

Modelling three multilevel models with lme4 package in R

NHZ

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Introduction

Lets fit some models with

1. Outcome: Clinical decision-making
2. Level 1 (Individual-level factors): Age, Gender, Education, Experience, post basic (PB), continous professional development (CPD), knowledge (NKS) and critical thinking (CTS)
3. Level 2 (Hospital-level factors): Unit, Department size, hospital settings and hospital size
4. Level 3 (Regional-level factors): State, state size

Install packages

```
install.packages("lme4")
```

```
install.packages("lmerTest")
```

```
install.packages("performance")
```

```
install.packages("reghelper")
```

Load the library

```
library(lme4) #multilevel analysis
```

Loading required package: Matrix

```
library(lmerTest) # to get p-value estimations
```

Attaching package: 'lmerTest'

The following object is masked from 'package:lme4':

```
lmer
```

The following object is masked from 'package:stats':

step

```
library(performance) # to get ICC  
library(reghelper) # to plot the interaction
```

Attaching package: 'reghelper'

The following object is masked from 'package:base':

beta

Import the data

```
library(readxl)  
CTCDMR <- read_excel("CTCDMR.xlsx", sheet = "sheet1")
```

Combine hospital and department ID within each region to create a unique identifier for **hosp.dep**

```
CTCDMR$hosp.dep <- paste(CTCDMR$Hospital, CTCDMR$DepartmentID, sep = "_")
```

Select Data

```
library(dplyr)
```

Attaching package: 'dplyr'

The following objects are masked from 'package:stats':

filter, lag

The following objects are masked from 'package:base':

intersect, setdiff, setequal, union

```
CTCDMR <- select(CTCDMR, NurseID, hosp.dep, DepartmentID, Hospital, Age, Gender, Education, I
head(CTCDMR, n=50)
```

A tibble: 50 x 20

	NurseID <dbl>	hosp.dep <chr>	DepartmentID <dbl>	Hospital <chr>	Age <dbl>	Gender <chr>	Education <chr>	Experience <dbl>
1	1	Hosp Segamat~	1	Hosp Se~	31	Female	Diploma	10
2	2	Hosp Segamat~	1	Hosp Se~	31	Female	Diploma	8
3	3	Hosp Segamat~	1	Hosp Se~	33	Female	Diploma	8
4	4	Hosp Segamat~	1	Hosp Se~	32	Female	Diploma	9
5	5	Hosp Segamat~	1	Hosp Se~	35	Female	Diploma	13
6	6	Hosp Segamat~	1	Hosp Se~	36	Female	Diploma	13
7	7	Hosp Segamat~	1	Hosp Se~	25	Female	Diploma	4
8	8	Hosp Segamat~	1	Hosp Se~	30	Female	Diploma	9
9	9	Hosp Segamat~	1	Hosp Se~	31	Female	Diploma	10
10	10	Hosp Segamat~	1	Hosp Se~	37	Female	Diploma	14

i 40 more rows

i 12 more variables: PB <chr>, CPD <dbl>, HospitalSet <chr>,

HospitalSize <dbl>, DepSize <dbl>, Unit <chr>, State <chr>, Region <chr>,

StateSize <dbl>, CDMS <dbl>, CTS <dbl>, NKS <dbl>

Two-level Multilevel analysis

Null model

What is the average score of the CDM for the entire group as well as for each individual?

```
library(lme4)
m0 <- lmer(CDMS ~ 1 + (1 | hosp.dep), data = CTCDMR, REML = FALSE)
summary(m0)
```

Linear mixed model fit by maximum likelihood . t-tests use Satterthwaite's
method [lmerModLmerTest]

Formula: CDMS ~ 1 + (1 | hosp.dep)

Data: CTCDMR

```

      AIC      BIC   logLik deviance df.resid
4752.1   4765.9  -2373.1   4746.1     716

Scaled residuals:
    Min       1Q   Median       3Q      Max
-2.6003 -0.7153  0.0565  0.7715  2.8980

Random effects:
 Groups   Name      Variance Std.Dev.
 hosp.dep (Intercept) 14.52    3.811
 Residual                38.71    6.221
Number of obs: 719, groups: hosp.dep, 36

Fixed effects:
              Estimate Std. Error      df t value Pr(>|t|)
(Intercept)  36.2638     0.6762  35.9611   53.63   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

```

The intra-class correlation (ICC):

```

library(performance)
performance::icc(m0)

```

Intraclass Correlation Coefficient

```

Adjusted ICC: 0.273
Unadjusted ICC: 0.273

```

Random intercept model

Add level 1 and 2 variables:

Do the CDMS is predicted by the nurse's individual-level and hospital-level variables?

```

ri <- lmer(CDMS ~ NKS + Age + Gender + Education + Experience + PB + CPD + CTS + Unit + DepS
summary(ri)

```

Linear mixed model fit by maximum likelihood . t-tests use Satterthwaite's
method [lmerModLmerTest]
Formula: CDMS ~ NKS + Age + Gender + Education + Experience + PB + CPD +

CTS + Unit + DepSize + HospitalSet + HospitalSize + (1 | hosp.dep)
 Data: CTCDMR

AIC	BIC	logLik	deviance	df.resid
3905.3	3978.5	-1936.6	3873.3	703

Scaled residuals:

Min	1Q	Median	3Q	Max
-3.523	-0.550	0.053	0.643	2.922

Random effects:

Groups	Name	Variance	Std.Dev.
hosp.dep	(Intercept)	0.1986	0.4456
	Residual	12.6223	3.5528

Number of obs: 719, groups: hosp.dep, 36

Fixed effects:

	Estimate	Std. Error	df	t value	Pr(> t)
(Intercept)	2.257e+00	2.221e+00	7.121e+02	1.016	0.3099
NKS	1.117e-01	9.831e-03	7.161e+02	11.364	<2e-16 ***
Age	-2.902e-02	7.965e-02	7.159e+02	-0.364	0.7157
GenderMale	2.337e-02	7.909e-01	7.179e+02	0.030	0.9764
EducationDiploma	-1.578e-01	6.274e-01	7.188e+02	-0.252	0.8015
EducationMaster	3.576e+00	2.626e+00	7.118e+02	1.362	0.1738
Experience	6.053e-02	8.160e-02	7.162e+02	0.742	0.4585
PBYES	4.119e-01	3.111e-01	7.102e+02	1.324	0.1859
CPD	1.690e-02	2.416e-02	4.105e+02	0.699	0.4848
CTS	5.660e-01	3.215e-02	7.161e+02	17.606	<2e-16 ***
UnitMedical	-4.530e-01	3.188e-01	3.781e+01	-1.421	0.1635
DepSize	1.348e-02	1.652e-02	4.749e+01	0.816	0.4184
HospitalSetGeneral	-1.589e+00	7.179e-01	3.669e+01	-2.214	0.0332 *
HospitalSize	-4.175e-04	5.965e-04	4.060e+01	-0.700	0.4880

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation matrix not shown by default, as p = 14 > 12.

Use print(x, correlation=TRUE) or
 vcov(x) if you need it

Random Slopes model

Do the CDMS is predicted by the variables at both individual-level and hospital level?

- Do the combined effect of nurse's knowledge and experience vary across different hospital department?
 - Outcome: Clinical decision-making
 - Fixed: **Knowledge, experience** and hospital settings
 - Random: **Knowledge and experience**
- Different scale?
 - So we gonna use grand mean centering: NKS -> NKS.GM

```
CTCDMR$NKS.GM <- scale(CTCDMR$NKS, scale = F)
CTCDMR$CTS.GM <- scale(CTCDMR$CTS, scale = F)
```

```
rs <- lmer(CDMS ~ NKS.GM + Experience + factor(HospitalSet) +
(1 + NKS.GM + Experience | hosp.dep),
data = CTCDMR, REML = FALSE, lmerControl(optimizer = 'bobyqa'))
summary(rs)
```

Linear mixed model fit by maximum likelihood . t-tests use Satterthwaite's method [lmerModLmerTest]

Formula: CDMS ~ NKS.GM + Experience + factor(HospitalSet) + (1 + NKS.GM + Experience | hosp.dep)

Data: CTCDMR

Control: lmerControl(optimizer = "bobyqa")

AIC	BIC	logLik	deviance	df.resid
4106.9	4157.2	-2042.4	4084.9	708

Scaled residuals:

Min	1Q	Median	3Q	Max
-3.1879	-0.6149	0.0070	0.6467	3.0585

Random effects:

Groups	Name	Variance	Std.Dev.	Corr
hosp.dep	(Intercept)	1.093e+01	3.30591	
	NKS.GM	3.031e-04	0.01741	0.57
	Experience	6.959e-02	0.26380	-0.99 -0.55
Residual		1.565e+01	3.95652	

Number of obs: 719, groups: hosp.dep, 36

Fixed effects:

	Estimate	Std. Error	df	t value	Pr(> t)	
(Intercept)	34.364635	0.730043	29.216304	47.072	< 2e-16	***
NKS.GM	0.197242	0.008952	31.100975	22.034	< 2e-16	***
Experience	0.194085	0.051109	28.750185	3.797	0.000699	***
factor(HospitalSet)General	-1.266490	0.454201	38.192612	-2.788	0.008213	**

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:

	(Intr)	NKS.GM	Exprnc
NKS.GM	0.528		
Experience	-0.919	-0.378	
fctr(HspS)G	-0.429	-0.602	0.136

Three-level Multilevel analysis

(1 | Region/hosp.dep)

or

(1 | Region) + (1 | Region:DepartmentID)

Both will give the **same** results, but there are some analysis that need to use the longer code

Null model

Short version

```
L3.M0a <- lmer(CDMS ~ 1
+ (1 | Region/hosp.dep), data = CTCDMR)
summary(L3.M0a)
```

Linear mixed model fit by REML. t-tests use Satterthwaite's method [
lmerModLmerTest]

Formula: CDMS ~ 1 + (1 | Region/hosp.dep)
Data: CTCDMR

REML criterion at convergence: 4744.4

Scaled residuals:

Min	1Q	Median	3Q	Max
-2.5720	-0.7162	0.0362	0.7438	2.9257

Random effects:

Groups	Name	Variance	Std.Dev.
hosp.dep:Region	(Intercept)	12.436	3.527
Region	(Intercept)	3.814	1.953
Residual		38.718	6.222

Number of obs: 719, groups: hosp.dep:Region, 37; Region, 6

Fixed effects:

	Estimate	Std. Error	df	t value	Pr(> t)
(Intercept)	36.076	1.031	4.200	35.01	2.43e-06 ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Longer version

```
L3.M0b <- lmer(CDMS ~ 1
+ (1|Region)
+ (1|Region: DepartmentID), data = CTCDMR)
summary(L3.M0b)
```

Linear mixed model fit by REML. t-tests use Satterthwaite's method [
lmerModLmerTest]

Formula: CDMS ~ 1 + (1 | Region) + (1 | Region:DepartmentID)

Data: CTCDMR

REML criterion at convergence: 4744.4

Scaled residuals:

Min	1Q	Median	3Q	Max
-2.5720	-0.7162	0.0362	0.7438	2.9257

Random effects:

Groups	Name	Variance	Std.Dev.
Region:DepartmentID	(Intercept)	12.436	3.527
Region	(Intercept)	3.814	1.953
Residual		38.718	6.222

Number of obs: 719, groups: Region:DepartmentID, 37; Region, 6

Fixed effects:

	Estimate	Std. Error	df	t value	Pr(> t)
(Intercept)	36.076	1.031	4.200	35.01	2.43e-06 ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Random intercept model

Do the CDMS is predicted by the nurse's individual and hospital department variables?

```
L3.ri <- lmer(CDMS ~ CTS + NKS + HospitalSize + (1|Region)
+ (1|Region: DepartmentID), data = CTCDMR, REML = FALSE)
summary(L3.ri)
```

Linear mixed model fit by maximum likelihood . t-tests use Satterthwaite's method [lmerModLmerTest]

Formula:

CDMS ~ CTS + NKS + HospitalSize + (1 | Region) + (1 | Region:DepartmentID)

Data: CTCDMR

	AIC	BIC	logLik	deviance	df.resid
	3906.6	3938.6	-1946.3	3892.6	712

Scaled residuals:

	Min	1Q	Median	3Q	Max
	-3.5960	-0.5589	0.0381	0.6226	2.6628

Random effects:

Groups	Name	Variance	Std.Dev.
Region:DepartmentID	(Intercept)	0.27588	0.5252
Region	(Intercept)	0.06633	0.2575
Residual		12.87336	3.5879

Number of obs: 719, groups: Region:DepartmentID, 37; Region, 6

Fixed effects:

	Estimate	Std. Error	df	t value	Pr(> t)
(Intercept)	1.847e+00	8.332e-01	3.356e+02	2.217	0.0273 *
CTS	5.957e-01	3.131e-02	7.092e+02	19.024	<2e-16 ***
NKS	1.075e-01	8.622e-03	4.433e+02	12.469	<2e-16 ***
HospitalSize	-9.103e-04	3.323e-04	4.838e+01	-2.739	0.0086 **

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:

	(Intr) CTS	NKS
CTS	-0.640	
NKS	-0.031	-0.712
HospitalSiz	0.044	0.111
		-0.404

Random Slope model

Do the CDMS is predicted by the variables at both individual-level, hospital level, and regional level? - Do the **CTS effect vary across different region?**

```
L3.RS <-lmer(CDMS ~ CTS.GM + Experience + Unit + HospitalSet
+ (1+ CTS.GM|Region)
+ (1|Region: DepartmentID),
data=CTCDMR, REML=FALSE,lmerControl(optimizer = 'bobyqa'))
summary(L3.RS)
```

Linear mixed model fit by maximum likelihood . t-tests use Satterthwaite's method [lmerModLmerTest]

Formula: CDMS ~ CTS.GM + Experience + Unit + HospitalSet + (1 + CTS.GM | Region) + (1 | Region:DepartmentID)

Data: CTCDMR

Control: lmerControl(optimizer = "bobyqa")

AIC	BIC	logLik	deviance	df.resid
4018.9	4064.6	-1999.4	3998.9	709

Scaled residuals:

Min	1Q	Median	3Q	Max
-3.3170	-0.6134	-0.0153	0.6388	2.8700

Random effects:

Groups	Name	Variance	Std.Dev.	Corr
Region:DepartmentID	(Intercept)	0.161755	0.40219	
Region	(Intercept)	0.716231	0.84630	
	CTS.GM	0.006558	0.08098	-0.01
Residual		14.734358	3.83854	

Number of obs: 719, groups: Region:DepartmentID, 37; Region, 6

Fixed effects:

	Estimate	Std. Error	df	t value	Pr(> t)
(Intercept)	34.07860	0.56786	25.76862	60.012	< 2e-16 ***
CTS.GM	0.82348	0.04292	7.81381	19.188	7.46e-08 ***
Experience	0.10075	0.02371	487.04291	4.250	2.56e-05 ***
UnitMedical	-0.04234	0.32014	27.42463	-0.132	0.895744
HospitalSetGeneral	1.35417	0.34664	36.16166	3.907	0.000394 ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:

	(Intr)	CTS.GM	Exprnc	UntMdc
CTS.GM	0.212			
Experience	-0.611	-0.268		
UnitMedical	-0.361	-0.014	0.143	
HsptlStGnrl	-0.356	-0.226	0.100	-0.004

Interactions and Cross-Level Interactions

Cross-level interaction: Experience (level 1) and hospitalSet (level 2)

Interactions: NKS and experience, CTS and NKS, CTS and Experience

```
L3.int <- lmer (CDMS ~ NKS.GM * Experience + CTS.GM * NKS.GM + CTS.GM * Experience + Experience * HospitalSet + (1|Region: DepartmentID), data = CTCDMR, REML = FALSE)
summary(L3.int)
```

Linear mixed model fit by maximum likelihood . t-tests use Satterthwaite's method [lmerModLmerTest]

Formula: CDMS ~ NKS.GM * Experience + CTS.GM * NKS.GM + CTS.GM * Experience + Experience * HospitalSet + (1 | Region) + (1 | Region:DepartmentID)

Data: CTCDMR

AIC	BIC	logLik	deviance	df.resid
3858.7	3913.7	-1917.4	3834.7	707

Scaled residuals:

Min	1Q	Median	3Q	Max
-3.7588	-0.5765	0.0370	0.6624	2.7531

Random effects:

Groups	Name	Variance	Std.Dev.
Region:DepartmentID	(Intercept)	0.34686	0.5889
Region	(Intercept)	0.05199	0.2280
Residual		11.82346	3.4385

Number of obs: 719, groups: Region:DepartmentID, 37; Region, 6

Fixed effects:

	Estimate	Std. Error	df	t value	Pr(> t)
(Intercept)	3.371e+01	5.668e-01	1.407e+02	59.464	< 2e-16
NKS.GM	8.787e-02	1.792e-02	6.863e+02	4.903	1.18e-06
Experience	2.408e-01	3.557e-02	4.891e+02	6.771	3.69e-11
CTS.GM	7.858e-01	6.637e-02	7.146e+02	11.839	< 2e-16
HospitalSetGeneral	1.939e+00	7.337e-01	2.421e+02	2.643	0.00876
NKS.GM:Experience	1.701e-03	1.246e-03	7.141e+02	1.365	0.17257
NKS.GM:CTS.GM	2.589e-03	9.005e-04	6.880e+02	2.875	0.00416
Experience:CTS.GM	-1.942e-02	4.393e-03	7.142e+02	-4.420	1.14e-05
Experience:HospitalSetGeneral	-2.473e-01	4.937e-02	6.301e+02	-5.010	7.08e-07

(Intercept)	***
NKS.GM	***
Experience	***
CTS.GM	***
HospitalSetGeneral	**
NKS.GM:Experience	
NKS.GM:CTS.GM	**
Experience:CTS.GM	***
Experience:HospitalSetGeneral	***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:

	(Intr)	NKS.GM	Exprnc	CTS.GM	HsptSG	NKS.GM:E	NKS.GM:C	E:CTS.
NKS.GM		0.227						
Experience	-0.865	-0.244						
CTS.GM	-0.137	-0.618	0.181					
HsptlStGnrl	-0.717	-0.446	0.657	0.104				
NKS.GM:Expr	-0.144	-0.851	0.251	0.464	0.404			
NKS.GM:CTS.	-0.310	0.319	0.251	0.278	-0.081	-0.340		
Expr:CTS.GM	0.242	0.515	-0.351	-0.870	-0.169	-0.500	-0.269	
Exprnc:HsSG	0.576	0.418	-0.714	-0.135	-0.832	-0.555	0.047	0.236

Plot interaction

```
graph_model(  
  model = L3.int,  
  y = CDMS,  
  x = Experience,  
  lines = HospitalSet,  
  errorbars = "none")
```

