March 31st
using ANOVA

Assumptions of ANOVA

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1 2 3 4 5 6 7

Very ungrammatical

Perfectly grammatical

Luka (2005) expt 4

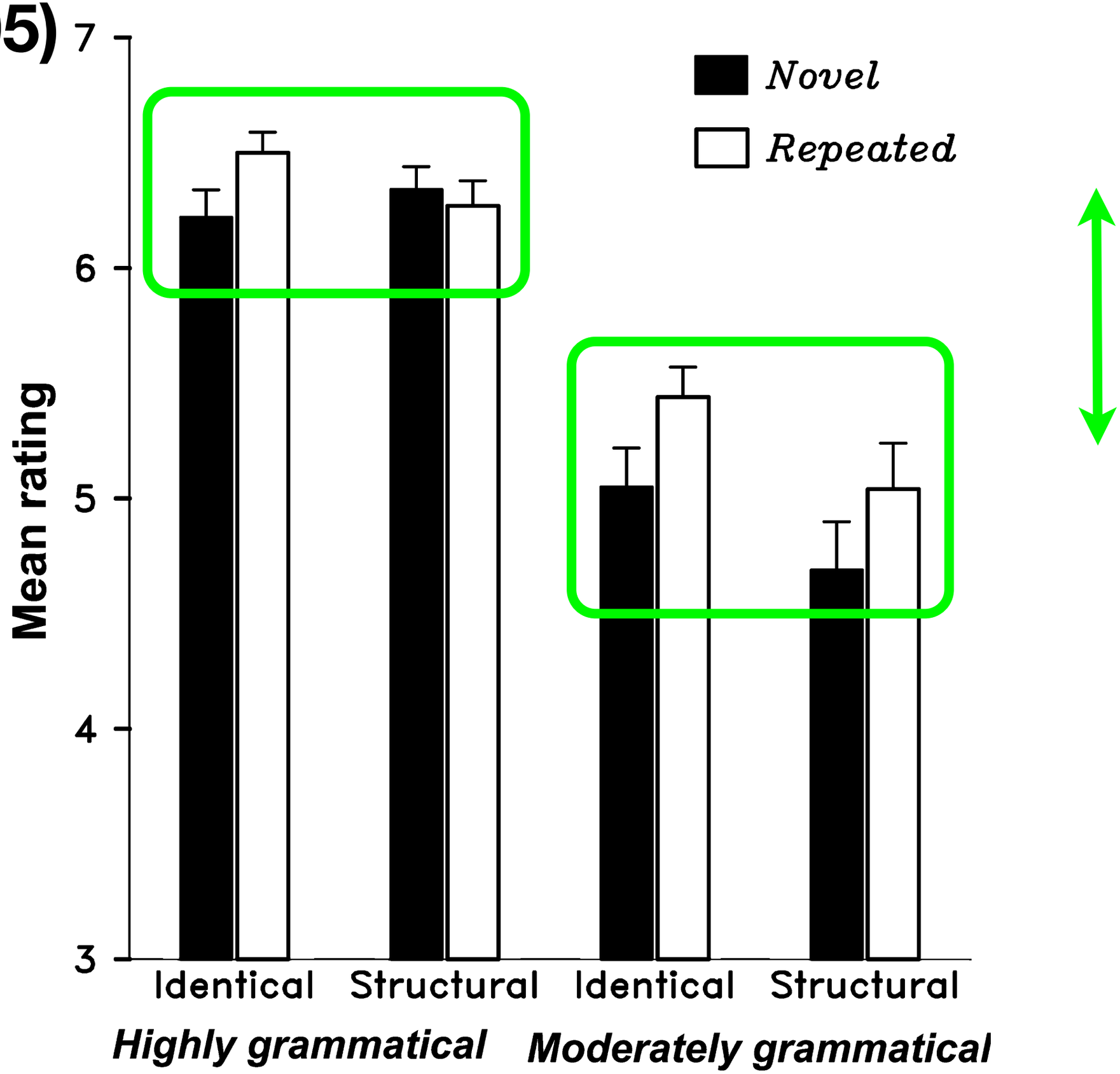
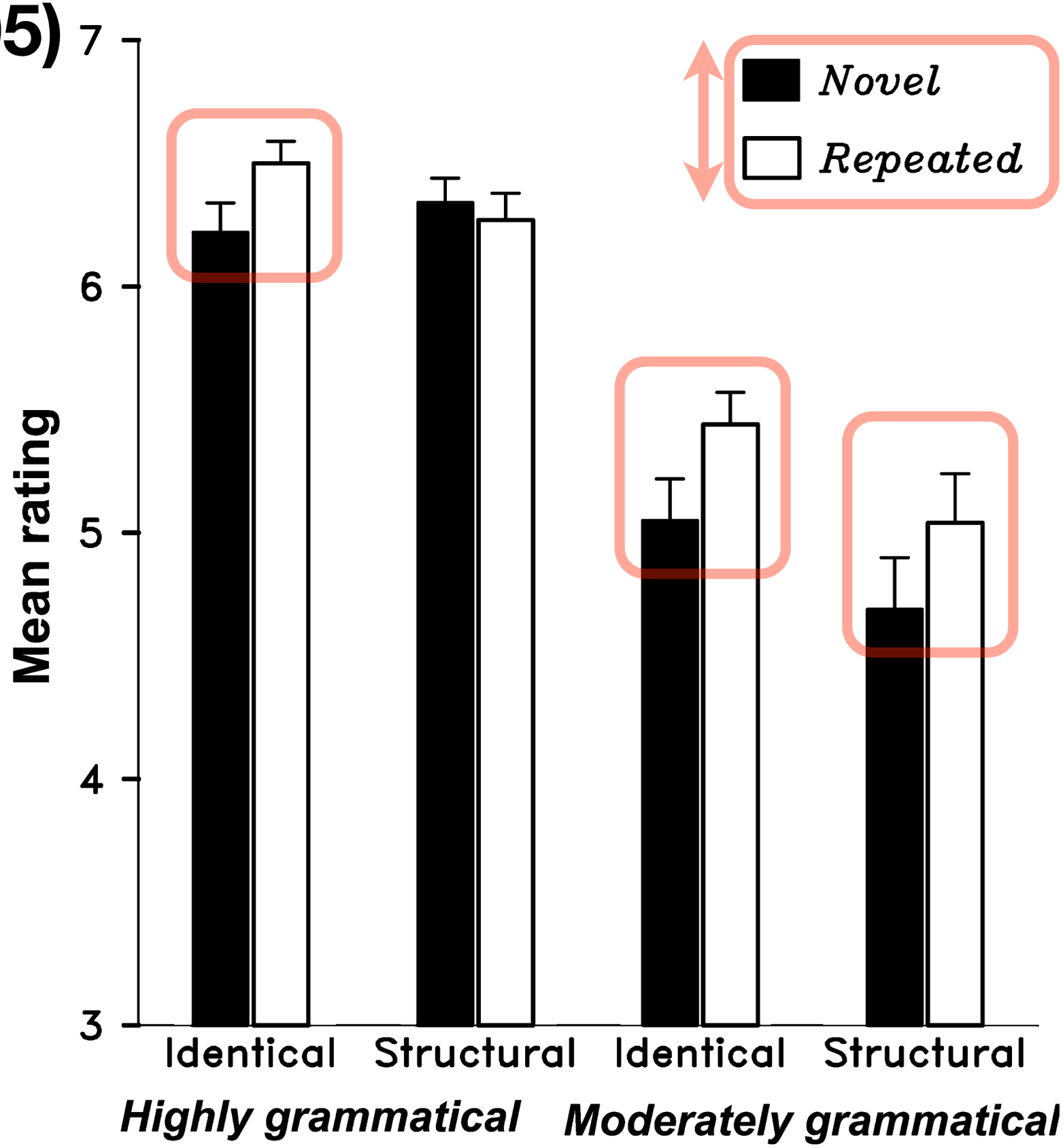


Fig. 2. Mean grammaticality ratings from Experiment 4 (error bars denote *SE*).

Luka (2005) expt 4



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What's the model?

```
Call:
lm(formula = RATING ~ GRAMMATICALITY * FAMILIARITY *
TYPE.TOKEN,
    data = LB1)

Residuals:
    Min      1Q  Median      3Q     Max
-2.7026 -0.3673  0.1269  0.4936  1.9487
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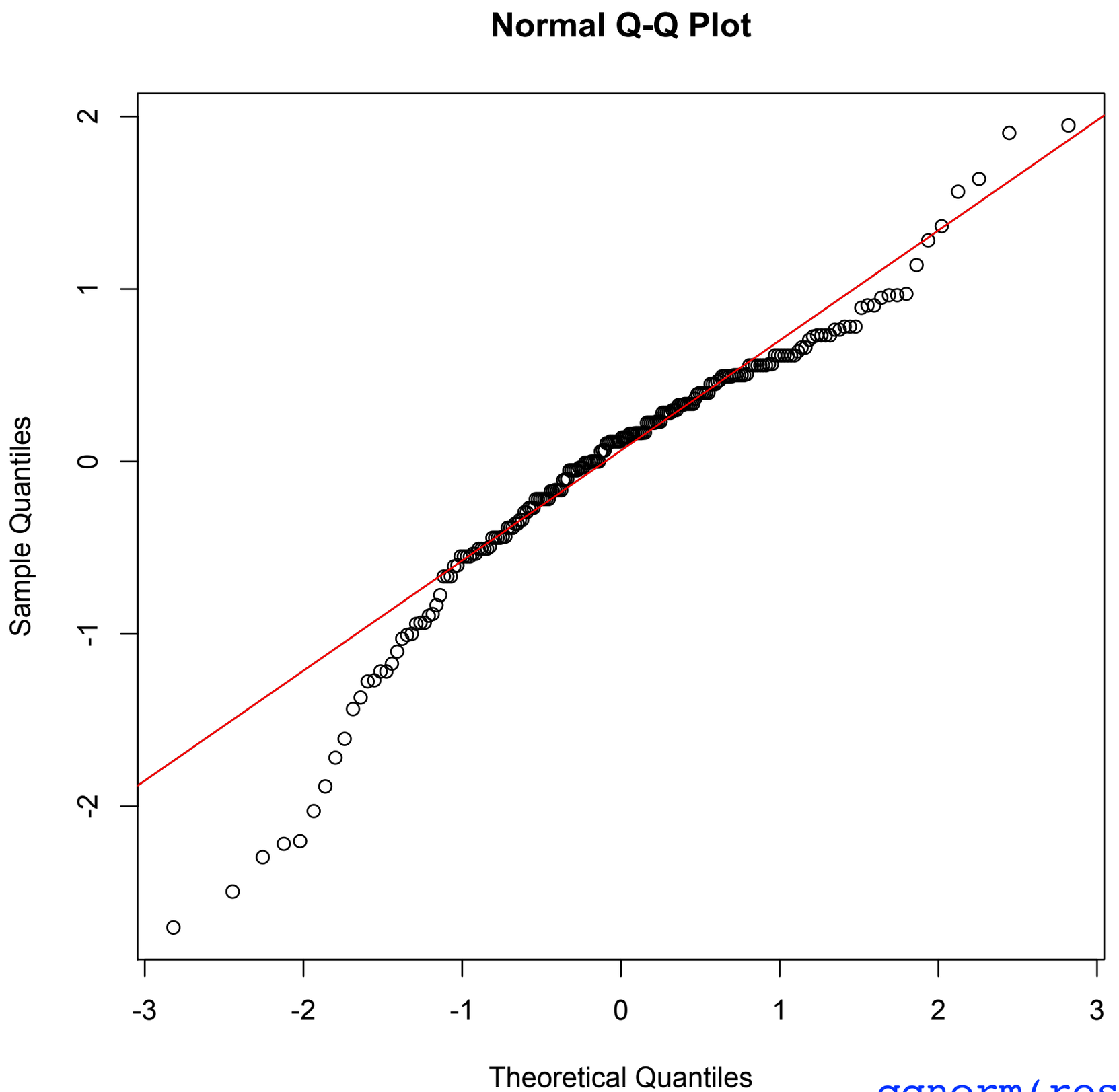
Response residuals are not normally-distribued




```
qqnorm(residuals(fitted))
```

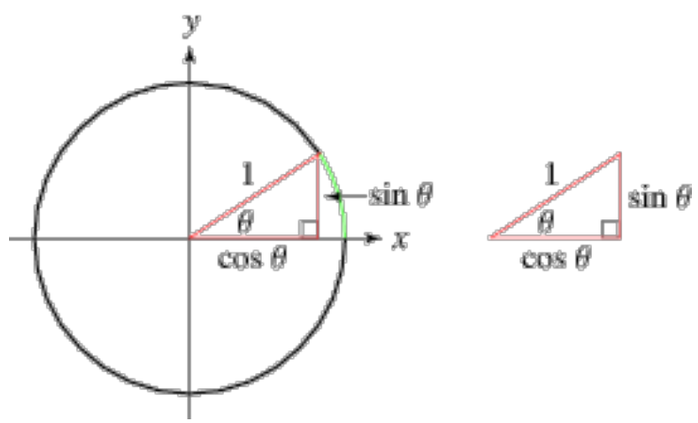
Transform the data

TABLE 3.8

THE "LADDER OF POWERS" FOR TRANSFORMING SCORES WHERE $Y' = Y^P$

Power, p	*Transformation*	*Name and Remarks*
2	Y^2	Square, useful when need to increase spread among higher scores relative to lower scores, e.g. with negatively skewed data
1	Y	Raw data, no transformation
$1/2$	$\sqrt{Y}$	Square root, helpful with positively skewed distributions
0	$\log_{10} Y$	Logarithmic, use when p estimated to be near zero, e.g., with extremely positively skewed distributions. Use $Y' = \log_{10}(Y + 1)$ if there are any zeros in data.
-1	$1/Y$	Reciprocal, e.g., transforming latency to speed. Use $Y' = 1/(Y + 1)$ if there are any zeros in data.

ANOVA on arcsine-transformed ratings



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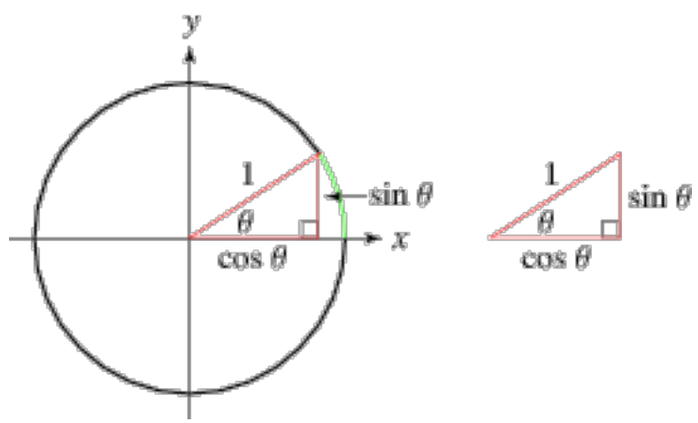

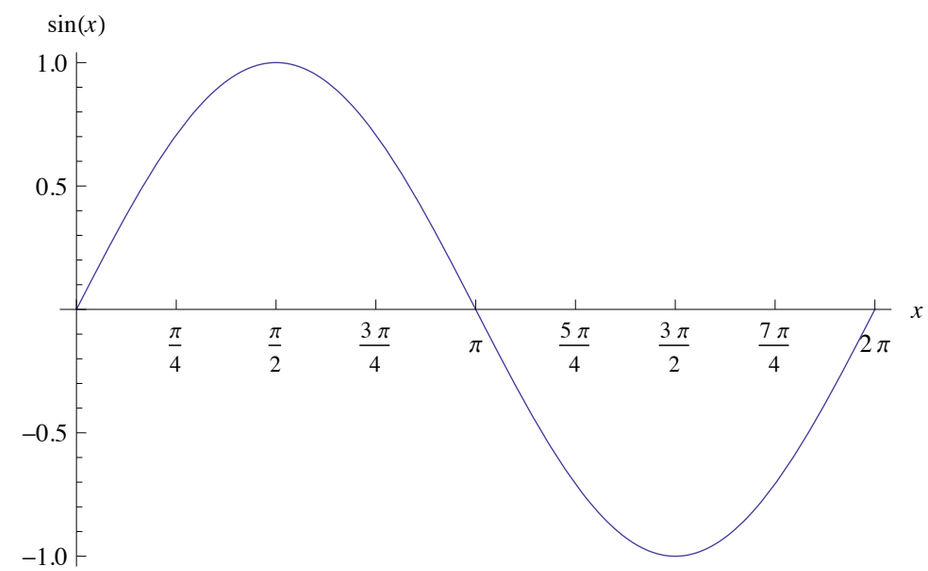

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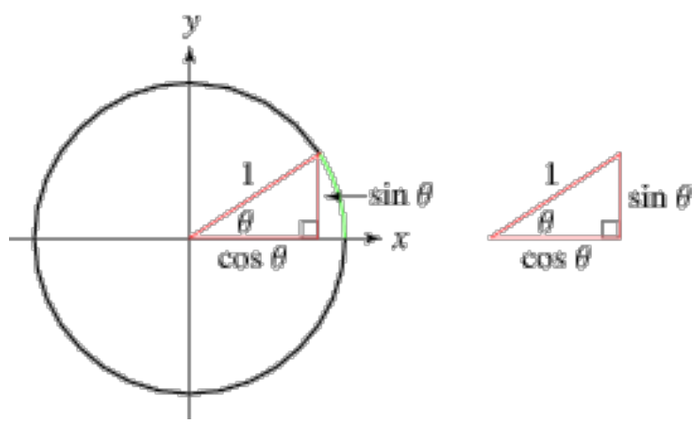
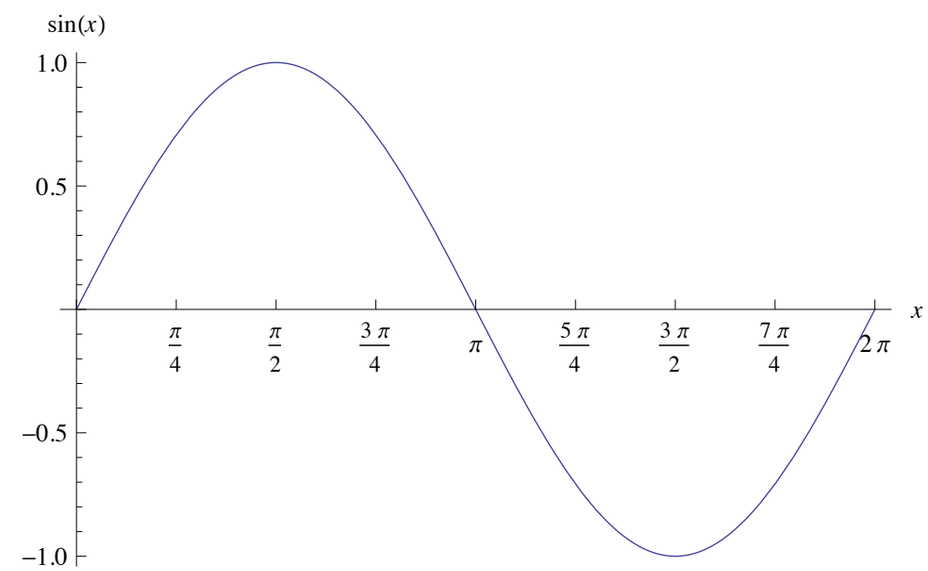
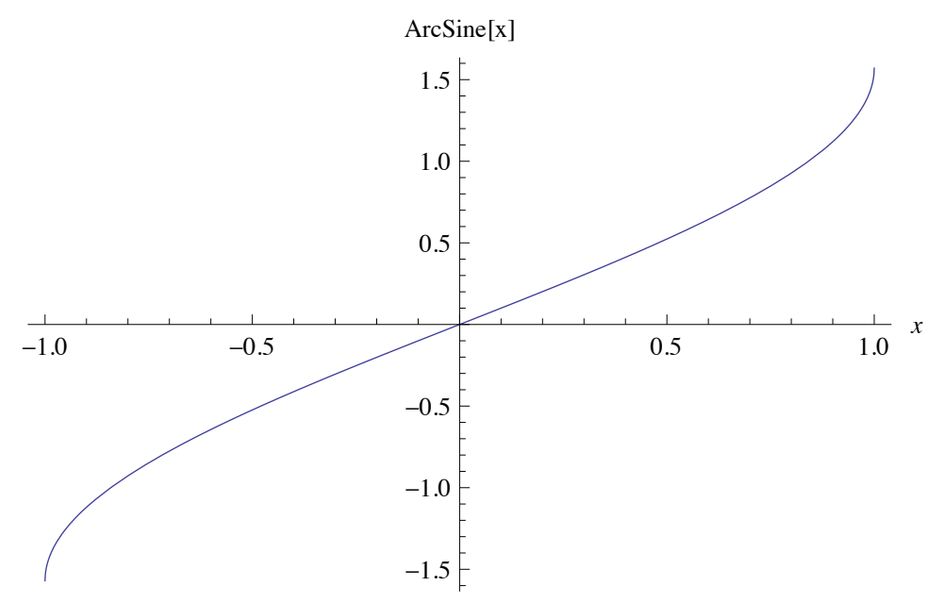
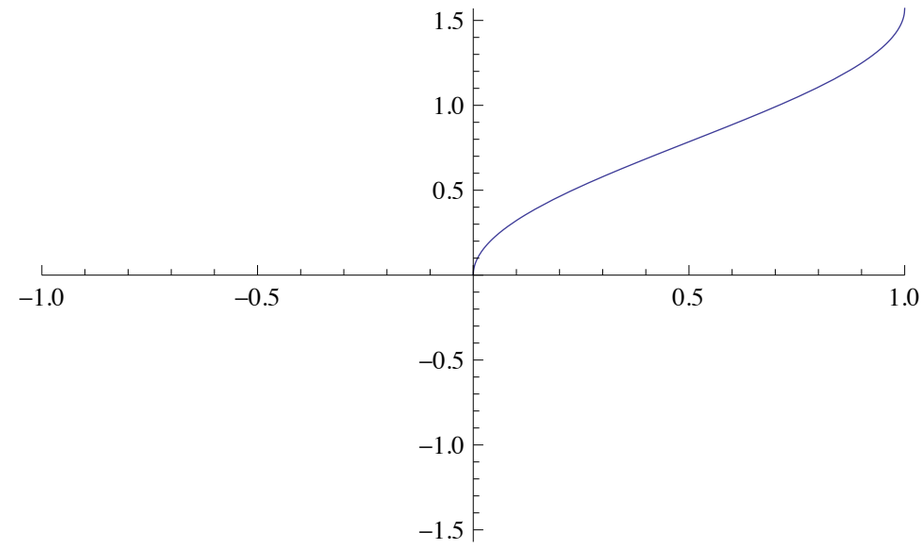






Arcsine of the square root is positive



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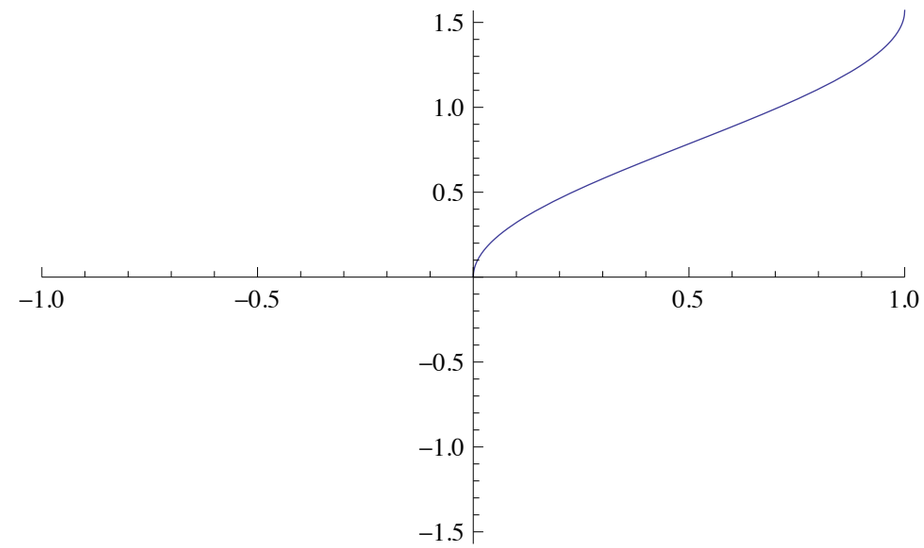
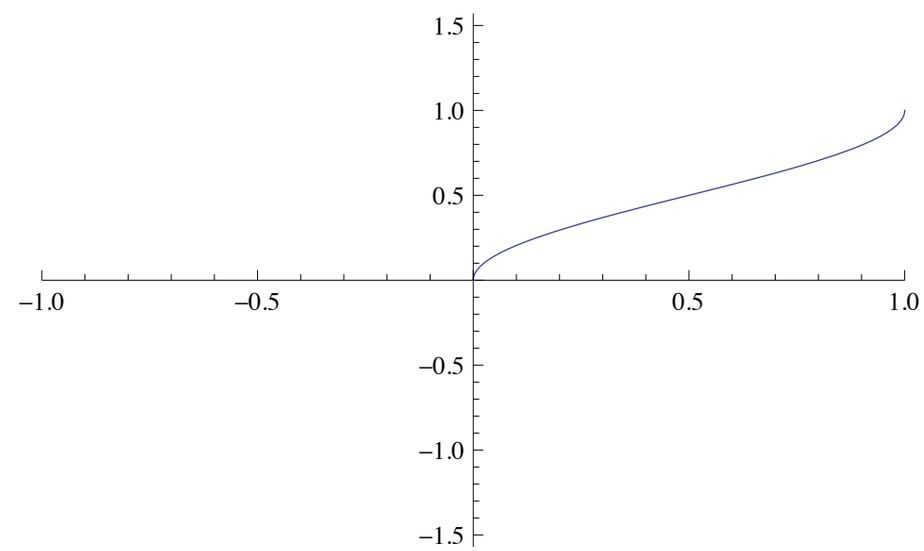


Scale to [0,1] by multiplying by reciprocal of π/2



Model of arcsine-transformed ratings

$$y = \frac{2}{\pi}\sin^{-1}(\sqrt{x})$$

```
lm(formula = 2/pi * asin(sqrt((RATING/7))) ~
GRAMMATICALITY *
    FAMILIARITY * TYPE.TOKEN, data = LB1)

Residuals:
     Min       1Q   Median       3Q      Max
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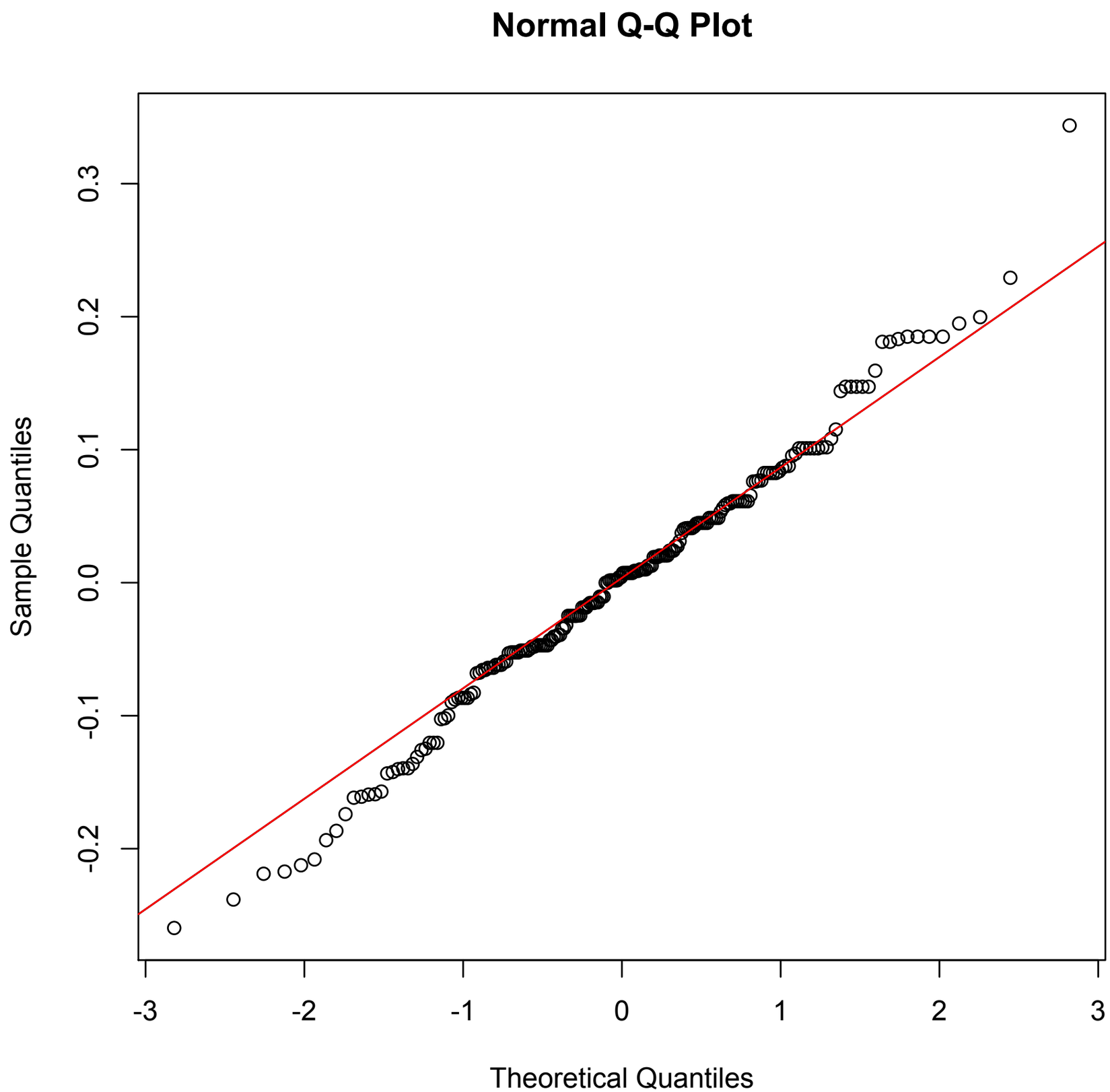
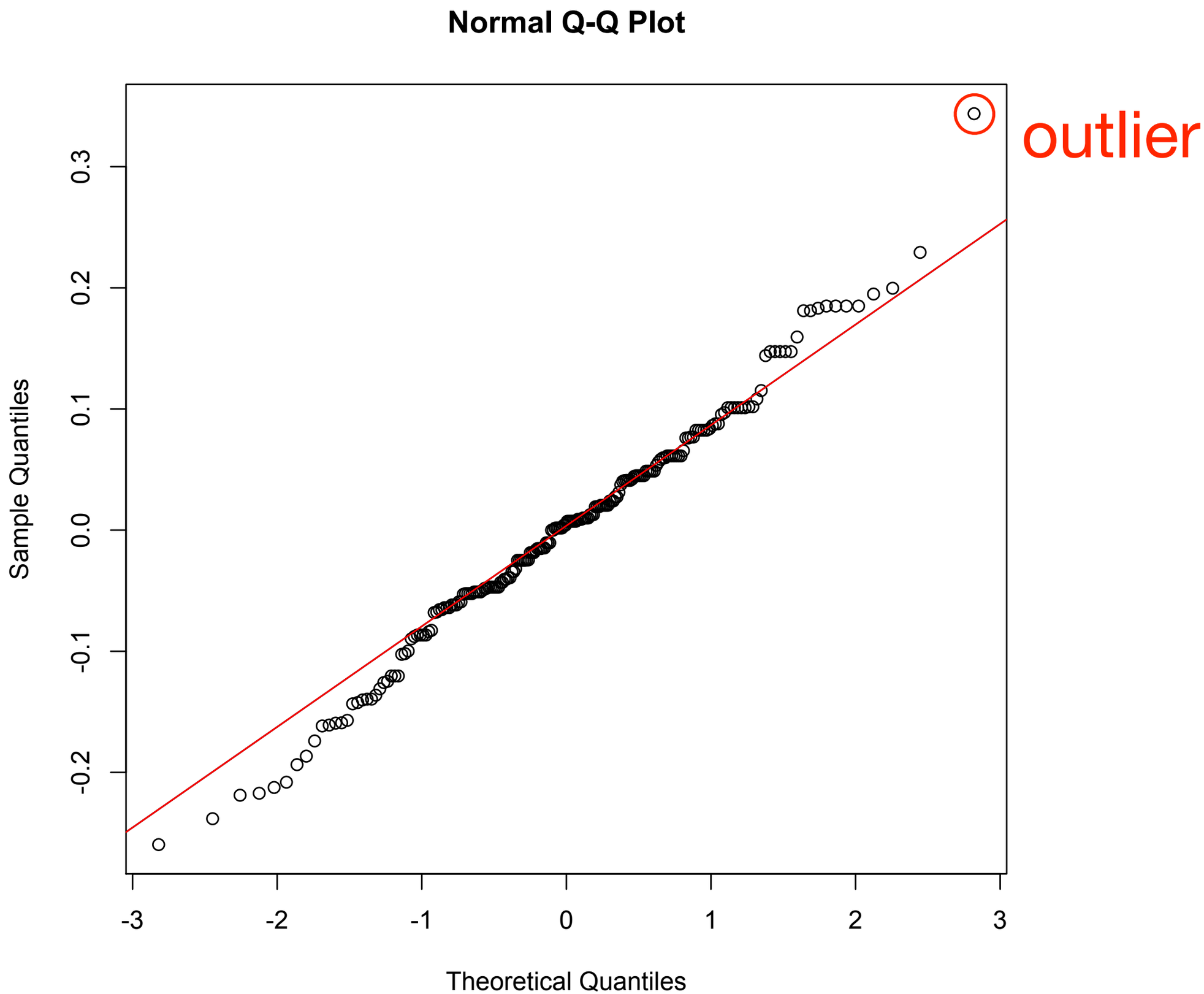

Normal Q-Q Plot
Sample Quantiles
0.3
0.2
0.1
0.0
-0.1
-0.2
-3
-2
-1
0
1
2
3
Theoretical Quantiles

Helped


Normal Q-Q Plot
outlier
Sample Quantiles
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-2
-1
0
1
2
3
Theoretical Quantiles

Random effects

Expected Mean-Squares for Repeated-Measurements ANOVA with Words Sampled Randomly

Source of variation	Label	*df*	Expected mean-squares
Treatment	A	$p - 1$	$\sigma_e^2 + \sigma_{W(A)S}^2 + q\sigma_{AS}^2 + n\sigma_{W(A)}^2 + nq\sigma_A^2$
Words (within Treatment)	W(A)	$p(q - 1)$	$\sigma_e^2 + \sigma_{W(A)S}^2 + n\sigma_{W(A)}^2$
Subjects	S	$n - 1$	$\sigma_e^2 + \sigma_{W(A)S}^2 + pq\sigma_S^2$
Treatment × Subjects	AS	$(p - 1)(n - 1)$	$\sigma_e^2 + \sigma_{W(A)S}^2 + q\sigma_{AS}^2$
Words × Subjects	W(A)S	$p(q - 1)(n - 1)$	$\sigma_e^2 + \sigma_{W(A)S}^2$

Note. p = number of levels of the treatment variable; n = number of subjects; q = number of items. Words and Subjects are assumed to be random effects.

Usual way of testing for an effect

$$F = \frac{E\left(MS_b\right) = \sigma_\epsilon^2 + n\sigma_\alpha^2}{E\left(MS_w\right) = \sigma_\epsilon^2}$$

Usual way of testing for an effect

pushes F>1 if there is a treatment effect

$$F = \frac{E\left(MS_b\right) = \sigma_\epsilon^2 + \boxed{n\sigma_\alpha^2}}{E\left(MS_w\right) = \sigma_\epsilon^2}$$

Quasi F-ratio

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Note. p = number of levels of the treatment variable; n = number of subjects; q = number of items. Words and Subjects are assumed to be random effects.

$$F' = \frac{MS_A + MS_{W(A)S}}{MS_{AS} + MS_{W(A)}}$$

Quasi F-ratio

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Note. p = number of levels of the treatment variable; n = number of subjects; q = number of items. Words and Subjects are assumed to be random effects.

$$F' = \frac{MS_A + MS_{W(A)S}}{MS_{AS} + MS_{W(A)}}$$

not based on independent sum-of-squares; only approximates an F distribution

A lower bound on the quasi F-ratio

$$minF' = \frac{MS_{\mathrm{A}}}{MS_{\mathrm{AS}} + MS_{\mathrm{W(A)}}} = \frac{F_1 F_2}{F_1 + F_2}$$

A lower bound on the quasi F-ratio

Table 4.9 MinF′ values (and the error degrees of freedom) in the analysis of Luka and Barsalou's data. The *F*-values found in the subjects analysis are shown in the first column. The second column shows the *F*-values from the items analysis. *F*-values that are significant at $p < 0.05$ are underlined.

	F1	F2	minF′	df
grammaticality	221.0	77.0	57.10	65
familiarity	10.5	9.4	4.96	65
repetition type	5.6	1.7	1.32	63
fam*rep	1.4	3.5	1.00	45
gram*fam*rep	3.7	1.3	0.95	65

Homework

Question 4 on page 141 of Johnson