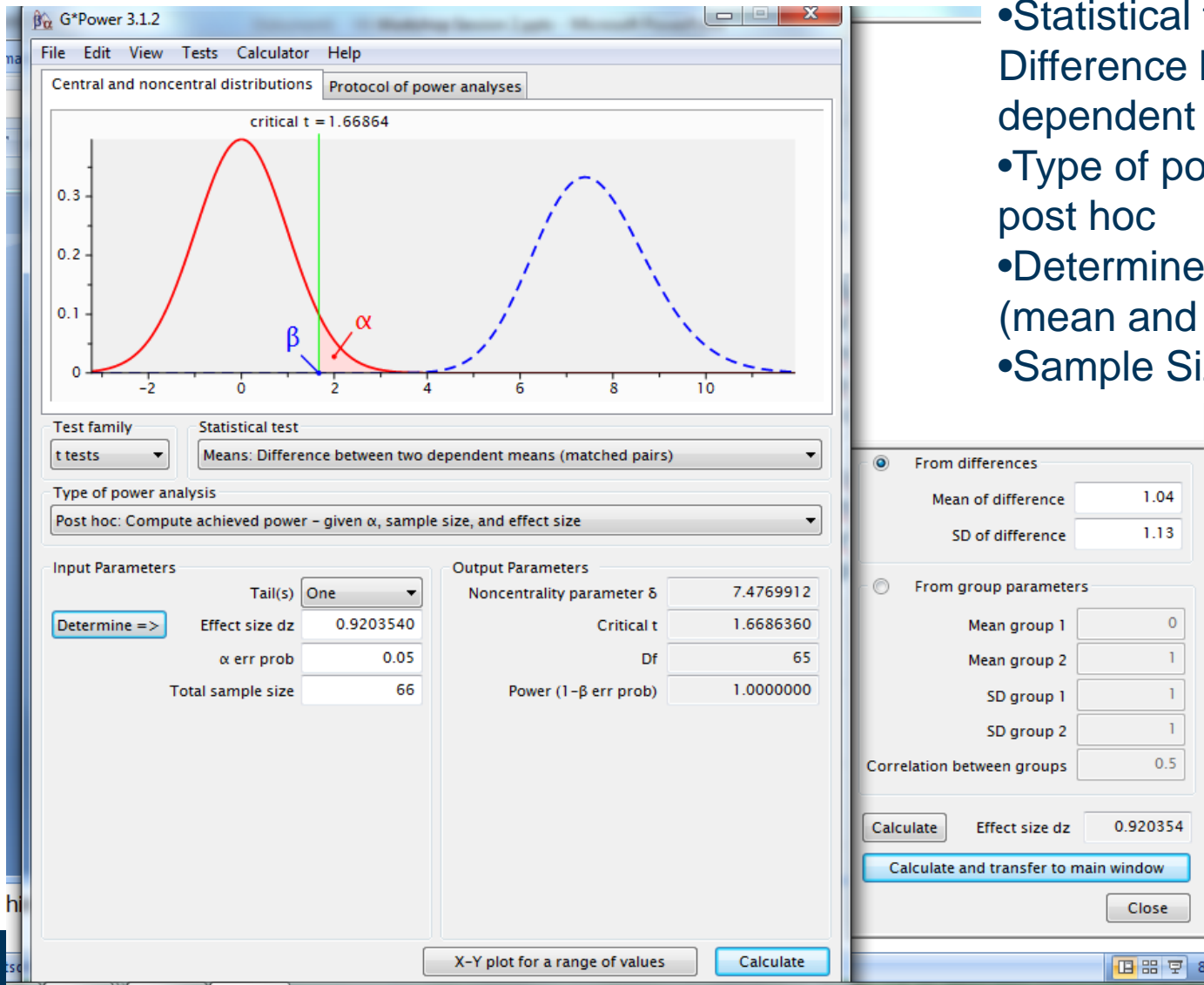
SPSS Output

Paired-Samples-Statistics ^a							
		Mean ^a	N ^a	Std. Deviation ^a	Std. Error Mean ^a		
Pair 1 ^a	error-rate-no-sound-condition ^a	4,19 ^a	66 ^a	1,282 ^a	,158 ^a		
	error-rate-sound-condition ^a	3,15 ^a	66 ^a	1,358 ^a	,167 ^a		

Paired-Samples-Test ^a									
		Paired-Differences ^a				t ^a	df ^a	Sig. (2-tailed) ^a	
		Mean	Std. Deviation	Std. Error Mean ^a	95% Confidence Interval of the Difference ^a				
Lower ^a	Upper ^a								
Pair 1 ^a	error-rate-no-sound-condition - error-rate-sound-condition ^a	1,035 ^a	1,128 ^a	,139 ^a	,758 ^a	1,313 ^a	7,455 ^a	65 ^a	,000 ^a

Effect size

- Test family: t tests
- Statistical test: Means: Difference between 2 dependent means
- Type of power analysis: post hoc
- Determine Effect Size (mean and SD of difference)
- Sample Size



Results

- H1: Integrating spatial sound in a VE leads to lower error rates in an orientation task than a no-sound display.
- $M_{\text{no sound}} = 4.19$ (SD = 1.28; n = 66)
- $M_{\text{spatial sound}} = 3.15$ (SD = 1.36; n = 66)
- $d = .92$ (large)
- $t = 7.46$; $df = 65$; $p < .0001$
- $\rightarrow H_0$ is rejected

ONE-WAY (1 FACTOR)

One-way ANOVA

- One-way, univariate:
 - 1 IV, more than 2 levels (nominal), 1 DV (metric)
 - Cross-sectional or repeated measures
 - One-way, univariate ANOVA (repeated measures)

FOR 20	FOR 90	FOR 270

IV: FOR (20 degrees/90 degrees/270 degrees)

DV: error rate in search task

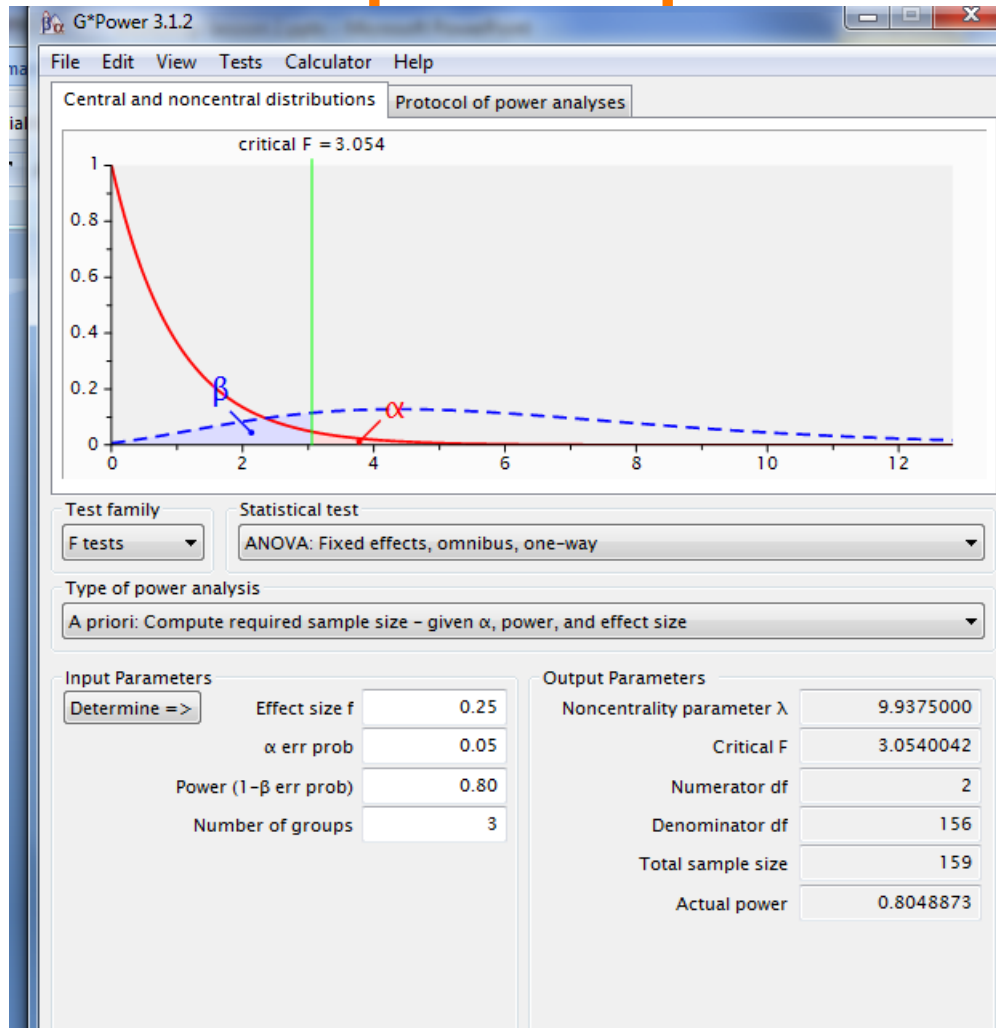
Which test?

- H1: Higher field of regard leads to reduced error rate in a search task.
- Hypothesis on a difference
- Independent samples / between-subjects
- 1 independent variable, 3 groups (FOR 20 / FOR90 / FOR270)
- 1 dependent variable (ratio)
- → One-way univariate ANOVA

Requirements ANOVA

- DV = interval / ratio
- normal distribution for DV
- $N > 20$ per cell
- $N_{\max} / n_{\min} < 1.5$
- Homogeneity of variances between samples
- Non-parametric alternative: Kruskal-Wallis-Test

A priori power analysis



- Test family: F tests
- Statistical test: ANOVA, fixed effects, omnibus, one-way
- Type of power analysis: A priori
- Medium effect size $f = .25$
- $\alpha = .05$
- $1-\beta = .80$
- Number of groups = 3
- Total sample size = 159

Data Set

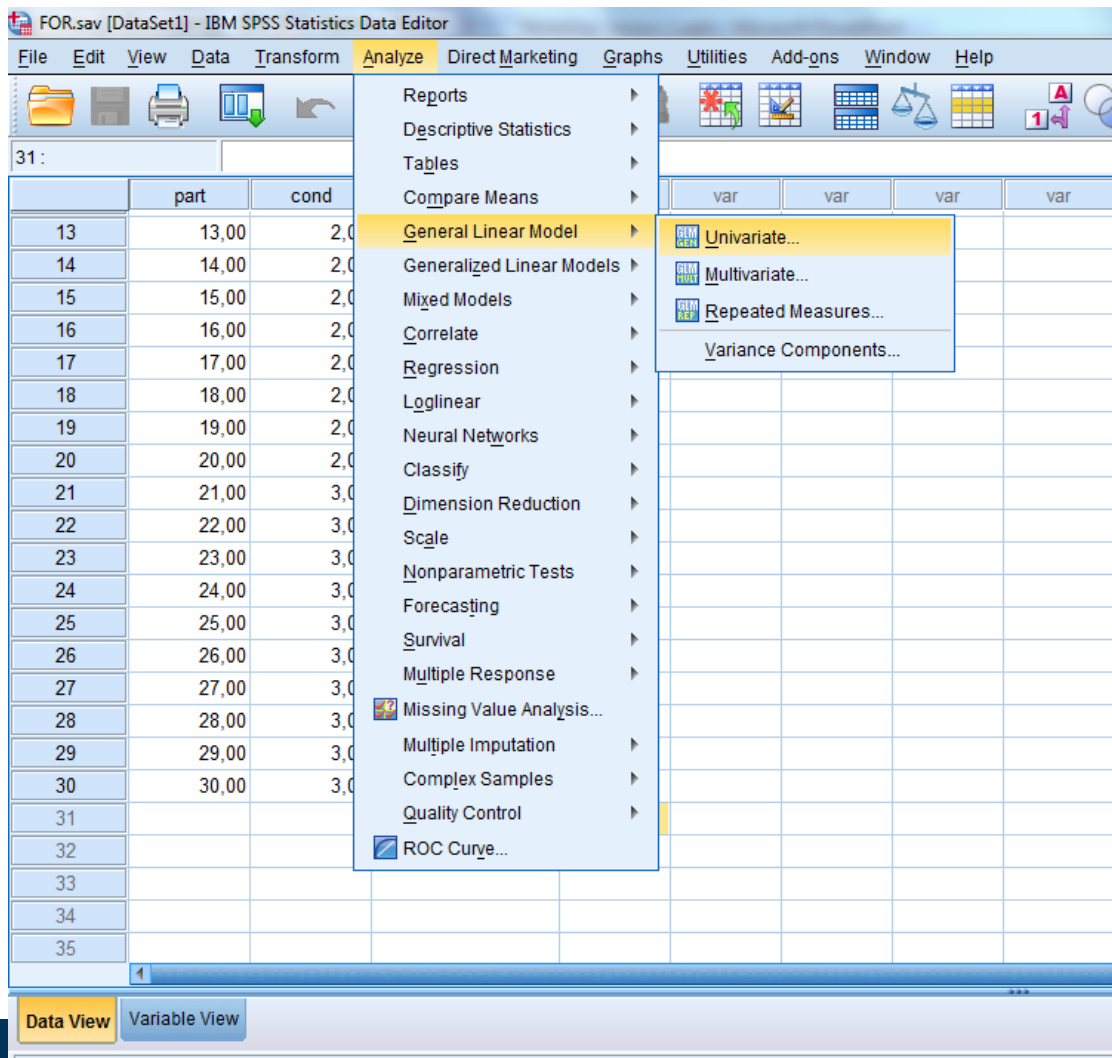
FOR.sav [DataSet1] - IBM SPSS Statistics Data Editor

File Edit View Data Transform Analyze Direct Marketing Graphs Utilities Add-ons

31 :

	part	cond	error	var	var	va
13	13,00	2,00	3,00			
14	14,00	2,00	5,00			
15	15,00	2,00	1,00			
16	16,00	2,00	2,00			
17	17,00	2,00	4,00			
18	18,00	2,00	2,00			
19	19,00	2,00	3,00			
20	20,00	2,00	3,00			
21	21,00	3,00	2,00			
22	22,00	3,00	,00			
23	23,00	3,00	3,00			
24	24,00	3,00	2,00			
25	25,00	3,00	1,00			
26	26,00	3,00	4,00			
27	27,00	3,00	2,00			
28	28,00	3,00	1,00			
29	29,00	3,00	3,00			
30	30,00	3,00	2,00			
31						
32						

One-way univariate ANOVA



Analyze /
General Linear Model/
Univariate

One-way univariate ANOVA

The screenshot shows the IBM SPSS Statistics Data Editor interface. The main window displays a dataset with the following data:

	part	cond	error	var	var	var	var	var	var	var	va
13	13,00	2,00	3,00								
14	14,00	2,00	5,00								
15	15,00	2,00	1,00								
16	16,00	2,00	2,00								
17	17,00	2,00	4,00								
18	18,00	2,00	2,00								
19	19,00	2,00	3,00								
20	20,00	2,00	3,00								
21	21,00	3,00	2,00								
22	22,00	3,00	,00								
23	23,00	3,00	3,00								
24	24,00	3,00	2,00								
25	25,00	3,00	1,00								
26	26,00	3,00	4,00								
27	27,00	3,00	2,00								
28	28,00	3,00	1,00								
29	29,00	3,00	3,00								
30	30,00	3,00	2,00								
31											
32											
33											
34											
35											

The Univariate dialog box is open, showing the following settings:

- Dependent Variable: Number of errors [err...]
- Fixed Factor(s): condition [cond]
- Random Factor(s):
- Covariate(s):
- WLS Weight:

Buttons: Model..., Contrasts..., Plots..., Post Hoc..., Save..., Options..., Bootstrap..., OK, Paste, Reset, Cancel, Help.

Determine DV and IV

Post hoc Tests

The screenshot shows the IBM SPSS Statistics Data Editor interface. The main window displays a data table with columns 'part', 'cond', and 'error'. The 'cond' column contains values 2, 3, and 4. A dialog box titled 'Univariate: Post Hoc Multiple Comparisons for Observed Means' is open, showing 'cond' as the factor for which post hoc tests are being configured. The 'Bonferroni' test is selected under 'Equal Variances Assumed'. The 'Games-Howell' test is selected under 'Equal Variances Not Assumed'. The 'Type I/Type II Error Ratio' is set to 100, and the 'Control Category' is set to 'Last'. The 'Test' options are set to '2-sided', '< Control', and '> Control'.

	part	cond	error	var	var	var	var	var	var	va
13	13,00	2,00	3,00							
14	14,00	2,00	5,00							
15	15,00	2,00	1,00							
16	16,00	2,00	2,00							
17	17,00	2,00	4,00							
18	18,00	2,00	2,00							
19	19,00	2,00	3,00							
20	20,00	2,00	3,00							
21	21,00	3,00	2,00							
22	22,00	3,00	,00							
23	23,00	3,00	3,00							
24	24,00	3,00	2,00							
25	25,00	3,00	1,00							
26	26,00	3,00	4,00							
27	27,00	3,00	2,00							
28	28,00	3,00	1,00							
29	29,00	3,00	3,00							
30	30,00	3,00	2,00							
31										
32										
33										

Pick post hoc tests for differences between groups

Options

The screenshot shows the IBM SPSS Statistics Data Editor interface. The background is a data table with columns 'part', 'cond', 'error', and 'var'. The 'Univariate: Options' dialog box is open, showing the following settings:

- Estimated Marginal Means:**
 - Factor(s) and Factor Interactions: (OVERALL), cond
 - Display Means for: (OVERALL), cond
 - Compare main effects
 - Confidence interval adjustment: LSD(none)
- Display:**
 - Descriptive statistics
 - Estimates of effect size
 - Observed power
 - Parameter estimates
 - Contrast coefficient matrix
 - Homogeneity tests
 - Spread vs. level plot
 - Residual plot
 - Lack of fit
 - General estimable function
- Significance level: .05 Confidence intervals are 95,0 %
- Buttons: Continue, Cancel, Help

- Display:
- descriptive statistics
 - Estimates of effect size
 - Observed power
 - Homogeneity tests

SPSS Output Descriptive Statistics

Between-Subjects-Factors			
		Value-Label	N
condition	1,00	FOR-20	10
	2,00	FOR-90	10
	3,00	FOR-270	10

Descriptive-Statistics			
Dependent-Variable: Number-of-errors			
condition	Mean	Std.-Deviation	N
FOR-20	3,6000	1,34990	10
FOR-90	2,9000	1,19722	10
FOR-270	2,0000	1,15470	10
Total	2,8333	1,36668	30

SPSS Output Homogeneity

Levene's Test of Equality of Error Variances ^a			
Dependent Variable: Number of errors			
F	df1	df2	Sig.
,945	2	27	,401

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + cond

Variances should be similar, therefore Levene's Test should show a non-significant result.

SPSS Output Between-Subjects Effects

Tests of Between-Subjects Effects ^a								
Dependent Variable: Number of errors ^a								
Source ^a	Type III Sum of Squares ^a	df ^a	Mean Square ^a	F ^a	Sig. ^a	Partial Eta Squared ^a	Noncent. Parameter ^a	Observed Power ^b
Corrected Model ^a	12,867 ^a	2	6,433 ^a	4,206	,026	,238	8,412	,689
Intercept ^a	240,833	1	240,833	157,446	,000	,854	157,446	1,000
cond ^a	12,867	2	6,433	4,206	,026	,238	8,412	,689
Error ^a	41,300	27	1,530					
Total ^a	295,000	30						
Corrected Total ^a	54,167	29						

a. R-Squared = ,238 (Adjusted R-Squared = ,181)

b. Computed using alpha = ,05

SPSS Output Post hoc Tests

Multiple Comparisons ^a							
Dependent Variable: Number of errors ^a							
	(I) condition ^a	(J) condition ^a	Mean Difference (I-J) ^a	Std. Error ^a	Sig. ^a	95% Confidence Interval ^a	
						Lower Bound ^a	Upper Bound ^a
Bonferroni ^a	FOR-20 ^a	FOR-90 ^a	,7000	,55311	,649	-,7118	2,1118
		FOR-270 ^a	1,6000*	,55311	,022	,1882	3,0118
	FOR-90 ^a	FOR-20 ^a	-,7000	,55311	,649	-2,1118	,7118
		FOR-270 ^a	,9000	,55311	,346	-,5118	2,3118
	FOR-270 ^a	FOR-20 ^a	-1,6000*	,55311	,022	-3,0118	-,1882
		FOR-90 ^a	-,9000	,55311	,346	-2,3118	,5118
Games-Howell ^a	FOR-20 ^a	FOR-90 ^a	,7000	,57057	,453	-,7580	2,1580
		FOR-270 ^a	1,6000*	,56174	,028	,1633	3,0367
	FOR-90 ^a	FOR-20 ^a	-,7000	,57057	,453	-2,1580	,7580
		FOR-270 ^a	,9000	,52599	,228	-,4426	2,2426
	FOR-270 ^a	FOR-20 ^a	-1,6000*	,56174	,028	-3,0367	-,1633
		FOR-90 ^a	-,9000	,52599	,228	-2,2426	,4426

Based on observed means. [¶]

^a. The error term is Mean Square(Error) = 1,530. ^a

*. The mean difference is significant at the .05 level. [¶]

Output JMP

FOR - JMP

File Edit Tables Rows Cols DOE Analyze Graph Tools View Window Help

FOR

	part	cond	error	experience
1	1	1	5	1
2	2	1	4	2
3	3	1	2	1
4	4	1	3	2
25	25	3	1	1
26	26	3	4	2
27	27	3	2	1
28	28	3	1	2
29	29	3	3	1
30	30	3	2	2

Columns (4/1)

- part
- cond
- error
- experience

Rows

- All rows 30
- Selected 0
- Excluded 0
- Hidden 0
- Labelled 0

Fit Y by X - Contextual - JMP

Distribution of Y for each X. Modeling types determine analysis.

Select Columns

- part
- cond
- error
- experience

Cast Selected Columns into Roles

Y, Response: error (optional)

X, Factor: cond (optional)

Block: optional

Weight: optional numeric

Freq: optional numeric

By: optional

Oneway

- Bivariate
- Oneway
- Logistic
- Contingency

Action

- OK
- Cancel
- Remove
- Recall
- Help

FOR - Fit Y by X of error by cond - JMP

Oneway Analysis of error By cond

Oneway Anova

Summary of Fit

Rsquare	0,237538
Adj Rsquare	0,18106
Root Mean Square Error	1,236782
Mean of Response	2,833333
Observations (or Sum Wgts)	30

Analysis of Variance

Source	DF	Squares	Mean Square	F Ratio	Prob > F
cond	2	12,866667	6,43333	4,2058	0,0257*
Error	27	41,200000	1,52062		
C. Total	29	54,166667			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1	10	3,60000	0,39110	2,7975	4,4025
2	10	2,90000	0,39110	2,0975	3,7025
3	10	2,00000	0,39110	1,1975	2,8025

Std Error uses a pooled estimate of error variance

Results

- H1: Higher field of regard leads to reduced error rate in a search task.
- $M_{\text{FOR20}} = 3.60$ (SD = 1.35; n = 10)
- $M_{\text{FOR90}} = 2.90$ (SD = 1.20; n = 10)
- $M_{\text{FOR270}} = 2.00$ (SD = 1.15; n = 10)
- Partial $\eta^2 = .24$ (large)
- $F = 4.21$; $df = 2$; $p = .026$
- $\rightarrow H_0$ is rejected for FOR20 and FOR270

MULTI-FACTORIAL, REPEATED MEASURES

Multi-factorial ANOVA

- Multi-factorial,
 - At least 2 IV,
at least 1 DV
 - Cross-sectional or
repeated measures
 - Interaction effects

	No sound	Spatial Sound
No sound first		
Sound first		

IV 1: sound (no sound / spatial sound)

IV 2: order of presentation (no sound first / spatial sound first)

DV: presence experienced (SUS Mean)

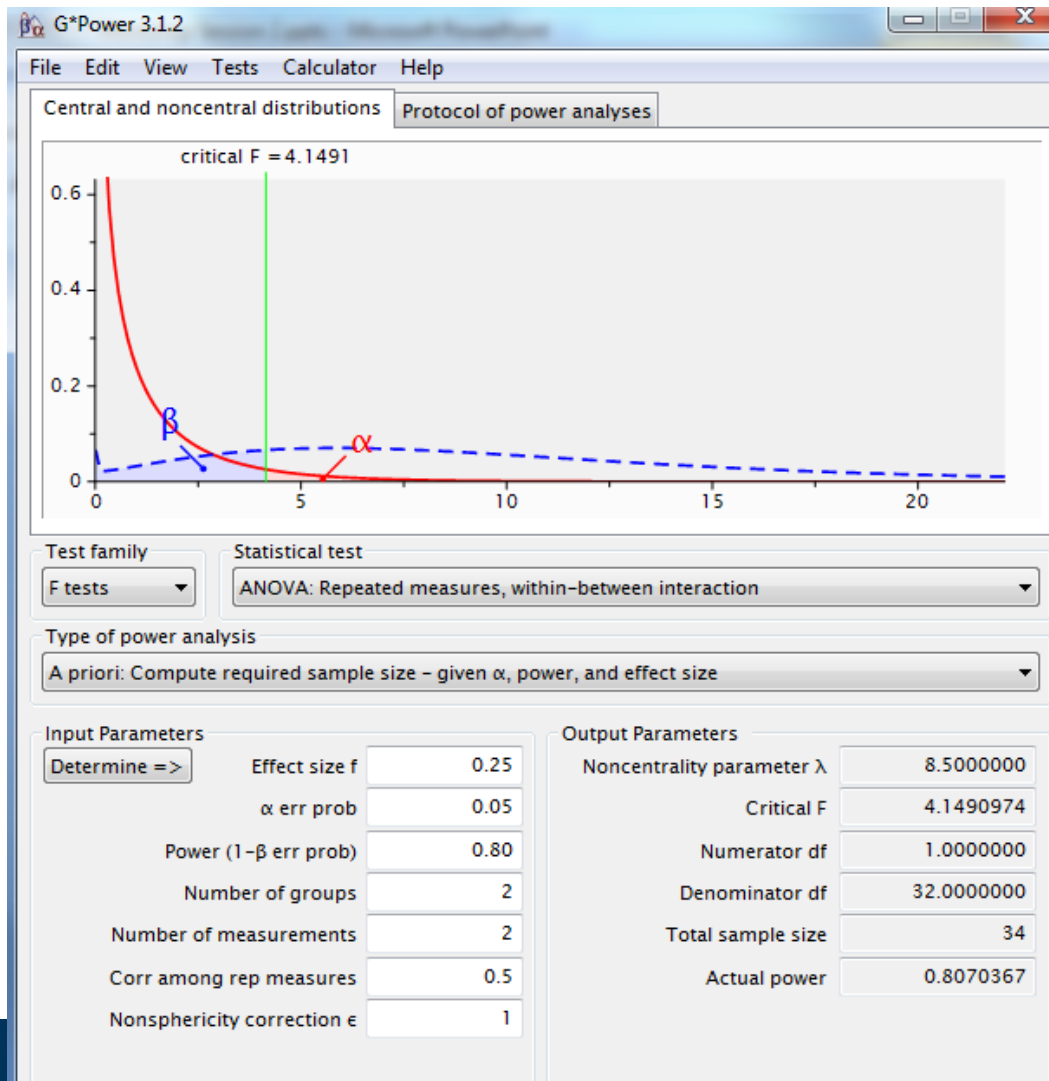
Which test?

- H1: Integrating spatial sound into a VR scene leads to higher levels of presence experienced than a no sound display.
- Hypothesis on a difference
- 1 within-subjects factor (sound), 1 between-subjects factor (order of presentation)
- 1 dependent variable (presence experienced, interval)
- → Two-way ANOVA, repeated measures

Requirements ANOVA, Repeated Measurements

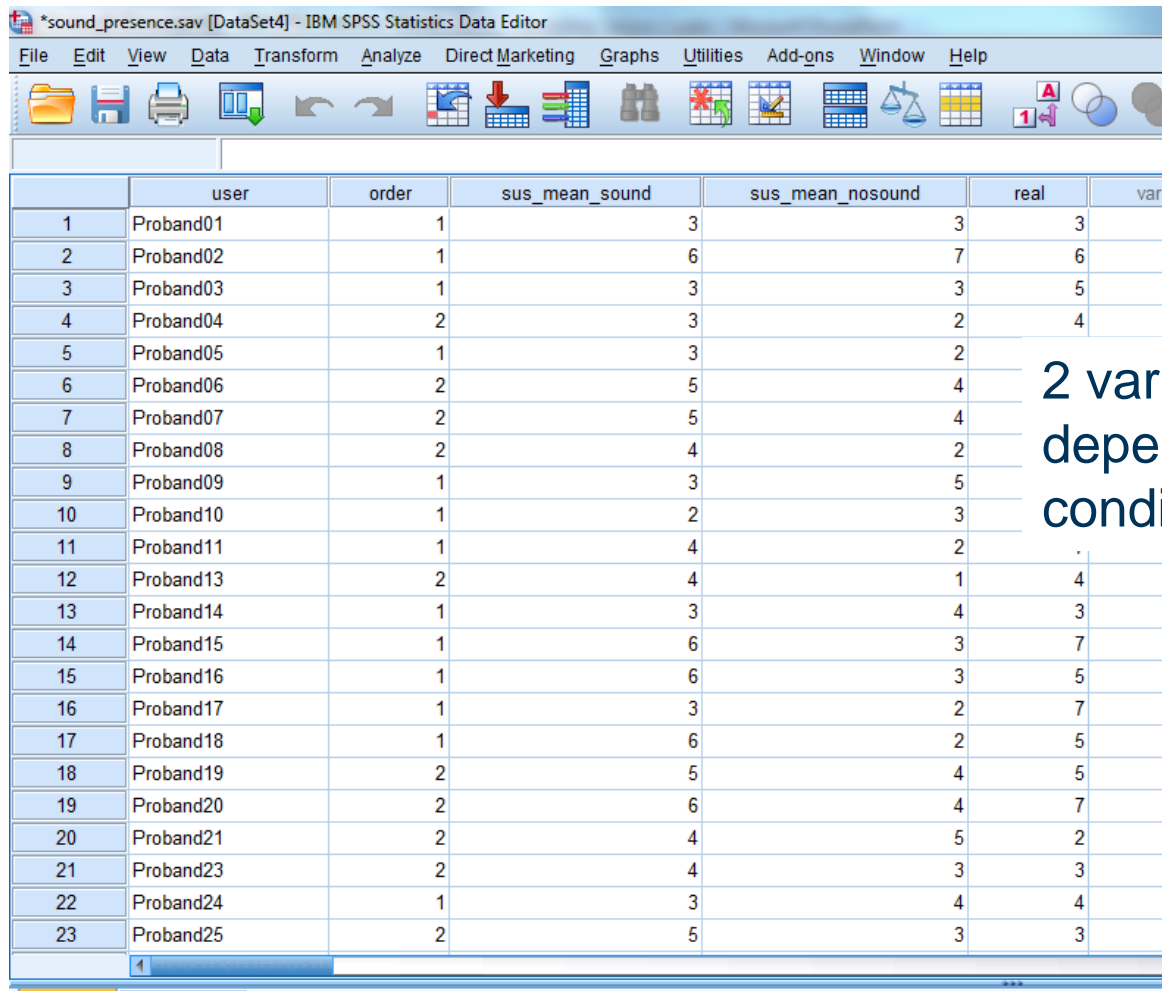
- DV = interval / ratio, normal distribution
- Complete dataset per participant for several measurements (conditions, points in time)
- Covariances between different measurements have to be similar (sphericity)
- Non-parametrical alternative: Friedman-Test

A priori power analysis



- Test family: F tests
- Statistical test: ANOVA, repeated measures, within-between interaction
- Type of power analysis: A priori
- Medium effect size $f = .25$
- $\alpha = .05$
- $1 - \beta = .80$
- Number of groups = 2
- Number of measurements = 2
- Total sample size = 34

Data Set



The screenshot shows the IBM SPSS Statistics Data Editor interface. The title bar reads '*sound_presence.sav [DataSet4] - IBM SPSS Statistics Data Editor'. The menu bar includes File, Edit, View, Data, Transform, Analyze, Direct Marketing, Graphs, Utilities, Add-ons, Window, and Help. The toolbar contains various icons for file operations, data manipulation, and analysis. The data grid below shows 23 rows of data with 7 columns: user, order, sus_mean_sound, sus_mean_nosound, real, and var. The 'real' column contains numerical values, and the 'var' column contains a single value of 4 for all rows.

	user	order	sus_mean_sound	sus_mean_nosound	real	var
1	Proband01	1	3	3	3	
2	Proband02	1	6	7	6	
3	Proband03	1	3	3	5	
4	Proband04	2	3	2	4	
5	Proband05	1	3	2		
6	Proband06	2	5	4		
7	Proband07	2	5	4		
8	Proband08	2	4	2		
9	Proband09	1	3	5		
10	Proband10	1	2	3		
11	Proband11	1	4	2		
12	Proband13	2	4	1	4	
13	Proband14	1	3	4	3	
14	Proband15	1	6	3	7	
15	Proband16	1	6	3	5	
16	Proband17	1	3	2	7	
17	Proband18	1	6	2	5	
18	Proband19	2	5	4	5	
19	Proband20	2	6	4	7	
20	Proband21	2	4	5	2	
21	Proband23	2	4	3	3	
22	Proband24	1	3	4	4	
23	Proband25	2	5	3	3	

2 variables / participant:
dependent variable for
condition 1 and condition 2

Two-way ANOVA, repeated measures

The screenshot shows the IBM SPSS Statistics Data Editor interface. The 'Analyze' menu is open, and the path 'General Linear Model' > 'Repeated Measures...' is selected. The data editor shows a dataset with 23 rows and 4 columns. The first column is 'user', and the other three columns are 'sus_mean_nosound'. The 'Analyze' menu options are listed on the right side of the screenshot.

	user			
1	Proband01			
2	Proband02			
3	Proband03			
4	Proband04			
5	Proband05			
6	Proband06			
7	Proband07			
8	Proband08			
9	Proband09			
10	Proband10			
11	Proband11			
12	Proband13			
13	Proband14			
14	Proband15			
15	Proband16			
16	Proband17			
17	Proband18			
18	Proband19			
19	Proband20			
20	Proband21			
21	Proband23	2	4	3
22	Proband24	1	3	4
23	Proband25	2	5	3

Reports
Descriptive Statistics
Tables
Compare Means
General Linear Model
Generalized Linear Models
Mixed Models
Correlate
Regression
Loglinear
Neural Networks
Classify
Dimension Reduction
Scale
Nonparametric Tests
Forecasting
Survival
Multiple Response
Missing Value Analysis...
Multiple Imputation
Complex Samples
Quality Control
ROC Curve...

Univariate...
Multivariate...
Repeated Measures...
Variance Components...

Analyze / General
Linear Model /
Repeated Measures

Two-way ANOVA, repeated measures

The screenshot shows the IBM SPSS Statistics Data Editor interface. The main window displays a dataset with the following columns: user, order, sus_mean_sound, sus_mean_nosound, real, and var. The data is organized into 25 rows, each representing a proband. A dialog box titled 'Repeated Measures Define Factor(s)' is open, allowing the user to define the within-subject factor and the measure name.

	user	order	sus_mean_sound	sus_mean_nosound	real	var
1	Proband01	1	3	3	3	
2	Proband02	1	6			
3	Proband03	1	3			
4	Proband04	2	3			
5	Proband05	1	3			
6	Proband06	2	5			
7	Proband07	2	5			
8	Proband08	2	4			
9	Proband09	1	3			
10	Proband10	1	2			
11	Proband11	1	4			
12	Proband13	2	4			
13	Proband14	1	3			
14	Proband15	1	6			
15	Proband16	1	6			
16	Proband17	1	3			
17	Proband18	1	6			
18	Proband19	2	5			
19	Proband20	2	6			
20	Proband21	2	4			
21	Proband23	2	4	3	3	
22	Proband24	1	3	4	4	
23	Proband25	2	5	3	3	

The 'Repeated Measures Define Factor(s)' dialog box is open, showing the following settings:

- Within-Subject Factor Name: sound
- Number of Levels: 2
- Measure Name: SUS_mean

Determine within-subjects factor (sound) and number of levels

Determine DV (measure name)

Two-way ANOVA, repeated measures

The screenshot shows the IBM SPSS Statistics Data Editor window with a dataset named 'resence.sav'. The dataset has columns for 'user', 'order', 'sus_mean_sound', 'sus_mean_nosound', 'real', 'var', and 'var'. The data is organized into rows for 'Proband01' through 'Proband24'. A 'Repeated Measures' dialog box is open, showing the following configuration:

- Within-Subjects Variables (sound):** sus_mean_sound(1,SU... and sus_mean_nosound(2,....
- Between-Subjects Factor(s):** order of presentatio...
- Covariates:** (empty)

The dialog box also includes buttons for 'Model...', 'Contrasts...', 'Plots...', 'Post Hoc...', 'Save...', 'Options...', 'OK', 'Paste', 'Reset', 'Cancel', and 'Help'.

Add DV to analysis
(NB: 2 variables!)

Determine between-
subjects factor (order
of presentation)

Two-way ANOVA, repeated measures

The screenshot shows the IBM SPSS Statistics Data Editor interface. The main window displays a dataset with the following columns: user, order, sus_mean_sound, sus_mean_nosound, real, var, and var. The data rows are numbered 1 to 23, with 'user' ranging from Proband01 to Proband25 and 'order' ranging from 1 to 2. A dialog box titled 'Repeated Measures: Post Hoc Multiple Comparisons for Observed Means' is open, showing 'order' as the factor for which post hoc tests are being calculated. The 'Equal Variances Assumed' section is active, with 'Bonferroni' selected. The 'Equal Variances Not Assumed' section is also visible, with 'Games-Howell' selected. The 'Test' options are set to '2-sided', '< Control', and '> Control'.

	user	order	sus_mean_sound	sus_mean_nosound	real	var	var
1	Proband01	1					
2	Proband02	1					
3	Proband03	1					
4	Proband04	2					
5	Proband05	1					
6	Proband06	2					
7	Proband07	2					
8	Proband08	2					
9	Proband09	1					
10	Proband10	1					
11	Proband11	1					
12	Proband13	2					
13	Proband14	1					
14	Proband15	1					
15	Proband16	1					
16	Proband17	1					
17	Proband18	1					
18	Proband19	2					
19	Proband20	2					
20	Proband21	2					
21	Proband23	2					
22	Proband24	1	3	4	4		
23	Proband25	2	5	3	3		

Check post hoc tests

Two-way ANOVA, repeated measures

The screenshot shows the IBM SPSS Statistics Data Editor with a dataset named 'resence.sav [DataSet4]'. The dataset has three columns: 'user', 'order', and 'sus_mean_sound'. The 'user' column lists probands from 01 to 25, and the 'order' column lists values 1, 2, and 3. The 'sus_mean_sound' column contains numerical values. The 'Repeated Measures: Options' dialog box is open, showing the following settings:

- Estimated Marginal Means:**
 - Factor(s) and Factor Interactions: (OVERALL), order, sound, order*sound
 - Display Means for: order, sound, order*sound
 - Compare main effects
 - Confidence interval adjustment: LSD(none)
- Display:**
 - Descriptive statistics
 - Estimates of effect size
 - Observed power
 - Transformation matrix
 - Homogeneity tests
 - Spread vs. level plot
 - Residual plot
 - Lack of fit
 - General estimable function
- Significance level: .05
- Confidence intervals are 95,0%

- Display:
- descriptive statistics for factors and interaction
 - Estimates of effect size
 - Observed power
 - Homogeneity tests

SPSS Output - Factors

Within-Subjects-Factors^α			
Measure: SUS mean ^α			
sound ^α	Dependent-Variable ^α		
1 ^α	sus mean sound ^α		
2 ^α	sus mean nosound ^α		
Between-Subjects-Factors^α			
		Value-Label ^α	N ^α
order-of-presentation	1 ^α	sound-first ^α	33 ^α
	2 ^α	no-sound-first ^α	33 ^α

SPSS Output – Descriptive Statistics

Descriptive Statistics				
	order of presentation	Mean	Std. Deviation	N
SUS Mean sound	sound first	3,70	1,163	33
	no sound first	4,68	1,219	33
	Total	4,19	1,282	66
SUS Mean no sound	sound first	2,76	1,289	33
	no sound first	3,55	1,326	33
	Total	3,15	1,358	66

SPSS Output – Levene's Test

Levene's Test of Equality of Error Variances ^a				
	F	df1	df2	Sig.
SUS-Mean-sound	,054	1	64	,817
SUS-Mean-no-sound	,259	1	64	,613

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + order
Within-Subjects Design: sound

Variances should be similar, therefore Levene's Test should show a non-significant result.

SPSS Output - Sphericity

Mauchly's Test of Sphericity ^b							
Measure: SUS mean							
Within-Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon ^a		
					Greenhouse-Geisser	Huynh-Feldt	Lower bound
sound	1,000	,000	0	.	1,000	1,000	1,000

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b. Design: Intercept + order
 Within-Subjects Design: sound

SPSS Output within-subjects effects

Tests of Within-Subjects Effects ^a									
Measure: SUS_mean ^a									
Source ^a		Type-III Sum of Squares ^a	df ^a	Mean Square ^a	F ^a	Sig. ^a	Partial Eta Squared ^a	Noncent. Parameter ^a	Observed Power ^a
sound ^a	Sphericity Assumed ^a	35,375	1	35,375	55,123	,000	,463	55,123	1,000
	Greenhouse-Geisser ^a	35,375	1,000	35,375	55,123	,000	,463	55,123	1,000
	Huynh-Feldt ^a	35,375	1,000	35,375	55,123	,000	,463	55,123	1,000
	Lower-bound ^a	35,375	1,000	35,375	55,123	,000	,463	55,123	1,000
sound*order ^a	Sphericity Assumed ^a	,304	1	,304	,474	,494	,007	,474	,104
	Greenhouse-Geisser ^a	,304	1,000	,304	,474	,494	,007	,474	,104
	Huynh-Feldt ^a	,304	1,000	,304	,474	,494	,007	,474	,104
	Lower-bound ^a	,304	1,000	,304	,474	,494	,007	,474	,104
Error(sound)	Sphericity Assumed ^a	41,072	64	,642					
	Greenhouse-Geisser ^a	41,072	64,000	,642					
	Huynh-Feldt ^a	41,072	64,000	,642					
	Lower-bound ^a	41,072	64,000	,642					

a. Computed using alpha = ,05

SPSS Output – Between-Subjects Effects

Tests of Between-Subjects Effects^a

Measure: SUS_mean¹

Transformed Variable: Average^a

Source ^a	Type III Sum of Squares ^a	df ^a	Mean Square ^a	F ^a	Sig. ^a	Partial Eta Squared ^a	Noncent. Parameter ^a	Observed Power ^a
Intercept ^a	1770,550	1	1770,550	715,524	,000	,918	715,524	1,000
order ^a	26,074	1	26,074	10,484	,002	,141	10,484	,890
Error ^a	159,173	64	2,487					

a. Computed using alpha = ,05¹

Results

- H1: Integrating spatial sound into a VR scene leads to higher levels of presence experienced than a no sound display.
- $M_{\text{no sound}} = 3.15$ (SD = 1.36; n = 66)
- $M_{\text{sound}} = 4.19$ (SD = 1.28; n = 66)
- Partial $\eta^2 = .46$ (large)
- $F = 55.12$; $df = 1$; $p = .002$
- $\rightarrow H_0$ is rejected

Further Reading

- Field, A. (2013). *Discovering Statistics Using IBM SPSS Statistics*. (4th ed.). Thousand Oaks: Sage Publications
- Howell, D. (2012). *Statistical Methods for Psychology*. (8th ed.). Cengage Learning Emea
- Marques de Sá, J. P. (2007). *Applied Statistics Using SPSS, STATISTICA, MATLAB and R*. (2nd ed.) Berlin: Springer.