36-763: Hierarchical Linear Models - HW05

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1. Three main experimental factors

(a) To compare the influence of the three main factors on Classical ratings, we first build four linear regression models, one with all the three factors, and the rest three each has two of the factors. We do ANOVA to the first model and each of the three models left to find out whether the eliminated factor is influential. The following are the results. It turns out that all of the three factors are significant.

- Harmony: p-value=0

```
Analysis of Variance Table

Model 1: Classical ~ Harmony + Instrument + Voice
Model 2: Classical ~ Instrument + Voice
  Res.Df   RSS Df Sum of Sq      F    Pr(>F)
1   2512 13871
2   2515 14132 -3   -261.26 15.772 3.677e-10 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

- Instrument: p-value=0

```
Analysis of Variance Table

Model 1: Classical ~ Harmony + Instrument + Voice
Model 2: Classical ~ Harmony + Voice
  Res.Df   RSS Df Sum of Sq      F    Pr(>F)
1   2512 13871
2   2514 18142 -2   -4271.4 386.78 < 2.2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

- Voice: p-value=0.00047

```
Analysis of Variance Table

Model 1: Classical ~ Harmony + Instrument + Voice
Model 2: Classical ~ Harmony + Instrument
  Res.Df   RSS Df Sum of Sq      F    Pr(>F)
1   2512 13871
2   2514 13955 -2   -84.813 7.6799 0.0004729 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

To determine how particular kinds of each factor affect ratings, we build linear models with all the three factors. The following is the R output. Here, the comparison group for each variable respectively are: I-IV-V for Harmony, guitar for Instrument and contrary for Voice. The estimate for each variable means the difference in classical ratings between the group and the comparison group, keeping all the other variables constant. And the intercept is the Classical rating when the three factors are all in the comparison group.

```
Call:
lm(formula = Classical ~ Harmony + Instrument + Voice, data = ratings)

Residuals:
    Min      1Q  Median      3Q     Max
-6.8627 -1.7222 -0.0164  1.7794 11.4705

Coefficients:
                 Estimate Std. Error t value Pr(>|t|)
(Intercept)       4.31722    0.13240  32.608  < 2e-16 ***
HarmonyI-V-IV    -0.05571    0.13240  -0.421 0.673931
HarmonyI-V-VI     0.73508    0.13240   5.552 3.12e-08 ***
HarmonyIV-I-V     0.04349    0.13240   0.328 0.742565
Instrumentpiano   1.27381    0.11466  11.109  < 2e-16 ***
Instrumentstring  3.16881    0.11466  27.637  < 2e-16 ***
Voicepar3rd      -0.41393    0.11466  -3.610 0.000312 ***
Voicepar5th      -0.35845    0.11466  -3.126 0.001791 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 2.35 on 2512 degrees of freedom
Multiple R-squared:  0.2498,        Adjusted R-squared:  0.2477
F-statistic: 119.5 on 7 and 2512 DF,  p-value: < 2.2e-16
```

(b) The repeated measures model

(i) In mathematical terms, the model can be written as:

$$\begin{aligned} y_i &= \alpha_{0j[i]} + \alpha_{1i}x_{1i} + \alpha_{2i}x_{2i} + \alpha_{3i}x_{3i} + \epsilon_i, \quad \epsilon_i \overset{i.i.d}{\sim} N(0, \sigma^2) \\ \alpha_{0j} &= \beta_0 + \eta_j, \quad \eta_j \overset{i.i.d}{\sim} N(0, \tau^2) \end{aligned}$$

in which y is the Classical rating. x_1, x_2, x_3 are Harmony, Instrument and Voice in each category.

(ii) We can compare the random intercept model with the conventional linear model we have built in the previous question, both with the three factor by comparing AIC, BIC. For the random intercept model, AIC is 10491.51, BIC is 10549.73. For the conventional linear model, AIC is 11230.45, BIC is 10549.73. It is clear that the multilevel model with random intercept is a lot better than the other one judging from both methods.

Model	AIC	BIC
LM	11467.34	11519.82
HLM	10755.46	10813.78

Another way to judge whether the random intercept is necessary is to use likelihood ratio test. The test result shows that the p-value is highly significant, which means that we should keep the random effect.

```
> exactRLRT(HM1.1)

        simulated finite sample distribution of RLRT.

        (p-value based on 10000 simulated values)

data:
RLRT = 736.0345, p-value < 2.2e-16
```

So the two methods give the same conclusion: keeping the random effects.

(iii) We can use ANOVA to test the whether the three factors are significant by comparing AIC, BIC and p-value.

- Harmony: p-value is significant, and AIC, BIC have improved.

```
> HM1.bh <- lmer(Classical ~ Instrument + Voice + (1 | Subject),
+                data = ratings)
> anova(HM1.bh, HM1.1)
Data: ratings
Models:
HM1.bh: Classical ~ Instrument + Voice + (1 | Subject)
HM1.1: Classical ~ Harmony + Instrument + Voice + (1 | Subject)
       Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM1.bh  7 10795 10836 -5390.5    10781
HM1.1  10 10733 10792 -5356.6    10713 67.847      3  1.233e-14 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

- Instrument: p-value is significant, AIC, BIC have improved

```
> HM1.bi <- lmer(Classical ~ Harmony + Voice + (1 | Subject),
+                data = ratings)
> anova(HM1.bi, HM1.1)
Data: ratings
Models:
HM1.bi: Classical ~ Harmony + Voice + (1 | Subject)
HM1.1: Classical ~ Harmony + Instrument + Voice + (1 | Subject)
       Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM1.bi  8 11655 11701 -5819.4    11639
HM1.1  10 10733 10792 -5356.6    10713 925.61      2  < 2.2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

- Voice: p-value is significant, AIC, BIC have improved.

```
> HM1.bv <- lmer(Classical ~ Harmony + Instrument + (1 | Subject),
+                data = ratings)
> anova(HM1.bv, HM1.1)
Data: ratings
Models:
```

```
HM1.bv: Classical ~ Harmony + Instrument + (1 | Subject)
HM1.1: Classical ~ Harmony + Instrument + Voice + (1 | Subject)
       Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM1.bv  8 10751 10798 -5367.7    10735
HM1.1  10 10733 10792 -5356.6    10713 22.231      2  1.488e-05 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

In conclusion, all of the three main factors are still significant in this repeated measurement model.

(c) Models with the new random effect terms

```
> HM.1c1 <- lmer(Classical ~ Harmony + Instrument + Voice + (1|Subject:Harmony) +
+                  (1 | Subject:Instrument)  + (1|Subject:Voice), data = ratings)
```

(i) Use AIC, BIC and DIC to compare with the model in Question 1a and Question 1b. Clearly, judging from these criteria, the model built here with three new random effect terms is the best.

Model	AIC	BIC	DIC
LM	11467.34	11519.82	-
HLM	10755.46	10813.78	10690.9
HLM2	10307.76	10377.75	10247.9

(ii) To test the influence of the three main factors, we first add all the three variables to the model and exclude one of them each time and use ANOVA the check their significance. It can be found that all of the three main effects are significant.

- Harmony: $p - value = 0$, significant

```
> HM.1c2h <- update(HM.1c2, . ~ .- Harmony)
> anova(HM.1c2, HM.1c2h)
Data: ratings
Models:
HM.1c2h: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM.1c2h:     (1 | Subject:Voice) + Instrument + Voice
HM.1c2: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM.1c2:     (1 | Subject:Voice) + Harmony + Instrument + Voice
        Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM.1c2h  9 10322 10374 -5152.0    10304
HM.1c2  12 10290 10360 -5132.9    10266 38.146      3  2.632e-08 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

- Instrument: $p - value = 0$, significant

```
> HM.1c2i <- update(HM.1c2, . ~ . - Instrument)
> anova(HM.1c2, HM.1c2i)
Data: ratings
Models:
HM.1c2i: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM.1c2i:     (1 | Subject:Voice) + Harmony + Voice
```

```
HM.1c2: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM.1c2:     (1 | Subject:Voice) + Harmony + Instrument + Voice
        Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM.1c2i 10 10390 10448 -5184.8    10370
HM.1c2  12 10290 10360 -5132.9    10266 103.69      2  < 2.2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

- Voice: $p - value = 7.93 \times 10^{-7}$, significant.

```
> HM.1c2v <- update(HM.1c2, . ~ . - Voice)
> anova(HM.1c2, HM.1c2v)
Data: ratings
Models:
HM.1c2v: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM.1c2v:     (1 | Subject:Voice) + Harmony + Instrument
HM.1c2: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM.1c2:     (1 | Subject:Voice) + Harmony + Instrument + Voice
        Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM.1c2v 10 10314 10372 -5147.0    10294
HM.1c2  12 10290 10360 -5132.9    10266 28.094      2  7.933e-07 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

From the summary of the model, we can see that the estimated variance components are: $\sigma_h^2 = 0.4431, \sigma_v^2 = 0.029, \sigma_i^2 = 2.199, \sigma_{res}^2 = 2.438$. So the random effect of the interaction of Subject and Instrument seems to be the most influential one. The variance of the residuals is also big, indicating that there may be other factors which should be included in the model.

(iii) The mathematical terms of the model:

$$
\begin{aligned}
y_i &= \alpha_{1j[i]} + \alpha_{2k[i]} + \alpha_{3l[i]} + \gamma_{1i}x_1 + \gamma_{2i}x_2 + \gamma_{3i}x_3 + \epsilon_i, \quad \epsilon_i \overset{i.i.d}{\sim} N(0, \sigma^2) \\
\alpha_{1j} &= \beta_{1j}z_{1j} + \eta_{1j}, \quad \eta_{1j} \overset{i.i.d}{\sim} N(0, \tau_1^2) \\
\alpha_{2k} &= \beta_{2k}z_{2k} + \eta_{2k}, \quad \eta_{2k} \overset{i.i.d}{\sim} N(0, \tau_2^2) \\
\alpha_{3l} &= \beta_{3l}z_{3l} + \eta_{3l}, \quad \eta_{3l} \overset{i.i.d}{\sim} N(0, \tau_3^2)
\end{aligned}
$$

in which $x_1,\ x_2,\ x_3$ are Harmony, Instrument, and Voice, and $z_1,\ z_2,\ z_3$ are the interaction of Subject and Harmony, Subject and Instrument, Subject and Voice.

2. Individual covariates

(a) First, adding the variables one by one to the model in the previous question, and using anova to judge whether the variable added is significant or not. If it is significant, we keep this variable and add the next variable.

- Selfdeclare: p-value = 0.442, not significant

```
> HM2.a1 <- update(HM.1c2, . ~ . + Selfdeclare)
> anova(HM2.a1, HM.1c2)
```

```
Data: ratings
Models:
HM.1c2: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM.1c2:     (1 | Subject:Voice) + Harmony + Instrument + Voice
HM2.a1: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM2.a1:     (1 | Subject:Voice) + Harmony + Instrument + Voice + Selfdeclare
       Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM.1c2 12 10290 10360 -5132.9    10266
HM2.a1 17 10295 10394 -5130.5    10261 4.7902      5      0.442
```

- OMSI: p-value = 0.9254, not significant.

```
> HM2.a2 <- update(HM.1c2, . ~ . + OMSI)
> anova(HM2.a2, HM.1c2)
```

```
Data: ratings
Models:
HM.1c2: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM.1c2:     (1 | Subject:Voice) + Harmony + Instrument + Voice
HM2.a2: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM2.a2:     (1 | Subject:Voice) + Harmony + Instrument + Voice + OMSI
       Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM.1c2 12 10290 10360 -5132.9    10266
HM2.a2 13 10292 10368 -5132.9    10266 0.0088      1     0.9254
```

- X16.minus.17: p-value = 0.003, significant.

```
> HM2.a3 <- update(HM.1c2, . ~. + X16.minus.17)
> anova(HM2.a3, HM.1c2)
```

```
Data: ratings
Models:
HM.1c2: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM.1c2:     (1 | Subject:Voice) + Harmony + Instrument + Voice
HM2.a3: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM2.a3:     (1 | Subject:Voice) + Harmony + Instrument + Voice + X16.minus.17
       Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM.1c2 12 10290 10360 -5132.9    10266
HM2.a3 13 10283 10359 -5128.5    10257 8.8944      1    0.00286 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

- ConsInstr: p-value=.62, not significant.

```
> HM2.a4 <- update(HM2.a3, . ~ . + ConsInstr)
> anova(HM2.a4, HM2.a3)
```

```
Data: ratings
Models:
HM2.a3: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM2.a3:     (1 | Subject:Voice) + Harmony + Instrument + Voice + X16.minus.17
HM2.a4: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM2.a4:     (1 | Subject:Voice) + Harmony + Instrument + Voice + X16.minus.17 +
HM2.a4:     ConsInstr
```

```
       Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM2.a3 13 10283 10359 -5128.5    10257
HM2.a4 14 10285 10366 -5128.4    10257 0.2459      1       0.62
```

- ConsNotes: p-value = 0.1968, not significant.

```
> HM2.a5 <- update(HM2.a3, .~.+ConsNotes)
> anova(HM2.a5, HM2.a3)

Data: ratings
Models:
HM2.a3: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM2.a3:     (1 | Subject:Voice) + Harmony + Instrument + Voice + X16.minus.17
HM2.a5: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM2.a5:     (1 | Subject:Voice) + Harmony + Instrument + Voice + X16.minus.17 +
HM2.a5:     ConsNotes
       Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM2.a3 13 10283 10359 -5128.5    10257
HM2.a5 14 10283 10365 -5127.6    10255 1.6662      1     0.1968
```

- Instr.minus.Notes: p-value = .2902, not significant.

```
> HM2.a6 <- update(HM2.a3, .~.+Instr.minus.Notes)
> anova(HM2.a6, HM2.a3)

Data: ratings
Models:
HM2.a3: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM2.a3:     (1 | Subject:Voice) + Harmony + Instrument + Voice + X16.minus.17
HM2.a6: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM2.a6:     (1 | Subject:Voice) + Harmony + Instrument + Voice + X16.minus.17 +
HM2.a6:     Instr.minus.Notes
       Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM2.a3 13 10283 10359 -5128.5    10257
HM2.a6 14 10284 10366 -5127.9    10256 1.1188      1     0.2902
```

- PachListen: p-value=0.5248, not significant

```
> HM2.a7 <- update(HM2.a3, . ~ . + PachListen)
> anova(HM2.a7, HM2.a3)

Data: ratings
Models:
HM2.a3: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM2.a3:     (1 | Subject:Voice) + Harmony + Instrument + Voice + X16.minus.17
HM2.a7: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM2.a7:     (1 | Subject:Voice) + Harmony + Instrument + Voice + X16.minus.17 +
HM2.a7:     PachListen
       Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM2.a3 13 10283 10359 -5128.5    10257
HM2.a7 14 10285 10366 -5128.3    10257 0.4045      1     0.5248
```

- ClsListen: p-value = 0.3812, not significant.

```
> HM2.a8 <- update(HM2.a3, . ~ . + ClsListen)
> anova(HM2.a8, HM2.a3)
```

```
Data: ratings
Models:
HM2.a3: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM2.a3:     (1 | Subject:Voice) + Harmony + Instrument + Voice + X16.minus.17
HM2.a8: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM2.a8:     (1 | Subject:Voice) + Harmony + Instrument + Voice + X16.minus.17 +
HM2.a8:     ClsListen
       Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM2.a3 13 10283 10359 -5128.5    10257
HM2.a8 17 10287 10386 -5126.4    10253 4.1874      4     0.3812
```

- KnowRob: p-value=0.7351, not significant.

```
> HM2.a9 <- update(HM2.a3, . ~ . + KnowRob)
> anova(HM2.a9, HM2.a3)
```

```
Data: ratings
Models:
HM2.a3: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM2.a3:     (1 | Subject:Voice) + Harmony + Instrument + Voice + X16.minus.17
HM2.a9: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM2.a9:     (1 | Subject:Voice) + Harmony + Instrument + Voice + X16.minus.17 +
HM2.a9:     KnowRob
       Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM2.a3 13 10283 10359 -5128.5    10257
HM2.a9 15 10286 10374 -5128.2    10256 0.6155      2     0.7351
```

- KnowAxis: p-value=0.2571, not significant.

```
> HM2.a10 <- update(HM2.a3, . ~ . + KnowAxis)
> anova(HM2.a10, HM2.a3)
```

```
Data: ratings
Models:
HM2.a3: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM2.a3:     (1 | Subject:Voice) + Harmony + Instrument + Voice + X16.minus.17
HM2.a10: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM2.a10:     (1 | Subject:Voice) + Harmony + Instrument + Voice + X16.minus.17 +
HM2.a10:     KnowAxis
        Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM2.a3  13 10283 10359 -5128.5    10257
HM2.a10 15 10284 10372 -5127.1    10254 2.7167      2     0.2571
```

- X1990s2000s: p-value = 0.8435, not significant.

```
> HM2.a11 <- update(HM2.a3, . ~ . + X1990s2000s)
> anova(HM2.a11, HM2.a3)
```

```
Data: ratings
Models:
HM2.a3: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM2.a3:     (1 | Subject:Voice) + Harmony + Instrument + Voice + X16.minus.17
HM2.a11: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM2.a11:     (1 | Subject:Voice) + Harmony + Instrument + Voice + X16.minus.17 +
```

```
HM2.a11:     X1990s2000s
        Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM2.a3  13 10283 10359 -5128.5    10257
HM2.a11 17 10290 10389 -5127.8    10256 1.4038      4     0.8435
```

- X1990s2000s.minus.1960s1970s: p-value=0.068, marginally significant, we can keep this variable.

```
> HM2.a12 <- update(HM2.a3, . ~ . + X1990s2000s.minus.1960s1970s)
> anova(HM2.a12, HM2.a3)

Data: ratings
Models:
HM2.a3: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM2.a3:     (1 | Subject:Voice) + Harmony + Instrument + Voice + X16.minus.17
HM2.a12: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM2.a12:     (1 | Subject:Voice) + Harmony + Instrument + Voice + X16.minus.17 +
HM2.a12:     X1990s2000s.minus.1960s1970s
        Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM2.a3  13 10283 10359 -5128.5    10257
HM2.a12 21 10284 10407 -5121.2    10242 14.534      8    0.06887 .
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

- CollegeMusic: p-value = 0.4967, not significant.

```
> HM2.a13 <- update(HM2.a12, . ~ . + CollegeMusic)
> anova(HM2.a13, HM2.a12)

Data: ratings
Models:
HM2.a12: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM2.a12:     (1 | Subject:Voice) + Harmony + Instrument + Voice + X16.minus.17 +
HM2.a12:     X1990s2000s.minus.1960s1970s
HM2.a13: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM2.a13:     (1 | Subject:Voice) + Harmony + Instrument + Voice + X16.minus.17 +
HM2.a13:     X1990s2000s.minus.1960s1970s + CollegeMusic
        Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM2.a12 21 10284 10407 -5121.2    10242
HM2.a13 22 10286 10414 -5121.0    10242 0.4619      1     0.4967
```

- NoClass: p-value=0.531, not significant.

```
> HM2.a14 <- update(HM2.a12, . ~ . + NoClass)
> anova(HM2.a14, HM2.a12)

Data: ratings
Models:
HM2.a12: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM2.a12:     (1 | Subject:Voice) + Harmony + Instrument + Voice + X16.minus.17 +
HM2.a12:     X1990s2000s.minus.1960s1970s
HM2.a14: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM2.a14:     (1 | Subject:Voice) + Harmony + Instrument + Voice + X16.minus.17 +
HM2.a14:     X1990s2000s.minus.1960s1970s + NoClass
```

```
        Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM2.a12 21 10284 10407 -5121.2    10242
HM2.a14 22 10286 10414 -5121.0    10242 0.3925      1      0.531
```

- p-value= 0.3737, not significant.

```
> HM2.a15 <- update(HM2.a12, . ~ . + APTheory)
> anova(HM2.a15, HM2.a12)

Data: ratings
Models:
HM2.a12: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM2.a12:     (1 | Subject:Voice) + Harmony + Instrument + Voice + X16.minus.17 +
HM2.a12:     X1990s2000s.minus.1960s1970s
HM2.a15: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM2.a15:     (1 | Subject:Voice) + Harmony + Instrument + Voice + X16.minus.17 +
HM2.a15:     X1990s2000s.minus.1960s1970s + APTheory
        Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM2.a12 21 10284 10407 -5121.2    10242
HM2.a15 22 10286 10414 -5120.8    10242 0.7913      1     0.3737
```

- Composing: p-value=0.3673, not significant.

```
> HM2.a16 <- update(HM2.a12, .~.+Composing)
> anova(HM2.a16, HM2.a12)

Data: ratings
Models:
HM2.a12: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM2.a12:     (1 | Subject:Voice) + Harmony + Instrument + Voice + X16.minus.17 +
HM2.a12:     X1990s2000s.minus.1960s1970s
HM2.a16: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM2.a16:     (1 | Subject:Voice) + Harmony + Instrument + Voice + X16.minus.17 +
HM2.a16:     X1990s2000s.minus.1960s1970s + Composing
        Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM2.a12 21 10284 10407 -5121.2    10242
HM2.a16 26 10289 10441 -5118.5    10237 5.4152      5     0.3673
```

- PianoPlay: p-value=0.1832, not significant.

```
> HM2.a17 <- update(HM2.a12, . ~ . + PianoPlay)
> anova(HM2.a17, HM2.a12)

Data: ratings
Models:
HM2.a12: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM2.a12:     (1 | Subject:Voice) + Harmony + Instrument + Voice + X16.minus.17 +
HM2.a12:     X1990s2000s.minus.1960s1970s
HM2.a17: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM2.a17:     (1 | Subject:Voice) + Harmony + Instrument + Voice + X16.minus.17 +
HM2.a17:     X1990s2000s.minus.1960s1970s + PianoPlay
        Df   AIC   BIC  logLik deviance Chisq Chi Df Pr(>Chisq)
HM2.a12 21 10284 10407 -5121.2    10242
HM2.a17 25 10286 10432 -5118.1    10236 6.221      4     0.1832
```

- GuitarPlay: p-value=0.0156, significant

```
> HM2.a18 <- update(HM2.a12, . ~ . + GuitarPlay)
> anova(HM2.a18, HM2.a12)

Data: ratings
Models:
HM2.a12: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM2.a12:     (1 | Subject:Voice) + Harmony + Instrument + Voice + X16.minus.17 +
HM2.a12:     X1990s2000s.minus.1960s1970s
HM2.a18: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM2.a18:     (1 | Subject:Voice) + Harmony + Instrument + Voice + X16.minus.17 +
HM2.a18:     X1990s2000s.minus.1960s1970s + GuitarPlay
        Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM2.a12 21 10284 10407 -5121.2    10242
HM2.a18 25 10280 10426 -5115.1    10230 12.247      4    0.01561 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

> HM2.a <- HM2.a18
```

So the list of variables selected:
X16.minus.17, X1990s2000s.minus.1960s1970s, GuitarPlay.

(b) Use likelihood ratio test to check the random effects.

- For Harmony, p-value=0, so we keep this random effect.

```
> m2.h <- lmer( Classical ~ (1 | Subject:Harmony) + Harmony + Instrument +
+                 Voice + X16.minus.17 + X1990s2000s.minus.1960s1970s +
+                 GuitarPlay, data = ratings)
> m2.0h <- update(HM2.a, . ~ . - (1 | Subject:Harmony))
> exactRLRT(m2.h, m0 = m2.0h, mA = HM2.a)

        simulated finite sample distribution of RLRT.

        (p-value based on 10000 simulated values)

data:
RLRT = 86.1279, p-value < 2.2e-16
```

- For Instrument, p-value=0, so we keep this random effect.

```
> m2.i <- lmer( Classical ~ (1 | Subject:Instrument) + Harmony + Instrument +
+                 Voice + X16.minus.17 + X1990s2000s.minus.1960s1970s +
+                 GuitarPlay, data = ratings)
> m2.0i <- update(HM2.a, . ~ . - (1 | Subject:Instrument))
> exactRLRT(m2.i, m0 = m2.0i, mA = HM2.a)

        simulated finite sample distribution of RLRT.

        (p-value based on 10000 simulated values)

data:
RLRT = 589.2569, p-value < 2.2e-16
```

- For Voice, p-value is not significant. So we do not keep this random effect.

```
> m2.v <- lmer(Classical ~ (1 | Subject:Voice) + Harmony + Instrument + Voice +
+                 X16.minus.17 + X1990s2000s.minus.1960s1970s +
+                 GuitarPlay, data = ratings)
> m2.0v <- update(HM2.a, . ~ . - (1 | Subject:Voice))
> exactRLRT(m2.v, m0 = m2.0v, mA = HM2.a)

        simulated finite sample distribution of RLRT.

        (p-value based on 10000 simulated values)

data:
RLRT = 0.1827, p-value = 0.3188
```

In conclusion, we exclude the random effects of the interaction of Subject and Voice.

(c) The following is the first five fixed effect estimates. For quantitative variables, they represent the change in Classical rating with one unit increase in the predictor, given that all the variables are the same. For categorical variables, they are the difference with the comparison group.

```
> HM2 <- update(HM2.a, . ~ . - (1|Subject:Voice))
> fixef(HM2)
```

(Intercept)	HarmonyI-V-IV
4.17920635	-0.05571429
HarmonyI-V-VI	HarmonyIV-I-V
0.73507937	0.04349206
Instrumentpiano	Instrumentstring
1.27380952	3.16880952
Voicepar3rd	Voicepar5th
-0.41392857	-0.35845238
X16.minus.17	X1990s2000s.minus.1960s1970s-3
-0.12016826	-0.31521904
X1990s2000s.minus.1960s1970s-2	X1990s2000s.minus.1960s1970s0
-2.44444444	0.40149712
X1990s2000s.minus.1960s1970s1	X1990s2000s.minus.1960s1970s2
-0.19536241	0.21455455
X1990s2000s.minus.1960s1970s3	X1990s2000s.minus.1960s1970s4
0.36748460	-0.57457936
X1990s2000s.minus.1960s1970s5	GuitarPlay1
-0.04302148	1.06518141
GuitarPlay2	GuitarPlay4
1.66311559	0.26986262
GuitarPlay5	
-0.12168408	

For random effect, we only list the first five for the interaction of Subject and Harmony. Each row represents the estimated intercept for the certain group.

```
> head(ranef(HM2.a)$`Subject:Harmony`)
```

```
           (Intercept)
15:I-IV-V -0.39800592
15:I-V-IV -0.49535523
15:I-V-VI  0.60137897
15:IV-I-V  0.48602606
16:I-IV-V  0.09791913
16:I-V-IV  0.13049263
```

3. Musicians vs. Non-musicians

Reclassify the Selfdeclare variable by putting 1 and 2 into "not self-declared musician" and the others into "self-declared musician". Denote the variable as Musicians.

```
  1   2   3   4   5   6
576 936 468 432  72  36
```

Add all the possible interaction terms with Musicians into the model. We get the following model. Using anova, these interaction terms as a total are significant with the p-value = 0.0001. AIC and DIC are also improved. But BIC is not as good as the model without these interaction terms.

- First add Musicians and compare it with the model in Question 2c. p-value=0.4037, it is not significant. And both AIC, BIC increase. But as we need to add the interaction terms, we will keep this variable in the model.

```
> HM3.1 <- update(HM2, . ~ . + Musicians)
> anova(HM3.1, HM2)

Data: ratings
Models:
HM2: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM2:     Harmony + Instrument + Voice + X16.minus.17 + X1990s2000s.minus.1960s1970s +
HM2:     GuitarPlay
HM3.1: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM3.1:     Harmony + Instrument + Voice + X16.minus.17 + X1990s2000s.minus.1960s1970s +
HM3.1:     GuitarPlay + Musicians
      Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM2   24 10278 10418 -5115.1    10230
HM3.1 25 10280 10425 -5114.8    10230 0.6972      1     0.4037
```

- Musicians*Harmony: p-value is significant.

```
> HM3.2 <- update(HM3.1, . ~ . + Musicians:Harmony)
> anova(HM3.2, HM3.1)

Data: ratings
Models:
HM3.1: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM3.1:     Harmony + Instrument + Voice + X16.minus.17 + X1990s2000s.minus.1960s1970s +
HM3.1:     GuitarPlay + Musicians
```

```
HM3.2: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM3.2:     Harmony + Instrument + Voice + X16.minus.17 + X1990s2000s.minus.1960s1970s +
HM3.2:     GuitarPlay + Musicians + Harmony:Musicians
      Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM3.1 25 10280 10425 -5114.8    10230
HM3.2 28 10259 10423 -5101.7    10203 26.236      3  8.512e-06 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

- Musicians*Instrument: p-value is not significant.

```
> HM3.3 <- update(HM3.2, . ~ . + Musicians*Instrument)
> anova(HM3.3, HM3.2)

Data: ratings
Models:
HM3.2: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM3.2:     Harmony + Instrument + Voice + X16.minus.17 + X1990s2000s.minus.1960s1970s +
HM3.2:     GuitarPlay + Musicians + Harmony:Musicians
HM3.3: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM3.3:     Harmony + Instrument + Voice + X16.minus.17 + X1990s2000s.minus.1960s1970s +
HM3.3:     GuitarPlay + Musicians + Harmony:Musicians + Instrument:Musicians
      Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM3.2 28 10259 10423 -5101.7    10203
HM3.3 30 10260 10435 -5100.0    10200 3.3502      2     0.1873
```

- Musicians*Voice: p-value=0.81, not significant.

```
> HM3.4 <- update(HM3.2, . ~ . + Musicians:Voice)
> anova(HM3.4, HM3.2)

Data: ratings
Models:
HM3.2: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM3.2:     Harmony + Instrument + Voice + X16.minus.17 + X1990s2000s.minus.1960s1970s +
HM3.2:     GuitarPlay + Musicians + Harmony:Musicians
HM3.4: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM3.4:     Harmony + Instrument + Voice + X16.minus.17 + X1990s2000s.minus.1960s1970s +
HM3.4:     GuitarPlay + Musicians + Harmony:Musicians + Voice:Musicians
      Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM3.2 28 10259 10423 -5101.7    10203
HM3.4 30 10263 10438 -5101.5    10203 0.4254      2     0.8084
```

- Musicians*X16.minus.17: p-value=0.005, significant.

```
> HM3.5 <- update(HM3.2, .~.+Musicians:X16.minus.17)
> anova(HM3.5, HM3.2)

Data: ratings
Models:
```

```
HM3.2: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM3.2:     Harmony + Instrument + Voice + X16.minus.17 + X1990s2000s.minus.1960s1970s +
HM3.2:     GuitarPlay + Musicians + Harmony:Musicians
HM3.5: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM3.5:     Harmony + Instrument + Voice + X16.minus.17 + X1990s2000s.minus.1960s1970s +
HM3.5:     GuitarPlay + Musicians + Harmony:Musicians + X16.minus.17:Musicians
      Df   AIC   BIC  logLik deviance Chisq Chi Df Pr(>Chisq)
HM3.2 28 10259 10423 -5101.7    10203
HM3.5 29 10254 10423 -5097.8    10196 7.816      1   0.005179 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

- Musicians*X1990s2000s.minus.1960s1970s: cannot be added because of the rank problem.

In conclusion, we add two interaction the interaction of *Musicians and Harmony*, and the interaction of *Musicians and X16.minus.17* in the model. If we compare this model with the model in Question 2c, the added variables as a total are significant. AIC and DIC decrease while BIC is not as better maybe due to the increase of model size.

```
> anova(HM3.5, HM2)

Data: ratings
Models:
HM2: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM2:     Harmony + Instrument + Voice + X16.minus.17 + X1990s2000s.minus.1960s1970s +
HM2:     GuitarPlay
HM3.5: Classical ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM3.5:     Harmony + Instrument + Voice + X16.minus.17 + X1990s2000s.minus.1960s1970s +
HM3.5:     GuitarPlay + Musicians + Harmony:Musicians + X16.minus.17:Musicians
      Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM2   24 10278 10418 -5115.1    10230
HM3.5 29 10254 10423 -5097.8    10196 34.749      5  1.689e-06 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

4. Classical vs. Popular

(a) Test the influence of the three main factors on popular ratings in both the conventional linear models and the hierarchical linear models.

(i) Conventional linear models. Repeat the process in Question 1a. The results of ANOVA show that only Instrument is significant at level .05.

- Harmony: p-value-0.09943, not significant

```
> anova(M4.1, M4.h)
Analysis of Variance Table

Model 1: Popular ~ Harmony + Instrument + Voice
```

```
Model 2: Popular ~ Instrument + Voice
  Res.Df   RSS Df Sum of Sq      F  Pr(>F)
1   2512 13571
2   2515 13605 -3   -33.879 2.0903 0.09943 .
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

- Instrument: p-value=0, highly significant

```
> anova(M4.1, M4.i)
Analysis of Variance Table

Model 1: Popular ~ Harmony + Instrument + Voice
Model 2: Popular ~ Harmony + Voice
  Res.Df   RSS Df Sum of Sq      F    Pr(>F)
1   2512 13571
2   2514 16351 -2   -2780.4 257.33 < 2.2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

- Voice: p-value=0.249, not significant.

```
> anova(M4.1, M4.v)
Analysis of Variance Table

Model 1: Popular ~ Harmony + Instrument + Voice
Model 2: Popular ~ Harmony + Instrument
  Res.Df   RSS Df Sum of Sq      F Pr(>F)
1   2512 13571
2   2514 13586 -2   -15.033 1.3913  0.249
```

(ii) The standard repeated measures model. Using LRT, we find that the random effect is necessary. With ANOVA, the three main factors are all significant in this model.

```
> HM4.a0 <- lmer(Popular ~ Harmony + Instrument + Voice + (1 | Subject),
+                data = ratings)
> exactRLRT(HM4.a0)

        simulated finite sample distribution of RLRT.

        (p-value based on 10000 simulated values)

data:
RLRT = 713.1173, p-value < 2.2e-16
```

- Harmony: p-value=0.02915, significant

```
> HM4.ah0 <- update(HM4.a0, . ~ . -Harmony)
> anova(HM4.a0, HM4.ah0)
Data: ratings
Models:
HM4.ah0: Popular ~ Instrument + Voice + (1 | Subject)
HM4.a0: Popular ~ Harmony + Instrument + Voice + (1 | Subject)
        Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
```

```
HM4.ah0  7 10704 10745 -5345.1    10690
HM4.a0  10 10701 10759 -5340.6    10681 9.0108      3    0.02915 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

- Instrument: p-value=0, significant

```
> HM4.ai0 <- update(HM4.a0, . ~ . -Instrument)
> anova(HM4.a0, HM4.ai0)
Data: ratings
Models:
HM4.ai0: Popular ~ Harmony + Voice + (1 | Subject)
HM4.a0: Popular ~ Harmony + Instrument + Voice + (1 | Subject)
        Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM4.ai0  8 11344 11391 -5664.2    11328
HM4.a0  10 10701 10759 -5340.6    10681 647.31      2  < 2.2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

- Voice: p-value=0.02522, significant

```
> HM4.av0 <- update(HM4.a0, . ~ . -Voice)
> anova(HM4.av0, HM4.ah0)
Data: ratings
Models:
HM4.ah0: Popular ~ Instrument + Voice + (1 | Subject)
HM4.av0: Popular ~ Harmony + Instrument + (1 | Subject)
        Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM4.ah0  7 10704 10745 -5345.1    10690
HM4.av0  8 10701 10748 -5342.6    10685 5.0085      1    0.02522 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

really, a crossed random effects model

(iii) Hierarchical linear models. Using the similar model in Question 1c, changing the response variable to Popular rating, and testing the significance of the three main effects with anova. It turns out that only Instrument is highly significant. Voice is marginally significant. While Harmony is not significant.

```
> HM4.a <- lmer(Popular ~ (1|Subject:Harmony) + (1|Subject:Instrument) +
+                (1|Subject:Voice)+ Harmony + Instrument + Voice,
+              data = ratings)
```

- Harmony: p-value=0.1328, not significant.

```
> HM4.ah <- update(HM4.a, . ~ . -Harmony)
> anova(HM4.a, HM4.ah)
Data: ratings
Models:
HM4.ah: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.ah:     (1 | Subject:Voice) + Instrument + Voice
HM4.a: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.a:     (1 | Subject:Voice) + Harmony + Instrument + Voice
       Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
```

```
HM4.ah  9 10329 10382 -5155.5    10311
HM4.a  12 10330 10400 -5152.7    10306 5.5989      3     0.1328
```

- Instrument: p-value=0, significant.

```
> HM4.ai <- update(HM4.a, . ~ . - Instrument)
> anova(HM4.a, HM4.ai)
Data: ratings
Models:
HM4.ai: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.ai:     (1 | Subject:Voice) + Harmony + Voice
HM4.a: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.a:     (1 | Subject:Voice) + Harmony + Instrument + Voice
       Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM4.ai 10 10403 10461 -5191.5    10383
HM4.a  12 10330 10400 -5152.7    10306 77.543      2  < 2.2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

- Voice: p-value=0.08844, marginally significant.

```
> HM4.av <- update(HM4.a, . ~ . - Voice)
> anova(HM4.a, HM4.av)
Data: ratings
Models:
HM4.av: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.av:     (1 | Subject:Voice) + Harmony + Instrument
HM4.a: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.a:     (1 | Subject:Voice) + Harmony + Instrument + Voice
       Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM4.av 10 10330 10389 -5155.2    10310
HM4.a  12 10330 10400 -5152.7    10306 4.8508      2    0.08844 .
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

The following table makes a comparison for the above three models for Popular rating in terms of AIC, BIC, and DIC. So we still use the model with three random effects in the following discussion.

Model	AIC	BIC	DIC
LM	11142.30	11464.79	-
HLM	10723.52	10781.84	10658.7
HLM2	10097.24	10167.09	10287.5

(b) As the three main effects are design variables, we keep them in the model anyway. Repeat the process in Question 2c.

- Selfdeclare: p-value = 0.0045, significant.

```
> HM4.b1 <- update(HM4.a, . ~ . + Selfdeclare)
> anova(HM4.b1, HM4.a)
```

```
Data: ratings
Models:
HM4.a: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.a:     (1 | Subject:Voice) + Harmony + Instrument + Voice
HM4.b1: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.b1:     (1 | Subject:Voice) + Harmony + Instrument + Voice + Selfdeclare
       Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM4.a  12 10330 10400 -5152.7    10306
HM4.b1 17 10322 10422 -5144.3    10288 16.988      5   0.004522 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

- OMSI: p-value=0.015, significant.

```
> HM4.b2 <- update(HM4.b1, . ~ . + OMSI)
> anova(HM4.b2, HM4.b1)
```

```
Data: ratings
Models:
HM4.b1: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.b1:     (1 | Subject:Voice) + Harmony + Instrument + Voice + Selfdeclare
HM4.b2: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.b2:     (1 | Subject:Voice) + Harmony + Instrument + Voice + Selfdeclare +
HM4.b2:     OMSI
       Df   AIC   BIC  logLik deviance Chisq Chi Df Pr(>Chisq)
HM4.b1 17 10322 10422 -5144.3    10288
HM4.b2 18 10319 10424 -5141.3    10283 5.925      1    0.01493 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

- X16.minus.17: p-value=0.1021, not significant

```
> HM4.b3 <- update(HM4.b2, . ~ . + X16.minus.17)
> anova(HM4.b3, HM4.b2)
```

```
Data: ratings
Models:
HM4.b2: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.b2:     (1 | Subject:Voice) + Harmony + Instrument + Voice + Selfdeclare +
HM4.b2:     OMSI
HM4.b3: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.b3:     (1 | Subject:Voice) + Harmony + Instrument + Voice + Selfdeclare +
HM4.b3:     OMSI + X16.minus.17
       Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM4.b2 18 10319 10424 -5141.3    10283
HM4.b3 19 10318 10429 -5140.0    10280 2.6725      1     0.1021
```

- ConsInstr: p-value=0.455, not significant.

```
> HM4.b4 <- update(HM4.b2, . ~ . + ConsInstr)
> anova(HM4.b4, HM4.b2)
```

```
Data: ratings
Models:
```

```
HM4.b2: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.b2:     (1 | Subject:Voice) + Harmony + Instrument + Voice + Selfdeclare +
HM4.b2:     OMSI
HM4.b4: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.b4:     (1 | Subject:Voice) + Harmony + Instrument + Voice + Selfdeclare +
HM4.b4:     OMSI + ConsInstr
       Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM4.b2 18 10319 10424 -5141.3    10283
HM4.b4 19 10320 10431 -5141.0    10282 0.5583      1      0.455
```

- ConsNotes: p-value=0.6188, not significant.

```
> HM4.b5 <- update(HM4.b2, . ~ . + ConsNotes)
> anova(HM4.b5, HM4.b2)

Data: ratings
Models:
HM4.b2: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.b2:     (1 | Subject:Voice) + Harmony + Instrument + Voice + Selfdeclare +
HM4.b2:     OMSI
HM4.b5: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.b5:     (1 | Subject:Voice) + Harmony + Instrument + Voice + Selfdeclare +
HM4.b5:     OMSI + ConsNotes
       Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM4.b2 18 10319 10424 -5141.3    10283
HM4.b5 19 10320 10431 -5141.2    10282 0.2475      1     0.6188
```

- Instr.minus.Notes: p-value=0.1821, not significant.

```
> HM4.b6 <- update(HM4.b2, . ~ . + Instr.minus.Notes)
> anova(HM4.b6, HM4.b2)

Data: ratings
Models:
HM4.b2: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.b2:     (1 | Subject:Voice) + Harmony + Instrument + Voice + Selfdeclare +
HM4.b2:     OMSI
HM4.b6: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.b6:     (1 | Subject:Voice) + Harmony + Instrument + Voice + Selfdeclare +
HM4.b6:     OMSI + Instr.minus.Notes
       Df   AIC   BIC  logLik deviance Chisq Chi Df Pr(>Chisq)
HM4.b2 18 10319 10424 -5141.3    10283
HM4.b6 19 10319 10430 -5140.5    10281  1.61      1     0.2045
```

- PachListen: p-value=0.8496, not significant.

```
> HM4.b7 <- update(HM4.b2, . ~ . + PachListen)
> anova(HM4.b7, HM4.b2)

Data: ratings
Models:
HM4.b2: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.b2:     (1 | Subject:Voice) + Harmony + Instrument + Voice + Selfdeclare +
HM4.b2:     OMSI
```

```
HM4.b7: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.b7:     (1 | Subject:Voice) + Harmony + Instrument + Voice + Selfdeclare +
HM4.b7:     OMSI + PachListen
       Df   AIC   BIC  logLik deviance Chisq Chi Df Pr(>Chisq)
HM4.b2 18 10319 10424 -5141.3    10283
HM4.b7 19 10320 10431 -5141.3    10282 0.036      1     0.8496
```

- ClsListen: p-value=0.2384, not significant.

```
> HM4.b8 <- update(HM4.b2, . ~ . + ClsListen)
> anova(HM4.b8, HM4.b2)

Data: ratings
Models:
HM4.b2: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.b2:     (1 | Subject:Voice) + Harmony + Instrument + Voice + Selfdeclare +
HM4.b2:     OMSI
HM4.b8: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.b8:     (1 | Subject:Voice) + Harmony + Instrument + Voice + Selfdeclare +
HM4.b8:     OMSI + ClsListen
       Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM4.b2 18 10319 10424 -5141.3    10283
HM4.b8 22 10321 10449 -5138.5    10277 5.5147      4     0.2384
```

- KnowRob: p-value=0.02066, significant.

```
> HM4.b9 <- update(HM4.b2, . ~ . + KnowRob)
> anova(HM4.b9, HM4.b2)

Data: ratings
Models:
HM4.b2: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.b2:     (1 | Subject:Voice) + Harmony + Instrument + Voice + Selfdeclare +
HM4.b2:     OMSI
HM4.b9: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.b9:     (1 | Subject:Voice) + Harmony + Instrument + Voice + Selfdeclare +
HM4.b9:     OMSI + KnowRob
       Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM4.b2 18 10319 10424 -5141.3    10283
HM4.b9 20 10315 10432 -5137.4    10275 7.7595      2    0.02066 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

- KnowAxis: p-value=0.04461, significant.

```
> HM4.b10 <- update(HM4.b9, . ~ . + KnowAxis)
> anova(HM4.b10, HM4.b9)

Data: ratings
Models:
HM4.b9: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.b9:     (1 | Subject:Voice) + Harmony + Instrument + Voice + Selfdeclare +
HM4.b9:     OMSI + KnowRob
HM4.b10: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
```

```
HM4.b10:     (1 | Subject:Voice) + Harmony + Instrument + Voice + Selfdeclare +
HM4.b10:     OMSI + KnowRob + KnowAxis
        Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM4.b9  20 10315 10432 -5137.4    10275
HM4.b10 22 10313 10441 -5134.3    10269 6.2197      2    0.04461 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

- X1990s2000s: p-value=0.681, not significant.

```
> HM4.b11 <- update(HM4.b10, . ~ . + X1990s2000s)
> anova(HM4.b11, HM4.b10)

Data: ratings
Models:
HM4.b10: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.b10:     (1 | Subject:Voice) + Harmony + Instrument + Voice + Selfdeclare +
HM4.b10:     OMSI + KnowRob + KnowAxis
HM4.b11: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.b11:     (1 | Subject:Voice) + Harmony + Instrument + Voice + Selfdeclare +
HM4.b11:     OMSI + KnowRob + KnowAxis + X1990s2000s
        Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM4.b10 22 10313 10441 -5134.3    10269
HM4.b11 26 10318 10470 -5133.2    10266 2.2986      4      0.681
```

- X1990s2000s.minus.19601970s: p-value=0.02556, significant.

```
> HM4.b12 <- update(HM4.b10, . ~ . + X1990s2000s.minus.1960s1970s)
> anova(HM4.b12, HM4.b10)

Data: ratings
Models:
HM4.b10: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.b10:     (1 | Subject:Voice) + Harmony + Instrument + Voice + Selfdeclare +
HM4.b10:     OMSI + KnowRob + KnowAxis
HM4.b12: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.b12:     (1 | Subject:Voice) + Harmony + Instrument + Voice + Selfdeclare +
HM4.b12:     OMSI + KnowRob + KnowAxis + X1990s2000s.minus.1960s1970s
        Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM4.b10 22 10313 10441 -5134.3    10269
HM4.b12 30 10311 10486 -5125.6    10251 17.472      8    0.02556 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

- CollegMusic: p-value=0.5527, not significant

```
> HM4.b13 <- update(HM4.b12, . ~ . + CollegeMusic)
> anova(HM4.b13, HM4.b12)

Data: ratings
Models:
HM4.b12: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.b12:     (1 | Subject:Voice) + Harmony + Instrument + Voice + Selfdeclare +
HM4.b12:     OMSI + KnowRob + KnowAxis + X1990s2000s.minus.1960s1970s
```

```
HM4.b13: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.b13:     (1 | Subject:Voice) + Harmony + Instrument + Voice + Selfdeclare +
HM4.b13:     OMSI + KnowRob + KnowAxis + X1990s2000s.minus.1960s1970s +
HM4.b13:     CollegeMusic
        Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM4.b12 30 10311 10486 -5125.6    10251
HM4.b13 31 10313 10494 -5125.4    10251 0.3524      1     0.5527
```

- NoClass: p-value=0.5771, not significant

```
> HM4.b14 <- update(HM4.b12, .~.+NoClass)
> anova(HM4.b14, HM4.b12)

Data: ratings
Models:
HM4.b12: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.b12:     (1 | Subject:Voice) + Harmony + Instrument + Voice + Selfdeclare +
HM4.b12:     OMSI + KnowRob + KnowAxis + X1990s2000s.minus.1960s1970s
HM4.b14: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.b14:     (1 | Subject:Voice) + Harmony + Instrument + Voice + Selfdeclare +
HM4.b14:     OMSI + KnowRob + KnowAxis + X1990s2000s.minus.1960s1970s +
HM4.b14:     NoClass
        Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM4.b12 30 10311 10486 -5125.6    10251
HM4.b14 31 10313 10494 -5125.4    10251 0.3109      1     0.5771
```

- APTheory: p-value=0.9699, not significant.

```
> HM4.b15 <- update(HM4.b12, .~.+APTheory)
> anova(HM4.b15, HM4.b12)

Data: ratings
Models:
HM4.b12: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.b12:     (1 | Subject:Voice) + Harmony + Instrument + Voice + Selfdeclare +
HM4.b12:     OMSI + KnowRob + KnowAxis + X1990s2000s.minus.1960s1970s
HM4.b15: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.b15:     (1 | Subject:Voice) + Harmony + Instrument + Voice + Selfdeclare +
HM4.b15:     OMSI + KnowRob + KnowAxis + X1990s2000s.minus.1960s1970s +
HM4.b15:     APTheory
        Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM4.b12 30 10311 10486 -5125.6    10251
HM4.b15 31 10313 10494 -5125.6    10251 0.0014      1     0.9699
```

- PianoPlay: p-value=0.408, not significant

```
> HM4.b16 <- update(HM4.b12, . ~.+PianoPlay)
> anova(HM4.b16, HM4.b12)

Data: ratings
Models:
HM4.b12: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.b12:     (1 | Subject:Voice) + Harmony + Instrument + Voice + Selfdeclare +
HM4.b12:     OMSI + KnowRob + KnowAxis + X1990s2000s.minus.1960s1970s
```

```
HM4.b16: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.b16:     (1 | Subject:Voice) + Harmony + Instrument + Voice + Selfdeclare +
HM4.b16:     OMSI + KnowRob + KnowAxis + X1990s2000s.minus.1960s1970s +
HM4.b16:     PianoPlay
        Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM4.b12 30 10311 10486 -5125.6    10251
HM4.b16 34 10315 10513 -5123.6    10247 3.9855      4      0.408
```

- GuitarPlay: p-value=0.3198, not significant.

```
> HM4.b17 <- update(HM4.b12, .~.+GuitarPlay)
> anova(HM4.b17, HM4.b12)

Data: ratings
Models:
HM4.b12: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.b12:     (1 | Subject:Voice) + Harmony + Instrument + Voice + Selfdeclare +
HM4.b12:     OMSI + KnowRob + KnowAxis + X1990s2000s.minus.1960s1970s
HM4.b17: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.b17:     (1 | Subject:Voice) + Harmony + Instrument + Voice + Selfdeclare +
HM4.b17:     OMSI + KnowRob + KnowAxis + X1990s2000s.minus.1960s1970s +
HM4.b17:     GuitarPlay
        Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM4.b12 30 10311 10486 -5125.6    10251
HM4.b17 34 10314 10513 -5123.2    10246 4.6973      4     0.3198
```

So the covariates selected are:
Selfdeclare, OMSI, KnowRob, KnowAxis, X1990s2000s.minus.1960s1970s

Then we test the random effects.

- For Harmony, p-value=0, so we keep this random effect.

```
> m4.h <- lmer(Popular ~ (1 | Subject:Harmony) + Harmony + Instrument +
+                      Voice + Selfdeclare + OMSI + KnowRob + KnowAxis +
+                      X1990s2000s.minus.1960s1970s,  data = ratings)
> m4.0h <- update(HM4.b, . ~ . - (1 | Subject:Harmony))
> exactRLRT(m4.h, m0 = m4.0h, mA = HM4.b)

        simulated finite sample distribution of RLRT.

        (p-value based on 10000 simulated values)

data:
RLRT = 72.9563, p-value < 2.2e-16
```

- For Instrument, p-value=0, so we keep this random effect.

```
> m4.i <- lmer(Popular ~ (1 | Subject:Instrument) + Harmony +
+                Instrument + Voice + Selfdeclare + OMSI + KnowRob +
+                KnowAxis + X1990s2000s.minus.1960s1970s, data = ratings)
> m4.0i <- update(HM4.b, . ~ . - (1 | Subject:Instrument))
> exactRLRT(m4.i, m0 = m4.0i, mA = HM4.b)
```

```
        simulated finite sample distribution of RLRT.

        (p-value based on 10000 simulated values)

data:
RLRT = 510.5206, p-value < 2.2e-16
```

- For Voice, p-value is not significant. So we do not keep this random effect.

```
> m4.v <- lmer(Popular ~ (1 | Subject:Voice) + Harmony + Instrument +
+   Voice + Selfdeclare + OMSI + KnowRob + KnowAxis +
+   X1990s2000s.minus.1960s1970s, data = ratings)
> m4.0v <- update(HM4.b, . ~ . - (1 | Subject:Voice))
> exactRLRT(m4.v, m0 = m4.0v, mA = HM4.b)

        simulated finite sample distribution of RLRT.

        (p-value based on 10000 simulated values)

data:
RLRT = 1.3328, p-value = 0.1164
```

As a result, we exclude the random effect of Subject:Voice from the final model.

```
> HM4.b.final <- update(HM4.b, . ~ . - (1 | Subject:Voice))
```

The following are the first 15 estimated coefficients for the fixed effects. For categorical variables, the coefficients are the difference with the comparison class. For quantitative variables, the coefficients are the average change in the Popular ratings with one unit increase in the variable, keeping all the other variables the constant.

Some interpretation of these results is needed!

```
> fixef(HM4.b.final)[1:15]
```

(Intercept)	HarmonyI-V-IV	HarmonyI-V-VI	HarmonyIV-I-V
4.399735578	-0.052063492	-0.293492063	-0.194603175
Instrumentpiano	Instrumentstring	Voicepar3rd	Voicepar5th
-1.030952381	-2.557023810	0.159642857	0.167738095
Selfdeclare2	Selfdeclare3	Selfdeclare4	Selfdeclare5
0.875043662	0.903840526	-0.065846278	1.014462548
Selfdeclare6	OMSI	KnowRob1	
0.120996398	0.001272357	0.624525619	

Below is the first five random effects for Subject:Harmony, each representing the random effects in the particular group.

```
> head(ranef(HM4.b.final)$`Subject:Harmony`)
```

```
          (Intercept)
15:I-IV-V  0.02997710
15:I-V-IV  0.18196427
15:I-V-VI -0.17680637
15:IV-I-V -0.29317154
```

```
16:I-IV-V -0.00885751
16:I-V-IV -0.04157697
```

(c) To add the variable Musician, we first exclude Selfdeclare from the model because they are providing the same information. Then repeat the process in Question 3. We get the following model with all possible interactions with Musicians. The anova shows that the added interaction terms as a total are significant, and AIC,DIC all improved comparing with the model with no interactions. But BIC is not as good as the model without these terms. The reason might be that BIC has more penalty because of so many predictors.

```
> HM4.c0 <- update(HM4.b.final, . ~ . - Selfdeclare + Musicians)
```

- Harmony*Musicians: p-value=0.006, significant

```
> HM4.c1 <- update(HM4.c0, . ~ . + Musicians:Harmony)
> anova(HM4.c1, HM4.c0)

Data: ratings
Models:
HM4.c0: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.c0:     Harmony + Instrument + Voice + OMSI + KnowRob + KnowAxis +
HM4.c0:     X1990s2000s.minus.1960s1970s + Musicians
HM4.c1: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.c1:     Harmony + Instrument + Voice + OMSI + KnowRob + KnowAxis +
HM4.c1:     X1990s2000s.minus.1960s1970s + Musicians + Harmony:Musicians
       Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM4.c0 25 10313 10459 -5131.7    10263
HM4.c1 28 10307 10470 -5125.4    10251 12.444      3   0.006008 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

- Instrument*Musicians: p-value=0.4463, not significant

```
> HM4.c2 <- update(HM4.c1, . ~ . + Musicians*Instrument)
> anova(HM4.c2, HM4.c1)

Data: ratings
Models:
HM4.c1: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.c1:     Harmony + Instrument + Voice + OMSI + KnowRob + KnowAxis +
HM4.c1:     X1990s2000s.minus.1960s1970s + Musicians + Harmony:Musicians
HM4.c2: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.c2:     Harmony + Instrument + Voice + OMSI + KnowRob + KnowAxis +
HM4.c2:     X1990s2000s.minus.1960s1970s + Musicians + Harmony:Musicians +
HM4.c2:     Instrument:Musicians
       Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM4.c1 28 10307 10470 -5125.4    10251
HM4.c2 30 10309 10484 -5124.6    10249 1.6133      2     0.4463
```

- Voice*Musicians: p-value=0.625, not significant

```
> HM4.c3 <- update(HM4.c1, .~.+Musicians:Voice)
> anova(HM4.c3, HM4.c1)
```

```
Data: ratings
Models:
HM4.c1: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.c1:     Harmony + Instrument + Voice + OMSI + KnowRob + KnowAxis +
HM4.c1:     X1990s2000s.minus.1960s1970s + Musicians + Harmony:Musicians
HM4.c3: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.c3:     Harmony + Instrument + Voice + OMSI + KnowRob + KnowAxis +
HM4.c3:     X1990s2000s.minus.1960s1970s + Musicians + Harmony:Musicians +
HM4.c3:     Voice:Musicians
       Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM4.c1 28 10307 10470 -5125.4    10251
HM4.c3 30 10310 10485 -5125.0    10250 0.9401      2      0.625
```

- OMSI*Musicians: p-value=0.3476, not significant

```
> HM4.c4 <- update(HM4.c1, . ~ . + OMSI:Musicians)
> anova(HM4.c4, HM4.c1)
```

```
Data: ratings
Models:
HM4.c1: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.c1:     Harmony + Instrument + Voice + OMSI + KnowRob + KnowAxis +
HM4.c1:     X1990s2000s.minus.1960s1970s + Musicians + Harmony:Musicians
HM4.c4: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.c4:     Harmony + Instrument + Voice + OMSI + KnowRob + KnowAxis +
HM4.c4:     X1990s2000s.minus.1960s1970s + Musicians + Harmony:Musicians +
HM4.c4:     OMSI:Musicians
       Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM4.c1 28 10307 10470 -5125.4    10251
HM4.c4 29 10308 10477 -5125.0    10250 0.8822      1     0.3476
```

- KnowRob*Musicians: p-value = 0.412, not significant

```
> HM4.c5 <- update(HM4.c1, . ~ . + KnowRob:Musicians)
> anova(HM4.c5, HM4.c1)
```

```
Data: ratings
Models:
HM4.c1: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.c1:     Harmony + Instrument + Voice + OMSI + KnowRob + KnowAxis +
HM4.c1:     X1990s2000s.minus.1960s1970s + Musicians + Harmony:Musicians
HM4.c5: Popular ~ (1 | Subject:Harmony) + (1 | Subject:Instrument) +
HM4.c5:     Harmony + Instrument + Voice + OMSI + KnowRob + KnowAxis +
HM4.c5:     X1990s2000s.minus.1960s1970s + Musicians + Harmony:Musicians +
HM4.c5:     KnowRob:Musicians
       Df   AIC   BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
HM4.c1 28 10307 10470 -5125.4    10251
HM4.c5 30 10309 10484 -5124.6    10249 1.7735      2      0.412
```

- KnowAxis:Musicians: cannot be added because of rank problem
- X1990s2000s.minus.1960s1970s:Musicians*Musicians: cannot be added because of rank problem

As a result, only the interaction between Musicians and Harmony is significant, so we add this interaction in the model.

4: 18
5: 16

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5. Brief Writeup

The methods used to analyze Classical rating and Popular rating are basically the same. Before doing any analysis, we need to deal with the missing values. In fact, for most of the variables in this data set, there is a high probability that these NAs are 0. For instance, if a participant leaves a blank for the question "How much did you concentrate on the notes while listening", it is likely that s/he has no idea of it and does not pay attention to this at all. So we first impute 0 for all of the NAs.

There are several options of models for this analysis: the conventional linear model, the standard repeated measures model and the hierarchical model with other random effects. In both cases, the standard repeated measures model is better than the model without random intercept, but not as good as models with more random effects, indicating that not only are there personal biases across the participants, but also the personal biases vary with the type of instrument, type of harmony and type of voice leading. Based on this model, we add other covariates and interactions, and test the random effects, until a best model is found.

As the results for Classical rating and Popular rating differ a lot, they are discussed separately below.

The writing is good above the line!

Classical Rating

THe writing below the line gets choppy and technical, and less helpful to a non-statistician

For Classical rating, all of the three main factors (Instrument, Harmony, & Voice) are statistically significant, as is shown in Question 1c. This means that the three main effects do have an influence on the Classical rating of each participant, with the inclusion of personal biases with each type of the main factors.
Starting with this model, we add the other covariates into the model one by one, and test whether they are significant. The process is shown in Question 2a. Covariates selected are:
X16.minus.17, X1990s2000s.minus.1960s1970s, GuitarPlay.
After the fixed effects are settled, once again we go back to check the random effects to see whether there should be any change in them. The likelihood ratio test shows that among the three random effects, the variance of Subject:Voice is not significantly different from 0, so we drop this random effect from the model. Based on this model, the interaction of the dichotomized musician variable and Harmony,X16.minus.17 are added into the model in Question 3. This improves the model in terms of p-value and AIC, DIC. But BIC is slightly larger than the previous model.

Popular Rating

For popular rating, in a hierarchical model with more than one random effects, among the three main factors, only Instrument is highly significant, while Voice is marginally significant with p-value=0.08, and Harmony is not significant. Additionally, from the answer of Question 4a, the significance of the three main effects vary in the three models. However,because they are design variables in the experiment, the three experimental factors are included in all models anyway. We still do the following analysis based on the hierarchical model with three random effects and fixed

effects of the three main factors.
The covariates significant for Popular rating are:
Selfdeclare, OMSI, KnowRob, KnowAxis, X1990s2000s.minus.1960s1970s.
After including the variable Musician, we drop Selfdeclare, and test all the possible interaction with Musician in the model. It turns out that only the interaction with Harmony is significant. Similar with Classical rating, AIC and DIC decrease while BIC is worse without the interactions.
The likelihood ratio test of random effects shows that in the case of Popular rating, the hypothesis that variance components of the random effect of Subject:Voice is 0 cannot be rejected. So in the final model, we only have two random effects.