Mixed Models Analysis of a psycholinguistic experiment

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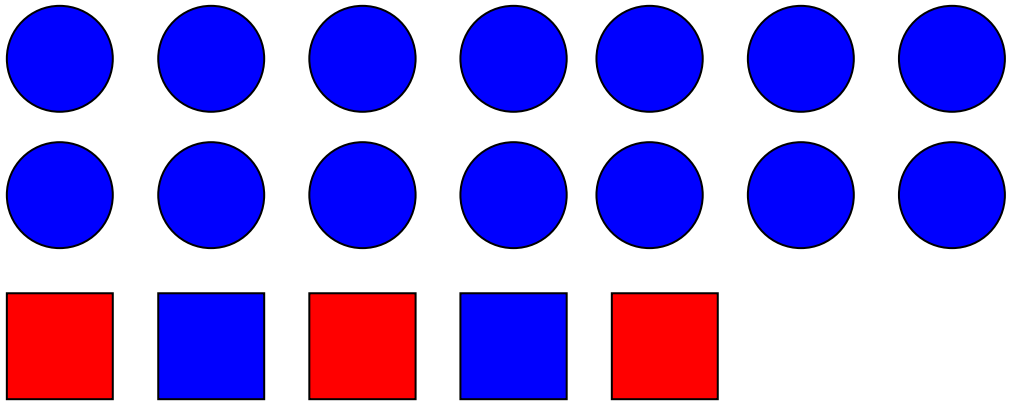
Seminar in Statistics and Methodology

17/05/2011

How is the truth value of ‘alle’ assessed?



Inhelder & Piaget (1964): “Are all the circles blue?”
Child: “No, there are two blue squares.”

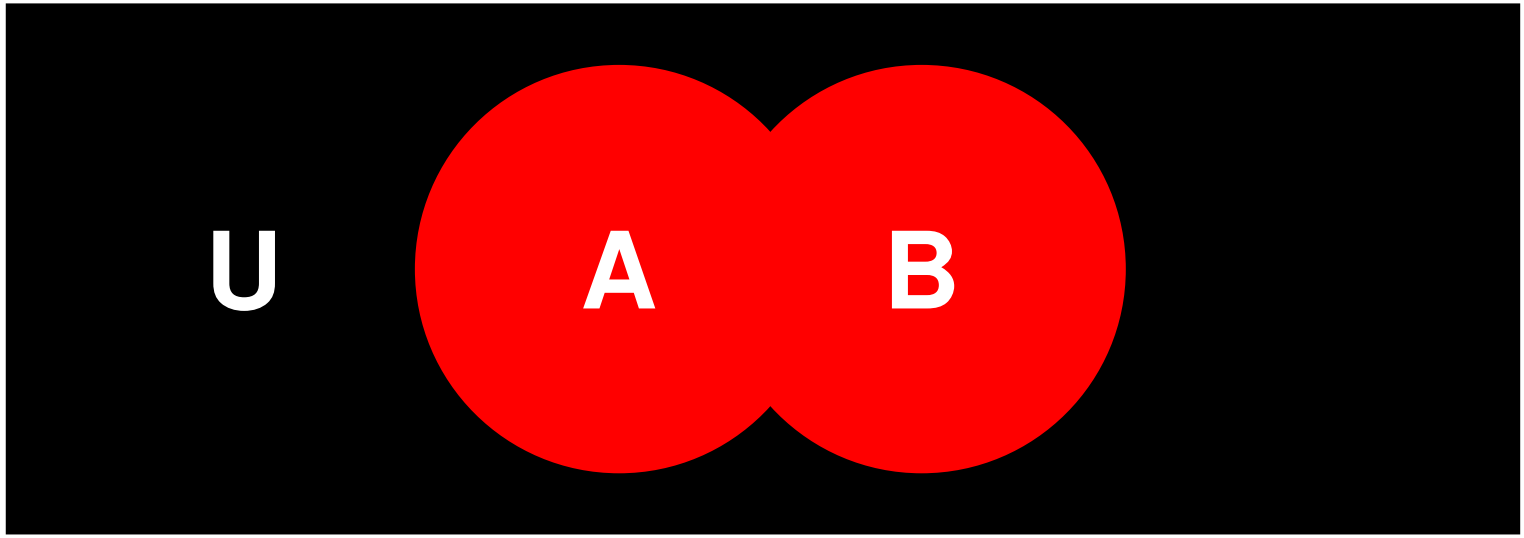
How is the truth value of ‘alle’ assessed?

- Alle(A,B) = 1 iff $A \subseteq B$
- Alle(A,B) = 1 iff $|A|-|A \cap B|=0$

- Conservativity (Barwise and Cooper, 1981) rules what is logically relevant in assessing the truth value of a generalized quantifier.

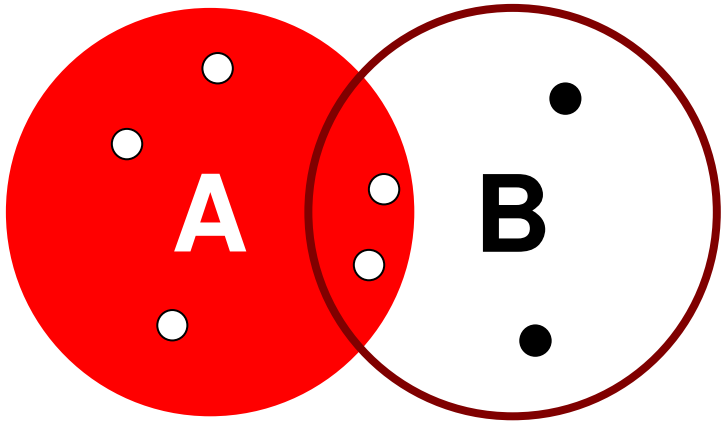
How is the truth value of ‘alle’ assessed?

- Conservativity rules that all that is in the universe U out of the union of A and B is irrelevant.



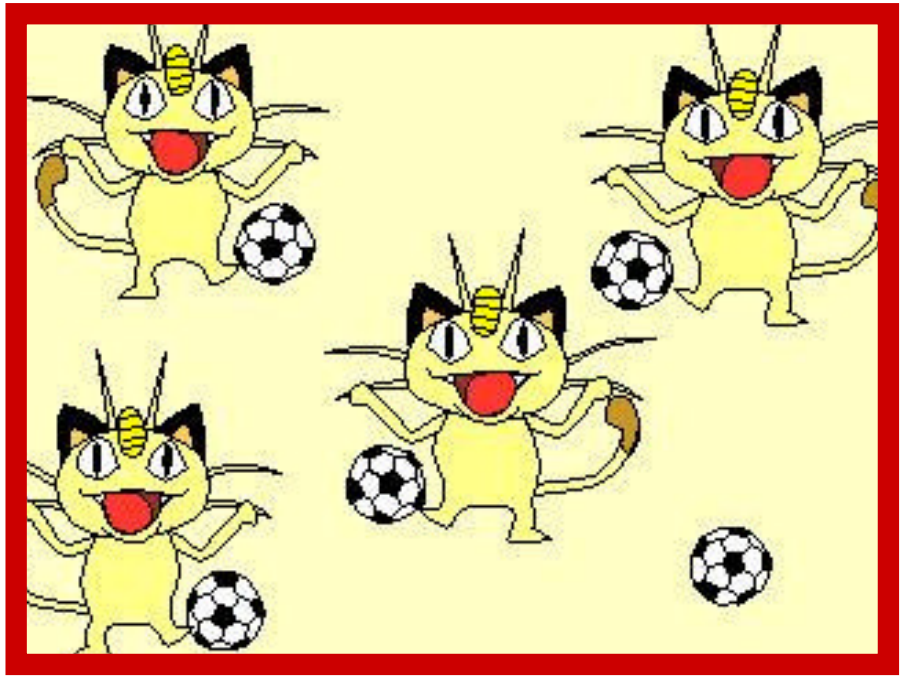
How is the truth value of ‘alle’ assessed?

- Conservativity also rules that all that all members of B out of the intersection with A are irrelevant.

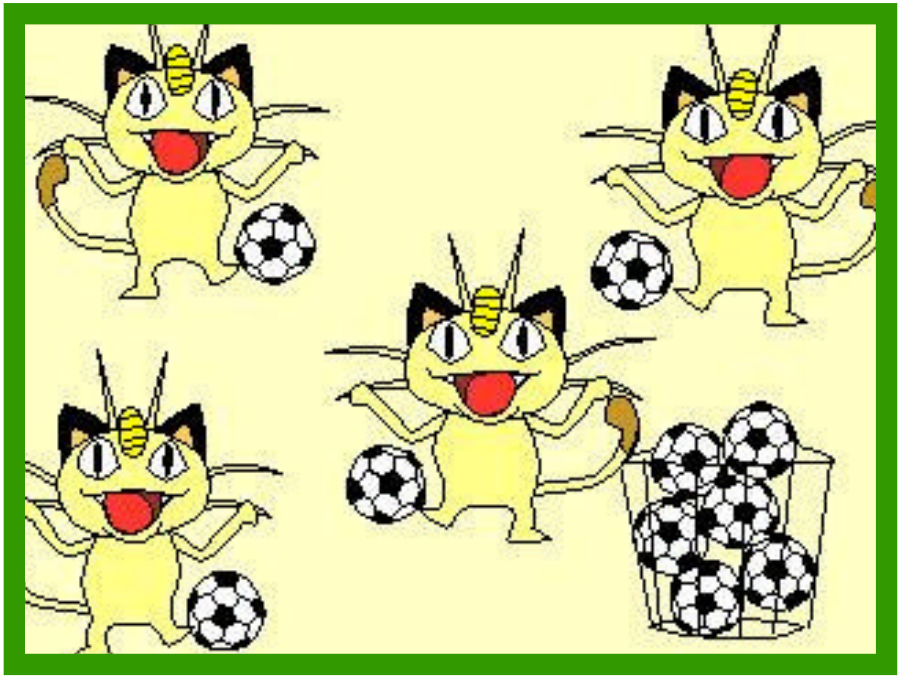


Sugisaki & Isobe (2001)

- 4 year old Japanese children.
- TVJT, question: “Are all cats kicking a ball?”



Control group:
35% correct answers



Experimental group:
85% correct answers

The research question

- Is the frequency of error occurrences a function of the ratio between the number of agents and objects in the context?

- Adults don’t make mistakes, but they can be tested in an online reaction time experiment.

The hypotheses

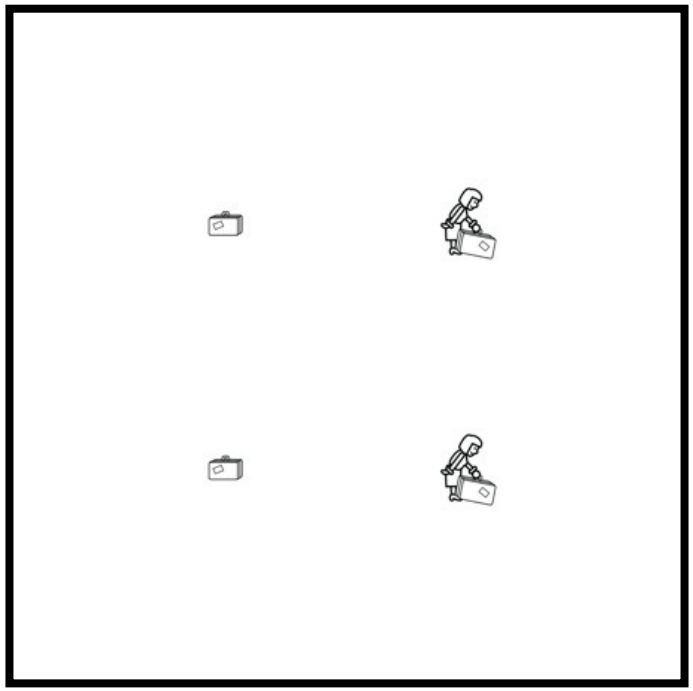
- If adults only use conservativity to assess the truth value of ‘alle’, the amount of extra-objects in the context will have no significant effect on RT.

- If adults also use Core Number cognition to assess the truth value of ‘alle’ they will answer significantly faster to the scenarios with more extra objects (ratio 1:2).

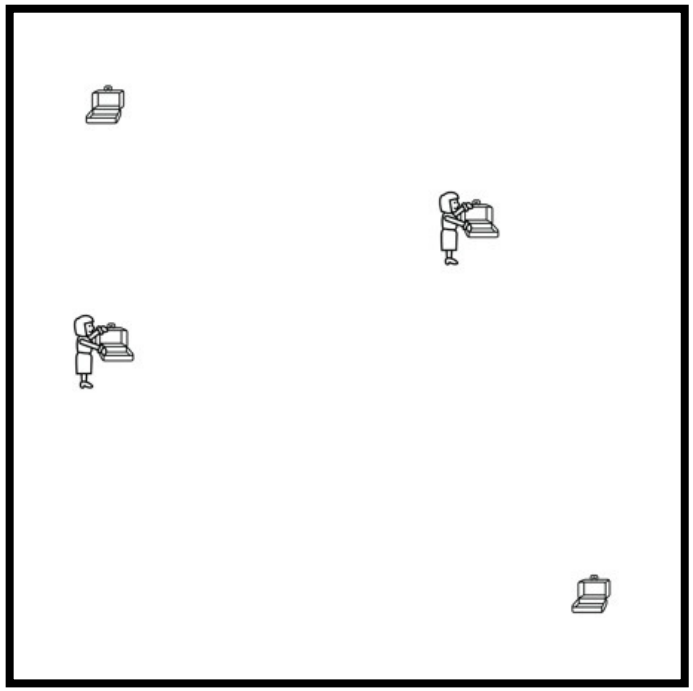
The Experiment

- Online TVJT
- Between subjects design
- Fixed factors:
  - Numerosity (four levels: 2, 4, 8 or 16 agents)
  - Ratio (two levels: 1:2 and 2:3)
  - Disposition (two levels: neat and not neat)
- Random factors:
  - Subjects, Sentences, Pictures, etc.

Video Stimuli:
Disposition: Neat vs. Not Neat

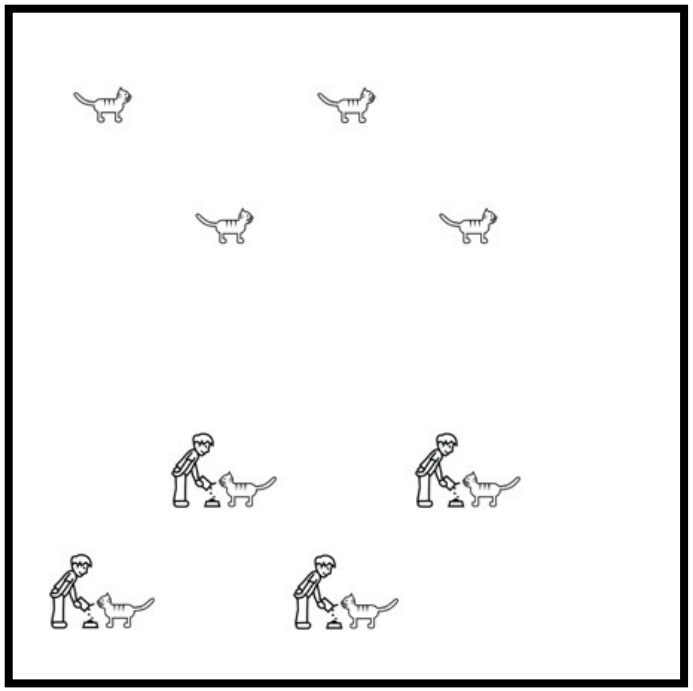


Neat

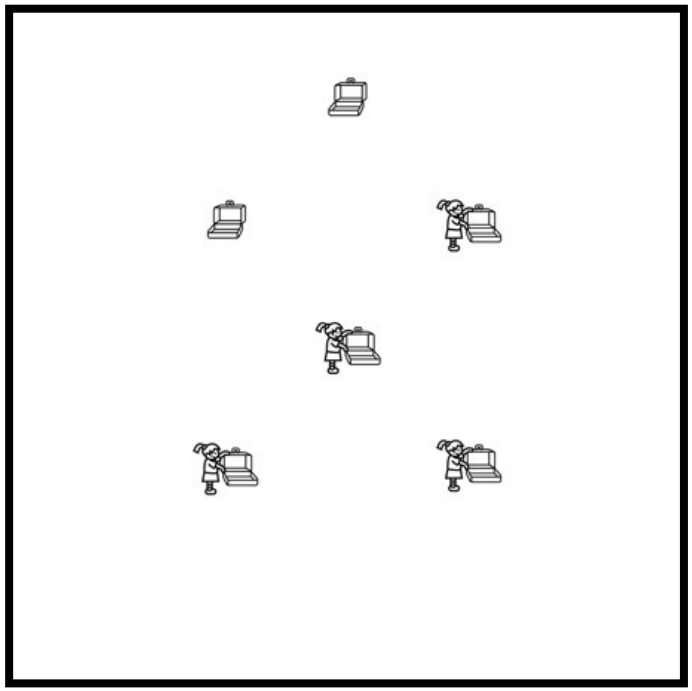


Not Neat

Video Stimuli:
Disposition: Ratio OK vs. Ratio Not OK



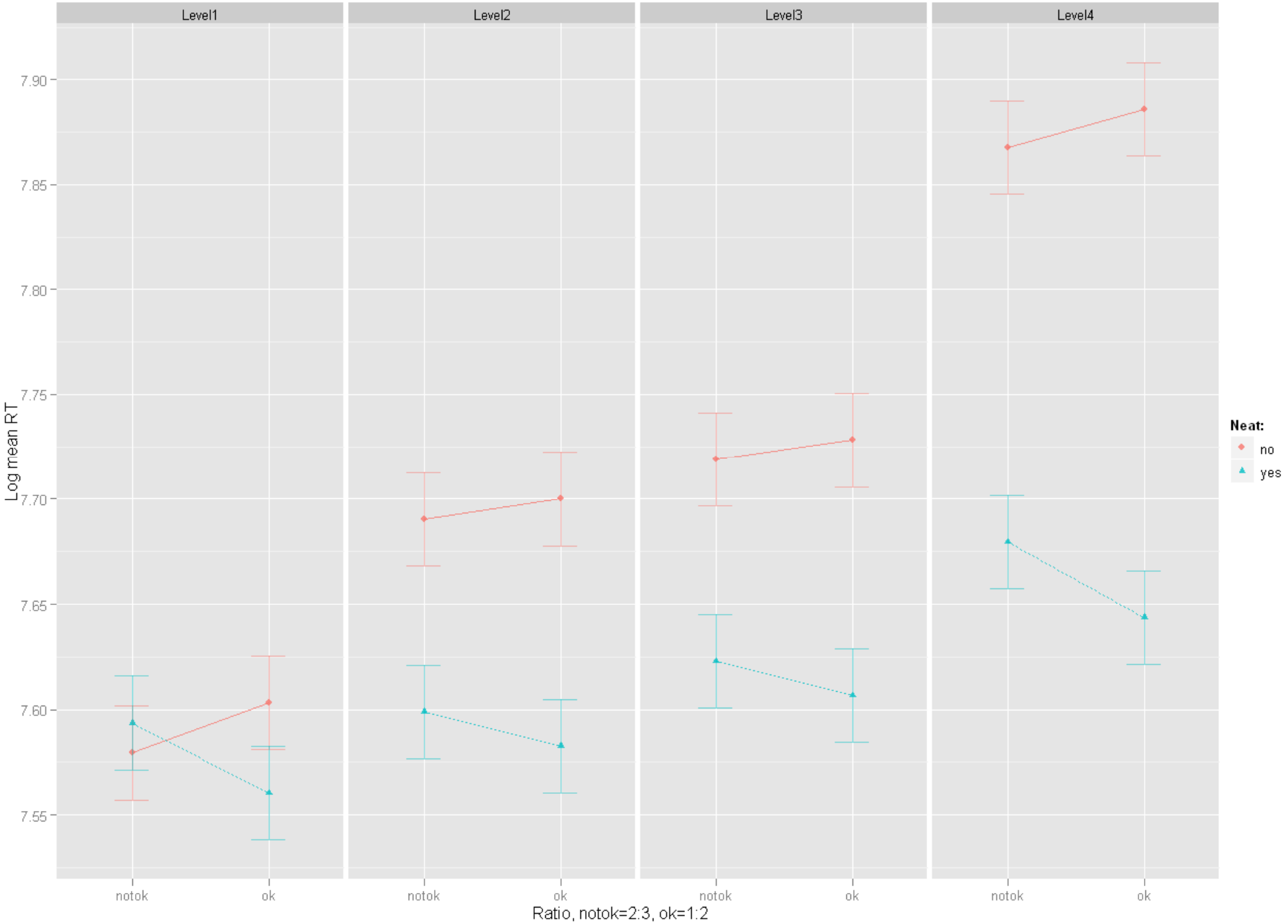
Ratio 1:2 (OK)



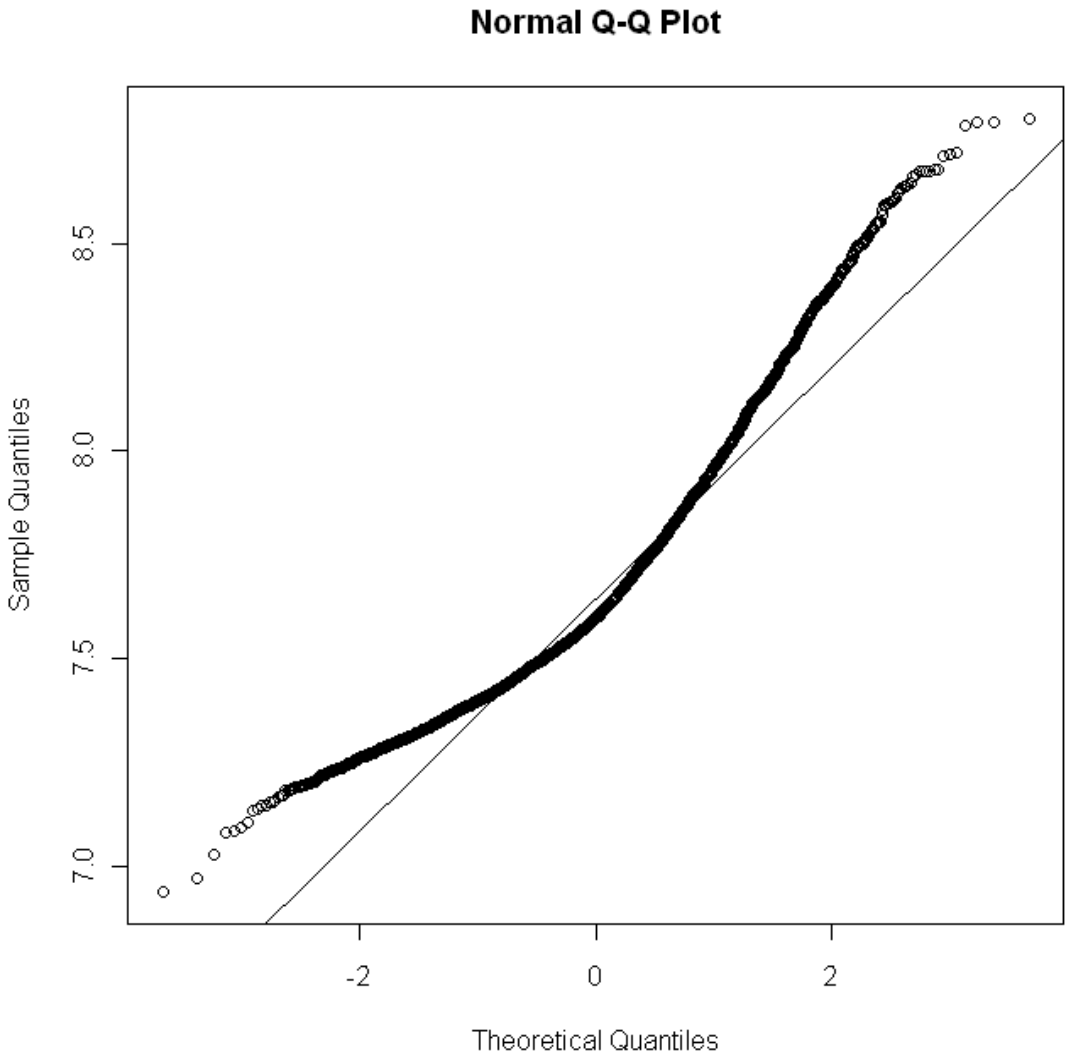
Ratio 2:3 (Not OK)

Repeated Measures ANOVA

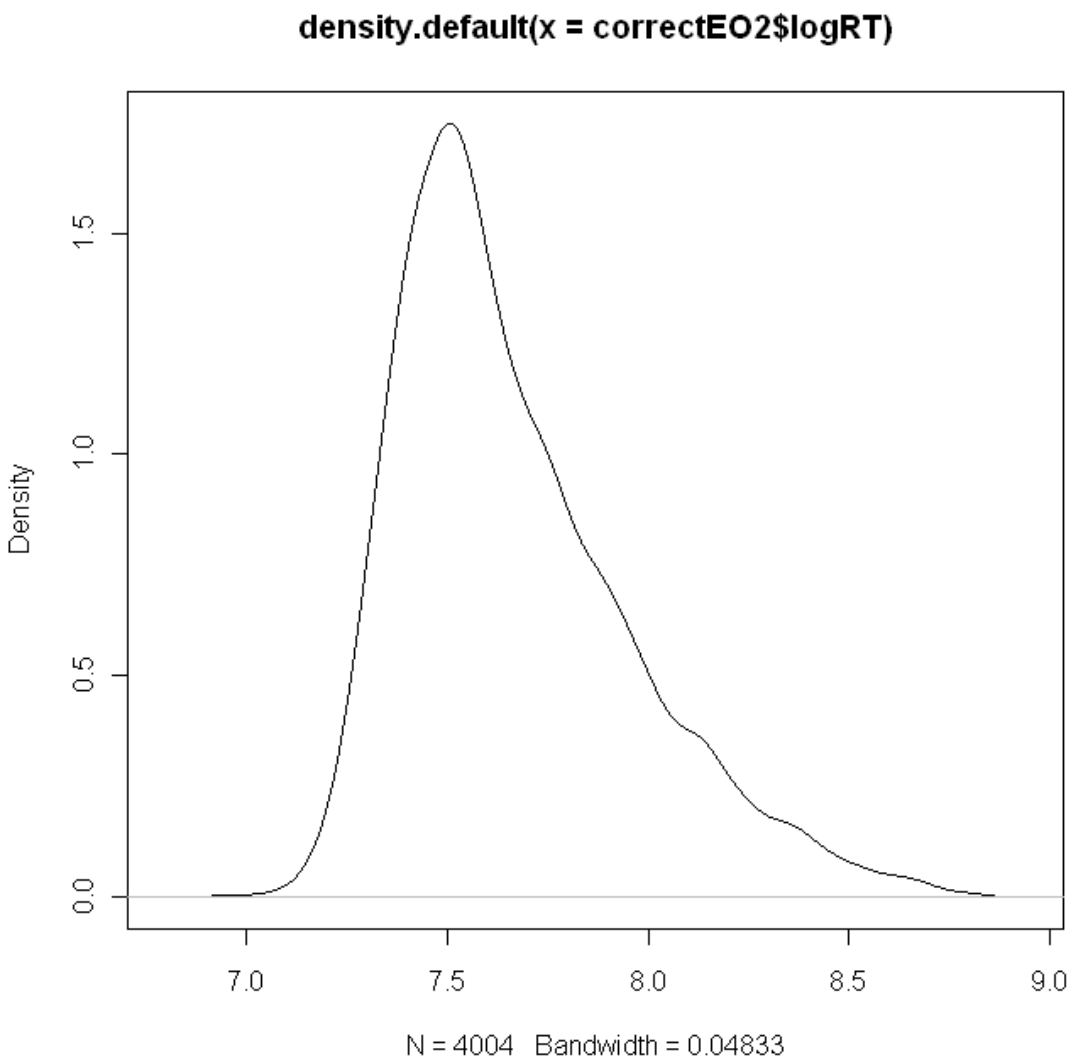
```
> ezANOVA(correctEO2,dv=.(logRT),wid=.(Subject),within=.(Level,Ratio,Neat))
$ANOVA
            Effect DFn DFd           F            p p<.05          ges
2            Level   3  93 71.97942690 3.709075e-24     * 1.703944e-01
3            Ratio   1  31  0.44566138 5.093422e-01       2.971024e-04
4             Neat   1  31 90.14442420 1.089989e-10     * 1.232637e-01
5       Level:Ratio   3  93  0.02491183 9.946475e-01       5.502225e-05
6        Level:Neat   3  93 24.14730492 1.212065e-11     * 5.493637e-02
7        Ratio:Neat   1  31 12.86863037 1.133075e-03     * 4.709438e-03
8 Level:Ratio:Neat   3  93  0.29599745 8.282006e-01       6.403810e-04

$`Sphericity Corrections`
            Effect       GGe        p[GG] p[GG]<.05       HFe        p[HF] p[HF]<.05
2            Level 0.7519158 9.456206e-19         * 0.8138892 4.206245e-20         *
5       Level:Ratio 0.9806883 9.941618e-01           1.0947120 9.946475e-01
6        Level:Neat 0.7095438 6.869697e-09         * 0.7633422 2.116625e-09         *
8 Level:Ratio:Neat 0.8728826 8.013284e-01           0.9606864 8.204090e-01
```


Level1
Level2
Level3
Level4
7.90
7.85
7.80
7.75
7.70
7.65
7.60
7.55
Log mean RT
notok
ok
Ratio, notok=2:3, ok=1:2
Neat:
no
yes

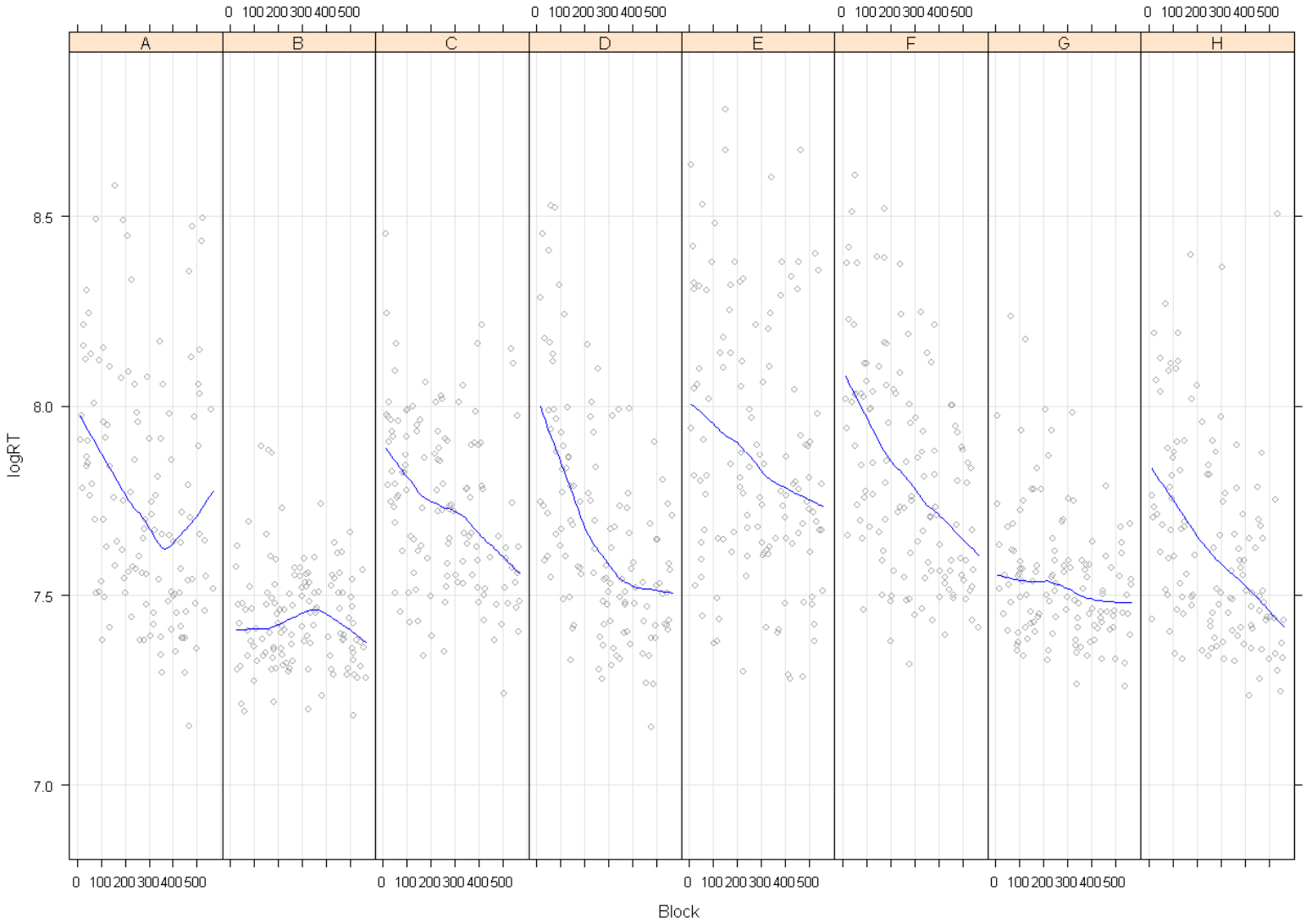
logRT Distribution



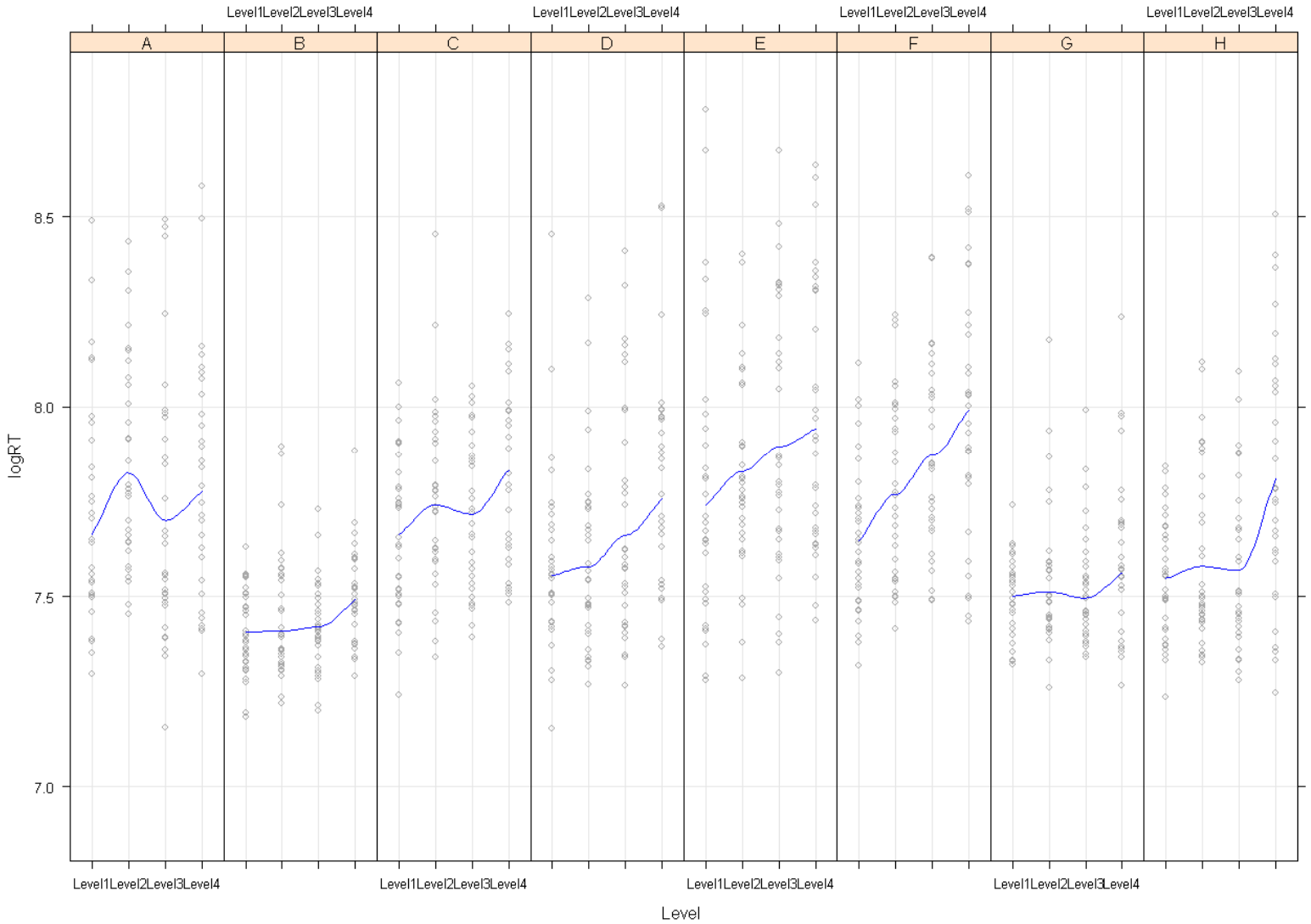
logRT Distribution



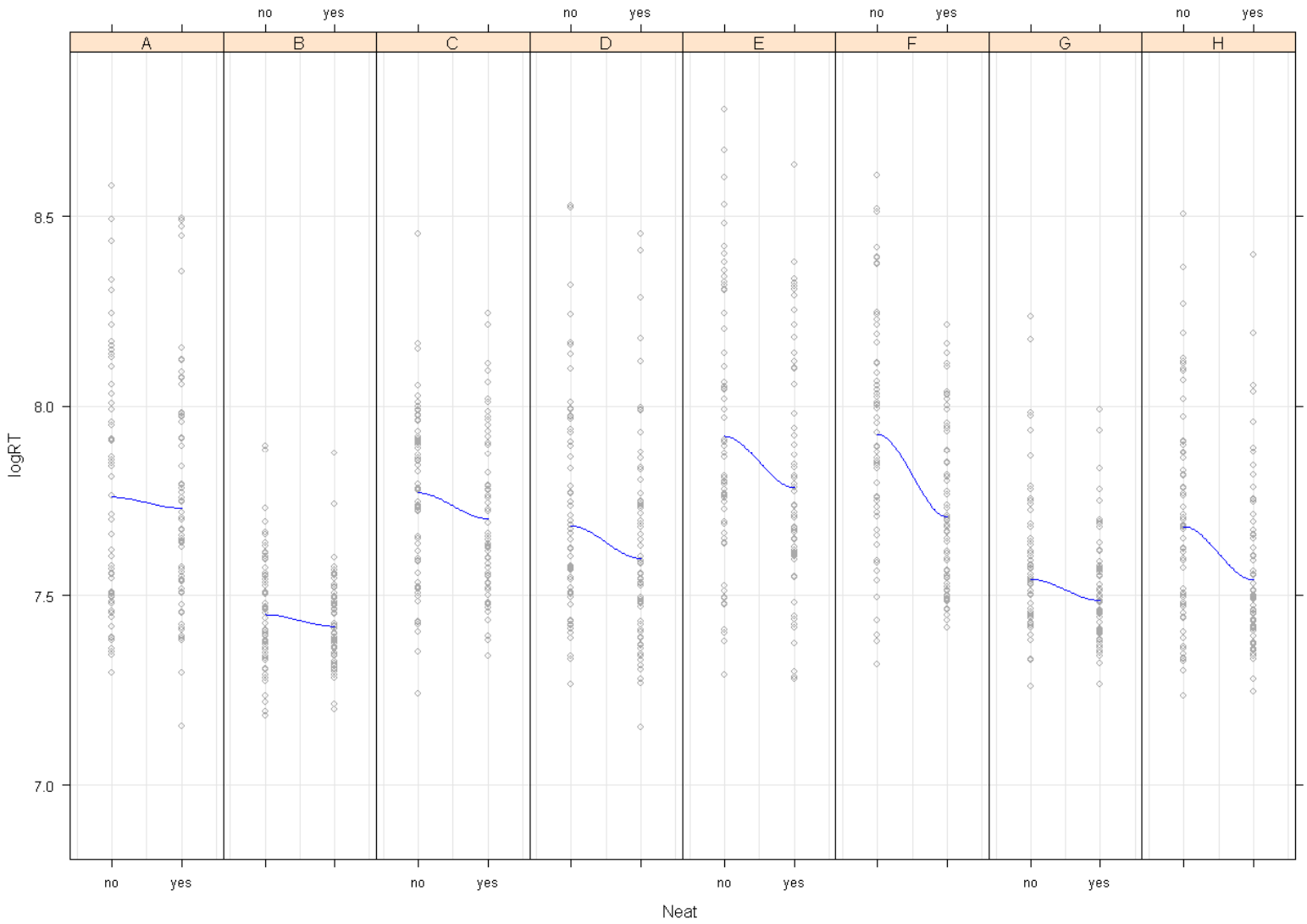
Fatigue and familiarization



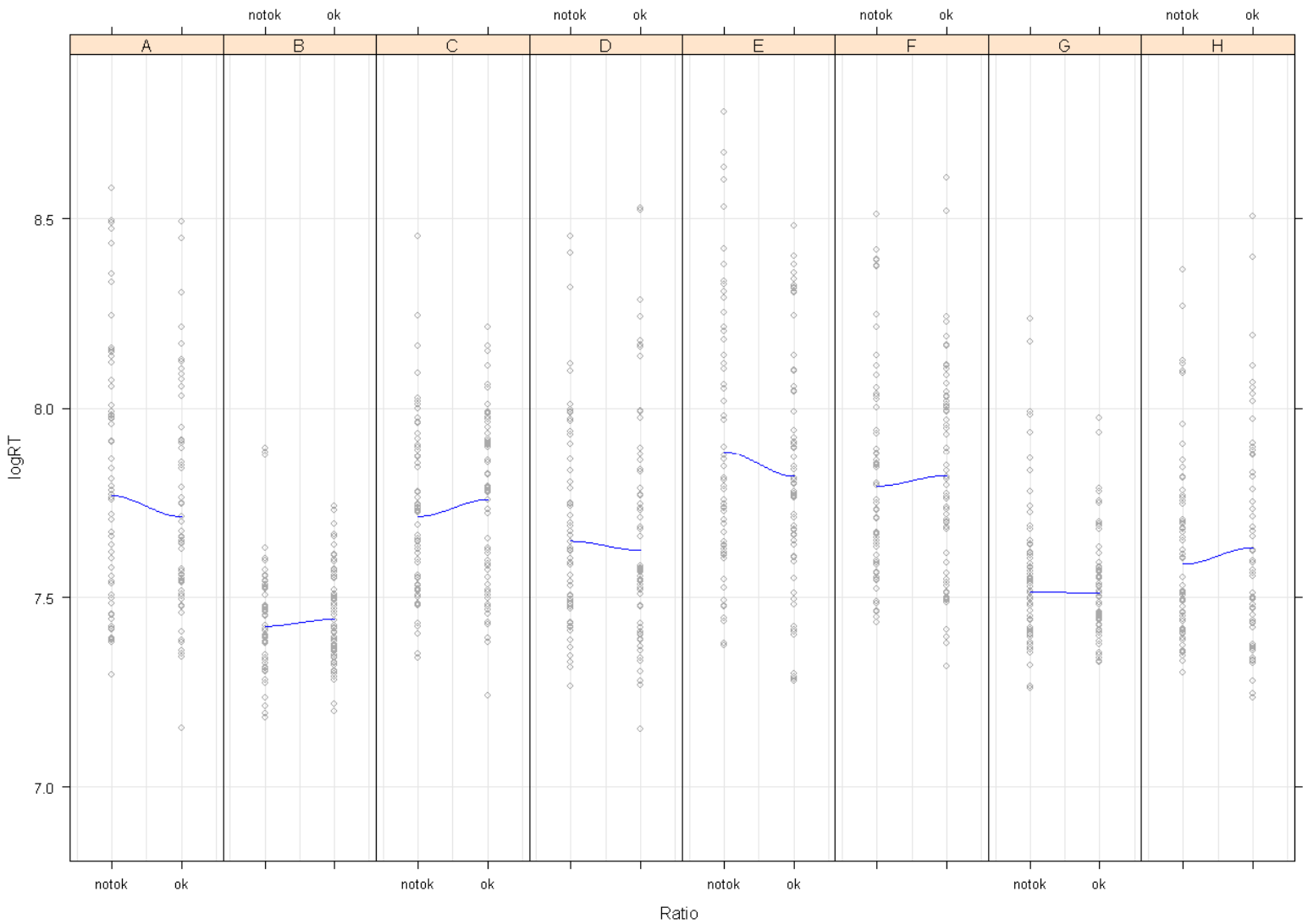
Level of numerosity (2,4,8,16)



Disposition (neat vs. not neat)



Ratio (notok[2:3] vs. ok[1:2])



Mixed Models analysis

Mmodel1 = Fixed effects + Random effect for Subjects

```
mmodel1=lmer(logRT~Level*Ratio*Neat +(1|Subject),correctEO2)
```

Mmodel2 = Mmodel1 + Random effect for Items

```
mmodel2=lmer(logRT~Level*Ratio*Neat+(1|Subject)+(1|AudioRef),correctEO2)
```

Mmodel3/4/5 + Random effect of Level/Ratio/Neat with by-Subject adjustments

```
mmodel3=lmer(logRT~Level*Ratio*Neat+(1+Level|Subject)+(1|AudioRef),
   correctEO2)
mmodel4=lmer(logRT~Level*Ratio*Neat+(1+Ratio|Subject)+(1|AudioRef),
   correctEO2)
mmodel5=lmer(logRT~Level*Ratio*Neat+(1+Neat|Subject)+(1|AudioRef),
   correctEO2)
```

First comparison

```
> anova(mmodel1,mmodel2,mmodel3,mmodel4,mmodel5)
Data: correctEO2
Models:
mmodel1: logRT ~ Level * Ratio * Neat + (1 | Subject)
mmodel2: logRT ~ Level * Ratio * Neat + (1 | Subject) + (1 | AudioRef)
mmodel4: logRT ~ Level * Ratio * Neat + (1 + Ratio | Subject) + (1 | AudioRef)
mmodel5: logRT ~ Level * Ratio * Neat + (1 + Neat | Subject) + (1 | AudioRef)
mmodel3: logRT ~ Level * Ratio * Neat + (1 + Level | Subject) + (1 | AudioRef)
        Df    AIC    BIC  logLik    Chisq Chi Df Pr(>Chisq)
mmodel1 18 449.24 562.55 -206.62
mmodel2 19 286.84 406.45 -124.42 164.3964      1     <2e-16 ***
mmodel4 21 290.79 422.98 -124.39   0.0567      2     0.9720
mmodel5 21 271.20 403.39 -114.60  19.5866      0     <2e-16 ***
mmodel3 28 275.32 451.58 -109.66   9.8796      7     0.1955
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Second comparison

```
> anova(mmodel2,mmodel5)
Data: correctEO2
Models:
mmodel2: logRT ~ Level * Ratio * Neat + (1 | Subject) + (1 | AudioRef)
mmodel5: logRT ~ Level * Ratio * Neat + (1 + Neat | Subject) + (1 | AudioRef)
        Df    AIC    BIC  logLik  Chisq Chi Df Pr(>Chisq)
mmodel2 19 286.84 406.45 -124.42
mmodel5 21 271.20 403.39 -114.60 19.643      2  5.426e-05 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Mixed Models analysis

Mmodel6 = Mmodel5 + Random effect Video stimuli

```
> mmodel6=lmer(logRT~Level*Ratio*Neat+(1+Neat|Subject)+(1|AudioRef)+(1|Video),
correctEO2)

> anova(mmodel5,mmodel6)
Data: correctEO2
Models:
mmodel5: logRT ~ Level * Ratio * Neat + (1 + Neat | Subject) + (1 | AudioRef)
mmodel6: logRT ~ Level * Ratio * Neat + (1 + Neat | Subject) + (1 | AudioRef) +
(1 | Video)

        Df   AIC    BIC logLik Chisq Chi Df Pr(>Chisq)
mmodel5 21 271.2 403.39 -114.6
mmodel6 22 273.2 411.69 -114.6     0      1     0.9991
```

Mixed Models analysis

Mmodel7 = Mmodel5 + Random effect Orientation angle

```
> mmodel7=lmer(logRT~Level*Ratio*Neat+(1+Neat|Subject)+(1|AudioRef)+(1|Angle),
correctEO2)

> anova(mmodel5,mmodel7)
Data: correctEO2
Models:
mmodel5: logRT ~ Level * Ratio * Neat + (1 + Neat | Subject) + (1 | AudioRef)
mmodel7: logRT ~ Level * Ratio * Neat + (1 + Neat | Subject) + (1 | AudioRef) +
mmodel7:     (1 | Angle)
          Df    AIC    BIC  logLik  Chisq Chi Df Pr(>Chisq)
mmodel5 21 271.20 403.39 -114.60
mmodel7 22 249.23 387.72 -102.62 23.966      1  9.804e-07 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Mixed Models analysis

Mmodel8 = Mmodel7 + Random effect Presentation order

```
> mmodel8=lmer(logRT~Level*Ratio*Neat+(1+Neat|Subject)+(1|AudioRef)+(1|Angle)
  +(1|Block), correctEO2)

> anova(mmodel8,mmodel7)
Data: correctEO2
Models:
mmodel7: logRT ~ Level * Ratio * Neat + (1 + Neat | Subject) + (1 | AudioRef) +
mmodel7:     (1 | Angle)
mmodel8: logRT ~ Level * Ratio * Neat + (1 + Neat | Subject) + (1 | AudioRef) +
mmodel8:     (1 | Angle) + (1 | Block)
          Df     AIC    BIC   logLik  Chisq Chi Df Pr(>Chisq)
mmodel7 22 249.232 387.72 -102.616
mmodel8 23 -31.656 113.13   38.828 282.89      1  < 2.2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Mixed Models analysis

Mmodel9 = Mmodel8 + Random effect Subject Noun

```
> mmodel9=lmer(logRT~Level*Ratio*Neat+(1+Neat|Subject)+(1|AudioRef)+(1|Angle)
  +(1|Block)+(1|Sub),correctEO2)

> anova(mmodel8,mmodel9)
Data: correctEO2
Models:
mmodel8: logRT ~ Level * Ratio * Neat + (1 + Neat | Subject) + (1 | AudioRef) +
mmodel8:     (1 | Angle) + (1 | Block)
mmodel9: logRT ~ Level * Ratio * Neat + (1 + Neat | Subject) + (1 | AudioRef) +
mmodel9:     (1 | Angle) + (1 | Block) + (1 | Sub)
          Df     AIC    BIC logLik  Chisq Chi Df Pr(>Chisq)
mmodel8 23 -31.656 113.13 38.828
mmodel9 24 -30.648 120.43 39.324 0.9914      1     0.3194
```

Mixed Models analysis

Mmodel10 = Mmodel8 + Random effect Verb

```
> mmodel10=lmer(logRT~Level*Ratio*Neat+(1+Neat|Subject)+(1|AudioRef)+(1|Angle)
  +(1|Block)+(1|Ver),correctEO2)

> anova(mmodel8,mmodel10)
Data: correctEO2
Models:
mmodel8: logRT ~ Level * Ratio * Neat + (1 + Neat | Subject) + (1 | AudioRef) +
mmodel8:     (1 | Angle) + (1 | Block)
mmodel10: logRT ~ Level * Ratio * Neat + (1 + Neat | Subject) + (1 | AudioRef) +
mmodel10:     (1 | Angle) + (1 | Block) + (1 | Ver)
           Df     AIC    BIC logLik  Chisq Chi Df Pr(>Chisq)
mmodel8  23 -31.656 113.13 38.828
mmodel10 24 -51.621  99.46 49.810 21.965      1  2.777e-06 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Mixed Models analysis

Mmodel11 = Mmodel10 + Random effect Object Noun

```
> mmodel11=lmer(logRT~Level*Ratio*Neat+(1+Neat|Subject)+(1|AudioRef)+(1|Angle)
+(1|Block)+(1|Ver)+(1|Obj),correctEO2)

> anova(mmodel11,mmodel10)
Data: correctEO2
Models:
mmodel10: logRT ~ Level * Ratio * Neat + (1 + Neat | Subject) + (1 | AudioRef) +
mmodel10:     (1 | Angle) + (1 | Block) + (1 | Ver)
mmodel11: logRT ~ Level * Ratio * Neat + (1 + Neat | Subject) + (1 | AudioRef) +
mmodel11:     (1 | Angle) + (1 | Block) + (1 | Ver) + (1 | Obj)
           Df     AIC    BIC logLik  Chisq Chi Df Pr(>Chisq)
mmodel10 24 -51.621  99.46 49.810
mmodel11 25 -52.813 104.56 51.407 3.1923      1    0.07399 .
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Mixed Models analysis

Mmodel12 = Mmodel11 + Random effect Subject Noun

```
> mmodel12=lmer(logRT~Level*Ratio*Neat+(1+Neat|Subject)+(1|AudioRef)+(1|Angle)
  +(1|Block)+(1|Ver)+(1|Obj)+(1|Sub),correctEO2)

> anova(mmodel11,mmodel12)
Data: correctEO2
Models:
mmodel11: logRT ~ Level * Ratio * Neat + (1 + Neat | Subject) + (1 | AudioRef) +
mmodel11:     (1 | Angle) + (1 | Block) + (1 | Ver) + (1 | Obj)
mmodel12: logRT ~ Level * Ratio * Neat + (1 + Neat | Subject) + (1 | AudioRef) +
mmodel12:     (1 | Angle) + (1 | Block) + (1 | Ver) + (1 | Obj) + (1 |
mmodel12:     Sub)
           Df     AIC    BIC logLik  Chisq Chi Df Pr(>Chisq)
mmodel11 25 -52.813 104.56 51.407
mmodel12 26 -54.469 109.20 53.234 3.6555      1    0.05588 .
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Mmodel12: random effects

```
> print(mmodel12,cor=F)
Linear mixed model fit by REML
Formula:      logRT~Level*Ratio*Neat+(1+Neat|Subject)+(1|AudioRef)+(1|Angle)
              +(1|Block)+(1|Ver)+(1|Obj)+(1|Sub)
   Data: correctEO2
  AIC   BIC logLik deviance REMLdev
 43.1 206.8  4.452   -106.5  -8.903
Random effects:
 Groups   Name        Variance   Std.Dev. Corr
 Block    (Intercept) 0.01110360 0.105374
 AudioRef (Intercept) 0.00227232 0.047669
 Subject  (Intercept) 0.01709711 0.130756
          Neatyes     0.00237379 0.048722 -0.778
 Sub      (Intercept) 0.00034812 0.018658
 Ver      (Intercept) 0.00235053 0.048482
 Angle    (Intercept) 0.00069177 0.026301
 Obj      (Intercept) 0.00034063 0.018456
 Residual             0.04671962 0.216147
```

Mmodel12: fixed effects

t-values indicate significance if |t| > 2 (two-tailed) or |t| > 1.65 (one-tailed)

Fixed effects:

	Estimate	Std. Error	t value	
(Intercept)	7.5767952	0.0384541	197.03	SIGNIFICANT
LevelLevel2	**0.1129928**	**0.0245675**	**4.60**	**SIGNIFICANT**
LevelLevel3	**0.1462290**	**0.0244640**	**5.98**	**SIGNIFICANT**
LevelLevel4	**0.2904699**	**0.0245638**	**11.83**	**SIGNIFICANT**
Ratiook	0.0227288	0.0202798	1.12	
Neatyes	0.0143520	0.0259591	0.55	
LevelLevel2:Ratiook	−0.0031763	0.0286682	−0.11	
LevelLevel3:Ratiook	−0.0147044	0.0284988	−0.52	
LevelLevel4:Ratiook	−0.0007167	0.0286523	−0.03	
LevelLevel2:Neatyes	**−0.1116301**	**0.0346372**	**−3.22**	**SIGNIFICANT**
LevelLevel3:Neatyes	**−0.1077708**	**0.0371904**	**−2.90**	**SIGNIFICANT**
LevelLevel4:Neatyes	**−0.1978349**	**0.0347636**	**−5.69**	**SIGNIFICANT**
Ratiook:Neatyes	**−0.0478176**	**0.0285923**	**−1.67**	**SIGNIFICANT**
LevelLevel2:Ratiook:Neatyes	0.0190140	0.0404963	0.47	
LevelLevel3:Ratiook:Neatyes	0.0210836	0.0403275	0.52	
LevelLevel4:Ratiook:Neatyes	0.0008960	0.0405194	0.02	

Problems I encountered

- How can I further normalize the distribution of the RT?
  - I only use the RT of correct answers and I can't expunge datapoints.
  - I log transformed the RT.
- There are possibly many more random effects I could consider (time of the experiment, filler data, etc.). Where is it convenient to stop?

Problems I encountered

- Several software errors which in the newest version of R do not allow to follow step by step the tutorials in Baayen (2007) and Baayen (2008).

Thank you

- I'll now give the word to Oscar…