Human-Computer Interaction Statistics III **Intermediate Inferential Statistics** Professor Bilge Mutlu

© Human-Computer Interaction | Professor Mutlu | Week 14: Methods: Statistics III: Intermediate Inferential Statistics



Today's Agenda

- **Lecture:** Multifactorial analysis + tutorials using example data \rightarrow
- **Bonus Lecture:** Writing and reporting \rightarrow
- **Reminder:** Please complete course evaluations at <u>HelioCampus</u> \rightarrow

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Currently



	Nominal	Categorical (2+)	Ordinal	Quantitative Discrete	Quantitative Non- Normal	Quantitative Normal
Nominal	Chi-squared, Fisher's	Chi-squared	Chi-squared Trend, Mann-Whitney	Mann-Whitney	Mann-Whitney, log- rank	Student's <i>t</i>
Categorical (2+)	Chi-squared	Chi-squared	Kruskal-Wallis	Kruskal-Wallis	Kruskal-Wallis	ANOVA
Ordinal	Chi-squared Trend, Mann-Whitney		Spearman rank	Spearman rank	Spearman rank	Spearman rank, linear regression
Quantitative Discrete	Logistic regression			Spearman rank	Spearman rank	Spearman rank, linear regression
Quantitative Non- Normal	Logistic regression				Plot data-Pearson, Spearman rank	Plot data-Pearson, Spearman rank & linear regression
Quantitative Normal	Logistic regression				Linear regression	Pearson, linear regression

Consider this dataset. Can we use multiple t-tests?

Group	Time	Coding
Standard	245	0
Standard	236	0
Standard	321	0
Standard	212	0
Standard	267	0
Standard	334	0
Standard	287	0
Standard	259	0
Prediction	246	1
Prediction	213	1
Prediction	265	1
Prediction	189	1
Prediction	201	1
Prediction	197	1
Prediction	289	1
Prediction	224	1
Speech-based dictation	178	2
Speech-based dictation	289	2
Speech-based dictation	222	2
Speech-based dictation	189	2
Speech-based dictation	245	2
Speech-based dictation	311	2
Speech-based dictation	267	2
Speech-based dictation	197	2

 H_0 : $\mu_1=\mu_2=\mu_3$, lpha=.05

3 pairwise tests: $(1 - \alpha)^3 = 0.86$

Reject H_0 when p < 0.14 instead of p < 0.05

→ **Type I error** (reject H_0 when it is true)

up	Time	Coding
ndard	245	0
ndard	236	0
ndard	321	0
ndard	212	0
ndard	267	0
ndard	334	0
ndard	287	0
ndard	259	0
diction	246	1
diction	213	1
diction	265	1
diction	189	1
diction	201	1
diction	197	1
diction	289	1
diction	224	1
ech-based dictation	178	2
ech-based dictation	289	2
ech-based dictation	222	2
ech-based dictation	189	2
ech-based dictation	245	2
ech-based dictation	311	2
ech-based dictation	267	2
ech-based dictation	197	2

What are errors in hypothesis testing?

Type I error: Rejecting H_0 when it is true

Type II error: Accepting H_0 when it is false

Type III error: Correctly rejecting H_0 for the wrong reason

	Null Hypothesis is true	Alternativ
Fail to reject	Right decision	Wrong dec Type II er (False neg
Reject	Wrong decision Type I error (False positive)	Right decis

ive Hypothesis is true

cision

error

gative)

ision

Analysis of Variance (ANOVA)

Definition: Analysis of variance (ANOVA) is a collection of statistical models and their associated estimation procedures (such as the "variation" among and between groups) used to analyze the differences among group means in a sample.¹

Pro	ocedures:	Models:		
1.	One-way (single factor)	1.	Fixed effects (be	
2.	Two-way (two factors)	2.	Random effects (
3.	Multi–way (multiple factors)	3.	Mixed effects (m	

¹Wikipedia: <u>ANOVA</u>

- tween)
- (within)
- nixed)

How do we choose among these procedures?



How do we conduct ANOVA?

We calculate the *F*-statistic.

$$egin{aligned} F &= rac{\sigma_{explained}}{\sigma_{unexplained}} = rac{SS_{treatment}/(k-1)}{SS_{error}/(n-k)} \ F &= rac{\sum n_i (M_i - \sum (Mi/k))^2/(k-1)}{\sum \sum (X_{it} - M_i)^2/(n-k)} \end{aligned}$$



k: number of populations

n: sample size

One-way ANOVA in R

```
model = aov(Time~Group,data=data)
summary(model)
```

	Df	Sum	Sq	Mean	Sq	F	value	Pr(>F)
Group	2	78	842	39	921		2.174	0.139
Residuals	21	378	80	18	304			

Participant ID	Group	Time	Coding
Participant 01	Standard	245	0
Participant 02	Standard	236	0
Participant 03	Standard	321	0
Participant 04	Standard	212	0
Participant 05	Standard	267	0
Participant 06	Standard	334	0
Participant 07	Standard	287	0
Participant 08	Standard	259	0
Participant 09	Prediction	246	1
Participant 10	Prediction	213	1
Participant 11	Prediction	265	1
Participant 12	Prediction	189	1
Participant 13	Prediction	201	1
Participant 14	Prediction	197	1
Participant 15	Prediction	289	1
Participant 16	Prediction	224	1
Participant 17	Speech-based dictation	178	2
Participant 18	Speech-based dictation	289	2
Participant 19	Speech-based dictation	222	2
Participant 20	Speech-based dictation	189	2
Participant 21	Speech-based dictation	245	2
Participant 22	Speech-based dictation	311	2
Participant 23	Speech-based dictation	267	2
Participant 24	Speech-based dictation	197	2

One-way ANOVA in JMP

Analyze > Fit X by Y

	_				1				
Summa	ry of	Fit							
Rsquare			0.1	71518					
Adj Rsquare	Э		0.0	92615					
Root Mean	Square	Error	42.	47149					
Mean of Re	sponse		24	45.125					
Observatior	ns (or Su	um Wgt	s)	24					
A nalysi	s of V	arian	Ce						
Analyon									
Source	DF	Squ	Jares	Mean	Squar	e	F Ratio	Prob > F	
Group	2	7842	2.250	:	3921.1	3	2.1738	0.1387	
Error	21	3788	0.375		1803.8	3			
C. Total	23	45722	2.625						
Means	for O	newa	y An	ova					
Level		1	Numbe	ər I	Mean	Std	Error	Lower 95%	Upper 95
Prediction				8 22	8.000	1	5.016	196.77	259.
Speech-bas	sed dict	ation		8 23	7.250	1	5.016	206.02	268.
Standard				8 27	0 125	1	5 016	238 90	301

11

Are we done?

The ANOVA analysis only told us whether the *methods* had a significant effect on *time*, not which method is more effective.

We can make two types of *pairwise* comparisons:

A priori comparisons (planned contrasts) 1.

 $H_0: \mu_1 = \mu_2; H_1: \mu_1 > \mu_2$

2. *Post hoc* comparisons (exploratory pairwise tests)

Test μ_1 vs μ_2 , μ_1 vs μ_3 , μ_2 vs μ_3

A priori comparisons in R

levels(data\$Group) comparison = c(1, -1, 0)mat = cbind(comparison) contrasts(data\$Group) <- mat</pre> model = aov(Time~Group, data= data) summary.aov(model, split = list(Group=list("mu1 vs mu2"=1))) Df Sum Sq Mean Sq F value Pr(>F) 2 7842 3921 Group 1 Group: mu1 vs mu2 342 342 Residuals 21 37880 1804

2.174 0.139 0.190 0.668

A priori comparisons in JMP

Compare Means > Each pair, Student's t

Means Comparisons Comparisons for each pair using Student's t **Confidence Quantile** V t Alpha 2.07961 0.05 LSD Threshold Matrix Abs(Dif)-LSD Standard Speech-based dictation Prediction Standard -44.162 -11.287 -2.037 Speech-based dictation -11.287 -44.162 -34.912 Prediction -2.037 -34.912 -44.162 Positive values show pairs of means that are significantly different. Connecting Letters Report Level Mean Standard A 270.12500 Speech-based dictation A 237.25000 Prediction A 228.00000 Levels not connected by same letter are significantly different. Ordered Differences Report Difference Std Err Dif Lower CL Upper CL p-Value Level - Level Prediction 42.12500 21.23574 -2.0371 86.28715 0.0605 Standard Speech-based dictation 21.23574 -11.2871 77.03715 0.1365 Standard 32.87500 Speech-based dictation Prediction 21.23574 -34.9121 53.41215 0.6676 9.25000

Post hoc comparison in R

TukeyHSD(model)

Tukey multiple comparisons of means 95% family-wise confidence level

Fit: aov(formula = Time ~ Group, data = data)

\$Group

diff lwr Speech-based dictation-Prediction 9.250 -44.27619 62.77619 0.9011856 Standard-Prediction Standard-Speech-based dictation 32.875 -20.65119 86.40119 0.2896872

- p adj upr
- 42.125 11.40119 95.65119 0.1409733

Post hoc comparison in JMP

Compare Means > All Pairs, Tukey HSD

Comparisons for	r all pairs using	Tukey-Kra	amer HSD)					
Confidence Qua	ntile								
q* Alpha									
2.52057 0.05									
HSD Threshold I	Matrix								
Abs(Dif)-HSD									
	Standard Speech-ba	sed dictation	Prediction						
Standard	-53.526	-20.651	-11.401						
Speech-based dictation	-20.651	-53.526	-44.276						
Prediction	-11.401	-44.276	-53.526						
different. Connecting Lette	ers Report								
Level	Mean								
Standard	A 270.12500								
Speech-based dictation	A 237.25000								
Prediction	A 228.00000								
Levels not connected by	same letter are significa	ntly different.							
Ordered Differen	ices Report								
Level	- Level	Difference	Std Err Dif	Lower CL	Upper CL	p-Value			
Standard	Prediction	42,12500	21,23574	-11.4012	95.65119	0.1410	1		/

21.23574

-20.6512 86.40119 0.2897

21.23574 -44.2762 62.77619 0.9012

32.87500

9.25000

Speech-based dictation

Standard

Speech-based dictation Prediction

What if we had a within-participants design?

We conduct a *repeated-measures* or *random-effects* one-way ANOVA.

pup	Time	Coding
ndard	245	0
diction	246	1
ech-based dictation	178	2
ndard	236	0
diction	213	1
ech-based dictation	289	2
ndard	321	0
diction	265	1
ech-based dictation	222	2
ndard	212	0
diction	189	1
ech-based dictation	189	2
ndard	267	0
diction	201	1
ech-based dictation	245	2
ndard	334	0
diction	197	1
ech-based dictation	311	2
ndard	287	0
diction	289	1
ech-based dictation	267	2
ndard	259	0
diction	224	1
ech-based dictation	197	2

Within-participants one-way ANOVA in R

model = aov(Time~Group+Error(Participant.ID/Group), data= data) summary(model)

Error: Participant.ID Df Sum Sq Mean Sq F value Pr(>F) Residuals 7 19113 2730

Error: Participant.ID:Group Df Sum Sq Mean Sq F value Pr(>F) 2 7842 3921 2.925 0.0868 . Group Residuals 14 18767 1341

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Within-participants one-way ANOVA in JMP

Using the *Full Factorial Repeated Measures* ANOVA Add-In:

Add-ins > Repeated Measures > Full-Factorial Design (Mixed Effects)

For additional options (e.g., comparisons):

Launch Dialog > Emphasis: Effect Leverage

Resp	onse Ti	me	•			
► Effect	t Summa	ary	,			
 Summ 	nary of F	it				
RSquare	.			0.4	48879	
RSquare Root Me	Adj an Square E	rror		0.44	40103 51292	
Mean of	Response			24	5.125	
Observat	tions (or Sur	n W	/gts)		24	
Parar	neter Es	tin	nate	es		
Rand	om Effe	ct I	Prec	dict	tions	
REML	. Variano	ce	Cor	npo	onent	Es
				_		V
Random	Effect	١	/ar Ra	atio	Comp	one
Participa	nt ID nt ID*Group	0.	.3456	318	463.	3214 10 50
Total					1803	8.827
-2 LogL	ikelihood =	224	1.2278	8050	2	
Note: Tota	al is the sun uding negat	n of ive é	the p	ositi ates	ve varia = 1803	nce 8 827
	ariance	Ma	atrix	of	- 1000	
Varia	ance Co	m	oon	ent	Estin	nat
Residual	is confound	ed ۱	with F	Partic	cipant ID)*Gr
been rem	oved.					
► Itera	ations					
Fixed	Effect T	es	ts			
Source	Nparm	DF	DFD	en	F Rat	io
Group	2	2		14	2.92	51
Effect	t Details					

Estimates

Var				Wald p-	
nent	Std Error	95% Lower	95% Upper	Value	Pct of Total
2143	514.98022	-546.0213	1472.6641	0.3683	25.685
.506	506.66363	718.52371	3334.1618	<.0001*	74.315
8274	592.26174	1037.3604	3890.013		100.000

ce components.

8274

ates

Group and has



Between-participants two-way ANOVA in R

Task type	Entry method	Participant Number	Task time	Task Type coding	Entry Method coding
Transcription	Standard	Participant 1	245	0	0
Transcription	Standard	Participant 2	236	0	0
Transcription	Prediction	Participant 9	246	0	1
Transcription	Prediction	Participant 10	213	0	1
Transcription	Speech-based dictation	Participant 17	178	0	2
Transcription	Speech-based dictation	Participant 18	289	0	2
Composition	Standard	Participant 25	256	1	0
Composition	Standard	Participant 26	269	1	0
Composition	Prediction	Participant 33	265	1	1
Composition	Prediction	Participant 34	232	1	1
Composition	Speech-based dictation	Participant 41	189	1	2
Composition	Speech-based dictation	Participant 42	321	1	2
Composition	Speech-based dictation	Participant 48	202	1	2

model = aov(Time~Group*Expertise, data=data) summary(model)

	Df	Sum Sc	q Mean
Group	2	7842	2 3
Expertise	1	1395	51
Group:Expertise	2	4030) 2
Residuals	18	32455	51

Sq F value Pr(>F) 3921 2.175 0.143 395 0.774 0.391 2015 1.117 0.349 1803

Between-participants two-way ANOVA in JMP

Analyze > Fit Model

		Fit Model				
Model Specification	า					
Select Columns	Pick Role Variable	2S	Personality:	Standard Least Squares		
 S Columns Participant ID 	Y	Time optional	Emphasis:	Minimal Report	\$	
dia Group dia Expertise			Help	Run		
TimeCoding	Weight	optional numeric	Recall	🔽 Keep dialog open		
	Freq	optional numeric	Remove			
	Validation	optional				
	Ву	optional				
	Construct Model	Effects				
	Add	Group				
	Cross	Group*Expertise				
	Nest					
	Macros 🔻					
	Degree 2					
	Transform 💌					
	No Intercep	ot				

Summary of Fit

Summary of Fit												
RSquare0.290171RSquare Adj0.092996Root Mean Square Error42.46257Mean of Response245.125Observations (or Sum Wgts)24				a								
Analys	is of	Varian	ce									
Source	DF	Sur Squa	n of ares	Mean S	quare	I	- Ratio					
Model	5	13267.	375	26	653.48		1.4716	5				
Error	18	32455.	250	18	803.07	P	rob > F					
C. Total	23	45722.	.625			().2477					
Param	eter	Estima	ates	;								
Term							Estir	nate	Std	Error	t Ratio	Prob> t
Intercept							245	.125	8.66	7635	28.28	<.0001*
Group[Pre	diction]						-17	.125	12.2	5789	-1.40	0.1794
Group[Spe	ech-ba	ased dicta	ation]				-7	.875	12.2	5789	-0.64	0.5287
Expertise[Expert]						-7	.625	8.66	7635	-0.88	0.3906
Group[Pre	diction]	*Expertis	e[Exp	pert]			-14	.625	12.2	5789	-1.19	0.2483
Group[Spe	eech-ba	ased dicta	ation]	*Expertis	se[Expe	rt]	16	6.875	12.2	5789	1.38	0.1855
Effect	Tests	5										
				Su	ım of							
Source		Nparm	DF	Squ	lares	F	Ratio	Pro	b > F			
Group		2	2	7842.	2500	2	.1747	0.1	426			
Expertise		1	1	1395.	3750	0	.7739	0.3	8906			
Group*Exp	pertise	2	2	4029.	7500	1	.1175	0.3	8488			

Summary of Fit												
RSquare	A!:		0.	.290171								
RSquare	Adj		0.	.092996								
Root Mea	an Squa	re Error	42	2.46257								
Nean of I	Respons		-)	245.125								
Observat	Observations (or Sum Wgts) 24											
	sis of	Varian	се									
		Sur	n of									
Source	DF	Squa	ares	Mean S	quare	F	Ratio)				
Model	5	13267.	375	26	653.48		1.4716	6				
Error	18	32455.	250	18	803.07	Pr	ob > F					
C. Total	23	45722.	625			0	.2477					
Param	Parameter Estimates											
Term							Estir	nate	Std	Error	t Ratio	Prob> t
Intercept							245	5.125	8.66	7635	28.28	<.0001*
Group[Pre	ediction]					-17	7.125	12.2	5789	-1.40	0.1794
Group[Sp	eech-ba	ased dicta	ation]				-7	'.875	12.2	5789	-0.64	0.5287
Expertise	[Expert]						-7	7.625	8.66	7635	-0.88	0.3906
Group[Pre	ediction]*Expertis	e[Exp	pert]			-14	.625	12.2	5789	-1.19	0.2483
Group[Sp	eech-ba	ased dicta	ation]	*Expertis	se[Expe	rt]	16	6.875	12.2	5789	1.38	0.1855
Effect	Tests	\$										
				Su	ım of							
Source		Nparm	DF	Squ	lares	F	Ratio	Pro	b > F			
Group		2	2	7842.	2500	2	.1747	0.1	426			
Expertise		1	1	1395.	.3750	0	.7739	0.3	8906			
Group*Ex	pertise	2	2	4029.	7500	1	.1175	0.3	8488			

Summ	Summary of Fit											
RSquare0.29017RSquare Adj0.092996Root Mean Square Error42.46257Mean of Response245.125Observations (or Sum Wgts)24												
Analys	sis of	Varian	се									
Source	DF	Sum Squa	n of res	Mean S	quare		F Ratio	,				
Model	5	13267.3	375	26	553.48		1.4716	5				
Error	18	32455.2	250	18	303.07	Ρ	rob > F					
C. Total	23	45722.0	625			(0.2477					
Param	eter	Estima	tes									
Term							Estir	nate	Std	Error	t Ratio	Prob> t
Intercept							245	.125	8.66	7635	28.28	<.0001*
Group[Pre	diction]]					-17	.125	12.2	5789	-1.40	0.1794
Group[Sp	eech-ba	ased dicta	tion]				-7	.875	12.2	5789	-0.64	0.5287
Expertise[Expert]						-7	.625	8.66	7635	-0.88	0.3906
Group[Pre	diction]	*Expertise	e[Exp	ert]			-14	.625	12.2	5789	-1.19	0.2483
Group[Sp	eech-ba	ased dicta	tion]'	Expertis	se[Expe	rtj	16	6.875	12.2	5789	1.38	0.1855
Effect	Tests	5										
				Su	ım of							
Source		Nparm	DF	Squ	lares	F	Ratio	Pro	b > F			
Group		2	2	7842.	2500	2	2.1747	0.1	1426			
Expertise		1	1	1395.	3750	().7739	0.3	3906			
Group*Ex	pertise	2	2	4029.	7500	1	1.1175	0.3	3488			

Within-participants two-way ANOVA in R

model = aov(Time~(Group*Task)+Error(Participant.ID/(Group*Task)), data= data)
summary(model)

Participant ID	Group	Task	Time
Participant 01	Standard	Complex	285
Participant 01	Prediction	Complex	160
Participant 01	Speech-based dictation	Complex	201
Participant 01	Standard	Simple	272
Participant 01	Prediction	Simple	191
Participant 01	Speech-based dictation	Simple	161
Participant 02	Standard	Complex	189
Participant 02	Prediction	Complex	250
Participant 02	Speech-based dictation	Complex	178
Participant 02	Standard	Simple	247
Participant 02	Prediction	Simple	288
Participant 02	Speech-based dictation	Simple	180
Participant 03	Standard	Complex	233
Participant 03	Prediction	Complex	285
Participant 03	Speech-based dictation	Complex	225
Participant 03	Standard	Simple	200
Participant 03	Prediction	Simple	202
Participant 03	Speech-based dictation	Simple	162

Error: Par	rtic	ipant.	ID		
	Df	Sum Sq	Mean Sq	F	va
Residuals	7	7224	1032		
Error: Pai	rtic	ipant.	ID:Group		
	Df	Sum Sq	Mean Sq	F	va
Group	2	1650	825.2		0.
Residuals	14	33441	2388.6		
Error: Pai	rtic	ipant.	ID:Task		
	Df	Sum Sq	Mean Sq	F	va
Task	1	341	341.3		0.
Residuals	7	20055	2865.0		
Error: Pai	rtic	ipant.	ID:Group	: Ta	ask
	Df	Sum So	q Mean So	q F	= v
Group:Task	< 2	184	5 922.	5	0
Residuals	14	2005	3 1432.3	3	

alue Pr(>F) alue Pr(>F) .345 0.714 alue Pr(>F) .119 0.74 k value Pr(>F) 0.644 0.54

Within-participants two-way ANOVA in JMP

Add-ins > Repeated Measures > Full-Factorial Design (Mixed Effects)

•••	Repeated Measures (Ful	l Factorial Design)	
▶ ? & ◆ 🕲	<u>}</u>		
Select Columns	Cast Selected Columns into Roles		Action
Participant ID Group Task Time	Y, Response	Time	Run Model
	Within-Subject Factors	📕 Group 📕 Task	Launch Dialog
		optional	Cancel
	Between-Subject Factors	optional	
			Recall
	Subject ID	🔒 Participant ID	
			Alpha: 0.05
		Remove Selected	🗸 Keep Dialog Open

RSquare	0.397171
RSquare Adj	0.325405
Root Mean Square Error	37.84614
Mean of Response	216.625
Observations (or Sum Wgts) 48

Parameter Estimates

Term	Estimate	Std Error	DFDen	t Ratio	Prob> t
Intercept	216.625	4.636889	7	46.72	<.0001*
Group[Prediction]	1.6875	9.976255	14	0.17	0.8681
Group[Speech-based dictation]	-7.875	9.976255	14	-0.79	0.4431
Task[Complex]	2.6666667	7.725769	7	0.35	0.7401
Group[Prediction]*Task[Complex]	-2.229167	7.725311	14	-0.29	0.7772
Group[Speech-based dictation]*Task[Complex]	8.4583333	7.725311	14	1.09	0.2920

Random Effect Predictions

		-					
REML Variance C	ompone	nt Estimat	es				
Random Effect	Var Ratio	Var Component	Std Error	95% Lower	95% Upper	Wald p- Value	Pct of Tota
Participant ID	-0.324559	-464.875	323.07858	-1098.097	168.34739	0.1502	0.000
Participant ID*Group	0.3338216	478.14286	526.34376	-553.4719	1509.7577	0.3637	20.022
Participant ID*Task	0.3334123	477.55655	541.42698	-583.6208	1538.7339	0.3778	19.998
Participant ID*Group*Task		1432.3304	541.36999	767.74244	3562.5512	<.0001*	59.980
Total		2388.0298	687.37698	1457.7831	4611.3193		100.000
-2 LogLikelihood = 455.1 Note: Total is the sum of the Total including negative est	5548778 e positive va imates = 19	riance compor 23.1548	nents.				
Covariance Mat	rix of						

Variance Component Estimates

Residual is confounded with Participant ID*Group*Task and has been removed.

Iterations

V	Fixed	Effect	Tests
---	-------	--------	-------

Source	Nparm	DF	DFDen	F Ratio	P
Group	2	2	14	0.3455	C
Task	1	1	7	0.1191	C
Group*Task	2	2	14	0.6441	C

rob > F 0.7138 0.7401 0.5400

Two-way mixed-effects ANOVA in R

model = aov(Time~(Group*Task)+Error(Participant.ID/Group)+Task,data=data)
summary(model)

Participant ID	Group	Task	Time
Participant 01	Standard	Complex	285
Participant 01	Prediction	Complex	160
Participant 01	Speech-based dictation	Complex	201
Participant 02	Standard	Simple	272
Participant 02	Prediction	Simple	191
Participant 02	Speech-based dictation	Simple	161
Participant 03	Standard	Complex	189
Participant 03	Prediction	Complex	250
Participant 03	Speech-based dictation	Complex	178
Participant 04	Standard	Simple	247
Participant 04	Prediction	Simple	288
Participant 04	Speech-based dictation	Simple	180
Participant 05	Standard	Complex	233
Participant 05	Prediction	Complex	285
Participant 05	Speech-based dictation	Complex	225
Participant 06	Standard	Simple	200
Participant 06	Prediction	Simple	202
Participant 06	Speech-based dictation	Simple	162

Error: Participant.ID				
I	Df S	Sum Sq	Mean Sq I	= va
Task	1	341	341.3	0.
Residuals :	14	27279	1948.5	
Error: Par	tic	ipant.I	D:Group	
	Df	Sum Sq	Mean Sq	F۱
Group	2	1650	825.2	e
Group:Task	2	1845	922.5	e
Residuals	28	53493	1910.5	

alue Pr(>F) 0.175 0.682

value Pr(>F) 0.432 0.654 0.483 0.622

Two-way mixed-effects ANOVA in JMP

Add-ins > Repeated Measures > Full-Factorial Design (Mixed Effects)

	Repeated Measures (Full	Factorial Design) 2	
ط 🕲			
Ca	ast Selected Columns into Roles		Action
	Y, Response	Time	Run Model
	Within-Subject Factors	droup optional	Launch Dialog
	Determine Onlying to Fragment		Cancel
	Between-Subject Factors	optional	Recall
	Subject ID	📕 Participant ID	
			Alpha: 0.05
		Remove Selected	Keep Dialog Open
	Ca	Repeated Measures (Full Cast Selected Columns into Roles Y, Response Within-Subject Factors Between-Subject Factors Subject ID	Repeated Measures (Full Factorial Design) 2 Cast Selected Columns into Roles Y, Response Within-Subject Factors Between-Subject Factors Subject ID Remove Selected

▼	Summary of Fit			
	RSquare	0.057814		
	RSquare Adj	-0.05435		
	Root Mean Square Error	43.70896		
	Mean of Response	216.625		
	Observations (or Sum Wgts)	48		
▼	Parameter Estimate	es		
	Term			E
	Intercept			2
	Task[Complex]			2.6
	Group[Prediction]			
	Group[Speech-based dictation	on]		
	Task[Complex]*Group[Predic	tion]		-2.
	Task[Complex]*Group[Speec	h-based dic	tation]	8.4
►	Random Effect Pre	dictions		
▼	REML Variance Con	mponent	t Esti	ma
				Va

		Var				Wald p-	
Random Effect	Var Ratio	Component	Std Error	95% Lower	95% Upper	Value	Pct of Total
Participant ID[Task]	0.0066379	12.681548	298.71885	-572.7966	598.15973	0.9661	0.659
Participant ID*Group[Task]		1910.4732	510.59544	1203.1556	3494.4955	<.0001*	99.341
Total		1923.1548	419.68502	1307.4704	3106.8671		100.000

-2 LogLikelihood = 457.81133323 Note: Total is the sum of the positive variance components. Total including negative estimates = 1923.1548

Covariance Matrix of Variance Component Estimates

Residual is confounded with Participant ID*Group[Task] and has been removed.

Iterations

Fixed Effect Tests

Source	Nparm	DF	DFDen	F Ratio	P
Task	1	1	14	0.1752	C
Group	2	2	28	0.4319	C
Task*Group	2	2	28	0.4829	0

Estimate	Std Error	DFDen	t Ratio	Prob> t
216.625	6.371352	14	34.00	<.0001*
2.6666667	6.371352	14	0.42	0.6819
1.6875	8.922054	28	0.19	0.8513
-7.875	8.922054	28	-0.88	0.3849
-2.229167	8.922054	28	-0.25	0.8045
8.4583333	8.922054	28	0.95	0.3512

rob > F 0.6819 0.6535 0.6221

What if I would like to include a covariate?

Participant ID	Group	Time	Years
Dertiein ent 64	Ctandard	0.45	10
Participant 01	Standard	245	12
Participant 02	Standard	236	5
Participant 03	Standard	321	6
Participant 04	Standard	212	13
Participant 05	Standard	267	19
Participant 06	Standard	334	18
Participant 07	Standard	287	18
Participant 08	Standard	259	18
Participant 09	Prediction	246	14
Participant 10	Prediction	213	3
Participant 11	Prediction	265	19
Participant 12	Prediction	189	13
Participant 13	Prediction	201	24
Participant 14	Prediction	197	21
Participant 15	Prediction	289	5
Participant 16	Prediction	224	18
Participant 17	Speech-based dictation	178	21
Participant 18	Speech-based dictation	289	18
Participant 19	Speech-based dictation	222	23
Participant 20	Speech-based dictation	189	16
Participant 21	Speech-based dictation	245	12
Participant 22	Speech-based dictation	311	15
Participant 23	Speech-based dictation	267	16
Participant 24	Speech-based dictation	197	9

for that factor.

We conduct what is called an analysis of covariance (ANCOVA).

Consider the one-way between-subjects analysis and also measuring the years of *experience* the user had in the task to control

One-way between-participants ANCOVA in R

model = aov(Time~Group+Years, data=data)
summary(model)

	Df	Sum Sq	Mean Sq	F value P
Group	2	7842	3921	2.090
Years	1	350	350	0.187
Residuals	20	37530	1877	

Because Years has no effect, we would remove it from our model (called *model simplification*) and rerun our analysis as an ANOVA.

r(>F) 0.15 0.67

One-way between-participants ANCOVA in JMP

Analyze > Fit Model

		Fit Model					
Model Specification	n						
Select Columns	Pick Role Variable	S	Personality:	Standard Least Squares			
 ✓4 Columns ▲ Participant ID 	Y	Time optional	Emphasis:	Minimal Report	¢		
La Group I Group I Time			Help	Run			
Years	Weight	optional numeric	Recall	🔽 Keep dialog open			
	Freq	optional numeric	Remove				
	Validation	optional					
	Ву	optional					
	Construct Model R	Effects					
	Add	Group Years					
	Cross						
	Nest						
	Macros 🔻						
	Degree 2						
	Transform						
	No Intercep	t					

Summany of Eit

Summ	nary o										
RSquare0.RSquare Adj0.Root Mean Square Error43				17917 05604 3.3188	2 8 1						
Mean of Response 2				245.12	5						
Observations (or Sum Wgts)				2	4						
Analysis of Variance											
Sum of			um of								
Source	DF	Sq	uares	Mean	Squar	re	F Ratio	0			
Model	3	819	92.233		2730.7	'4	1.4552				
Error	20	3753	30.392	2 1876.52		52	Prob > F				
C. Total	23	4572	22.625			0.2568					
Parameter Estimates											
Term				Est	imate	Sto	d Error	t F	Ratio	Prob> t	
Intercept				255.22257 2			4.99753		0.21	<.0001*	
Group[Prediction]				-17.	26682 12.50938			-	-1.38	0.1827	
Group[Speech-based dictation]			-6.910626 12.70288			-	-0.54	0.5924			
Years			-0.6	80735	0735 1.576272			-0.43	0.6705		
Effect Tests											
			Su	m of							
Source	Nparm	DF	Squ	lares	F Ra	itio	Prob >	> F			
Group	2	2	7341.	1619	1.95	561	0.167	75			
Years	1	1	349.	9828	0.18	365	0.670)5			

Summary of Fit										
RSquare 0.1			17917	2						
RSquare Adj 0.0			05604	В						
Root Mean Square Error 43				3.3188	1					
Mean of Response 2				245.12	5					
Observat	24	4								
Analysis of Variance										
	Sum of									
Source	DF	Sc	quares	Mean	Squar	е	F Ratio	o		
Model	3	819	92.233		2730.7	'4	1.455	2		
Error	20	375	30.392		1876.5	2 Prob > F				
C. Total	23	4572	22.625			0.2568				
Parameter Estimates										
Term				Esti	mate	Sto	Error	t F	Ratio	Prob> t
Intercept				255.22257 24.99753			.99753	1	0.21	<.0001*
Group[Prediction]				-17.26682 12.50938				-1.38	0.1827	
Group[Speech-based dictation]			-6.910626 12.70288				-0.54	0.5924		
Years				-0.680735 1.576272 -0.43 0.670					0.6705	
Effect Tests										
			Su	ım of					Í .	
Source	Nparm	DF	Squ	lares	F Ra	tio	Prob >	> F		
Group	2	2	7341.	1619	1.95	561	0.167	'5		
Years	1	1	349.	9828	0.18	365	0.670)5		

Data files used in Statistics I, II, and III

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