

# Hierarchical bayesian data analysis of Persian data

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July 29, 2013

## 1 Standard analysis as in the paper

```
> ## make results exactly replicable
> set.seed(987654321)
```

subj	expt	item	condition
Min. : 1.0	Length:2556	Min. : 1.0	Length:2556
1st Qu.: 28.0	Class :character	1st Qu.: 7.0	Class :character
Median : 55.0	Mode :character	Median :13.0	Mode :character
Mean : 55.4		Mean :12.6	
3rd Qu.: 83.0		3rd Qu.:19.0	
Max. :110.0		Max. :24.0	

pos	word	response	rt
Length:2556	Length:2556	Min. :0.000	Min. : 735
Class :character	Class :character	1st Qu.:1.000	1st Qu.: 3362
Mode :character	Mode :character	Median :1.000	Median : 4572
		Mean :0.851	Mean : 6276
		3rd Qu.:1.000	3rd Qu.: 6619
		Max. :1.000	Max. :162748

```
a b c d
88 87 82 84
```

```
a b c d
-0.23098 -0.23059 -0.21813 -0.21938
```

Generalized linear mixed model fit by the Laplace approximation

Formula: response ~ pron + rc + inter + (1 | subj) + (1 | item)

Data: questions

AIC BIC logLik deviance

1990 2025 -989 1978

Random effects:

Groups Name Variance Std.Dev.

subj (Intercept) 0.316 0.563

```

item (Intercept) 0.522 0.723
Number of obs: 2533, groups: subj, 109; item, 24

```

Fixed effects:

	Estimate	Std. Error	z value	Pr(> z )
(Intercept)	2.04818	0.16995	12.05	<2e-16 ***
pron	-0.00571	0.11875	-0.05	0.9616
rc	-0.40322	0.11894	-3.39	0.0007 ***
inter	0.12260	0.11910	1.03	0.3033

---

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

Correlation of Fixed Effects:

	(Intr)	pron	rc
pron	0.006		
rc	-0.036	0.069	
inter	0.024	-0.086	0.022

Linear mixed model fit by REML

Formula: -1000/rt ~ pron + rc + inter + (1 | subj) + (1 | item)

Data: subset(questions, rt > 738)

	AIC	BIC	logLik	deviance	REMLdev
	-5082	-5041	2548	-5133	-5096

Random effects:

Groups	Name	Variance	Std.Dev.
subj	(Intercept)	0.00232	0.0482
item	(Intercept)	0.00103	0.0321
Residual		0.00685	0.0828

Number of obs: 2532, groups: subj, 109; item, 24

Fixed effects:

	Estimate	Std. Error	t value
(Intercept)	-0.224640	0.008185	-27.44
pron	-0.000397	0.003306	-0.12
rc	0.012652	0.003308	3.83
inter	-0.001100	0.003308	-0.33

Correlation of Fixed Effects:

	(Intr)	pron	rc
pron	0.005		
rc	0.007	0.028	
inter	0.006	0.031	0.028

[1] 96 4

[1] 96 4

[1] TRUE

[1] TRUE

[1] TRUE

[1] 110

Linear mixed model fit by REML

Formula:  $-1000/rt \sim \text{pron} + \text{rc} + \text{inter} + (1 | \text{subj}) + (1 | \text{item})$

Data: subset(data.final, region == "crit" & rt > 250)

AIC	BIC	logLik	deviance	REMLdev
4590	4631	-2288	4555	4576

Random effects:

Groups	Name	Variance	Std.Dev.
subj	(Intercept)	0.1633	0.404
item	(Intercept)	0.0848	0.291
Residual		0.2946	0.543

Number of obs: 2592, groups: subj, 110; item, 24

Fixed effects:

	Estimate	Std. Error	t value
(Intercept)	-1.5255	0.0717	-21.29
pron	-0.0467	0.0213	-2.19
rc	-0.0282	0.0213	-1.32
inter	-0.0239	0.0213	-1.12

Correlation of Fixed Effects:

	(Intr)	pron	rc
pron	-0.001		
rc	0.001	0.000	
inter	0.000	0.002	-0.003

Linear mixed model fit by REML

Formula:  $rt \sim \text{pron} + \text{rc} + \text{inter} + (1 | \text{subj}) + (1 | \text{item})$

Data: subset(data.final, region == "crit" & rt > 250)

AIC	BIC	logLik	deviance	REMLdev
41570	41611	-20778	41592	41556

Random effects:

Groups	Name	Variance	Std.Dev.
subj	(Intercept)	132200	364
item	(Intercept)	57815	240
Residual		489800	700

Number of obs: 2592, groups: subj, 110; item, 24

Fixed effects:

	Estimate	Std. Error	t value
--	----------	------------	---------

(Intercept)	917.0	61.6	14.87
pron	-8.3	27.5	-0.30
rc	-37.4	27.5	-1.36
inter	13.6	27.5	0.49

Correlation of Fixed Effects:

	(Intr)	pron	rc
pron	-0.001		
rc	0.001	0.000	
inter	0.000	0.002	-0.003

Linear mixed model fit by REML

Formula:  $\log(\text{rt}) \sim \text{pron} + \text{rc} + \text{inter} + (1 \mid \text{subj}) + (1 \mid \text{item})$

Data: subset(data.final, region == "crit" & rt > 250)

AIC	BIC	logLik	deviance	REMLdev
-----	-----	--------	----------	---------

3351	3392	-1668	3314	3337
------	------	-------	------	------

Random effects:

Groups	Name	Variance	Std.Dev.
subj	(Intercept)	0.0908	0.301
item	(Intercept)	0.0526	0.229
Residual		0.1833	0.428

Number of obs: 2592, groups: subj, 110; item, 24

Fixed effects:

	Estimate	Std. Error	t value
(Intercept)	6.62423	0.05559	119.2
pron	-0.02568	0.01683	-1.5
rc	-0.02547	0.01683	-1.5
inter	-0.00777	0.01683	-0.5

Correlation of Fixed Effects:

	(Intr)	pron	rc
pron	-0.001		
rc	0.001	0.000	
inter	0.000	0.002	-0.003

Linear mixed model fit by REML

Formula:  $-1000/\text{rt} \sim \text{c1} + \text{c2} + \text{c3} + (1 \mid \text{subj}) + (1 \mid \text{item})$

Data: subset(data.final, region == "crit" & rt > 250)

AIC	BIC	logLik	deviance	REMLdev
-----	-----	--------	----------	---------

4588	4629	-2287	4555	4574
------	------	-------	------	------

Random effects:

Groups	Name	Variance	Std.Dev.
subj	(Intercept)	0.1633	0.404
item	(Intercept)	0.0848	0.291
Residual		0.2946	0.543

Number of obs: 2592, groups: subj, 110; item, 24

Fixed effects:

	Estimate	Std. Error	t value
(Intercept)	-1.5255	0.0717	-21.29
c1	-0.0228	0.0301	-0.76
c2	-0.0707	0.0302	-2.34
c3	-0.0282	0.0213	-1.32

Correlation of Fixed Effects:

	(Intr)	c1	c2
c1	-0.001		
c2	-0.001	0.000	
c3	0.001	0.002	-0.002

	gap	pron
1	1865	3461
2	3064	638
3	4434	945
4	766	1308
5	586	850
6	1209	942
7	2505	1298
8	1459	2324
9	902	1054
10	701	961
11	1253	1715
12	1170	2586
13	1128	1211
14	786	570
15	759	823
16	1076	2239
17	4006	2015
18	1431	2625
19	1507	865
20	603	843
21	837	606
22	1401	703
23	2809	2501
24	1744	1055
25	1772	2535
26	934	1866
27	939	682
28	1593	1595
29	1105	803
30	2876	1947

31	1764	1567
32	818	1625
33	839	629
34	1233	1958
35	2192	1592
36	808	887
37	1188	1119
38	3216	924
39	1311	1179
40	889	1539
41	1470	1357
42	2737	1384
43	1238	688
44	2131	1656
45	4107	1716
46	722	1313
47	1069	79550
48	778	598
49	7066	28560
50	703	1014
51	975	1158
52	3336	2112
53	7483	3534
54	3196	2464
55	1409	1970
56	829	796
57	775	1064
58	705	1171
59	1019	421
60	NA	1134
61	692	1281
62	1284	812
63	796	795
64	814	879
65	771	657
66	1507	1639
67	921	993
68	3207	3629
69	1540	663
70	1453	1817
71	1035	703
72	1300	1822
73	847	989
74	979	868
75	4061	3666
76	902	765

77	2985	3158
78	866	790
79	674	1047
80	591	781
81	1935	5747
82	1471	1409
83	2604	1835
84	1478	1418
85	1032	1095
86	610	732
87	932	599
88	776	736
89	1513	1852
90	1056	942
91	765	482
92	701	1326
93	1447	946
94	4598	480
95	1007	820
96	814	1332
97	5042	720
98	2828	1640
99	1152	608
100	943	1138
101	1658	3064
102	1121	867
103	1228	900
104	880	710
105	811	2647
106	900	1028
107	941	826
108	2621	1980
109	1524	564
110	2586	3713

Linear mixed model fit by REML

Formula:  $-1000/rt \sim \text{pron} + \text{rc} + \text{inter} + (1 | \text{subj}) + (1 | \text{item})$

Data: subset(data.final, region == "post.crit")

	AIC	BIC	logLik	deviance	REMLdev
	4459	4500	-2222	4423	4445

Random effects:

Groups	Name	Variance	Std.Dev.
subj	(Intercept)	0.1752	0.419
item	(Intercept)	0.0283	0.168
Residual		0.2779	0.527

Number of obs: 2610, groups: subj, 110; item, 24

Fixed effects:

	Estimate	Std. Error	t value
(Intercept)	-1.79136	0.05365	-33.4
pron	-0.06328	0.02066	-3.1
rc	0.00537	0.02065	0.3
inter	-0.01234	0.02065	-0.6

Correlation of Fixed Effects:

	(Intr)	pron	rc
pron	-0.001		
rc	0.001	-0.001	
inter	0.000	0.001	-0.002

Linear mixed model fit by REML

Formula:  $-1000/rt \sim \text{pron} + \text{rc} + \text{inter} + (1 | \text{subj}) + (1 | \text{item})$

Data: subset(data.final, region == "post.crit" & rt > 250)

AIC	BIC	logLik	deviance	REMLdev
4306	4347	-2146	4270	4292

Random effects:

Groups	Name	Variance	Std.Dev.
subj	(Intercept)	0.1635	0.404
item	(Intercept)	0.0269	0.164
Residual		0.2639	0.514

Number of obs: 2600, groups: subj, 110; item, 24

Fixed effects:

	Estimate	Std. Error	t value
(Intercept)	-1.78394	0.05207	-34.3
pron	-0.06725	0.02017	-3.3
rc	0.00783	0.02016	0.4
inter	-0.00771	0.02016	-0.4

Correlation of Fixed Effects:

	(Intr)	pron	rc
pron	-0.001		
rc	0.001	0.001	
inter	0.000	0.001	-0.003

Linear mixed model fit by REML

Formula:  $-1000/rt \sim \text{pron} + \text{rc} + \text{inter} + (1 + \text{pron} + \text{rc} + \text{inter} | \text{subj}) + (1 + \text{pron} + \text{rc} | \text{item})$

Data: subset(data.final, region == "post.crit" & rt > 250)

AIC	BIC	logLik	deviance	REMLdev
4336	4483	-2143	4264	4286

Random effects:

Groups	Name	Variance	Std.Dev.	Corr
--------	------	----------	----------	------



```

subj      (Intercept) 1.64e-01 0.404490
          pron        6.89e-04 0.026247 1.000
          rc          1.18e-02 0.108597 0.043 0.043
          inter       1.22e-03 0.034998 0.166 0.166 -0.978
item      (Intercept) 2.72e-02 0.164802
          pron        2.09e-04 0.014443 1.000
          rc          5.88e-07 0.000767 1.000 1.000
          inter       8.51e-05 0.009225 -1.000 -1.000 -1.000
Residual                2.60e-01 0.510144
Number of obs: 2600, groups: subj, 110; item, 24

```

Fixed effects:

	Estimate	Std. Error	t value
(Intercept)	-1.78399	0.05216	-34.2
pron	-0.06708	0.02039	-3.3
rc	0.00770	0.02256	0.3
inter	-0.00773	0.02039	-0.4

Correlation of Fixed Effects:

	(Intr)	pron	rc
pron	0.183		
rc	0.020	0.004	
inter	-0.039	-0.009	-0.077

Linear mixed model fit by REML

Formula: log(rt) ~ pron + rc + inter + (1 | subj) + (1 | item)

Data: subset(data.final, region == "post.crit" & rt > 250)

AIC	BIC	logLik	deviance	REMLdev
2843	2885	-1415	2805	2829

Random effects:

Groups	Name	Variance	Std.Dev.
subj	(Intercept)	0.0710	0.267
item	(Intercept)	0.0127	0.112
Residual		0.1521	0.390

Number of obs: 2600, groups: subj, 110; item, 24

Fixed effects:

	Estimate	Std. Error	t value
(Intercept)	6.42259	0.03511	182.9
pron	-0.04015	0.01531	-2.6
rc	0.00153	0.01530	0.1
inter	-0.00919	0.01531	-0.6

Correlation of Fixed Effects:

	(Intr)	pron	rc
pron	-0.002		

```
rc      0.001  0.001
inter   0.000  0.001 -0.003
```

Linear mixed model fit by REML

Formula:  $rt \sim \text{pron} + \text{rc} + \text{inter} + (1 \mid \text{subj}) + (1 \mid \text{item})$

Data: subset(data.final, region == "post.crit" & rt > 250 & rt < 79000)

AIC BIC logLik deviance REMLdev

41645 41686 -20815 41665 41631

Random effects:

Groups	Name	Variance	Std.Dev.
subj	(Intercept)	71227	267
item	(Intercept)	9805	99
Residual		500066	707

Number of obs: 2599, groups: subj, 110; item, 24

Fixed effects:

	Estimate	Std. Error	t value
(Intercept)	716.01	35.37	20.24
pron	-26.65	27.76	-0.96
rc	23.28	27.75	0.84
inter	4.38	27.76	0.16

Correlation of Fixed Effects:

	(Intr)	pron	rc
pron	-0.002		
rc	0.001	0.000	
inter	0.000	0.001	-0.002

Linear mixed model fit by REML

Formula:  $-1000/rt \sim c1 + c2 + c3 + (1 \mid \text{subj}) + (1 \mid \text{item})$

Data: subset(data.final, region == "post.crit" & rt > 250)

AIC BIC logLik deviance REMLdev

4305 4346 -2145 4270 4291

Random effects:

Groups	Name	Variance	Std.Dev.
subj	(Intercept)	0.1635	0.404
item	(Intercept)	0.0269	0.164
Residual		0.2639	0.514

Number of obs: 2600, groups: subj, 110; item, 24

Fixed effects:

	Estimate	Std. Error	t value
(Intercept)	-1.78394	0.05207	-34.3
c1	-0.05954	0.02850	-2.1
c2	-0.07496	0.02853	-2.6
c3	0.00783	0.02016	0.4

Correlation of Fixed Effects:

```
(Intr) c1      c2
c1 -0.001
c2 -0.001  0.000
c3  0.001  0.002 -0.001
```

[1] -1.6663

	rel.cl	pronoun	region	M	SE	N
1	no.rel.cl	gap	crit	-1.5182	0.025651	109
2	no.rel.cl	gap	post.crit	-1.7663	0.021373	109
3	no.rel.cl	pron	crit	-1.5326	0.022759	110
4	no.rel.cl	pron	post.crit	-1.8236	0.020377	110
5	rel.cl	gap	crit	-1.5336	0.024152	109
6	rel.cl	gap	post.crit	-1.7473	0.026397	109
7	rel.cl	pron	crit	-1.5836	0.020483	110
8	rel.cl	pron	post.crit	-1.8247	0.020154	110

% latex table generated in R 2.15.1 by xtable 1.7-0 package

% Mon Jul 29 15:45:45 2013

\begin{table}[ht]

\begin{center}

\begin{tabular}{rllllrrr}

\hline

& rel.cl & pronoun & region & M & SE & N \\\

\hline

1 & no.rel.cl & gap & crit & -1.52 & 0.03 & 109.00 \\\

3 & no.rel.cl & pron & crit & -1.53 & 0.02 & 110.00 \\\

5 & rel.cl & gap & crit & -1.53 & 0.02 & 109.00 \\\

7 & rel.cl & pron & crit & -1.58 & 0.02 & 110.00 \\\

\hline

\end{tabular}

\end{center}

\end{table}

% latex table generated in R 2.15.1 by xtable 1.7-0 package

% Mon Jul 29 15:45:45 2013

\begin{table}[ht]

\begin{center}

\begin{tabular}{rllllrrr}

\hline

& rel.cl & pronoun & region & M & SE & N \\\

\hline

2 & no.rel.cl & gap & post.crit & -1.77 & 0.02 & 109.00 \\\

4 & no.rel.cl & pron & post.crit & -1.82 & 0.02 & 110.00 \\\

6 & rel.cl & gap & post.crit & -1.75 & 0.03 & 109.00 \\\

```

      8 & rel.cl & pron & post.crit & -1.82 & 0.02 & 110.00 \\
    \hline
\end{tabular}
\end{center}
\end{table}

```

## 2 What we have from the above code

We have the data, and the lmer output:

```

> head(data.final)

  item condition pos subj  expt   rt pron  rc inter region c1 c2  c3 pronoun
1  14          b  12   93 Farsi  723  0.5 -0.5 -0.5   crit 0.5 0 -0.5   pron
2  14          b  12   25 Farsi 1827  0.5 -0.5 -0.5   crit 0.5 0 -0.5   pron
3  14          b  12   77 Farsi  658  0.5 -0.5 -0.5   crit 0.5 0 -0.5   pron
4  14          b  12   17 Farsi 1576  0.5 -0.5 -0.5   crit 0.5 0 -0.5   pron
5  14          b  12   61 Farsi  352  0.5 -0.5 -0.5   crit 0.5 0 -0.5   pron
6  14          b  12   49 Farsi 3969  0.5 -0.5 -0.5   crit 0.5 0 -0.5   pron

  rel.cl
1 no.rel.cl
2 no.rel.cl
3 no.rel.cl
4 no.rel.cl
5 no.rel.cl
6 no.rel.cl

> m.crit

Linear mixed model fit by REML
Formula: -1000/rt ~ pron + rc + inter + (1 | subj) + (1 | item)
Data: subset(data.final, region == "crit" & rt > 250)
   AIC   BIC logLik deviance REMLdev
4590 4631 -2288    4555    4576
Random effects:
Groups   Name             Variance Std.Dev.
subj     (Intercept)  0.1633    0.404
item     (Intercept)  0.0848    0.291
Residual                    0.2946    0.543
Number of obs: 2592, groups: subj, 110; item, 24

Fixed effects:
              Estimate Std. Error t value
(Intercept) -1.5255     0.0717  -21.29
pron         -0.0467     0.0213   -2.19
rc           -0.0282     0.0213   -1.32

```

```

inter          -0.0239      0.0213    -1.12

Correlation of Fixed Effects:
      (Intr) pron    rc
pron  -0.001
rc     0.001  0.000
inter  0.000  0.002 -0.003

> m.post.crit

Linear mixed model fit by REML
Formula: -1000/rt ~ pron + rc + inter + (1 | subj) + (1 | item)
Data: subset(data.final, region == "post.crit" & rt > 250)
AIC   BIC logLik deviance REMLdev
4306 4347 -2146    4270    4292
Random effects:
Groups   Name             Variance Std.Dev.
subj     (Intercept)  0.1635    0.404
item     (Intercept)  0.0269    0.164
Residual                    0.2639    0.514
Number of obs: 2600, groups: subj, 110; item, 24

Fixed effects:
              Estimate Std. Error t value
(Intercept) -1.78394    0.05207   -34.3
pron         -0.06725    0.02017    -3.3
rc           0.00783    0.02016     0.4
inter        -0.00771    0.02016    -0.4

Correlation of Fixed Effects:
      (Intr) pron    rc
pron  -0.001
rc     0.001  0.001
inter  0.000  0.001 -0.003

```

### 3 Critical region

We fit the model with varying intercepts for item and subject:

```

> m1<-m.crit
> ## estimated sd of varying intercept:
> (sigma.u<-attr(VarCorr(m1)$subj,"stddev"))

(Intercept)
0.40408

> (sigma.w<-attr(VarCorr(m1)$item,"stddev"))

```

```

(Intercept)
  0.29128

> ## estimated residual sd:
> (sigma.e<-attr(VarCorr(m1),"sc"))

[1] 0.54275

> ## fixed effects:
> (beta<-fixef(m1))

(Intercept)      pron      rc      inter
-1.525473    -0.046737   -0.028176   -0.023926

> crit.data<-subset(data.final,region=="crit" & rt>250)
> crit.data$region<-factor(crit.data$region)
> crit.data$rtrt<- -1000/crit.data$rt
> crit.dat <- list( subj = sort(as.integer( factor(crit.data$subj) )),
+                  item = sort(as.integer( factor(crit.data$item) )),
+                  rtrt = crit.data$rtrt,
+                  pron = crit.data$pron,
+                  rc = crit.data$rc,
+                  inter = crit.data$inter,
+                  N = nrow(crit.data),
+                  I = length( unique(crit.data$subj) ),
+                  K = length( unique(crit.data$item) )
+                  )

```

Set up four chains:

```

> crit.ini <- list( list( sigma.e = sigma.e/3,
+                        sigma.u = sigma.u/3,
+                        sigma.w = sigma.w/3,
+                        beta = beta  /3 ),
+                  list( sigma.e = sigma.e*3,
+                        sigma.u = sigma.u*3,
+                        sigma.w = sigma.w*3,
+                        beta = beta  *3 ),
+                  list( sigma.e = sigma.e/3,
+                        sigma.u = sigma.u*3,
+                        sigma.w = sigma.w*3,
+                        beta = beta  /3 ),
+                  list( sigma.e = sigma.e*3,
+                        sigma.u = sigma.u/3,
+                        sigma.w = sigma.w/3,
+                        beta = beta  *3 ) )

```

The JAGS model below assumes that we have negative reciprocal rts.

```

> cat("
+ # Fixing data to be used in model definition
+ model
+ {
+   # The model for each observational unit
+   #   (each row is a subject's data point)
+   for( j in 1:N )
+   {
+     mu[j] <- beta[1] + beta[2] * ( pron[j] ) + beta[3] * ( rc[j] ) + beta[4] * ( inter|
+     rrt[j] ~ dnorm( mu[j], tau.e )
+   }
+
+   # Random effects for each person
+   for( i in 1:I )
+   {
+     u[i] ~ dnorm(0,tau.u)
+   }
+
+   # Random effects for each item
+   for( k in 1:K )
+   {
+     w[k] ~ dnorm(0,tau.w)
+   }
+
+   # Uninformative priors:
+
+   # Fixed effect intercept and slope
+   beta[1] ~ dnorm(0.0,1.0E-5)
+   beta[2] ~ dnorm(0.0,1.0E-5)
+   beta[3] ~ dnorm(0.0,1.0E-5)
+   beta[4] ~ dnorm(0.0,1.0E-5)
+
+   # Residual (within-person) variance
+   tau.e <- pow(sigma.e,-2)
+   sigma.e ~ dunif(0,100)
+
+   # Between-person variation
+   tau.u <- pow(sigma.u,-2)
+   sigma.u ~ dunif(0,10)
+
+   # Between-item variation
+   tau.w <- pow(sigma.w,-2)
+   sigma.w ~ dunif(0,10)
+ }",
+   file="critcrossedrandom.jag" )

```

```

> track.variables<-c("beta","sigma.e","sigma.u","sigma.w")
> library(rjags)
> system.time(
+ crit.mod <- jags.model( file = "critcrossedrandom.jag",
+                         data = crit.dat,
+                         n.chains = 4,
+                         inits = crit.ini,
+                         n.adapt =2000 ))

```

```

Compiling model graph
  Resolving undeclared variables
  Allocating nodes
  Graph Size: 15912

```

Initializing model

```

      user  system elapsed
22.636    0.103   27.522

```

```

> system.time(
+ crit.res <- coda.samples(crit.mod,
+                          var = track.variables,
+                          n.iter = 10000,
+                          thin = 20))

```

```

      user  system elapsed
107.157    0.515  124.327

```

```

> summary( crit.res )

```

```

Iterations = 2020:12000
Thinning interval = 20
Number of chains = 4
Sample size per chain = 500

```

1. Empirical mean and standard deviation for each variable,  
plus standard error of the mean:

	Mean	SD	Naive SE	Time-series SE
beta[1]	-1.5237	0.03180	0.000711	0.000736
beta[2]	-0.0406	0.03943	0.000882	0.000970
beta[3]	-0.0525	0.04033	0.000902	0.000927
beta[4]	-0.0294	0.03990	0.000892	0.000823
sigma.e	0.6873	0.00969	0.000217	0.000214
sigma.u	0.2444	0.02416	0.000540	0.000575
sigma.w	0.0767	0.04230	0.000946	0.001938



2. Quantiles for each variable:

	2.5%	25%	50%	75%	97.5%
beta[1]	-1.58738	-1.5437	-1.5236	-1.50195	-1.4638
beta[2]	-0.11680	-0.0682	-0.0410	-0.01334	0.0398
beta[3]	-0.13080	-0.0791	-0.0519	-0.02438	0.0231
beta[4]	-0.10981	-0.0558	-0.0284	-0.00243	0.0458
sigma.e	0.66808	0.6809	0.6873	0.69383	0.7060
sigma.u	0.19976	0.2283	0.2430	0.25996	0.2938
sigma.w	0.00545	0.0462	0.0746	0.10538	0.1659

```
> str(crit.res)
```

List of 4

```
$ : mcmc [1:500, 1:7] -1.51 -1.56 -1.49 -1.53 -1.47 ...
..- attr(*, "dimnames")=List of 2
.. ..$ : NULL
.. ..$ : chr [1:7] "beta[1]" "beta[2]" "beta[3]" "beta[4]" ...
..- attr(*, "mcpair")= num [1:3] 2020 12000 20
$ : mcmc [1:500, 1:7] -1.54 -1.56 -1.49 -1.44 -1.48 ...
..- attr(*, "dimnames")=List of 2
.. ..$ : NULL
.. ..$ : chr [1:7] "beta[1]" "beta[2]" "beta[3]" "beta[4]" ...
..- attr(*, "mcpair")= num [1:3] 2020 12000 20
$ : mcmc [1:500, 1:7] -1.55 -1.5 -1.57 -1.56 -1.54 ...
..- attr(*, "dimnames")=List of 2
.. ..$ : NULL
.. ..$ : chr [1:7] "beta[1]" "beta[2]" "beta[3]" "beta[4]" ...
..- attr(*, "mcpair")= num [1:3] 2020 12000 20
$ : mcmc [1:500, 1:7] -1.48 -1.53 -1.51 -1.54 -1.51 ...
..- attr(*, "dimnames")=List of 2
.. ..$ : NULL
.. ..$ : chr [1:7] "beta[1]" "beta[2]" "beta[3]" "beta[4]" ...
..- attr(*, "mcpair")= num [1:3] 2020 12000 20
- attr(*, "class")= chr "mcmc.list"
```

```
> post<-jags.samples(crit.mod,
+                    var=track.variables,
+                    n.iter=10000)
> ## pronoun:
> ## chain 1:
> counts<-table(post$beta[2,,][,1]<0)
> 100*counts[2]/(sum(counts))
```

TRUE  
83.1

```

> ## rc:
> #hist(post$beta[3,,][,4])
> median(post$beta[3,,][,4])

[1] -0.05401

> counts<-table(post$beta[3,,][,4]<0)
> 100*counts[2]/(sum(counts))

TRUE
92.04

> ## interaction:
> hist(post$beta[4,,][,4])
> median(post$beta[4,,][,4])

[1] -0.0289

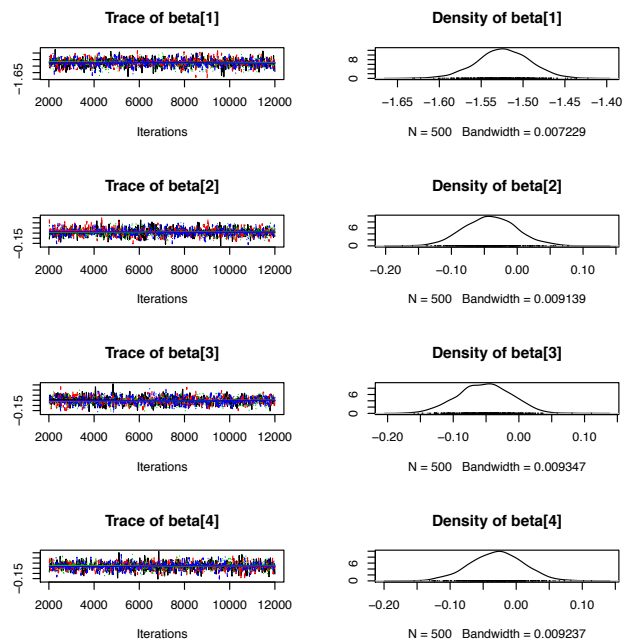
> counts<-table(post$beta[4,,][,4]<0)
> 100*counts[2]/(sum(counts))

TRUE
76.15

>

> par( mfrow=c(3,3) )
> plot(crit.res)

```



## 4 Post-critical region

We fit the model with varying intercepts for item and subject:

```
> m1<-m.post.crit
> ## estimated sd of varying intercept:
> (sigma.u<-attr(VarCorr(m1)$subj,"stddev"))

(Intercept)
  0.40435

> (sigma.w<-attr(VarCorr(m1)$item,"stddev"))

(Intercept)
  0.16403

> ## estimated residual sd:
> (sigma.e<-attr(VarCorr(m1),"sc"))

[1] 0.51368

> (beta<-fixef(m1))
```

```

(Intercept)      pron      rc      inter
-1.7839403 -0.0672497  0.0078287 -0.0077092

```

We will just call the post-critical region data crit.data.

```

> crit.data<-subset(data.final,region=="post.crit" & rt>250)
> crit.data$region<-factor(crit.data$region)
> crit.data$rrt<- -1000/crit.data$rt
> crit.dat <- list( subj = sort(as.integer( factor(crit.data$subj) )),
+                  item = sort(as.integer( factor(crit.data$item) )),
+                  rrt = crit.data$rrt,
+                  pron = crit.data$pron,
+                  rc = crit.data$rc,
+                  inter = crit.data$inter,
+                  N = nrow(crit.data),
+                  I = length( unique(crit.data$subj) ),
+                  K = length( unique(crit.data$item) )
+                )

```

Set up four chains:

```

> crit.ini <- list( list( sigma.e = sigma.e/3,
+                        sigma.u = sigma.u/3,
+                        sigma.w = sigma.w/3,
+                        beta = beta  /3 ),
+                  list( sigma.e = sigma.e*3,
+                        sigma.u = sigma.u*3,
+                        sigma.w = sigma.w*3,
+                        beta = beta  *3 ),
+                  list( sigma.e = sigma.e/3,
+                        sigma.u = sigma.u*3,
+                        sigma.w = sigma.w*3,
+                        beta = beta  /3 ),
+                  list( sigma.e = sigma.e*3,
+                        sigma.u = sigma.u/3,
+                        sigma.w = sigma.w/3,
+                        beta = beta  *3 ) )

```

The JAGS model below assumes that we have negative reciprocal rts.

```

> cat("
+ # Fixing data to be used in model definition
+ model
+ {
+   # The model for each observational unit
+   #   (each row is a subject's data point)
+   for( j in 1:N )

```

```

+     {
+       mu[j] <- beta[1] + beta[2] * ( pron[j] ) + beta[3] * ( rc[j] ) + beta[4] * ( inter|
+       rrt[j] ~ dnorm( mu[j], tau.e )
+     }
+
+   # Random effects for each person
+   for( i in 1:I )
+   {
+     u[i] ~ dnorm(0,tau.u)
+   }
+
+   # Random effects for each item
+   for( k in 1:K )
+   {
+     w[k] ~ dnorm(0,tau.w)
+   }
+
+   # Uninformative priors:
+
+   # Fixed effect intercept and slope
+   beta[1] ~ dnorm(0.0,1.0E-5)
+   beta[2] ~ dnorm(0.0,1.0E-5)
+   beta[3] ~ dnorm(0.0,1.0E-5)
+   beta[4] ~ dnorm(0.0,1.0E-5)
+
+   # Residual (within-person) variance
+   tau.e <- pow(sigma.e,-2)
+   sigma.e ~ dunif(0,100)
+
+   # Between-person variation
+   tau.u <- pow(sigma.u,-2)
+   sigma.u ~ dunif(0,10)
+
+   # Between-item variation
+   tau.w <- pow(sigma.w,-2)
+   sigma.w ~ dunif(0,10)
+ }",
+   file="postcritcrossedrandom.jag" )
> track.variables<-c("beta","sigma.e","sigma.u","sigma.w")
> library(rjags)
> system.time(
+ crit.mod <- jags.model( file = "postcritcrossedrandom.jag",
+   data = crit.dat,
+   n.chains = 4,
+   inits = crit.ini,

```

```

+                                n.adapt =2000 ))

Compiling model graph
  Resolving undeclared variables
  Allocating nodes
  Graph Size: 15958

Initializing model

      user  system elapsed
22.461    0.095   26.872

> system.time(
+ crit.res <- coda.samples(crit.mod,
+                           var = track.variables,
+                           n.iter = 10000,
+                           thin = 20))

      user  system elapsed
106.452    0.402  123.599

> summary( crit.res )

Iterations = 2020:12000
Thinning interval = 20
Number of chains = 4
Sample size per chain = 500

1. Empirical mean and standard deviation for each variable,
   plus standard error of the mean:

      Mean      SD Naive SE Time-series SE
beta[1] -1.77986 0.02603 0.000582      0.000670
beta[2] -0.07125 0.03383 0.000756      0.000810
beta[3]  0.01021 0.03293 0.000736      0.000672
beta[4] -0.00336 0.03439 0.000769      0.000751
sigma.e  0.65315 0.00905 0.000202      0.000198
sigma.u  0.14043 0.02188 0.000489      0.000598
sigma.w  0.07789 0.03301 0.000738      0.001335

2. Quantiles for each variable:

      2.5%    25%    50%    75%    97.5%
beta[1] -1.8333 -1.7962 -1.77983 -1.7632 -1.72654
beta[2] -0.1366 -0.0939 -0.07164 -0.0485 -0.00674
beta[3] -0.0567 -0.0113  0.01012  0.0313  0.07471
beta[4] -0.0699 -0.0271 -0.00457  0.0197  0.06604

```

```
sigma.e 0.6359 0.6471 0.65278 0.6592 0.67127
sigma.u 0.0980 0.1252 0.14044 0.1552 0.18412
sigma.w 0.0128 0.0553 0.07873 0.0994 0.14032
```

Compute probabilities:

```
> post<-jags.samples(crit.mod,
+                    var=track.variables,
+                    n.iter=10000)
> ## pronoun:
> ## chain 1:
> #hist(post$beta[2,,][,1])
> counts<-table(post$beta[2,,][,1]<0)
> 100*counts[2]/(sum(counts))
```

```
TRUE
98.26
```

```
> ## rc:
> #hist(post$beta[3,,][,1])
> #median(post$beta[3,,][,1])
> counts<-table(post$beta[3,,][,1]<0)
> 100*counts[2]/(sum(counts))
```

```
TRUE
39.66
```

```
> ## interaction:
> #hist(post$beta[4,,][,4])
> #median(post$beta[4,,][,4])
> counts<-table(post$beta[4,,][,4]<0)
> 100*counts[2]/(sum(counts))
```

```
TRUE
53.94
```

```
>
```

```
> par( mfrow=c(3,3) )
> plot(crit.res)
```

