

Linear Mixed Models

Students within classrooms

(Stress and test scores; testing done in groups)

Individuals within couples

(Perceived similarity and commitment)

Experimental trials within participants

(Reaction time by stimulus valence)

Attitude objects within participants

(Comparing attitude objects)

Non-independent observations

Groups/clusters of participants:

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(Stress and test scores; testing done in groups)

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Within-participant (repeated measures) designs:

Experimental trials within participants

(Reaction time by stimulus valence)

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(Comparing attitude objects)

Assumptions of linear regression

Observations are independent

Distribution of residuals is close to normal

All residuals come from the same distribution

- Residual distribution has constant mean
(No big departures from linearity)
- Residual distribution has constant variance
(Not too much heteroscedasticity)

Non-independent observations

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Within-participant (repeated measures) designs:

Experimental trials within participants

(Reaction time by stimulus valence)

Attitude objects within participants

(Comparing attitude objects)

What to do with grouping variable?

Include it as a predictor?

```
lm(testScore ~ stress + classroom)
```

```
lm(attitude ~ targetReligion + participant)
```

Let it interact with other variable(s)?

```
lm(testScore ~ stress * classroom)
```

```
lm(attitude ~ targetReligion * participant)
```

What to do with grouping variable?

Random intercept

(sort of like including the grouping variable as a main effect)

Random slope(s) and intercept

(sort of like including interactions with the grouping variable)

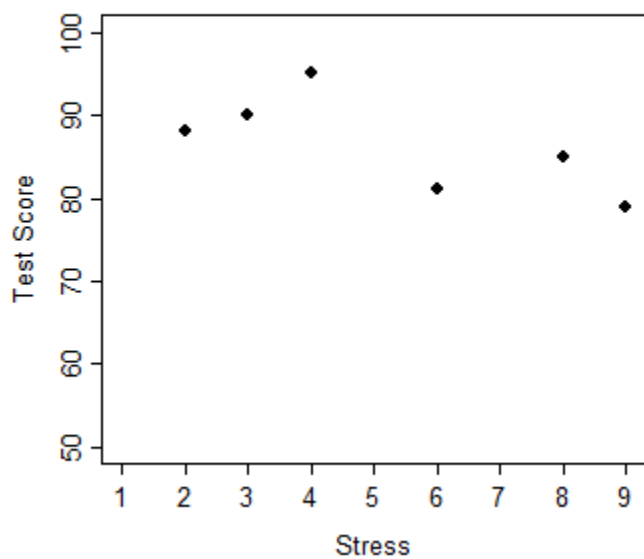
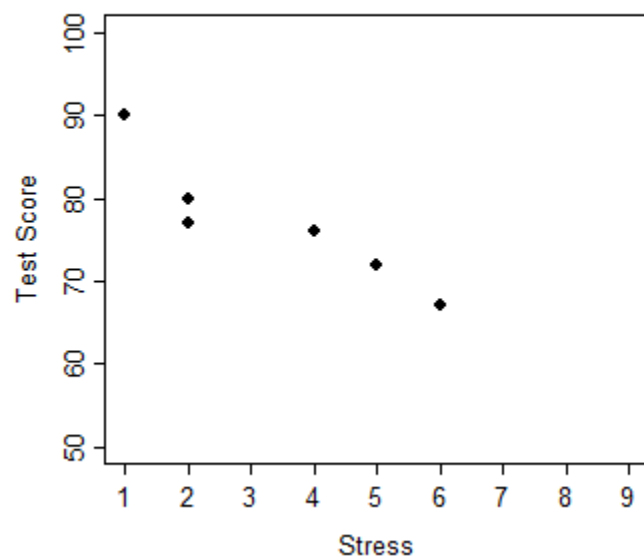
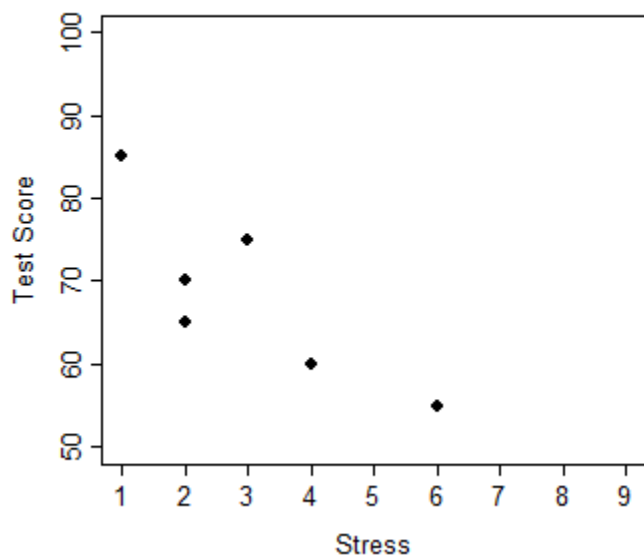
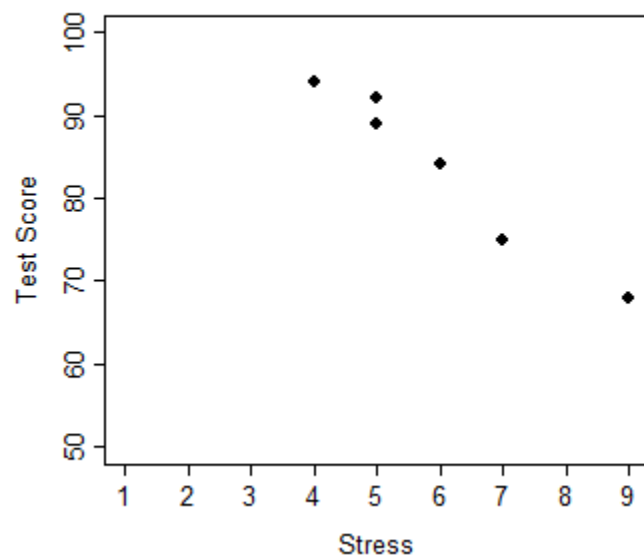
Alternative names

Linear mixed model (LMM)

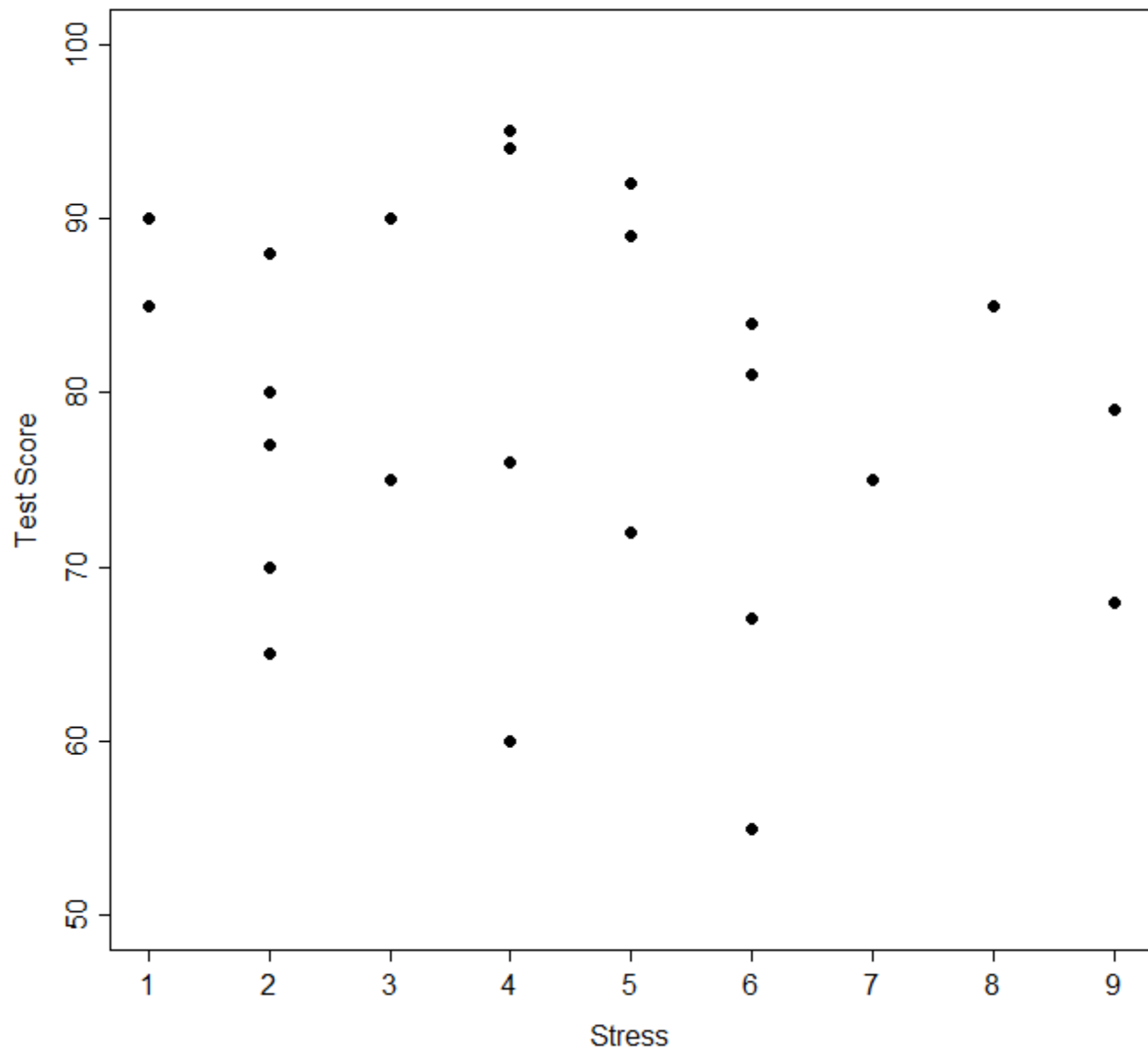
Linear mixed-effects model

Multilevel model (MLM)

Hierarchical linear model (HLM)

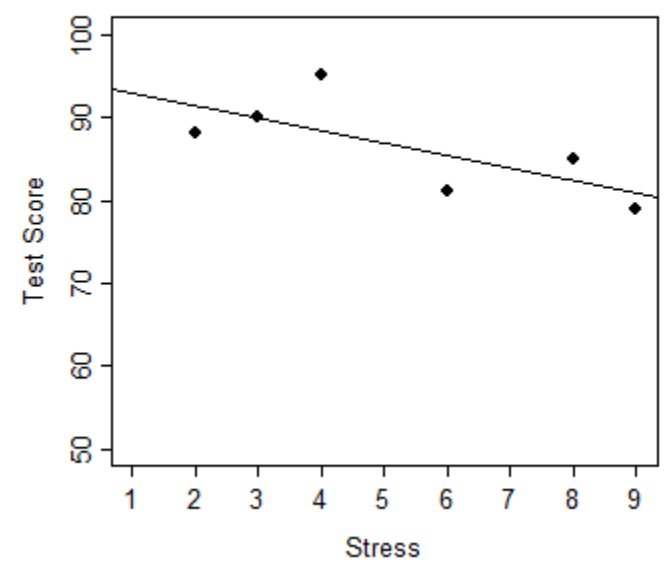
Classroom 1**Classroom 2****Classroom 3****Classroom 4**

Overall Result

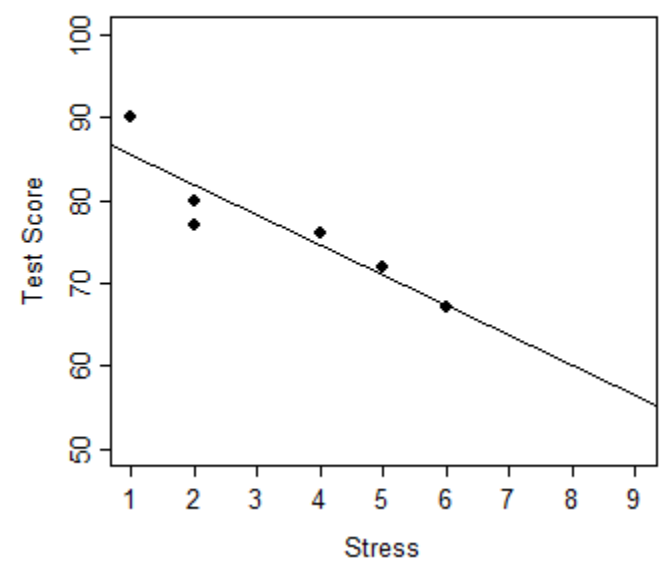


`lm(testScore ~ stress * classroom)`

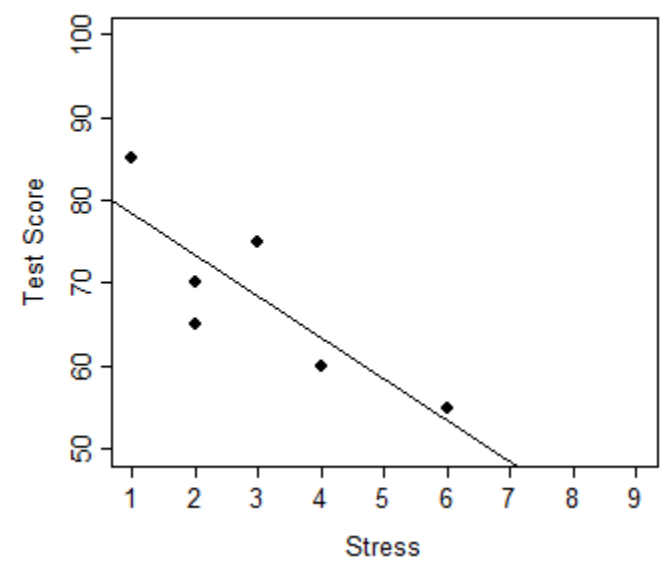
Classroom 1



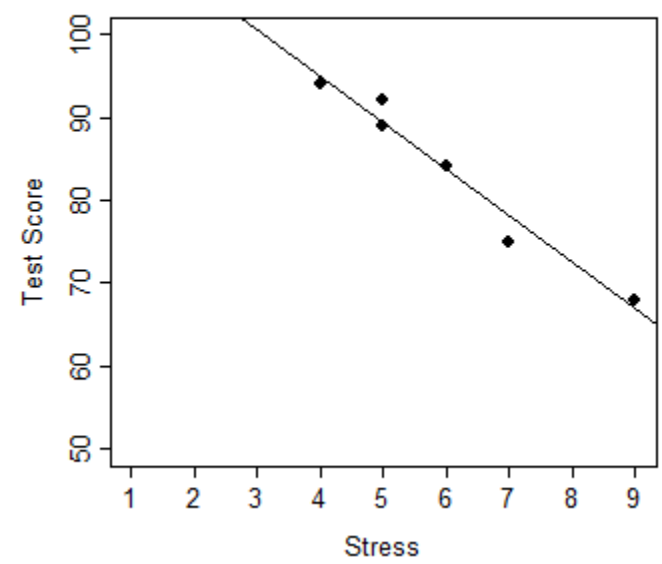
Classroom 2



Classroom 3

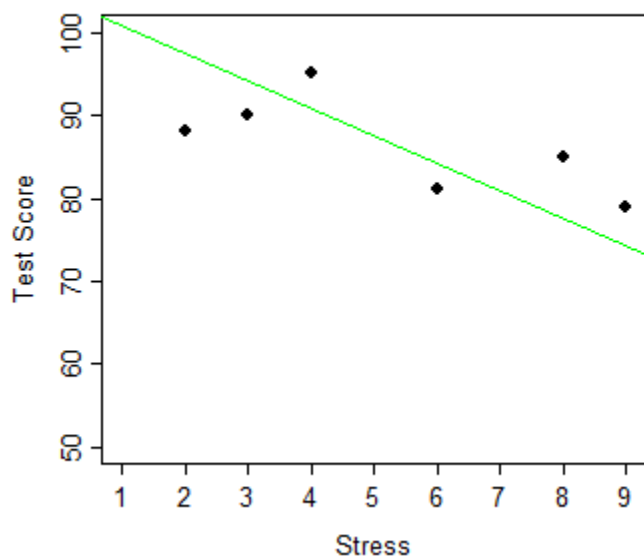


Classroom 4

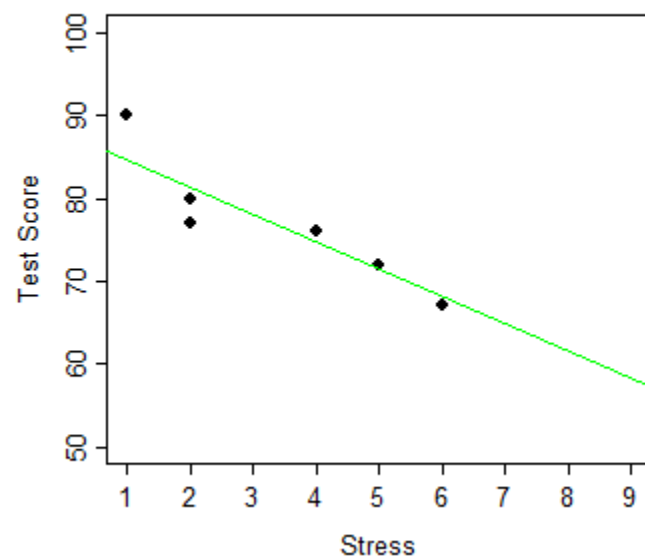


`lm(testScore ~ stress + classroom)`

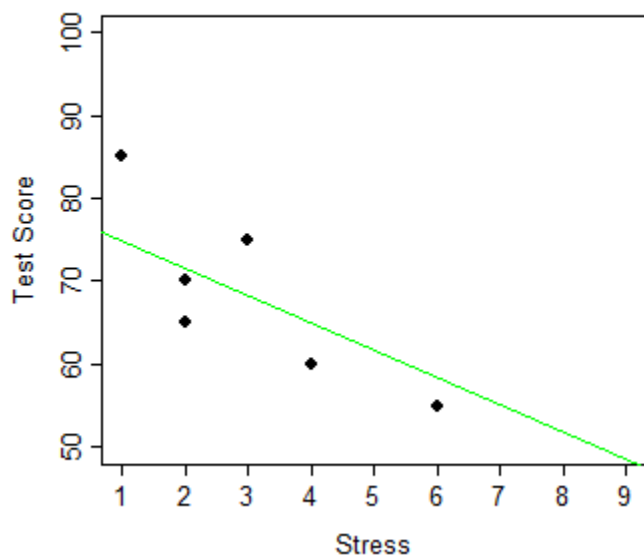
Classroom 1



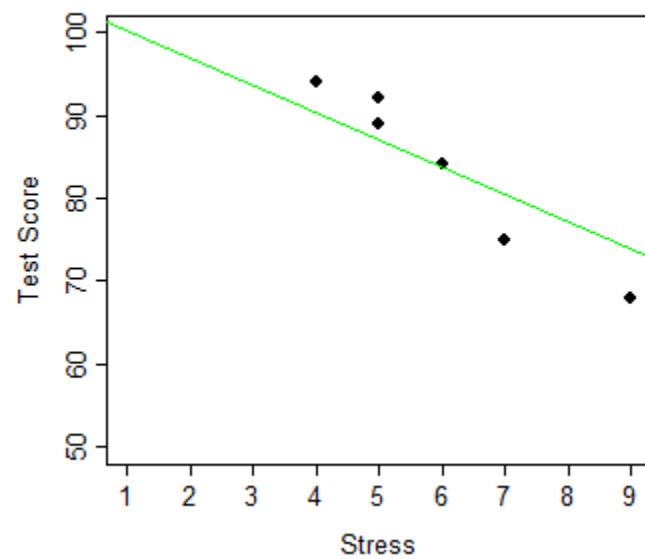
Classroom 2



Classroom 3



Classroom 4



What to do with grouping variable?

```
library(nlme)
```

Random intercept

(sort of like including the grouping variable as a main effect)

```
lme(testScore ~ stress, random=~1|classroom)
```

Random slope(s) and intercept

(sort of like including interactions with the grouping variable)

```
lme(testScore ~ stress, random=~1+stress|classroom)
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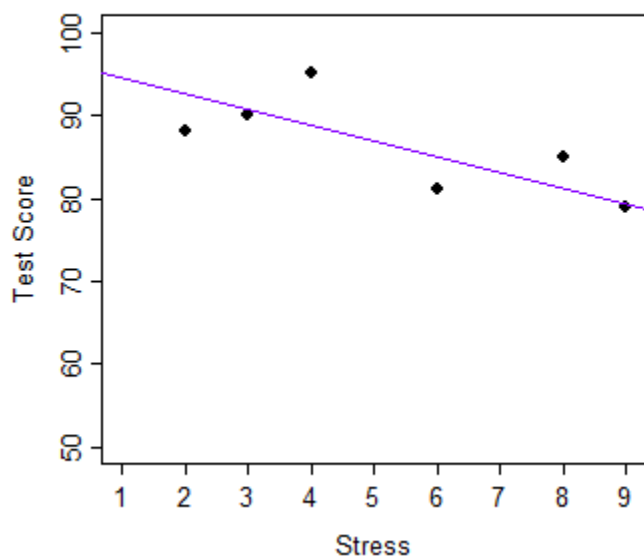
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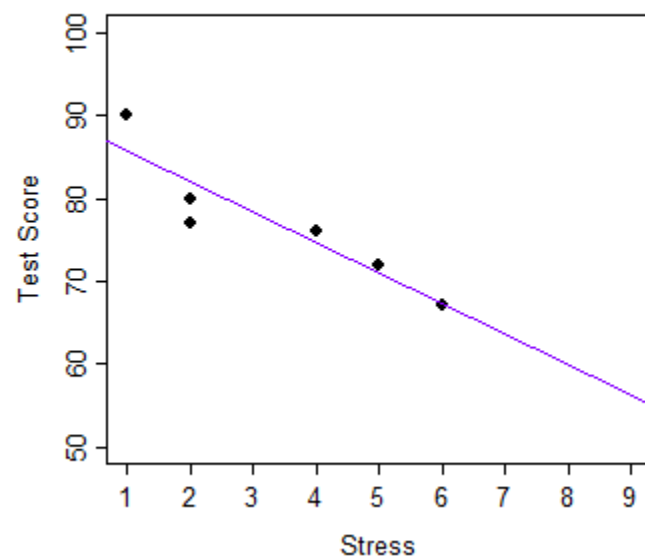
```
lme(testScore ~ stress, random=~1+stress|classroom)
```

`lme(testScore ~ stress, random=~1+stress|classroom)`

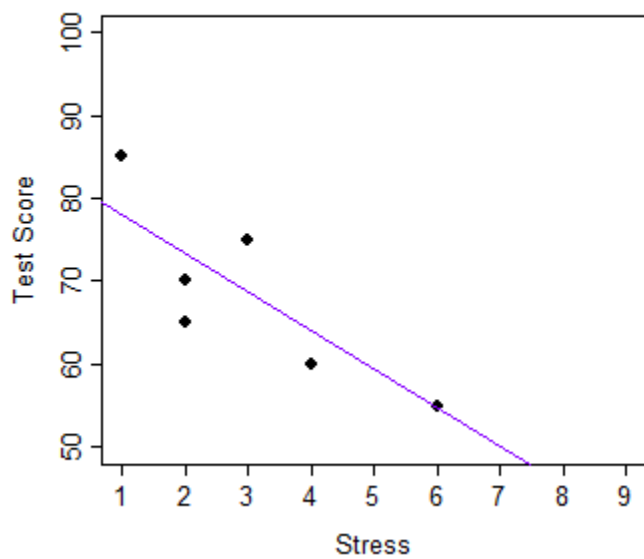
Classroom 1



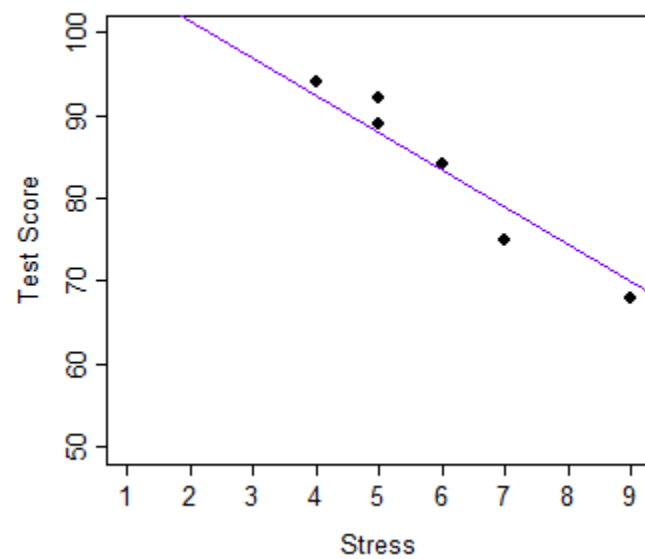
Classroom 2



Classroom 3

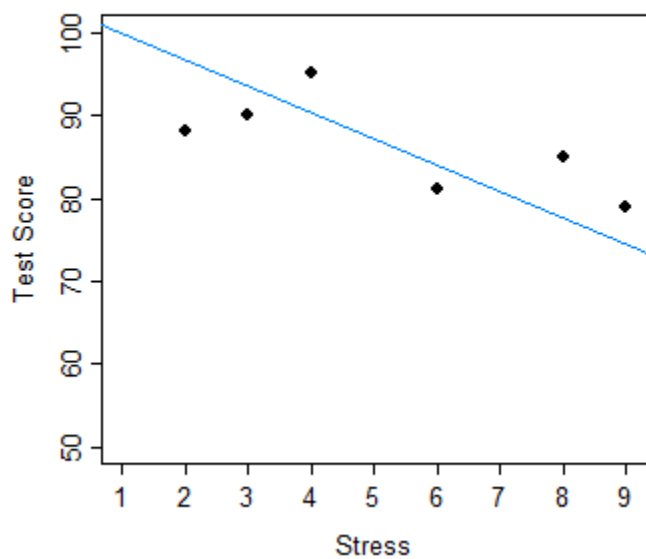


Classroom 4

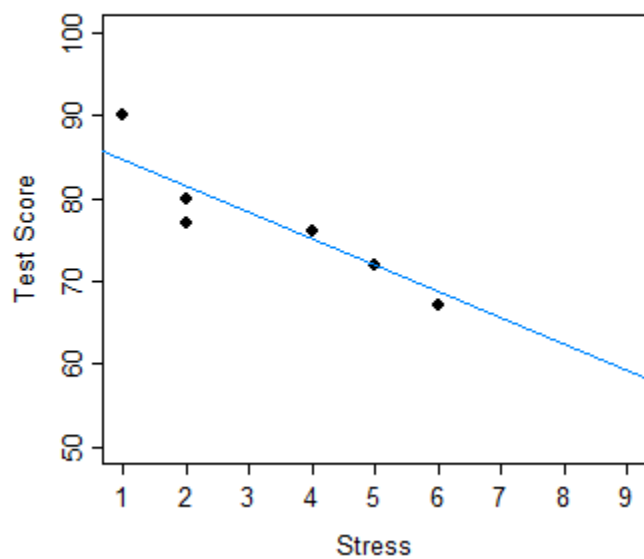


`lme(testScore ~ stress, random=~1|classroom)`

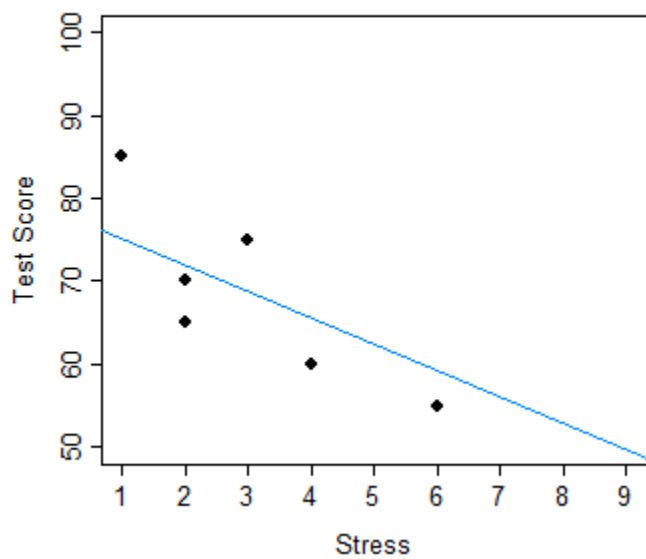
Classroom 1



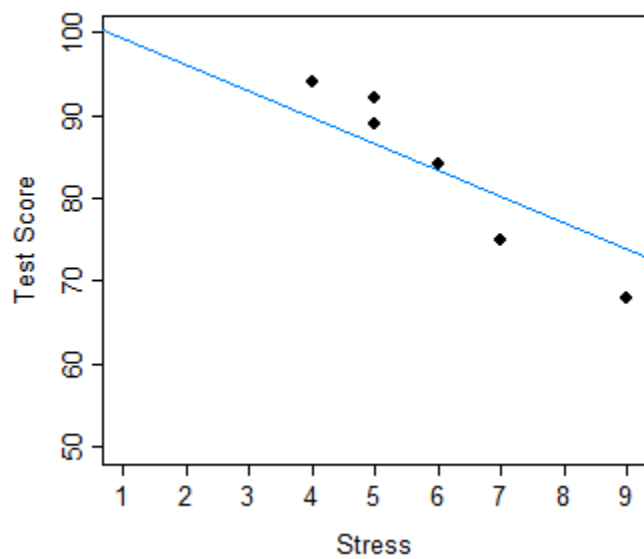
Classroom 2

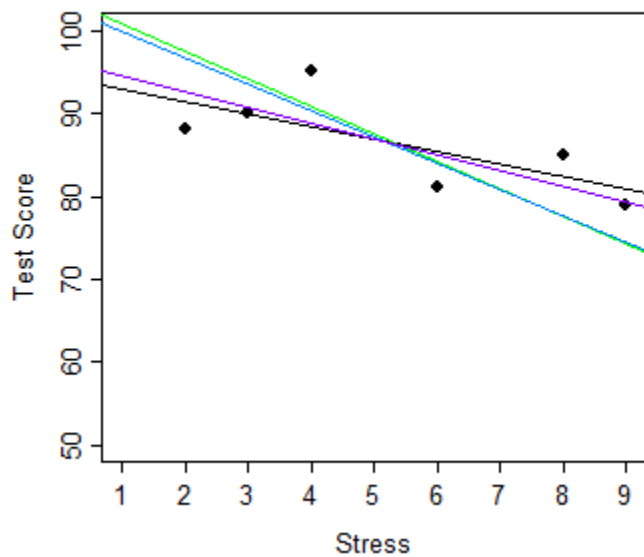
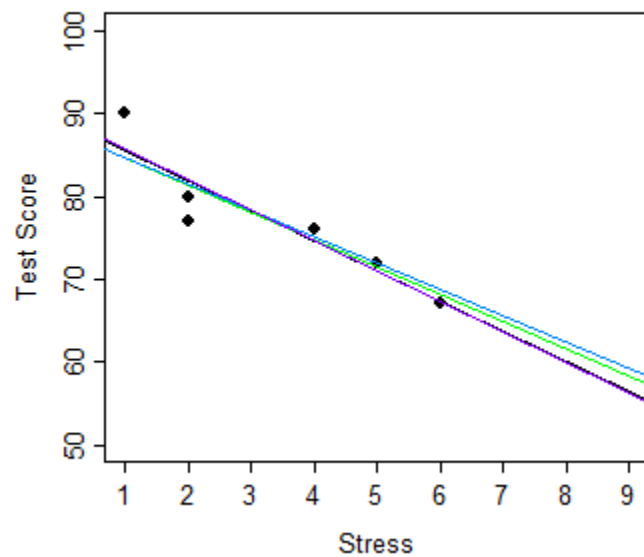
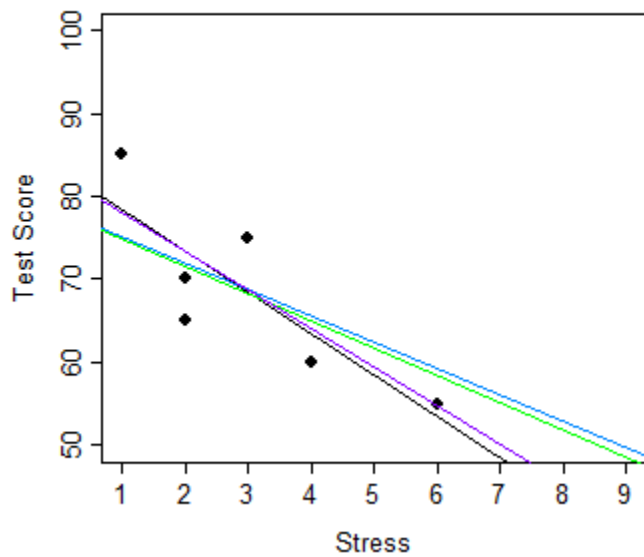
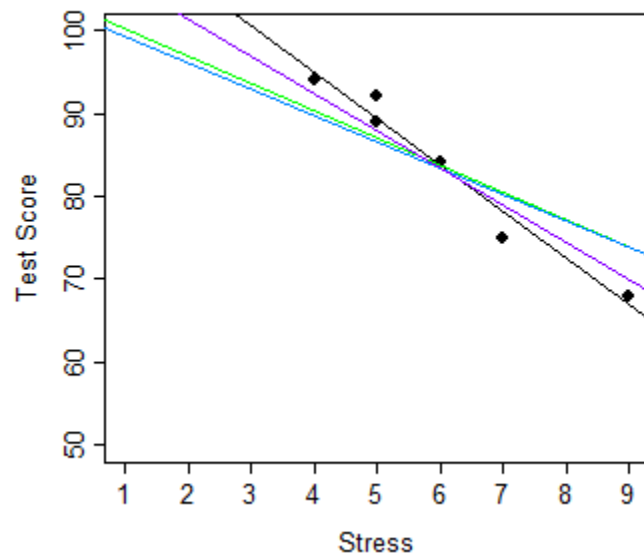


Classroom 3



Classroom 4



Classroom 1**Classroom 2****Classroom 3****Classroom 4**

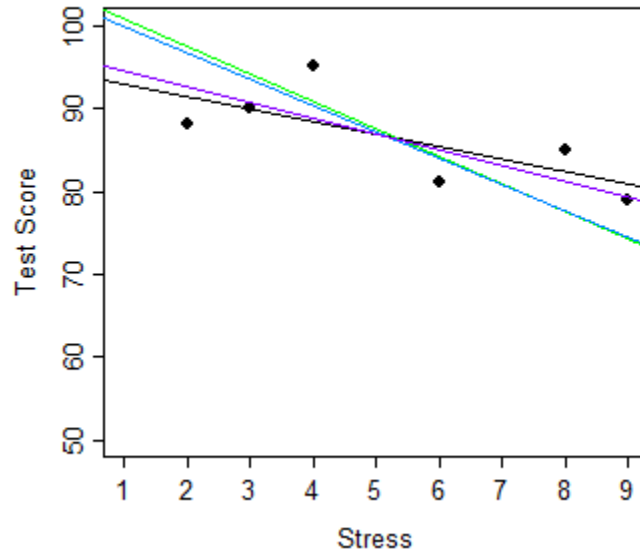
stress * classroom
(interaction with classroom)

~1+stress|classroom
(random slope by classroom)

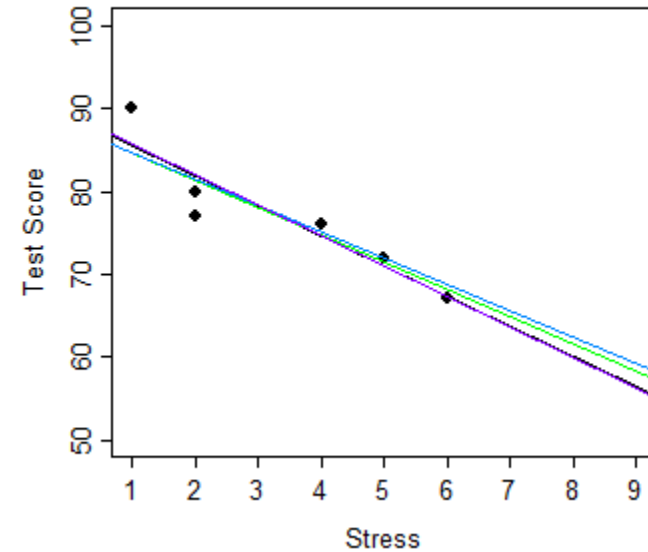
stress + classroom
(main effect of classroom)

~1|classroom
(random intercept by classroom)

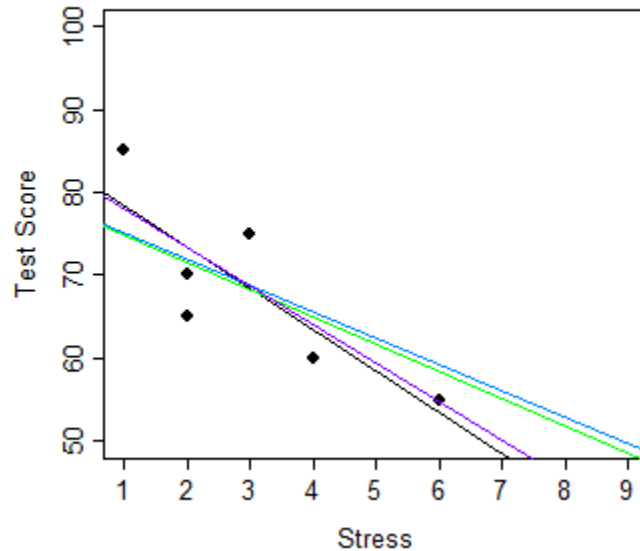
Classroom 1



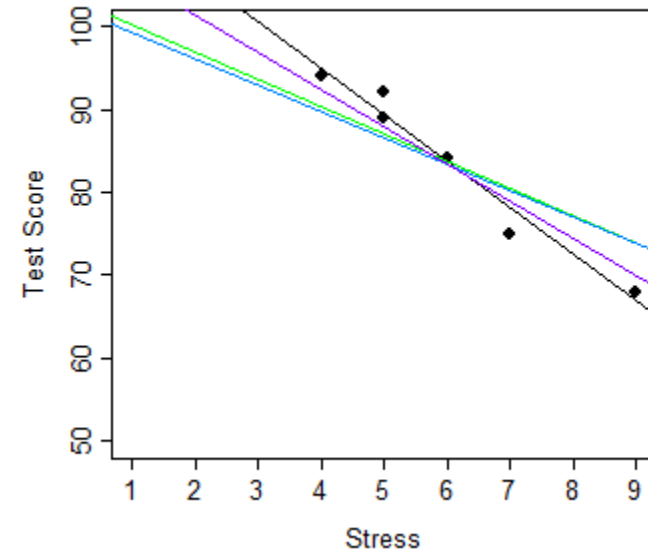
Classroom 2



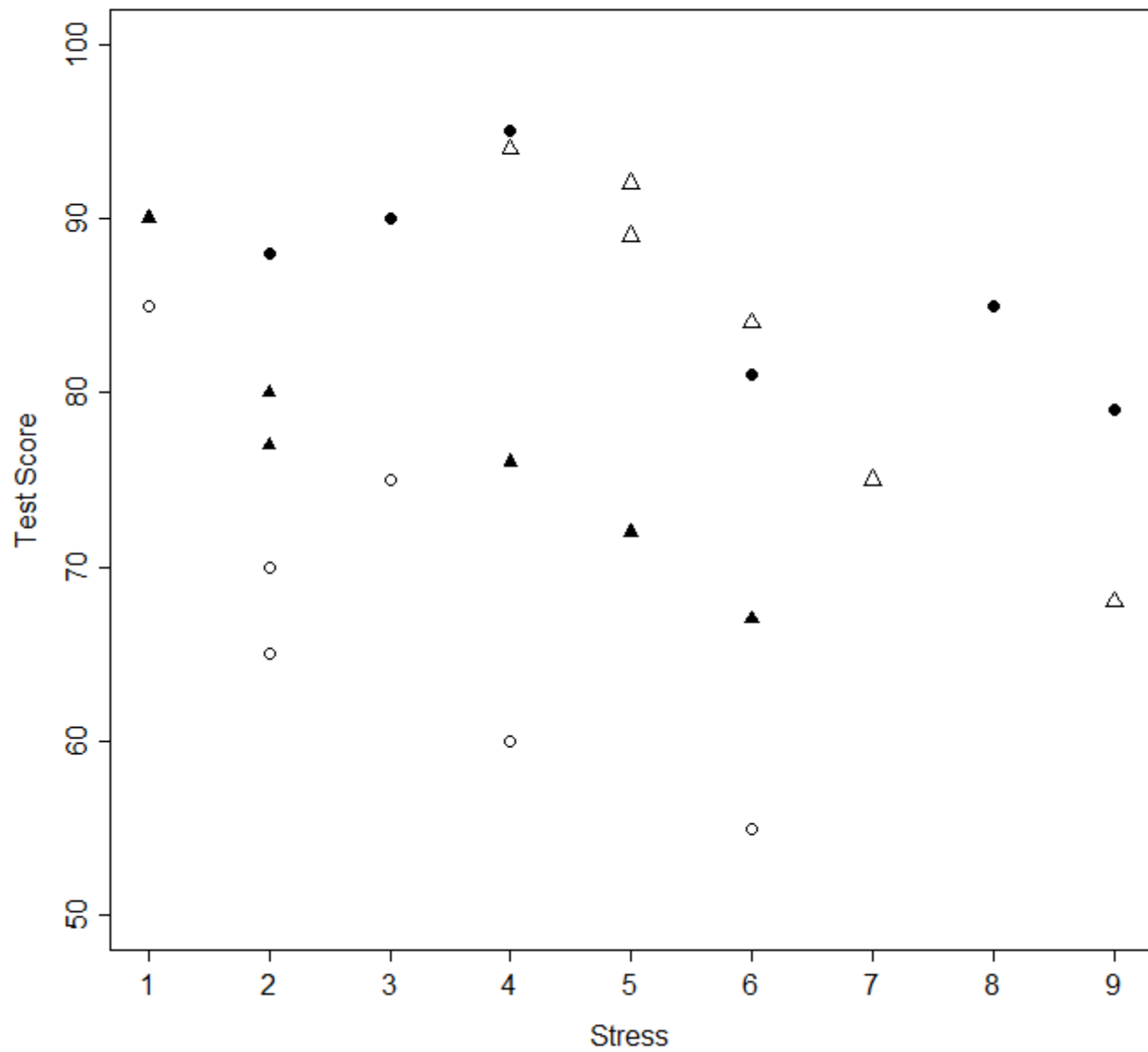
Classroom 3



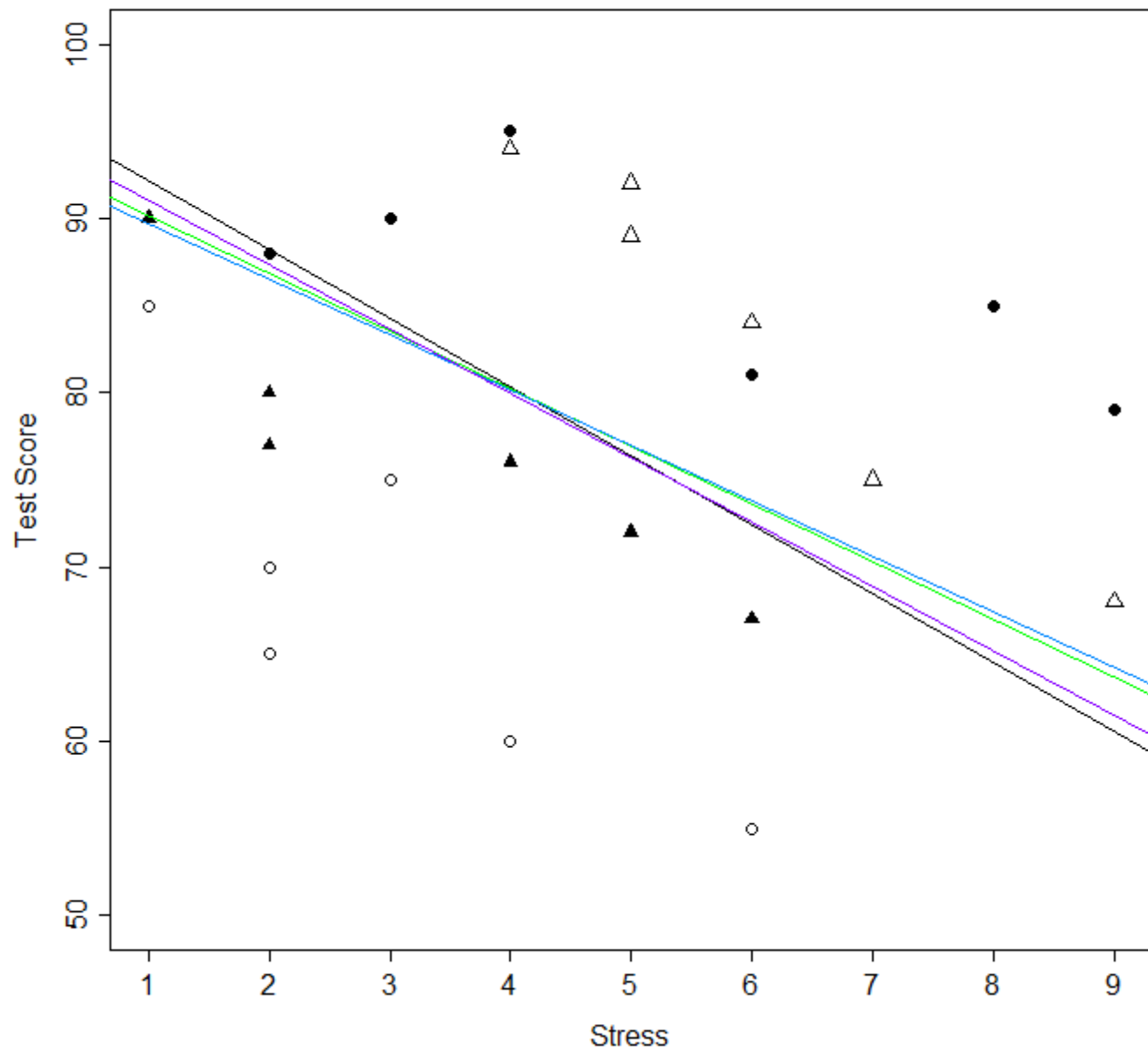
Classroom 4



Overall Result



Overall Result



Example output

```
library(nlme)
```

```
TestModel <- lme(testScore ~ stress,  
  random = ~1+stress|classroom, data = Tests)  
summary(TestModel)
```

Example output

Linear mixed-effects model fit by REML

Data: NULL

AIC	BIC	logLik
164.5976	171.1439	-76.29882

Random effects:

Formula: ~1 + stress | classroom

Structure: General positive-definite, Log-Cholesky parametrization

	StdDev	Corr
(Intercept)	12.537125	(Intr)
stress	1.517793	-0.116
Residual	4.626979	

Fixed effects: testScore ~ stress

	Value	Std.Error	DF	t-value	p-value
(Intercept)	94.69530	6.726823	19	14.077269	0e+00
stress	-3.69068	0.913499	19	-4.040156	7e-04

Correlation:

(Intr)

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Correlation:

(Intr)

stress -0.27

Standardized Within-Group Residuals:

Min	Q1	Med	Q3	Max
-1.79306524	-0.74071654	0.01242541	0.47465769	1.52140761

Number of Observations: 24

Number of Groups: 4

Example sentences

	Value	Std.Error	DF	t-value	p-value
(Intercept)	94.69530	6.726823	19	14.077269	0e+00
stress	-3.69068	0.913499	19	-4.040156	7e-04

I fit a linear mixed model with stress predicting test scores within classrooms. This model included a random intercept by classroom and a random slope of stress by classroom. I obtained p -values based on default t -tests in the “nlme” package for R (Pinheiro et al., 2022). Overall, stress was associated with lower test scores, $b = -3.69$, $SE = 0.91$, $p < .001$.

nlme VS. lme4

```
library(nlme)
```

```
# Model with random intercept
```

```
lme(testScore ~ stress, random=~1|classroom)
```

```
# Model with random slope
```

```
lme(testScore ~ stress, random=~1+stress|classroom)
```

```
library(lme4)
```

```
# Model with random intercept
```

```
lmer(testScore ~ stress + (1|classroom))
```

```
# Model with random slope
```

```
lmer(testScore ~ stress + (1+stress|classroom))
```

Usual approach

```
library(nlme)
```

```
# Many observations in each group
```

```
TestModel <- lme(testScore ~ stress,  
  random = ~1+stress|classroom, data = Tests,  
  na.action = na.omit)
```

```
summary(TestModel)
```

```
# Each observation is a unique combination
```

```
AttModel <- lme(attitude ~ targetReligion,  
  random = ~1|participant, data = Attitudes,  
  na.action = na.omit)
```

```
summary(AttModel)
```

Convergence issues

```
Error in lme.formula(score ~ teacherRating,  
  random = ~1 + teacherRating | classroom :  
  nlminb problem, convergence error code = 1  
  message = iteration limit reached without  
  convergence (10)
```