

# **MEDB 5502, Module 12, Longitudinal data**

# Topics to be covered

- What you will learn
  - Mathematical formulation of random intercepts model
  - Description of HIV-intervention data
  - Random intercepts model using hiv-intervention data
  - Mathematical formulation of random slopes model
  - Assumptions and complications

# Longitudinal data

- Measurements taken at different times
  - Emphasis in changes over time

## Speaker notes

In the previous module, I talked about hierarchical models and mentioned a particular case, longitudinal data, that I want to talk more about in this presentation.

Longitudinal data is similar to repeated measures data. With both, you measure the same subject repeatedly. With longitudinal data, often the emphasis is in changes that occur over time. Repeated measurements, in contrast, emphasize different treatments with the hope that the time gaps between the measurements are small enough that you don't see changes over time.

The differences between longitudinal data, repeated measures data, or hierarchical data are subtle. Perhaps these are distinctions without a difference. I decided to separate out longitudinal data for a different module perhaps more out of the desire to split a complex topic into smaller bite-sized pieces.

# Random intercepts model, 1 of 3

- Simplest pattern for longitudinal data
- $Y_{ij}$ ,  $i = 1, \dots, n$ ;  $j = 1, \dots, k$ 
  - $n$  subjects,  $k$  time points
- $t_j$ , time of  $j$ th measurement
  - First time is often zero

## Speaker notes

The simplest longitudinal model has  $n$  subjects and  $k$  time points. The first time point is often set to zero. The times are often evenly spaced, but they don't have to be.

# Random intercepts model, 2 of 3

- $Y_{ij} = \beta_0 + u_{0i} + \beta_1 t_j + \epsilon_{ij}$ 
  - $\beta_0$  and  $\beta_1$  are unknown constants
  - $u_{0i}$  and  $\epsilon_{ij}$  are normally distributed
    - $SD(u_{0i}) = \sigma_{intercept}$
    - $SD(\epsilon_{ij}) = \sigma_{error}$

## Speaker notes

There are two sources of random variation in the random intercepts model,  $u_{0i}$  and  $\epsilon_{ij}$ .



# Random intercepts model, 3 of 3

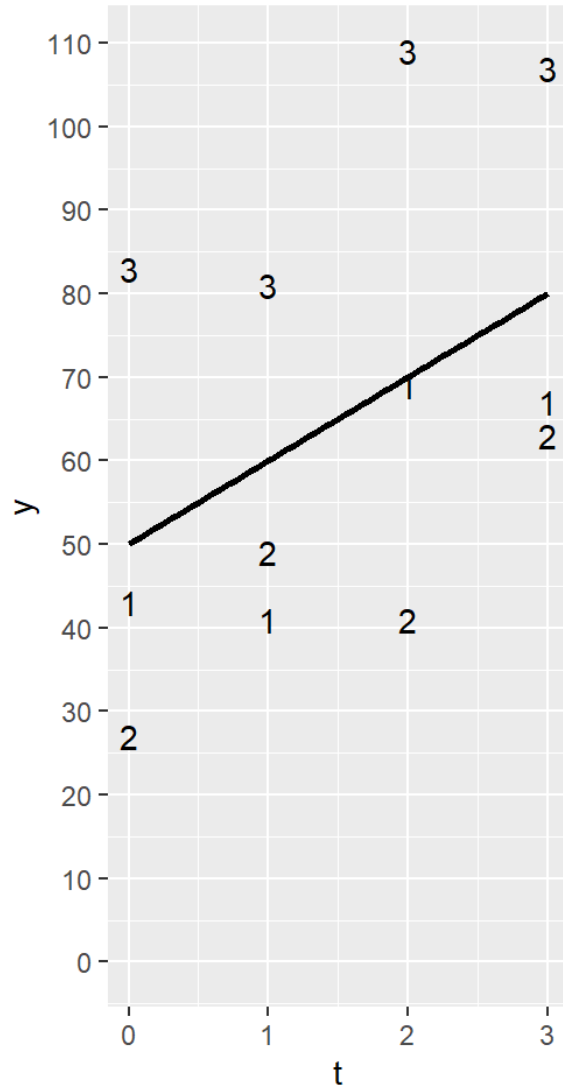
- $SD(Y_{ij}) = \sqrt{\sigma_{intercept}^2 + \sigma_{error}^2}$
- $Corr(Y_{ij}, Y_{im}) = \frac{\sigma_{intercept}^2}{\sigma_{intercept}^2 + \sigma_{error}^2}$

## Speaker notes

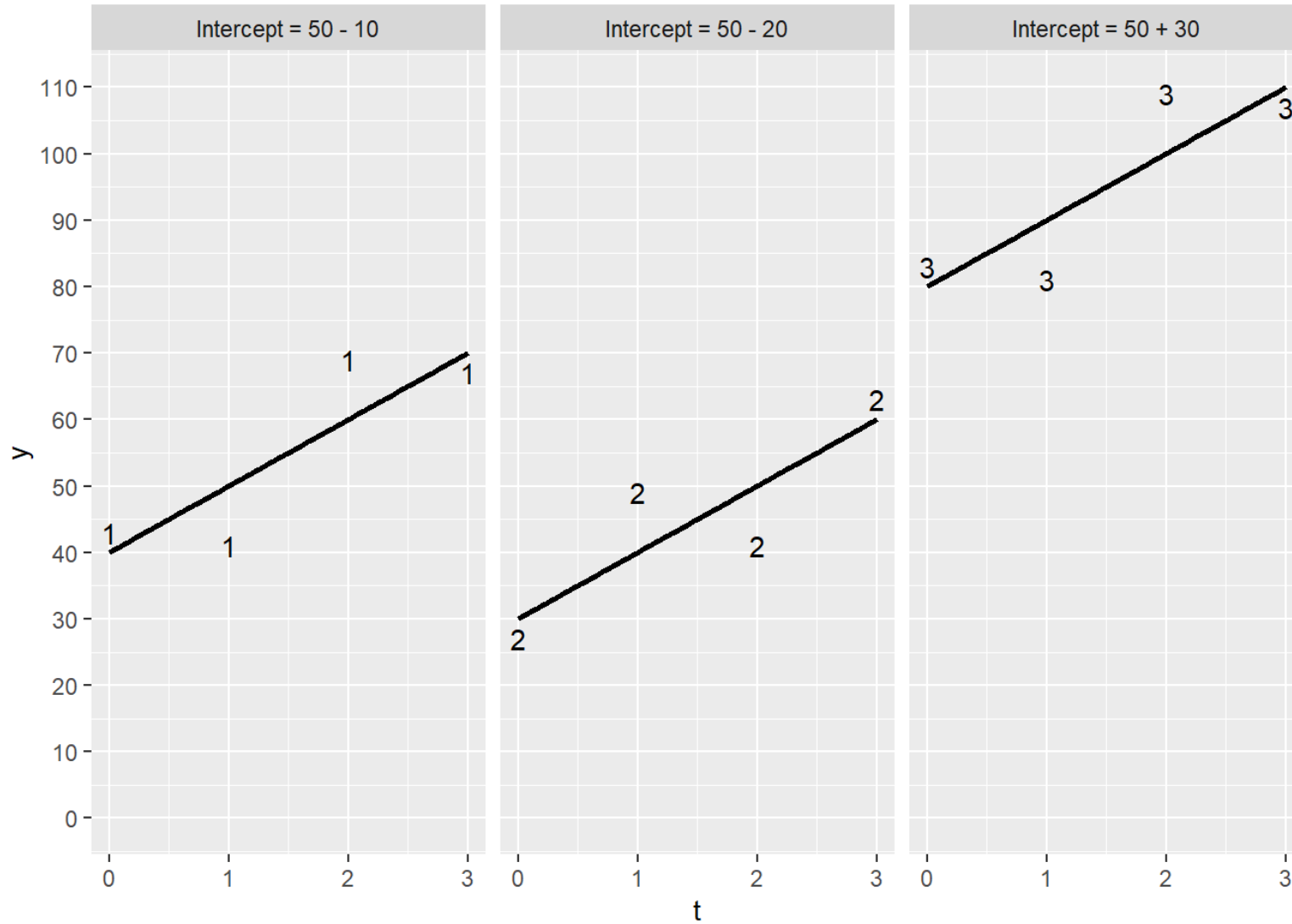
The standard deviation for any individual observation combines the standard deviation for the random intercepts and the standard deviation for the error terms. They combine in a Pythagorean way.

The correlation of two measurements on the same patient is comparable to a measure we defined in the last module, the intraclass correlation.

# Random intercepts illustrated, 1 of 2



# Random intercepts illustrated, 2 of 2



# Break #1

- What you have learned
  - Mathematical formulation of random intercepts model
- What's coming next
  - Description of HIV-intervention data

# Description of hiv-intervention data, 1 of 2

data\_dictionary: hiv-intervention.txt

source: OzDASL website

description: |

This is a longitudinal study of an intervention in 14-18 adolescents intended to increase the frequency of condom protected sex. Subjects were allocated randomly to treatment or control groups. All were evaluated prior to the intervention, immediately after the intervention, 6 months and 12 months after the intervention. The outcome variable is the logarithm-transformed frequency of condom-protected sex (  $\log(Y+1)$  )."

## Speaker notes

Here is a dataset I will use to illustrate the random intercepts model. It actually might require a more sophisticated model than the random intercepts, but it is always a good idea to start with the simplest model, even if you know it is an oversimplification. Slowly add layers of complexity, and don't fit the final model too early. You want to wade in from the shallow end of the pool rather than jump right away into the deep end.

# Description of hiv-intervention data, 2 of 2

BST:

label: treatment group

values:

'1': BST intervention

'0': control

Pre:

label: Log-frequency of protected sex before the intervention

Post:

label: Log-frequency of protected sex after the intervention

FU6:

label: Log-frequency of protected sex reported at the 6 months follow-up

FU12:

label: Log-frequency of protected sex reported at the 12 months follow-up








## Speaker notes

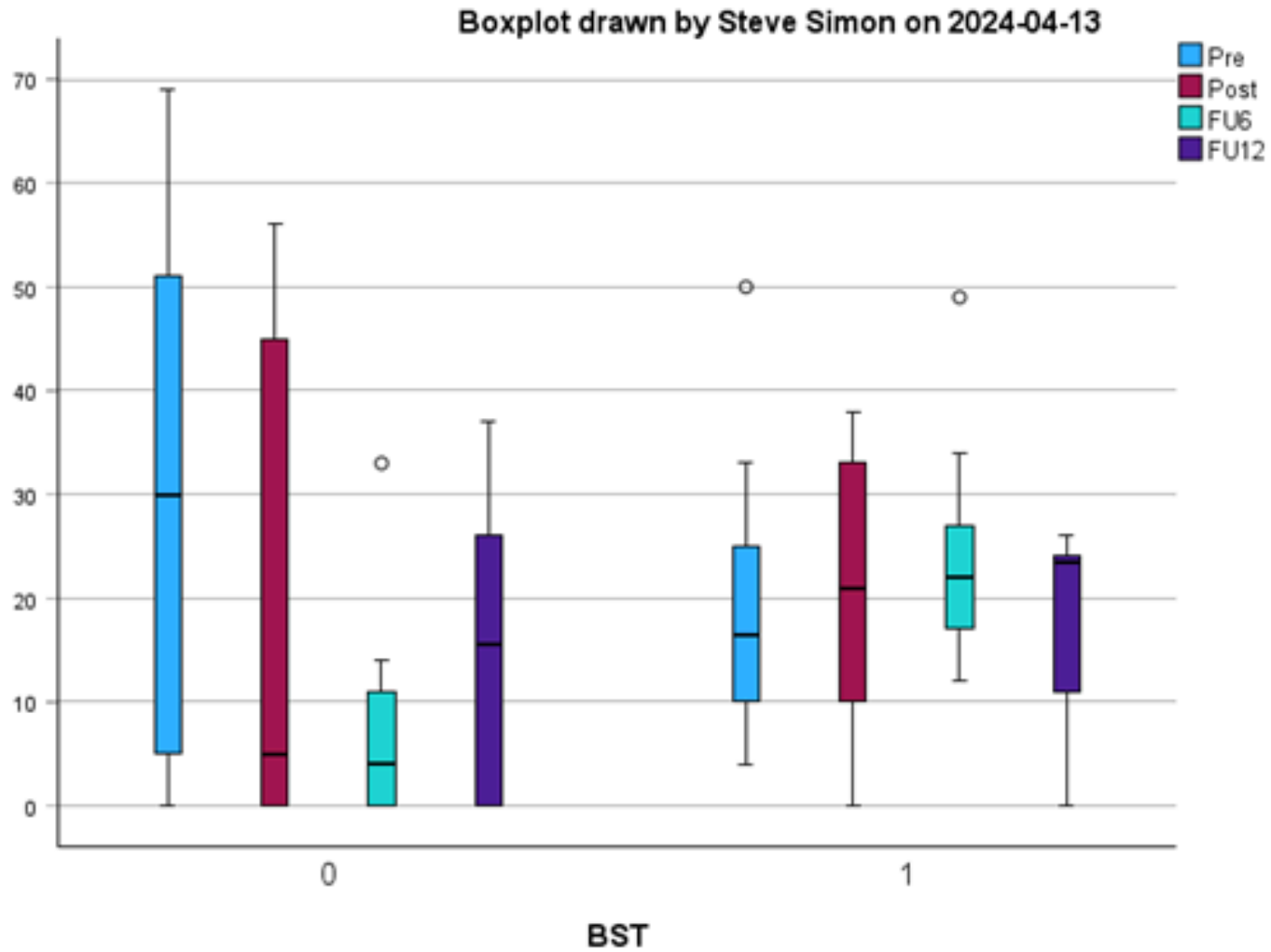
Here are the first three variables. The actual times associated with the Pre and Post measurements are unclear. It turns out that it will be best to hold the Pre measurement back for the time being and start the clock at time=0 for the Post measurement. Remember that you are wading in from the shallow end of the pool.

The remaining two variables FU6 and FU12 represent time=6 and time=12, respectively.

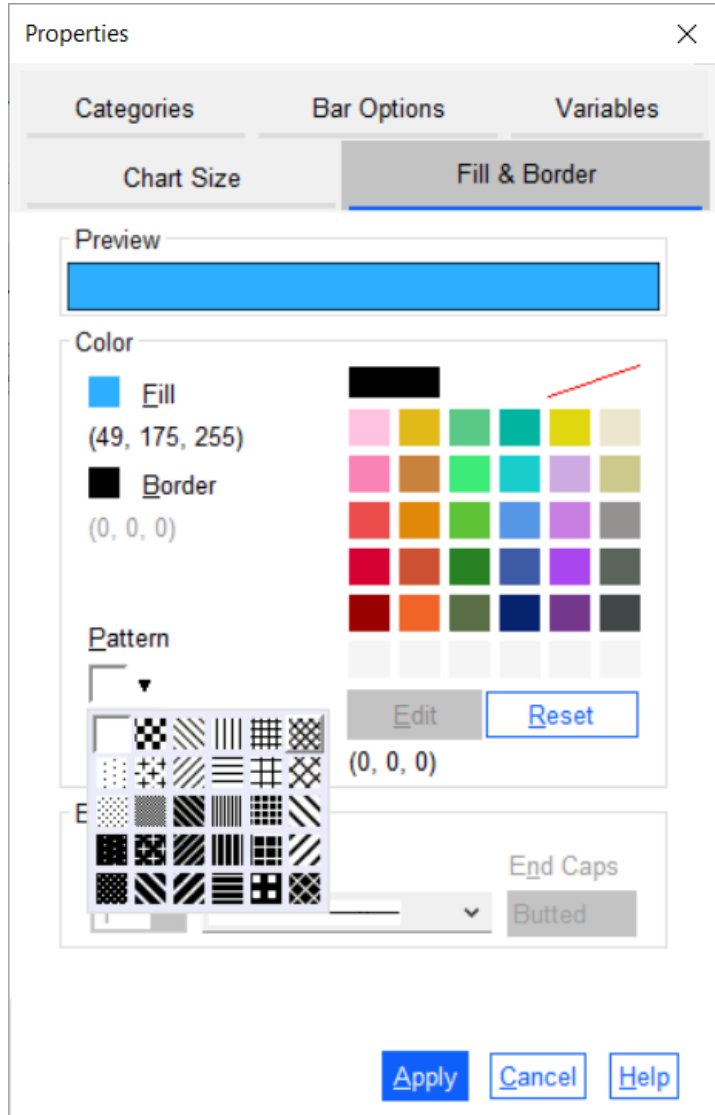
# Wide format

	 BST	 Pre	 Post	 FU6	 FU12	
1	1	7	22	13	14	
2	1	25	10	17	24	
3	1	50	36	49	23	
4	1	16	38	34	24	
5	1	33	25	24	25	
6	1	10	7	23	26	
7	1	13	33	27	24	
8	1	22	20	21	11	
9	1	4	0	12	0	
10	1	17	16	20	10	
11	0	0	0	0	0	
12	0	69	56	14	36	
13	0	5	0	0	5	







# Boxplots



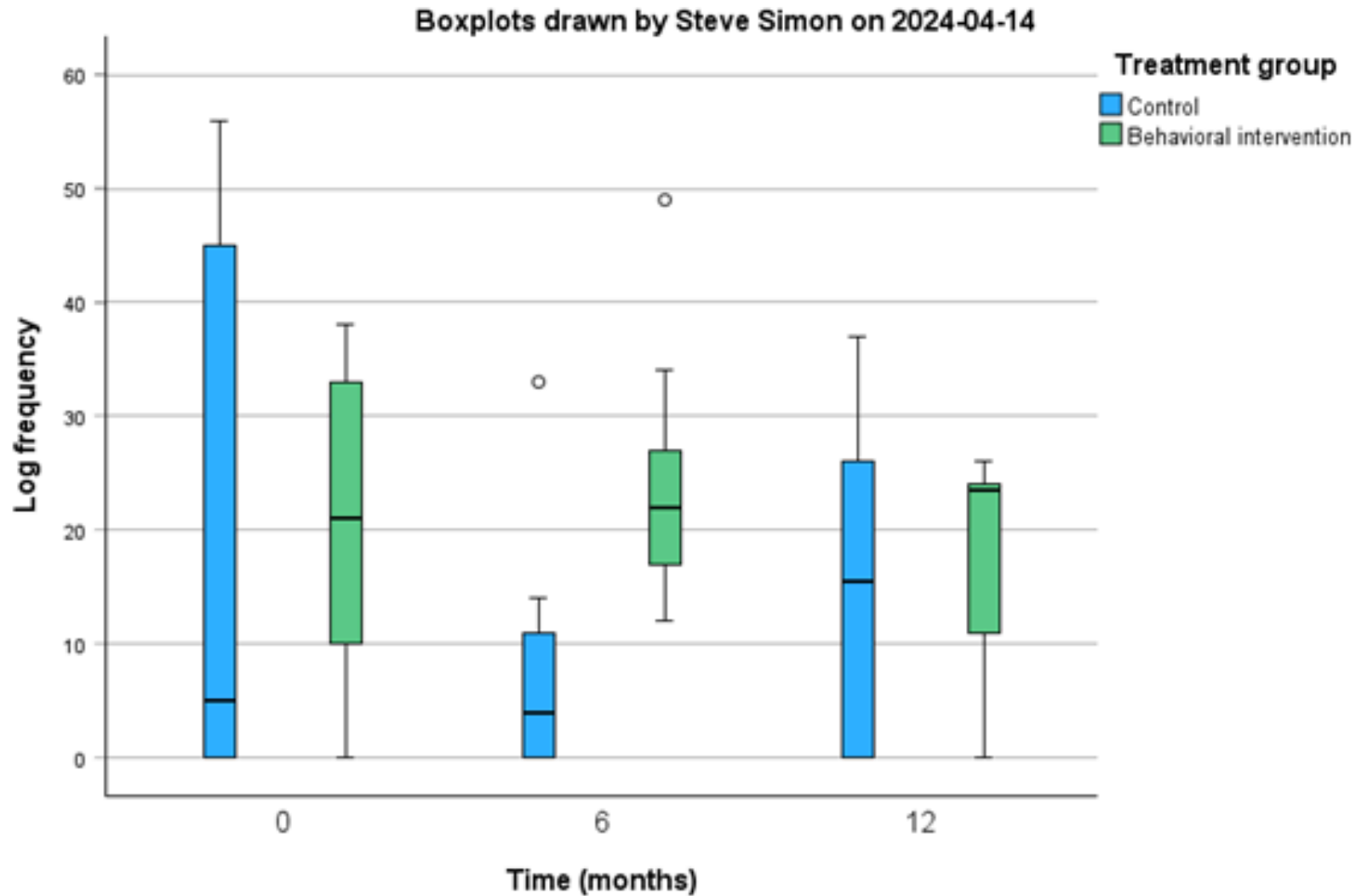
# Colors and patterns



# Tall format

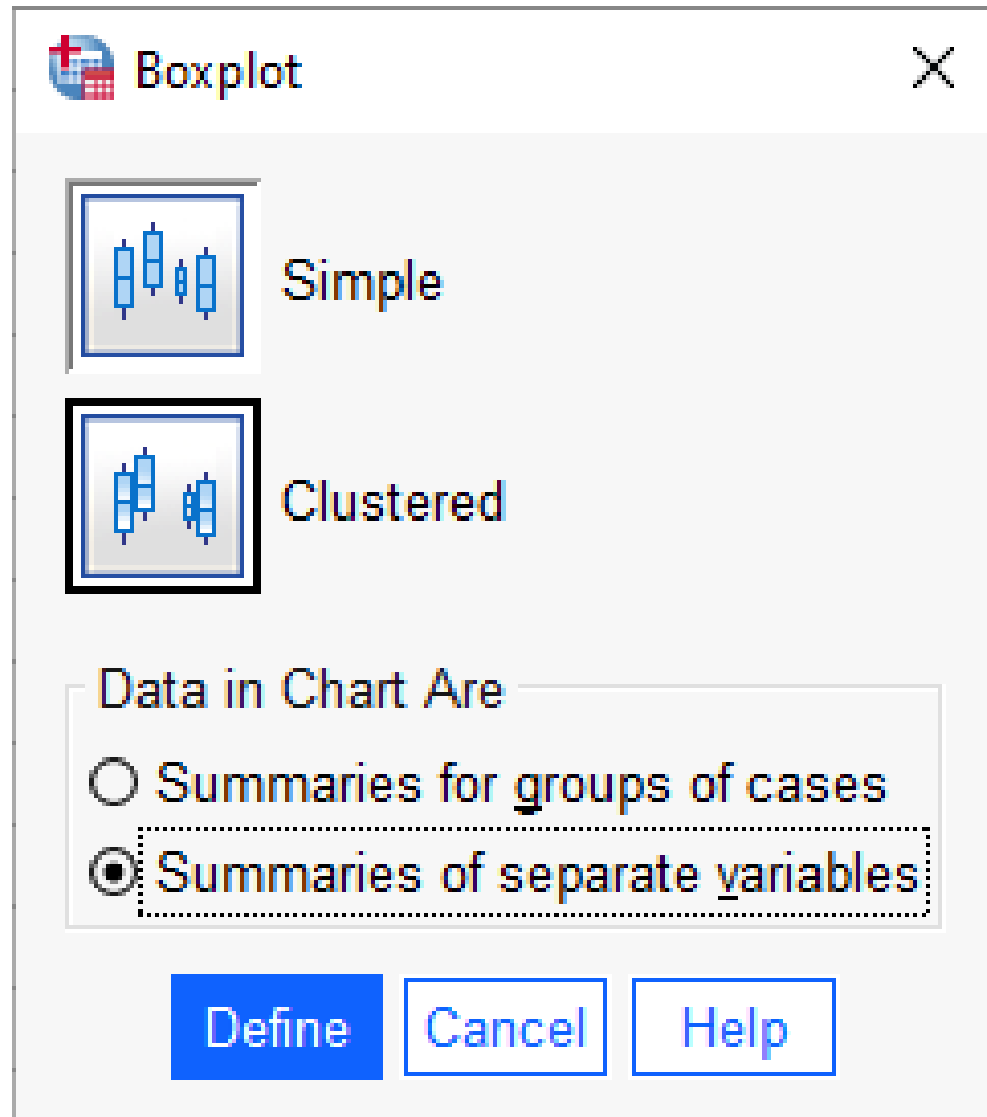
	 id	 BST	 Pre	 Index1	 log_frequency	 time
1	1	1	7	Post	22	0
2	1	1	7	FU6	13	6
3	1	1	7	FU12	14	12
4	2	1	25	Post	10	0
5	2	1	25	FU6	17	6
6	2	1	25	FU12	24	12
7	3	1	50	Post	36	0
8	3	1	50	FU6	49	6
9	3	1	50	FU12	23	12
10	4	1	16	Post	38	0
11	4	1	16	FU6	34	6
12	4	1	16	FU12	24	12
13	5	1	22	Post	25	0

# Alternate clustering of boxplots



# Live demo, restructuring and boxplots

# After menu Graph | Boxplot





# After button Define

Define Clustered Boxplot: Summaries of Separate Variables

Boxes Represent:

Options...

Pre  
Post  
FU6  
FU12

Category Axis:

BST

Label Cases by :

Panel by

Rows:

Nest variables (no empty rows)


Columns:

Nest variables (no empty columns)

Filter by:


OK Paste Reset Cancel Help

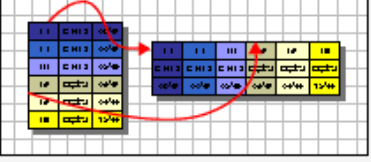
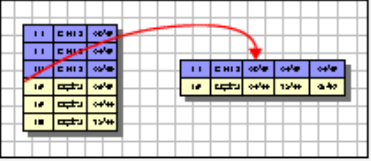
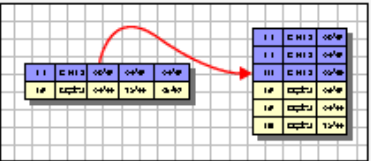
# After menu Data | Restructure

 Restructure Data Wizard ✕

## Welcome to the Restructure Data Wizard!

This wizard helps you to restructure your data from multiple variables (columns) in a single case to groups of related cases (rows) or vice versa, or you can choose to transpose your data.

 The wizard replaces the current data set with the restructured data. Note that data restructuring cannot be undone.



What do you want to do?

☒ Restructure selected variables into cases  
Use this when each case in your current data has some variables that you would like to rearrange into groups of related cases in the new data set.

☐ Restructure selected cases into variables  
Use this when you have groups of related cases that you want to rearrange so that data from each group are represented as a single case in the new data set.

☐ Transpose all data  
All cases will become variables and selected variables will become cases in the new data set. (Choosing this option will end the wizard, and the Transpose dialog will appear.)

< Back Next > Finish Cancel Help

# After button Next

Restructure Data Wizard - Step 2 of 7

Variables to Cases: Number of Variable Groups

You have chosen to restructure selected variables into groups of related cases in the new file.

A group of related variables, called a variable group, represents measurements on one variable.

For example, the variable may be width. If it is recorded in three separate measurements, each one representing a different point in time--w1, w2, and w3, then the data are arranged in a group of variables.

If there is more than one variable in the file often it is also recorded in a variable group, for example height, recorded in h1, h2, and h3.

1	2	3	4
1	8	4	3
2	5	6	7

1
8
4
3
2
5
6
7

How many variable groups do you want to restructure?

☒ One (for example, w1, w2, and w3)

1	2	3	4	5	6
1	8	4	0.3	0.9	0.4
2	5	6	0.7	0.1	0.7

1	0.3
8	0.9
4	0.4
2	0.7
5	0.1
6	0.7

☐ More than one (for example, w1, w2, w3 and h1, h2, h3, etc.)

How Many?

< Back

Next >

Finish

Cancel

Help

# After button Next

Restructure Data Wizard - Step 3 of 7

×

**Variables to Cases: Select Variables**

For each variable group you have in the current data the restructured file will have one target variable.

In this step, choose how to identify case groups in the restructured data, and choose which variables belong with each target variable.

Optionally, you can also choose variables to copy to the new file as Fixed Variables.

Variables in the Current File:

BST

Pre

Post

FU6

FU12

Case Group Identification

Use case number

Name:

Variables to be Transposed

Target Variable:

↑

↓

Post

FU6

FU12

Fixed Variable(s):

BST

Pre

< Back

Next >

Finish

Cancel

Help

22

# After button Next

Restructure Data Wizard - Step 4 of 7

Variables to Cases: Create Index Variables

In the current data, values for a variable group appear in a single case in multiple variables. For example, a single case contains the values for w1, w2, and w3.

In the new data, values for a variable group will appear in multiple cases in a single variable. For example, there will be three cases, one each for w1, w2, and w3.

An index is a new variable that identifies the group of new cases that was created from the original case. For example, an index named "w" would have the values 1, 2, and 3.

1	1	1	0.07
1	1	2	0.11
1	1	3	0.05
2	1	1	0.08
2	1	2	0.04
2	1	3	0.06

1	1	1	1	0.07
1	1	1	2	0.11
1	1	1	3	0.05
1	1	2	1	0.08
1	1	2	2	0.04
1	1	2	3	0.06

1	1	0.08	2	0.07
2	1	0.11	2	0.11
3	1	0.07	2	0.05
4	1	0.06	2	0.08
5	1	0.09	2	0.04
6	1	0.02	2	0.06

How many index variables do you want to create?

☒ One  
Use this when a variable group records the effects of a single factor, treatment or condition.

☐ More than one    How many?   
Use this when a variable group records the effects of more than one factor, treatment or condition.

☐ None  
Use this if index information is stored in one of the sets of variables to be transposed.

< Back


Next >

Finish

Cancel

Help

# After button Next

 Restructure Data Wizard - Step 5 of 7 ✕

**Variables to Cases: Create One Index Variable**

You have chosen to create one index variable. The variable's values can be sequential numbers or the names of variables in a group.

In the table you can specify the name and label for the index variable.

What kind of index values?

☐ Sequential numbers  
Index Values: 1, 2, 3

☒ Variable names  
Index Values: Post, FU6, FU12

Edit the Index Variable Name and Label:

	Name	Label	Levels	Index Values
1	Index1		3	Post, FU6, FU12

< Back

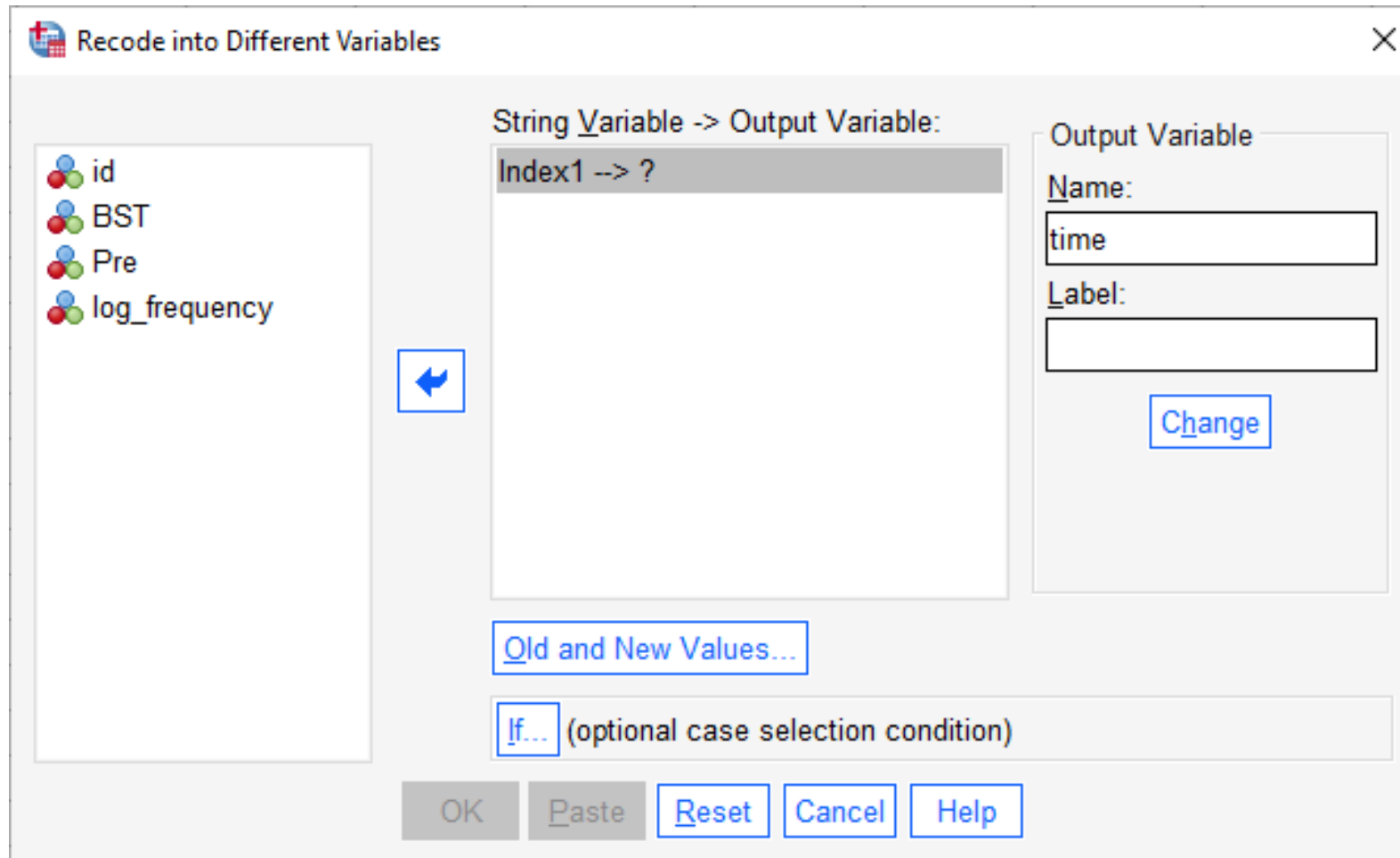
Next >

Finish

Cancel

Help

# After menu Transform | Recode into Different Variables



The image shows the 'Recode into Different Variables' dialog box in SPSS. On the left, a list of variables includes 'id', 'BST', 'Pre', and 'log\_frequency'. A blue arrow button points from this list to the 'String Variable -> Output Variable:' box. This box contains 'Index1 --> ?'. To the right, the 'Output Variable' section has a 'Name:' field with 'time' and an empty 'Label:' field, with a 'Change' button below. At the bottom, there are buttons for 'Old and New Values...', 'If...' (with the text '(optional case selection condition)'), 'OK', 'Paste', 'Reset', 'Cancel', and 'Help'.

Recode into Different Variables

String Variable -> Output Variable:

Index1 --> ?

Output Variable

Name: time

Label:

Change

Old and New Values...

If... (optional case selection condition)

OK Paste Reset Cancel Help

# After button Old and New Values

SPSS Recode into Different Variables: Old and New Values

**Old Value**

☐ Value:

☐ System-missing

☐ System- or user-missing

☐ Range:

through

☐ Range, LOWEST through value:

☐ Range, value through HIGHEST:

☒ All other values

**New Value**

☒ Value:

☐ System-missing

☐ Copy old value(s)

**Old -> New:**

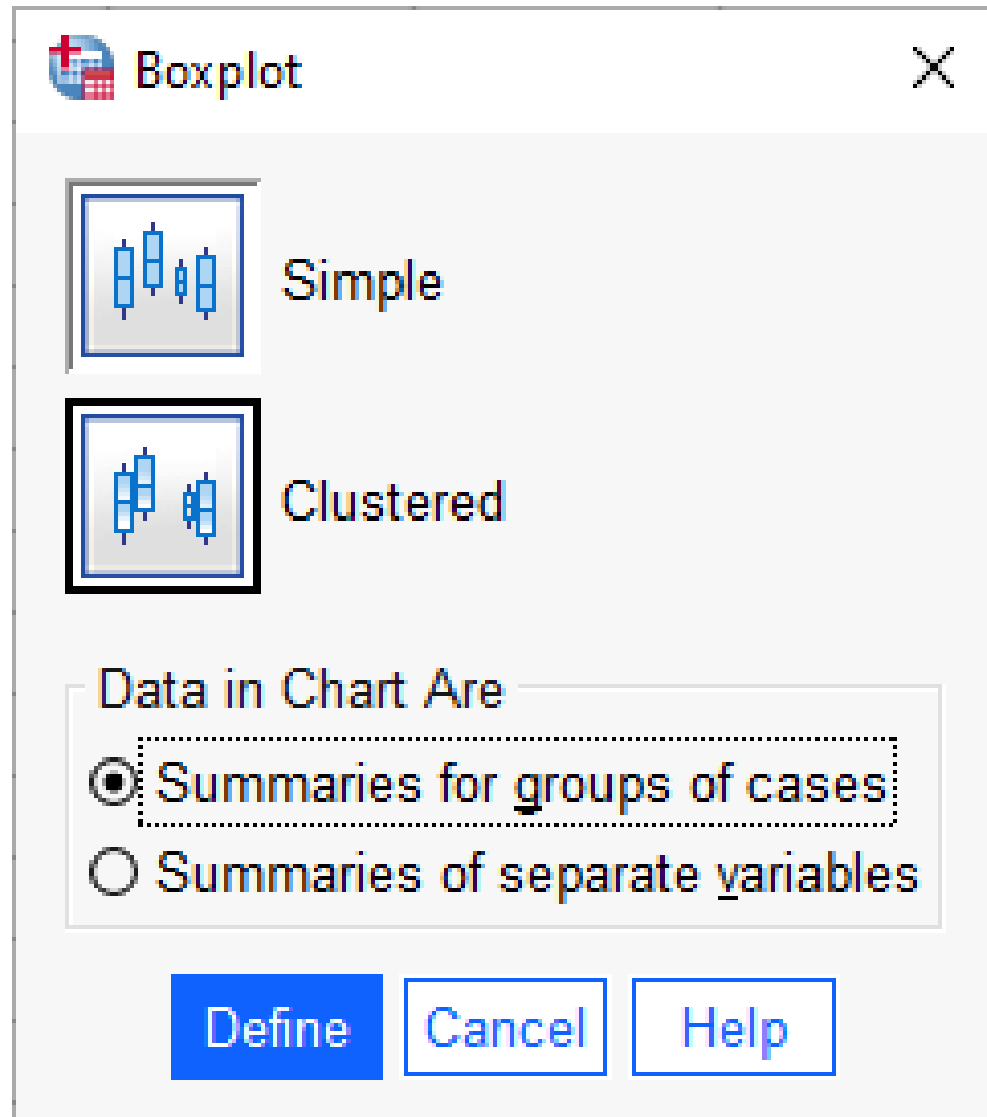
MISSING -> SYSMIS  
'Post' -> 0  
'FU6' -> 6  
'FU12' -> 12  
ELSE -> 99

☐ Output variables are strings Width: 8

☐ Convert numeric strings to numbers ('5' -> 5)



# After menu Graphs | Boxplot



# After button Define

Define Clustered Boxplot: Summaries for Groups of Cases

id  
Pre  
Index1

Variable:  
log\_frequency

Category Axis:  
time

Define Clusters by :  
BST

Label Cases by :

Panel by

Rows:

☐ Nest variables (no empty rows)

Columns:

☐ Nest variables (no empty columns)

Filter by:

OK Paste Reset Cancel Help

# Break #2

- What you have learned
  - Description of HIV-intervention data
- What's coming next
  - Random intercepts model using hiv-intervention data

# Random intercepts analysis, 1 of 6

**Model Dimension<sup>a</sup>**

		Number of Levels	Covariance Structure	Number of Parameters	Subject Variables
Fixed Effects	Intercept	1		1	
	BST	2		1	
	time	1		1	
Random Effects	Intercept	1	Variance Components	1	id
Residual				1	
Total		5		5	

a. Dependent Variable: log\_frequency.



# Random intercepts analysis, 2 of 6

## Information Criteria<sup>a</sup>

-2 Restricted Log Likelihood	473.80460947
Akaike's Information Criterion (AIC)	477.80460947
Hurvich and Tsai's Criterion (AICC)	478.02683170
Bozdogan's Criterion (CAIC)	483.89071201
Schwarz's Bayesian Criterion (BIC)	481.89071201

The information criteria are displayed in smaller-is-better form.

a. Dependent Variable: log\_frequency.



# Random intercepts analysis, 3 of 6

## Coefficients of Determination

Pseudo-R Square Measures	Marginal	.064
	Conditional	.395





# Random intercepts analysis, 4 of 6

## Type III Tests of Fixed Effects<sup>a</sup>

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	38.556	37.935	<.001
BST	1	18.002	2.110	.164
time	1	39.000	.723	.400

a. Dependent Variable: log\_frequency.



# Random intercepts analysis, 5 of 6

**Estimates of Fixed Effects<sup>a</sup>**

Parameter	Estimate	Std. Error	df	t	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Intercept	22.508	3.935	28.633	5.720	<.001	14.455	30.561
[BST=0]	-7.133	4.910	18.002	-1.453	.164	-17.450	3.183
[BST=1]	0 <sup>b</sup>	0	.	.	.	.	.
time	-.263	.309	39.000	-.850	.400	-.887	.362

a. Dependent Variable: log\_frequency.

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



# Random intercepts analysis, 6 of 6

## Estimates of Covariance Parameters<sup>a</sup>

Parameter		Estimate	Std. Error
Residual		137.199	31.070
Intercept [subject = id]	Variance	74.827	41.497

a. Dependent Variable: log\_frequency.



# Live demo, Random Intercepts Model



# After menu Analyze | Mixed Models | Linear

Linear Mixed Models: Specify Subjects and Repeated

Click Continue for models with uncorrelated terms.  
Specify Subject variable for models with correlated random effects.  
Specify both Repeated and Subject variables for models with correlated residuals within the random effects.

Subjects:

id

Repeated:

Repeated Covariance Type:

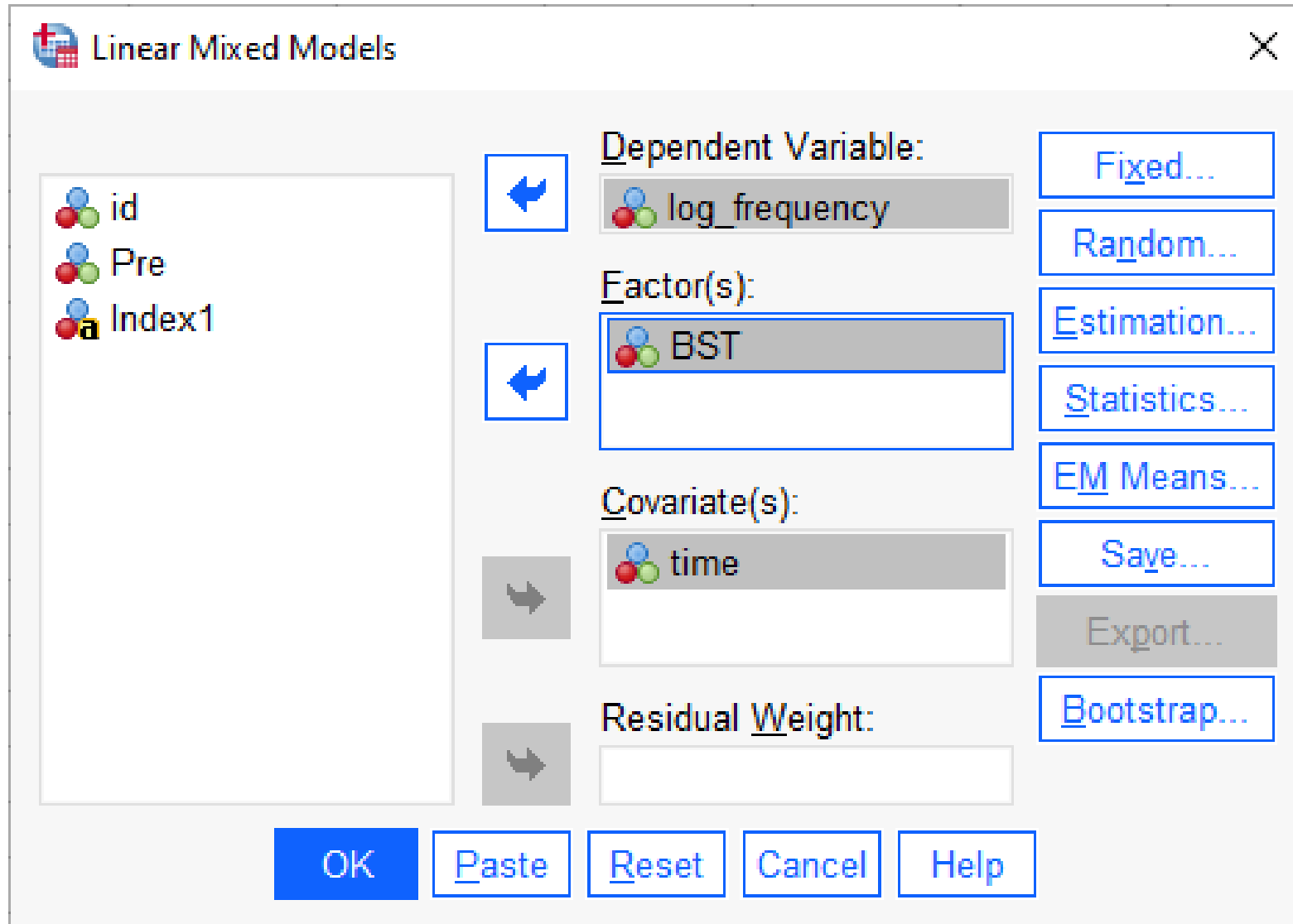
Diagonal

Kronecker Measures:

Spatial Covariance Coordinates:

Continue Reset Cancel Help

# After button Continue



The image shows a 'Linear Mixed Models' dialog box. On the left is a list of variables: 'id', 'Pre', and 'Index1'. In the center, there are four sections with arrows pointing to them from the list: 'Dependent Variable:' with 'log\_frequency', 'Factor(s):' with 'BST', 'Covariate(s):' with 'time', and 'Residual Weight:' which is empty. On the right, there are buttons for 'Fixed...', 'Random...', 'Estimation...', 'Statistics...', 'EM Means...', 'Save...', 'Export...', and 'Bootstrap...'. At the bottom are buttons for 'OK', 'Paste', 'Reset', 'Cancel', and 'Help'.

Linear Mixed Models

id  
Pre  
Index1

Dependent Variable:  
log\_frequency

Factor(s):  
BST

Covariate(s):  
time

Residual Weight:

Fixed...  
Random...  
Estimation...  
Statistics...  
EM Means...  
Save...  
Export...  
Bootstrap...

OK Paste Reset Cancel Help

# After button Fixed

Linear Mixed Models: Fixed Effects

Fixed Effects

☒ Build terms ☐ Build nested terms

Factors and Covariates:

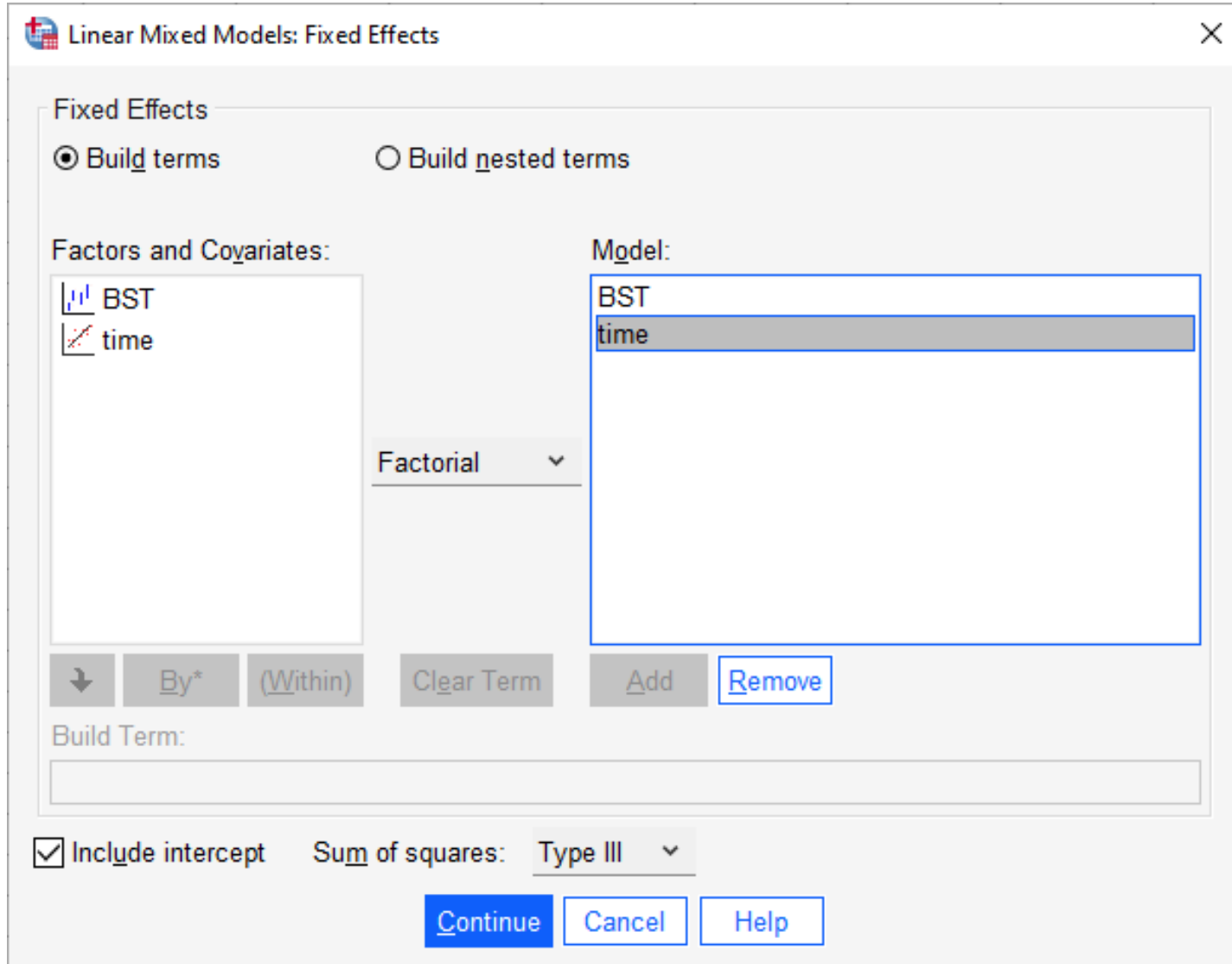
Model:

Factorial

Build Term:

☒ Include intercept Sum of squares: Type III

Continue Cancel Help



# After button Random

Linear Mixed Models: Random Effects

Random Effect 1 of 1

Previous Next

Covariance Type: Variance Components

Random Effects

☒ Build terms ☐ Build nested terms ☒ Include intercept

Factors and Covariates: Model:

BST  
time

Factorial

By\* (Within) Clear Term Add Remove

Build Term:

Subject Groupings

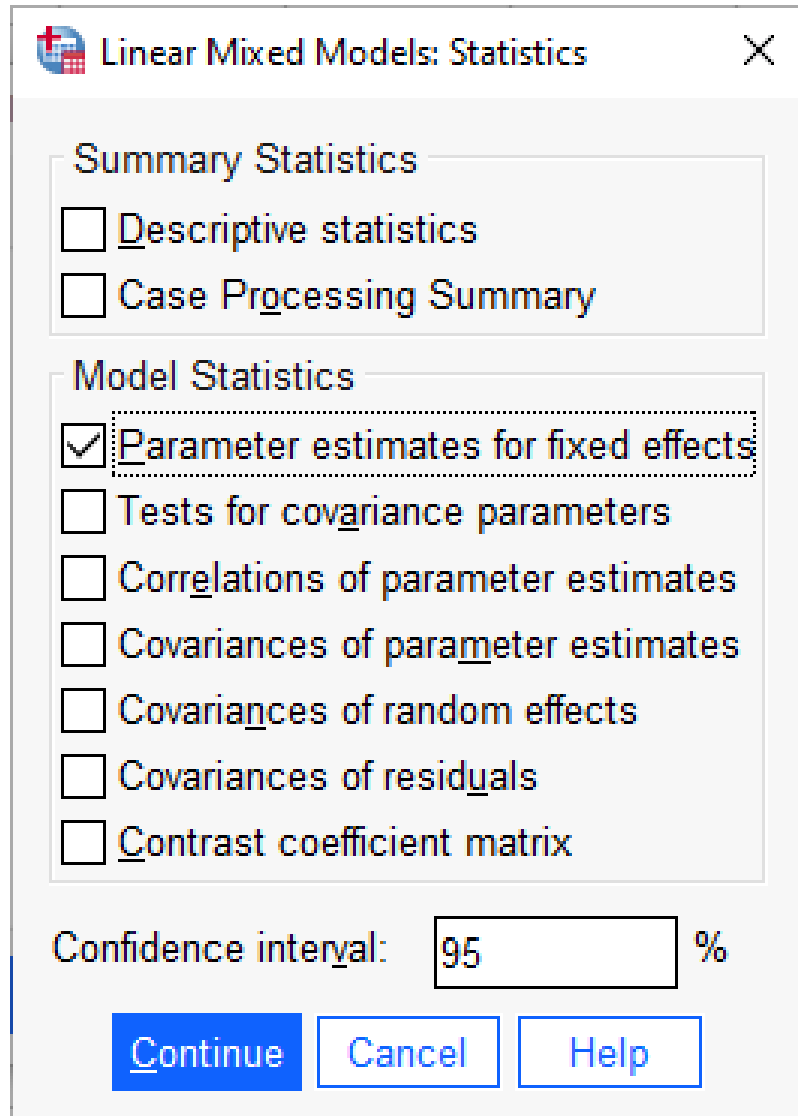
Subjects: Combinations:

id id

☒ Display parameter predictions for this set of random effects

Continue Cancel Help

# After button Statistics



The image shows the 'Linear Mixed Models: Statistics' dialog box in SPSS. It has a title bar with the SPSS logo, the text 'Linear Mixed Models: Statistics', and a close button. The dialog is divided into two main sections: 'Summary Statistics' and 'Model Statistics'. In the 'Summary Statistics' section, there are two unchecked checkboxes: 'Descriptive statistics' and 'Case Processing Summary'. In the 'Model Statistics' section, there are seven checkboxes: 'Parameter estimates for fixed effects' (checked), 'Tests for covariance parameters', 'Correlations of parameter estimates', 'Covariances of parameter estimates', 'Covariances of random effects', 'Covariances of residuals', and 'Contrast coefficient matrix'. At the bottom, there is a 'Confidence interval:' label, a text box containing '95', and a '%' symbol. Below these are three buttons: 'Continue' (highlighted in blue), 'Cancel', and 'Help'.

Linear Mixed Models: Statistics

Summary Statistics

- ☐ Descriptive statistics
- ☐ Case Processing Summary

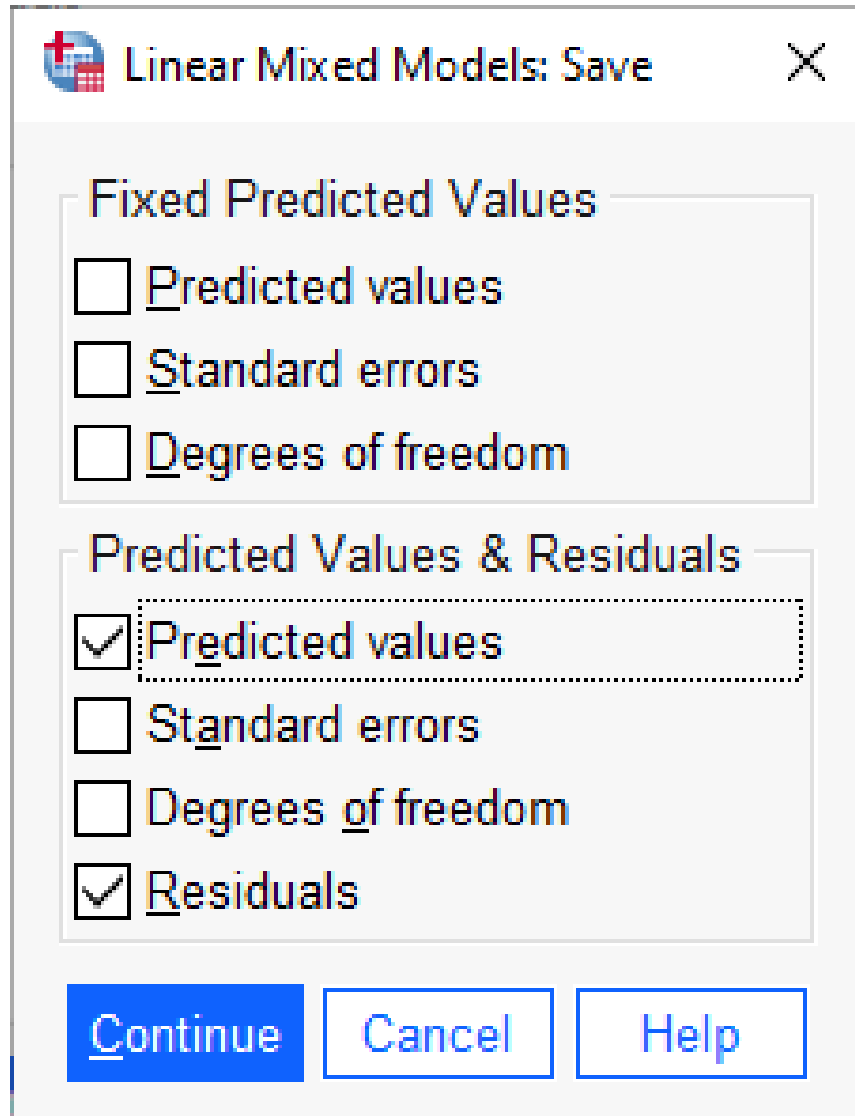
Model Statistics

- ☒ Parameter estimates for fixed effects
- ☐ Tests for covariance parameters
- ☐ Correlations of parameter estimates
- ☐ Covariances of parameter estimates
- ☐ Covariances of random effects
- ☐ Covariances of residuals
- ☐ Contrast coefficient matrix

Confidence interval: 95 %

Continue Cancel Help

# After button Save



A screenshot of a software dialog box titled "Linear Mixed Models: Save". The dialog box has a standard Windows-style title bar with a close button (X) in the top right corner. It contains two main sections for selecting output options. The first section, "Fixed Predicted Values", has three unchecked checkboxes: "Predicted values", "Standard errors", and "Degrees of freedom". The second section, "Predicted Values & Residuals", has four checkboxes: "Predicted values" (checked), "Standard errors" (unchecked), "Degrees of freedom" (unchecked), and "Residuals" (checked). The "Predicted values" checkbox in the second section is highlighted with a dotted border. At the bottom of the dialog are three buttons: "Continue" (blue), "Cancel" (white with blue border), and "Help" (white with blue border).

Linear Mixed Models: Save

Fixed Predicted Values

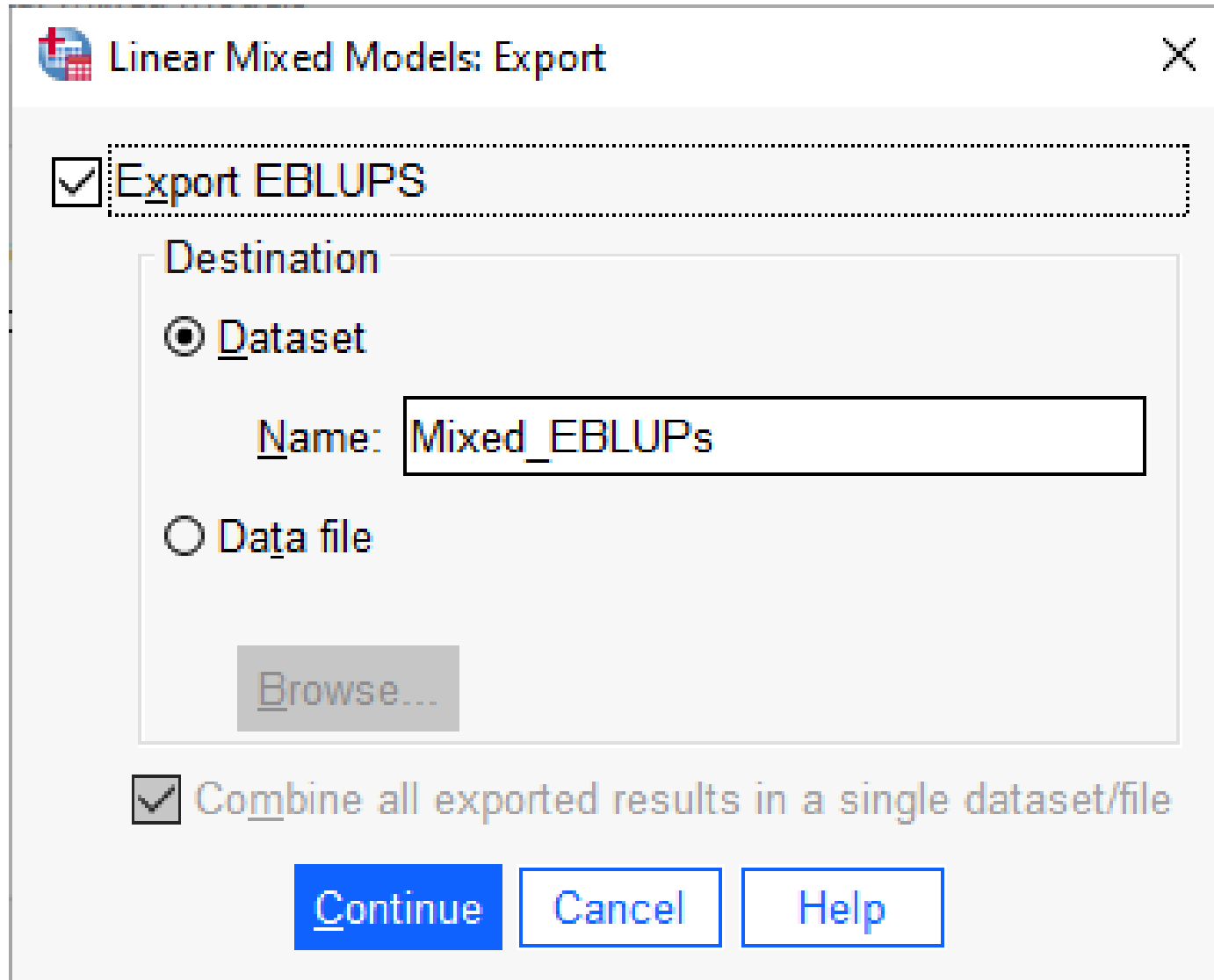
- ☐ Predicted values
- ☐ Standard errors
- ☐ Degrees of freedom

Predicted Values & Residuals

- ☒ Predicted values
- ☐ Standard errors
- ☐ Degrees of freedom
- ☒ Residuals

Continue Cancel Help

# After button Export



The image shows a software dialog box titled "Linear Mixed Models: Export". It has a standard window icon with a plus sign and a close button (X) in the top right corner. The main content area is light gray. At the top, there is a checked checkbox labeled "Export EBLUPS". Below this, there is a section titled "Destination" in a slightly larger font. Inside this section, there are two radio button options: "Dataset" (which is selected) and "Data file". Under the "Dataset" option, there is a text input field labeled "Name:" containing the text "Mixed\_EBLUPs". Below the "Data file" option, there is a disabled "Browse..." button. At the bottom of the dialog, there is another checked checkbox labeled "Combine all exported results in a single dataset/file". Below the checkboxes are three buttons: "Continue" (highlighted in blue), "Cancel", and "Help".

Linear Mixed Models: Export

☒ Export EBLUPS

Destination

☒ Dataset

Name: Mixed\_EBLUPs

☐ Data file

Browse...

☒ Combine all exported results in a single dataset/file

Continue Cancel Help

# Break #3

- What you have learned
  - Random intercepts model using hiv-intervention data
- What's coming next
  - Mathematical formulation of random slopes model



# Random slopes model, 1 of 2

- Same notation for the time and outcome variables
- $Y_{ij}$ ,  $i = 1, \dots, n$ ;  $j = 1, \dots, k$ 
  - n subjects, k time points
- $t_j$ , time of jth measurement

## Speaker notes

The random slopes model has the same basic notation for the time and outcome variables. The outcome variable has two subscripts on for the individual patient and one for each time measurement.

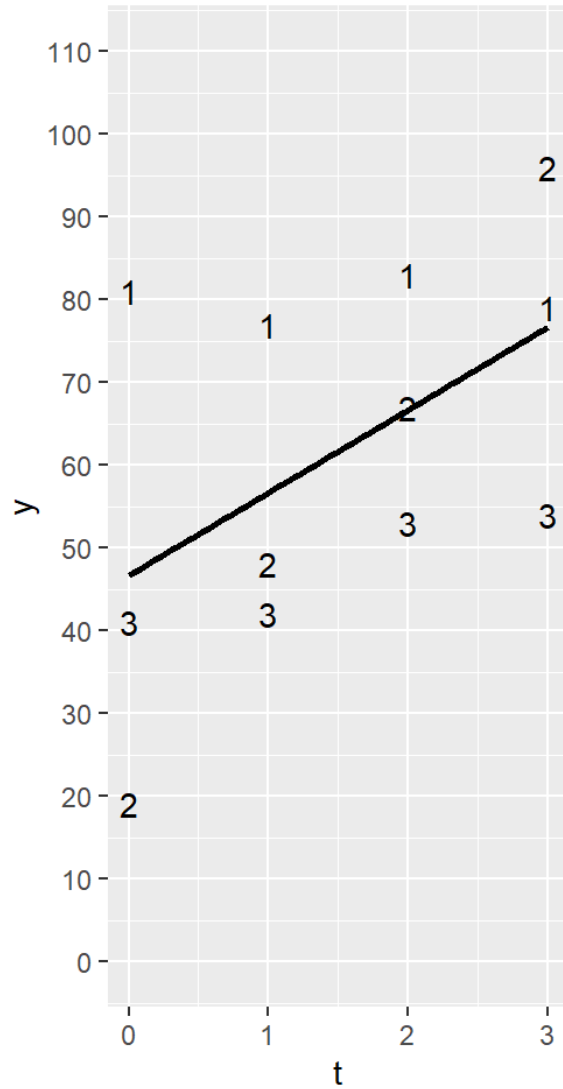
# Random slopes model, 2 of 2

- $Y_{ij} = \beta_0 + u_{0i} + \beta_1 t_j + u_{0i} t_j + \epsilon_{ij}$ 
  - $\beta_0$  and  $\beta_1$  are unknown constants
  - $u_{0i}$ ,  $u_{1i}$ , and  $\epsilon_{ij}$  are normally distributed
    - $SD(u_{0i}) = \sigma_{intercept}$
    - $SD(u_{1i}) = \sigma_{slope}$
    - $SD(\epsilon_{ij}) = \sigma_{error}$

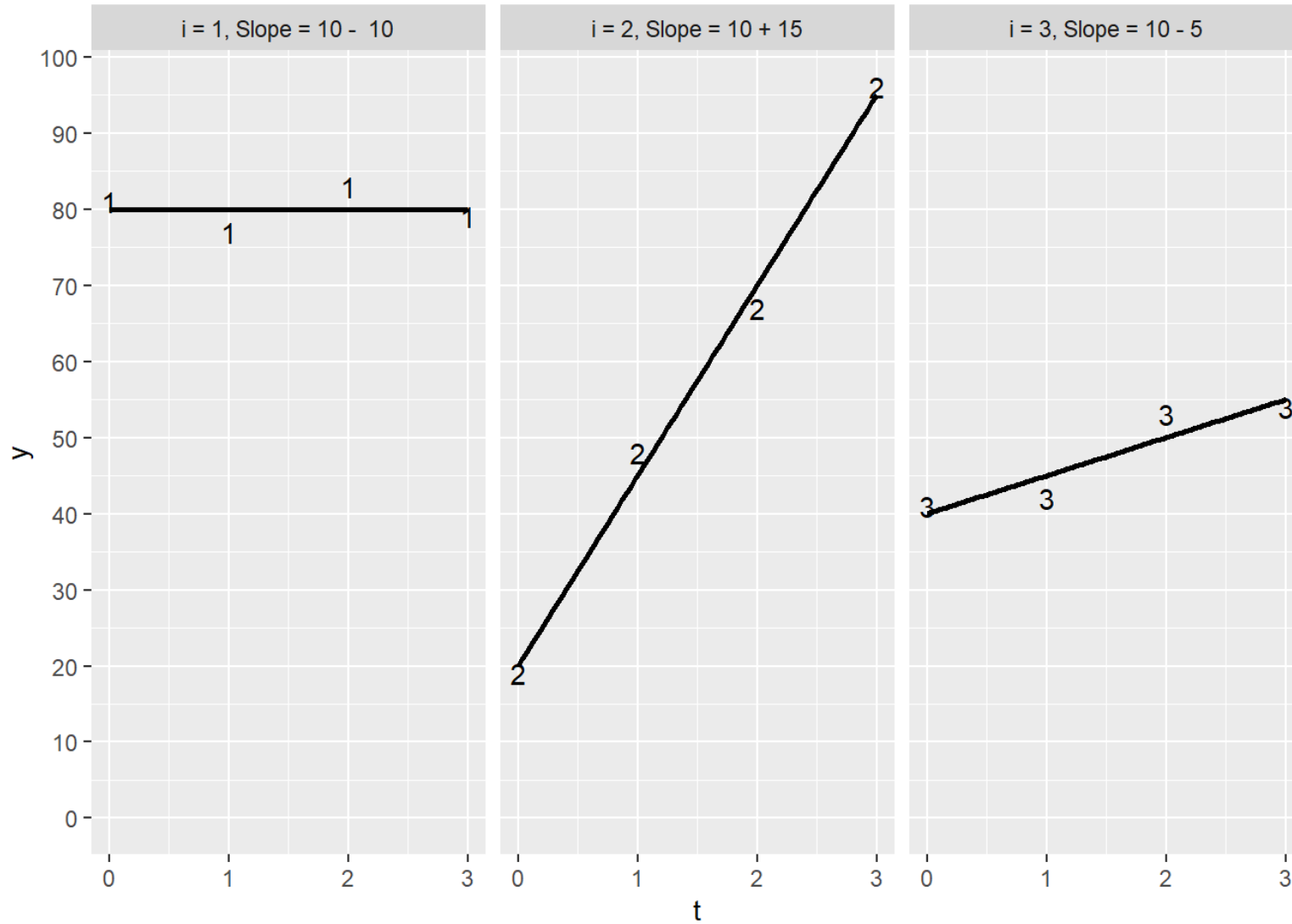
## Speaker notes

There are three sources of random variation in the random slopes model,  $u_{0i}$ ,  $u_{1i}$ , and  $\epsilon_{ij}$ .

# Random slopes illustrated, 1 of 2



# Random slopes illustrated, 2 of 2



# Break #4

- What you have learned
  - Mathematical formulation of random slopes model
- What's coming next
  - Assumptions and complications

# Assumptions

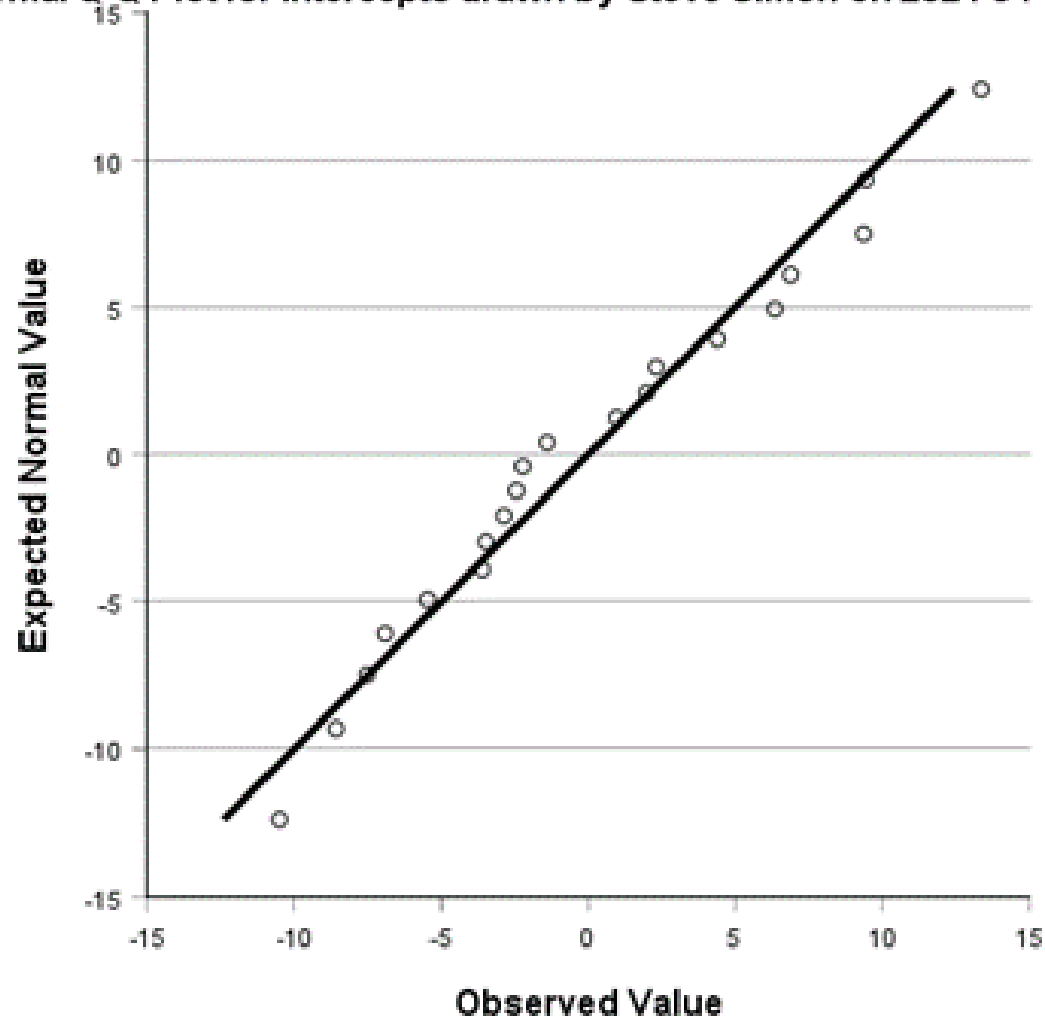
- Independence
  - Only between subjects
- Normality
  - Residuals
  - Random intercepts and/or slopes
- Linearity





# Normality check, 1 of 2

Normal Q-Q Plot for intercepts drawn by Steve Simon on 2024-04-14

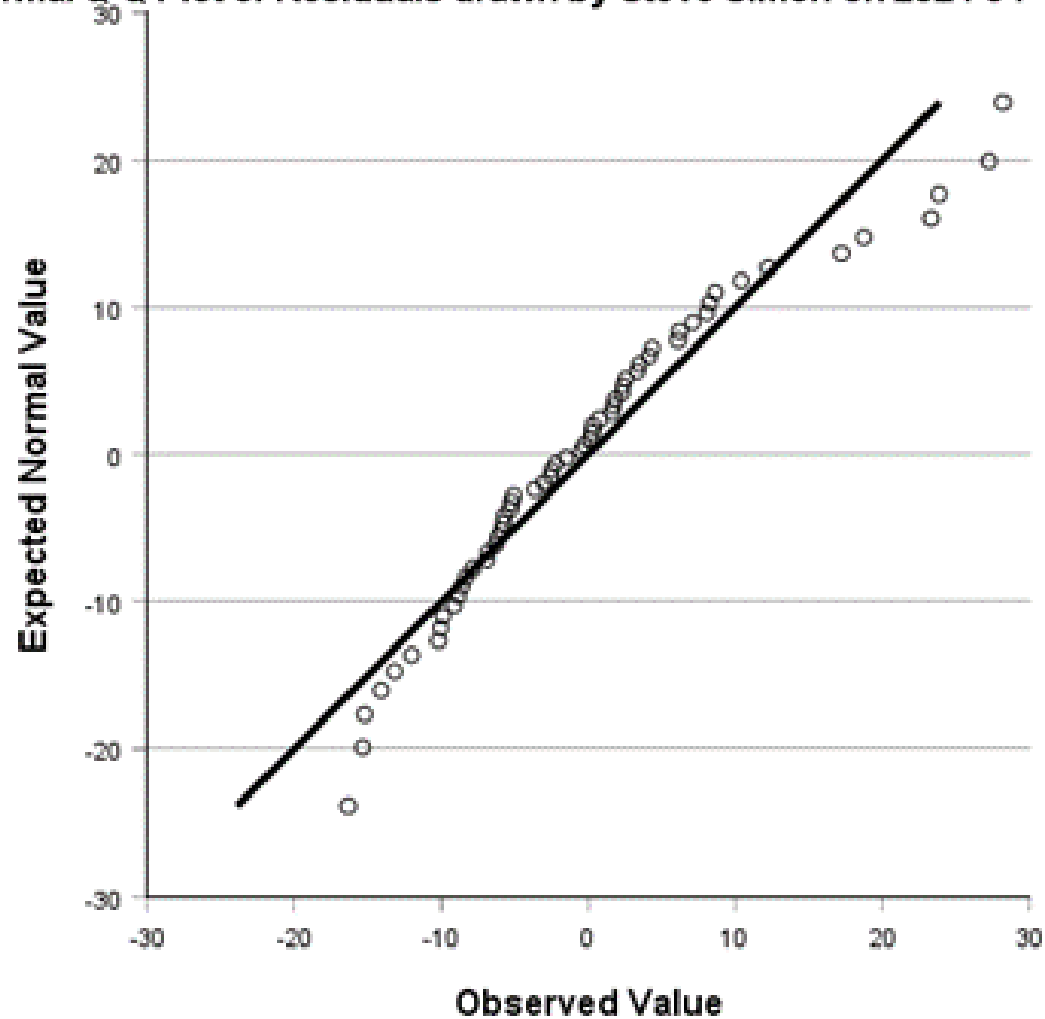


## Speaker notes

The residuals represent the deviations of individual time measurements from the regression line for an individual patient. That means the deviation from a trend line that has been randomly shifted up or down (random intercepts) and/or a randomly steeper or flatter trend line (random slopes). In this dataset, the normal probability plot looks fairly close to a straight line.

# Normality check, 2 of 2

Normal Q-Q Plot of Residuals drawn by Steve Simon on 2024-04-14





# Linearity check

# Complications

- Not a problem
  - Missing values
  - Better than Last Observation Carried Forward
- Problems (more tedious than difficult)
  - Interactions
  - Nonlinear trends
  - Covariates
    - Between patients
    - Within patients

## Speaker notes

Missing values are normally a big headache, but less so for the random intercepts or slopes models. If a patient missed a visit at a particular time point, you can easily extrapolate from the visits before and after. You are assuming linearity, after all.

In some clinical trials, if a patient came at the intermediate evaluation but did not show up at the final evaluation, the research team would replace the missing final outcome with the intermediate outcome. This technique, called Last Observation Carried Forward (LOCF) was not very popular when it was introduced and has been pretty much discredited. The random intercepts or slopes model would extrapolate the trend from the intermediate value, which works much better.

Interactions are always difficult, and when the interactions involve time, it can get a bit messy. Nonlinear trends over time are also a bit of a problem. In both cases, though, the work is more tedious than difficult. Interactions and nonlinearity mean that your interpretation of the results will require a bit more thought and you can't come up with as simple a story to tell.

A covariate is a variable which is not of direct interest in the research, but one that you must take account of in order to produce a credible analysis. In just about any cancer study, you should track whether the patient is a smoker. It's not something you're interested in testing. The role of smoking in lung cancer and most other types of cancer was established many decades ago. You still have to account for smoking though because it can explain so much of the variation in your outcome. Failure to account for smoking would greatly reduce your power and precision.

There are two types of covariates. The ones that are fixed and do not change over time are called time constant covariates or between subject covariates. Patient demographics are time constant. Measurements done at baseline to assess how ill the patient was at the start of the study are time constant.

Covariates that change over time are called time varying covariates or within subject covariates. The extent to which a patient complies with taking his/her medication is a time varying covariate. Seasonal changes in temperature, humidity, or pollen counts are time varying covariates.

There is one important distinction between time constant and time varying covariates. The latter are much better at removing variation from your outcome, and can greatly improve your power and precision.



# Live demo, normality checks

# Summary

- What you have learned
  - Mathematical formulation of random intercepts model
  - Description of HIV-intervention data
  - Random intercepts model using hiv-intervention data
  - Mathematical formulation of random slopes model
  - Assumptions and complications

# Additional topics??



- Learning objectives for mixed models
  - Set up a data set for a Repeated Measures ANOVA
  - Explain when a n-way RM ANOVA would be used to analyze data
  - Explain the data requirements for a n-way RM ANOVA
  - Write a research question for a n-way RM ANOVA
  - Write the Null and Research Hypotheses for a n-way RM ANOVA
  - Run a complete n-way RM ANOVA
  - List the assumptions for a n-way RM ANOVA
  - Explain the tests for the assumptions for a n-way RM ANOVA
  - Run the assumptions tests for a n-way RM ANOVA
  - Interpret the assumptions tests for a n-way RM ANOVA
  - Explain the issue that arises if the assumption of sphericity is violated
  - Explain how the Epsilon correction works
  - Explain the condition of a significant interaction effect
  - Explain the process to run simple main effects for a Repeated Measures n-way ANOVA
  - Run simple main effects for a Repeated Measures n-way ANOVA
  - Interpret simple main effects for a Repeated Measures n-way ANOVA
  - Explain the special considerations for simple main effects for a Repeated Measures n-way ANOVA with a factor with >2 levels
  - Explain the process to run main effects for a Repeated Measures n-way ANOVA
  - Run main effects for a Repeated Measures n-way ANOVA
  - Interpret main effects for a Repeated Measures n-way ANOVA
  - Summarize the output of a complete n-way RM ANOVA
  - Define the meaning of mixed model
  - Define Between Subjects in relation to the mixed model
  - Define Within Subjects in relation to the mixed model
  - Be familiar with the various names for a mixed model ANOVA
  - List the purpose of running a mixed model ANOVA
  - Identify Between and Within factors for a mixed model ANOVA
  - List the type of data that can be used to define the levels in a mixed model ANOVA
  - List the assumptions for a mixed model ANOVA
  - Successfully run the statistical analysis tests for the assumptions of a mixed model ANOVA

- Successfully run the statistical analysis tests for the assumptions of a mixed model ANOVA
- Interpret the statistical analysis tests for the assumptions of a mixed model ANOVA
- Explain how normality of the data is assessed
- Explain the rules for violation of the assumption of homogeneity of variances
- Define Homogeneity of Covariances
- Identify Box's Test
- Develop a research question for a mixed model ANOVA
- Write the Null and Alternative for a mixed model ANOVA
- Set up data for a mixed model ANOVA in the SPSS data editor
- Run a two-way mixed model ANOVA analysis using SPSS
- Interpret the output of a two-way mixed model ANOVA analysis
- Understand the process of determining the presence or not of an interaction effect
- Define Simple Main Effects
- Determine when Simple Main Effects would be run
- Define Main Effects
- Determine when Main Effects would be run
- Run the Simple Main Effects following a decision about the interaction effect
- Interpret the Simple Main Effects
- Run the Main Effects following a decision about the interaction effect
- Interpret the Main Effects
- Interpret Pair-Wise comparisons
- Create a complete write up of a mixed model ANOVA analysis

