

LVC_models

Preparation

Load Packages

```
library(brms)

## Loading required package: Rcpp

## Loading 'brms' package (version 2.16.2). Useful instructions
## can be found by typing help('brms'). A more detailed introduction
## to the package is available through vignette('brms_overview').

##
## Attaching package: 'brms'

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

library(ggplot2)
library(tidyverse)

## -- Attaching packages ----- tidyverse 1.3.1 --
## v tibble  3.1.5    v dplyr   1.0.7
## v tidyr   1.1.4    v stringr 1.4.0
## v readr   2.0.2    vforcats 0.5.1
## v purrr   0.3.4

## -- Conflicts ----- tidyverse_conflicts() --
## x dplyr::filter() masks stats::filter()
## x dplyr::lag()   masks stats::lag()

library(vcd)

## Loading required package: grid

library(ggthemes)
library(party)

## Loading required package: mvtnorm

## Loading required package: modeltools

## Loading required package: stats4

##
## Attaching package: 'modeltools'

## The following object is masked from 'package:brms':
##
##     prior
```

```

## Loading required package: strucchange
## Loading required package: zoo
##
## Attaching package: 'zoo'
## The following objects are masked from 'package:base':
##   as.Date, as.Date.numeric
## Loading required package: sandwich
##
## Attaching package: 'strucchange'
## The following object is masked from 'package:stringr':
##   boundary
library(future)

```

Load data

```

#path to data
df = read.csv("~/data_lifespan_brm.csv", header=TRUE)

```

Standardize and centralize age

```

## centralize and standardize age (age - mean(age)) / sd(age) ##
df$age_sd <- scale(df$age)
#sanity check
str(df)

```

```

## 'data.frame': 16629 obs. of 17 variables:
## $ index      : int 20839 20868 985459 55738 495224 ...
## $ author     : chr "2 William Prynne (1600-1669)" ...
## $ date       : int 1626 1626 1684 1684 1684 1684 1684 ...
## $ genre      : chr "prose" ...
## $ lhs         : chr "nded for a time : but yet the habituall graces and fruits of Gods holy Spirit"
## $ match      : chr "anointing" ...
## $ rhs         : chr "of Gods Spirit , and that fruite and seed of grace which Gods holy Spirit hath"
## $ gerund     : chr "NG" ...
## $ verb_type   : chr "lex" ...
## $ func        : chr "subj" ...
## $ det         : chr "the" ...
## $ generation  : chr "G1" ...
## $ gender      : chr "M" ...
## $ age         : int 26 ...
## $ incarcerated: chr "no" ...
## $ university  : chr "yes" ...
## $ age_sd      : num [-1.572, -1.572, -0.134, -0.134, -0.134, ...]
## ..- attr(*, "scaled:center")= num 45.7
## ..- attr(*, "scaled:scale")= num 12.5

```

Run models

Base models

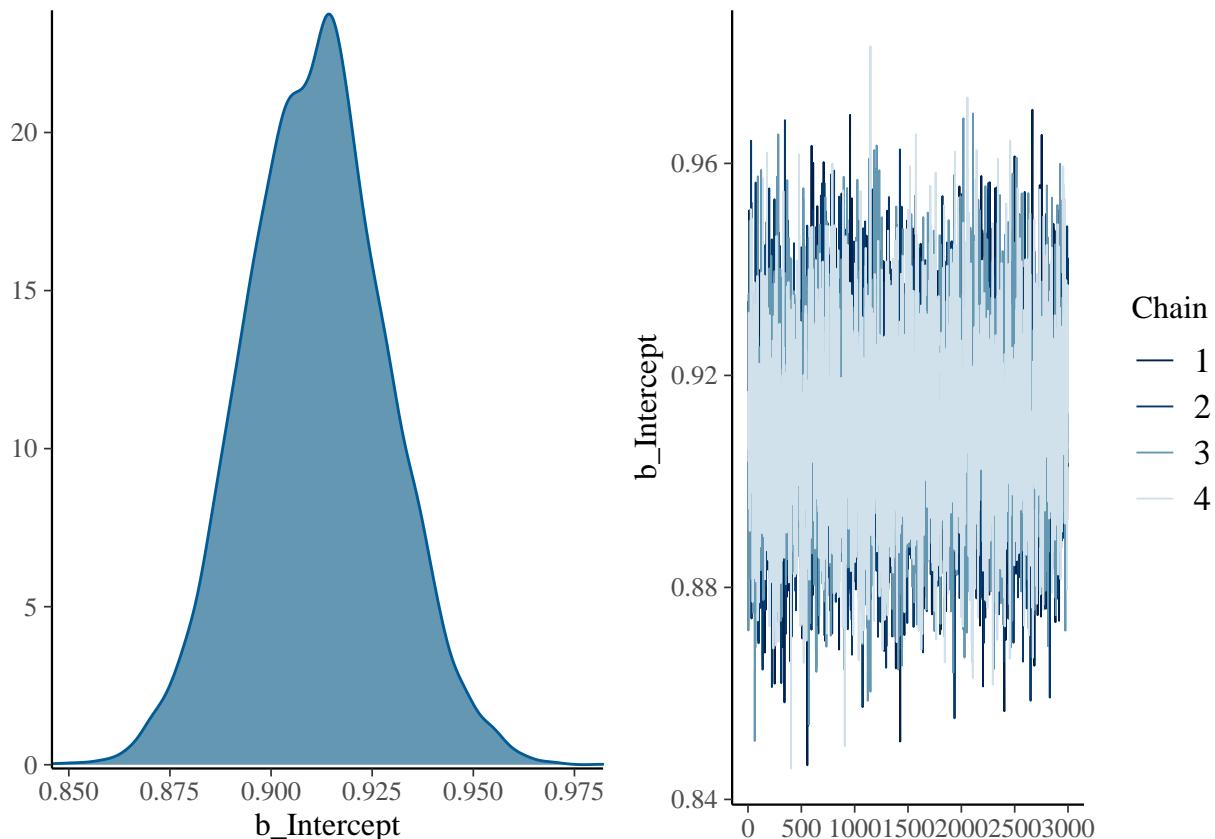
Base intercept model

Run and save model:

```
## regularizing prior for beta coefficients - helps sampling ##  
base <- brm(gerund ~ 1, data=df, family = bernoulli(),  
           chains = 4, iter = 4000, warmup = 1000, cores = 4,  
           prior = c(set_prior("normal(0, 1)", "Intercept")),  
           save_model = "base.stan",  
           file = "base",  
           file_refit="never")
```

Plot + coefficient table:

```
# inspect trace plots for divergences - traces should be well-mixed #  
plot(base)
```



```
# summary of coefficients - rhats should be close to 1 #  
summary(base)
```

```
## Family: bernoulli  
## Links: mu = logit  
## Formula: gerund ~ 1  
## Data: df (Number of observations: 16629)  
## Draws: 4 chains, each with iter = 4000; warmup = 1000; thin = 1;  
##          total post-warmup draws = 12000
```

```

## Population-Level Effects:
##             Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept      0.91     0.02     0.88     0.95 1.00     4053     6642
##
## Draws were sampled using sampling(NUTS). For each parameter, Bulk_ESS
## and Tail_ESS are effective sample size measures, and Rhat is the potential
## scale reduction factor on split chains (at convergence, Rhat = 1).
# predicted probabilities
inverse_logit <- function(a){
  exp(a)/(1+exp(a))
}

inverse_logit(0.95)

```

[1] 0.7211152

Add WAIC:

```

# add waic for model comparison #
base <- add_criterion(base, 'waic', file="base")

```

Add psis-loo:

```

# add psis-loo for model comparison #
base <- add_criterion(base, 'loo', file="base")

```

Base author intercept model

Run and save model:

```

## intercept + random intercept##
## regularizing prior for beta coefficients - helps sampling ##
base_author <- brm(gerund ~ 1 + (1|author), data=df, family = bernoulli(),
  chains = 4, iter = 4000, warmup = 1000, cores = 4,
  prior = c(set_prior("normal(0, 1)", "Intercept")),
  save_model = "base_author.stan",
  file = "base_author",
  file_refit="on_change")

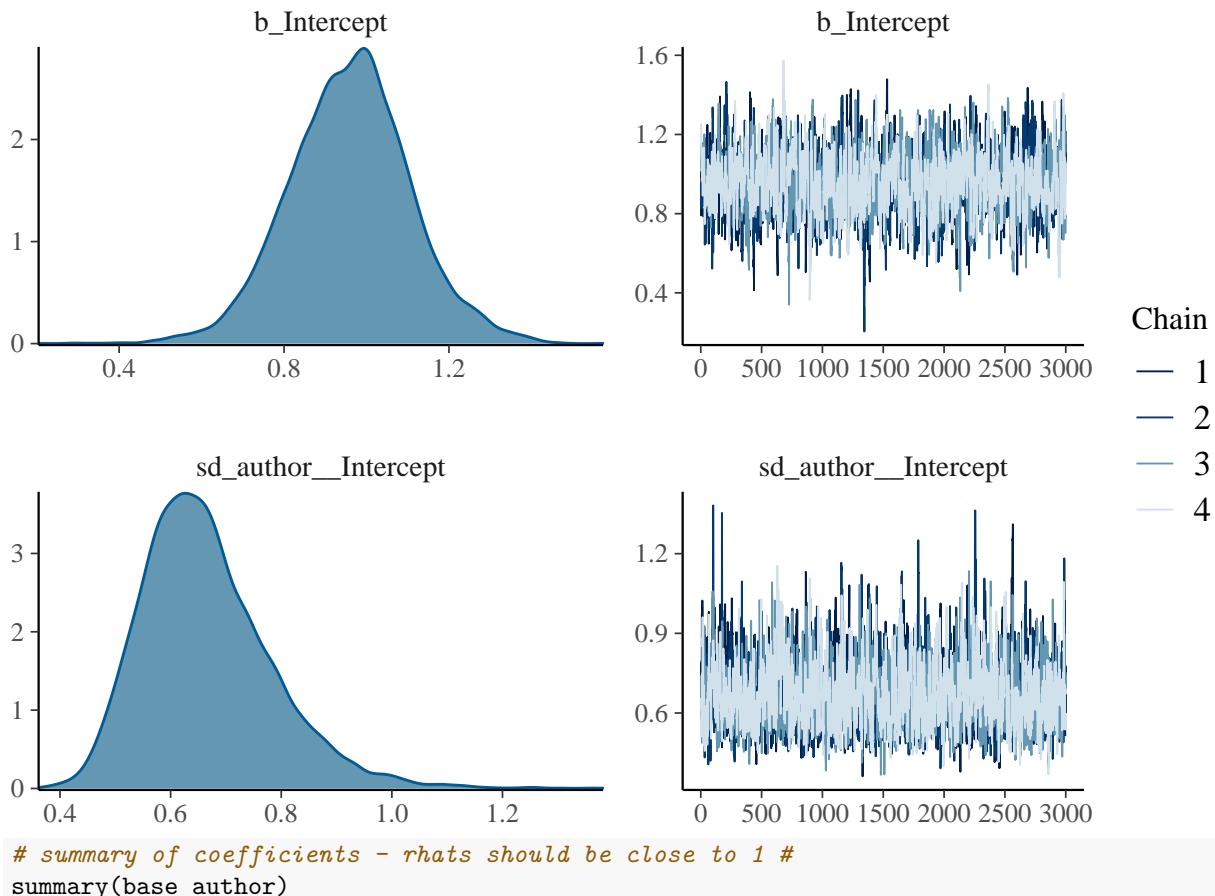
```

Plot + coefficient table:

```

# inspect trace plots for divergences - traces should be well-mixed #
plot(base_author)

```



```
# summary of coefficients - rhats should be close to 1 #
summary(base_author)
```

```
## Family: bernoulli
## Links: mu = logit
## Formula: gerund ~ 1 + (1 | author)
## Data: df (Number of observations: 16629)
## Draws: 4 chains, each with iter = 4000; warmup = 1000; thin = 1;
##         total post-warmup draws = 12000
##
## Group-Level Effects:
## ~author (Number of levels: 21)
##             Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sd(Intercept)    0.67     0.12     0.48     0.94 1.00      1561     2293
## 
## Population-Level Effects:
##             Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept       0.96     0.15     0.67     1.26 1.00      1315     1886
## 
## Draws were sampled using sampling(NUTS). For each parameter, Bulk_ESS
## and Tail_ESS are effective sample size measures, and Rhat is the potential
## scale reduction factor on split chains (at convergence, Rhat = 1).
```

```
inverse_logit(1.24)
```

```
## [1] 0.775564
```

Add WAIC:

```
# add waic for model comparison #
base_author <- add_criterion(base_author, 'waic', file ="base_author")
```

Add psis-loo:

```
# add psis-loo for model comparison #
base_author <- add_criterion(base_author, 'loo', file ="base_author")
```

Age models

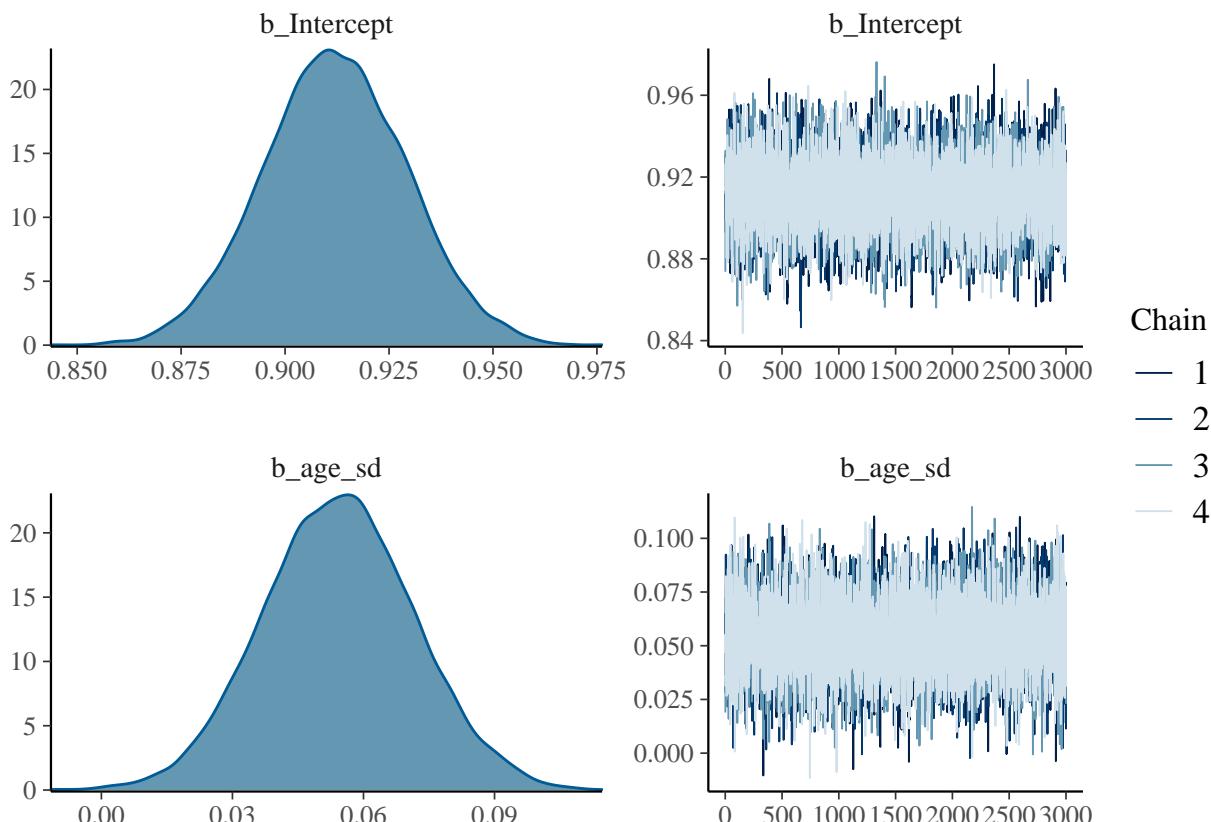
Age main effect only

Run and save model:

```
## regularizing prior for beta coefficients - helps sampling ##
M1_age <- brm(gerund ~ age_sd, data=df, family = bernoulli(),
               chains = 4, iter = 4000, warmup = 1000, cores = 4,
               prior = c(set_prior("normal(0, 1)", "b")),
               save_model = "M1_age.stan",
               file = "M1_age",
               file_refit="never")
```

Plot + coefficient table:

```
# inspect trace plots for divergences - traces should be well-mixed #
plot(M1_age)
```



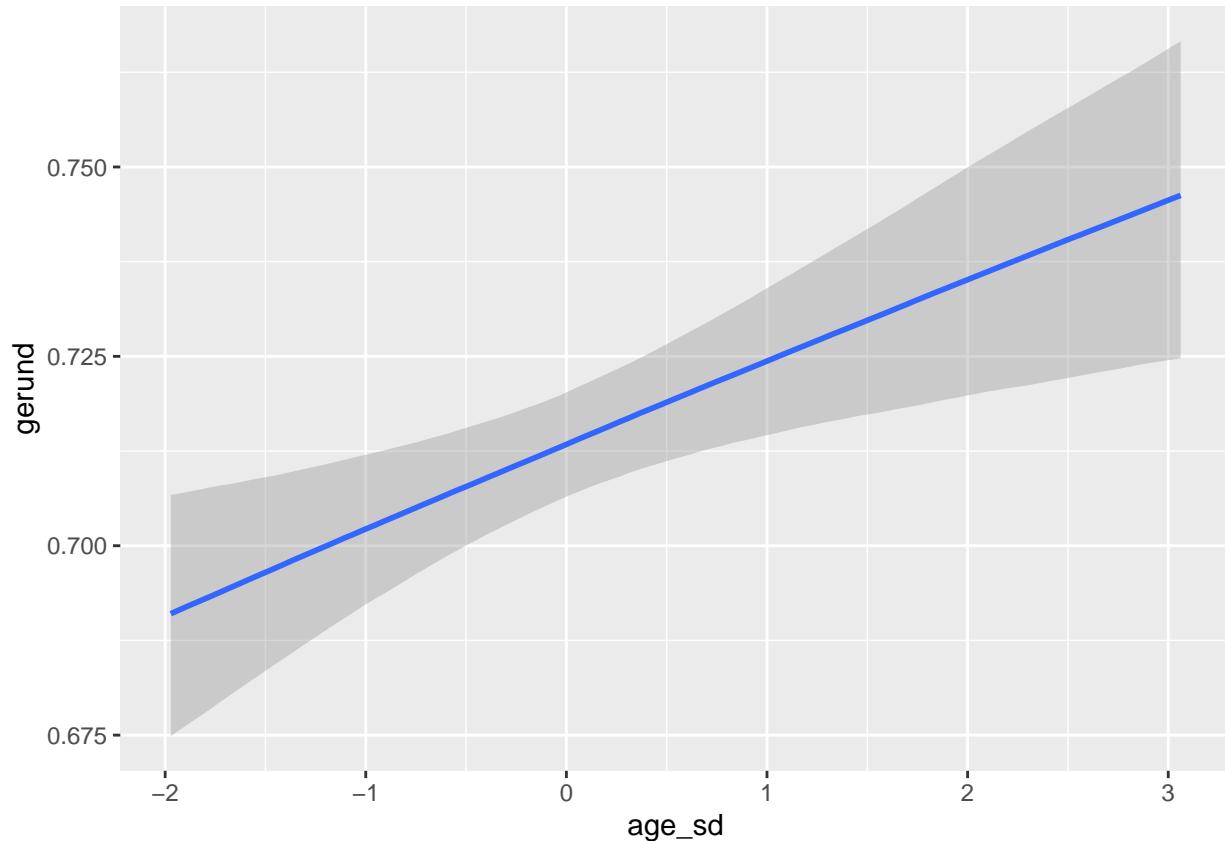
```
# summary of coefficients - rhats should be close to 1 #
summary(M1_age)
```

```
## Family: bernoulli
```

```

##   Links: mu = logit
## Formula: gerund ~ age_sd
##   Data: df (Number of observations: 16629)
##   Draws: 4 chains, each with iter = 4000; warmup = 1000; thin = 1;
##          total post-warmup draws = 12000
##
## Population-Level Effects:
##             Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept      0.91     0.02     0.88     0.95 1.00    9231    7164
## age_sd        0.05     0.02     0.02     0.09 1.00   10366    7730
##
## Draws were sampled using sampling(NUTS). For each parameter, Bulk_ESS
## and Tail_ESS are effective sample size measures, and Rhat is the potential
## scale reduction factor on split chains (at convergence, Rhat = 1).
# posterior predictive distribution #
conditional_effects(M1_age)

```



Add WAIC:

```

# add waic for model comparison #
M1_age <- add_criterion(M1_age, 'waic', file="M1_age")

```

Add psis-loo:

```

# add waic for model comparison #
M1_age <- add_criterion(M1_age, 'loo', file="M1_age")

```

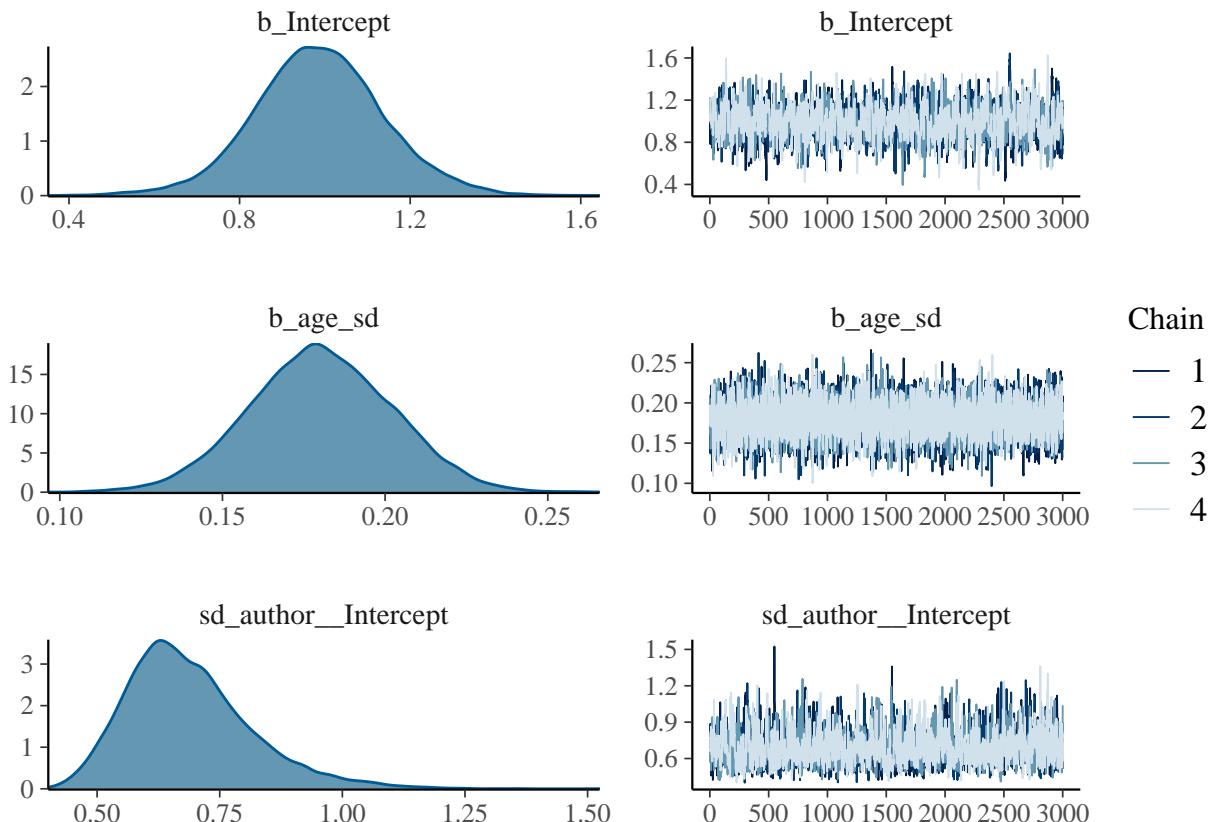
Age main effect with random author intercept

Run and save model:

```
## regularizing prior for beta coefficients - helps sampling ##
M1_age_author <- brm(gerund ~ age_sd + (1|author), data=df, family = bernoulli(),
                      chains = 4, iter = 4000, warmup = 1000, cores = 4,
                      prior = c(set_prior("normal(0, 1)", "b")),
                      save_model = "M1_age_author.stan",
                      file = "M1_age_author",
                      file_refit="on_change")
```

Plot + Coefficient table:

```
# inspect trace plots for divergences - traces should be well-mixed #
plot(M1_age_author)
```



```
# summary of coefficients - rhats should be close to 1 #
summary(M1_age_author)
```

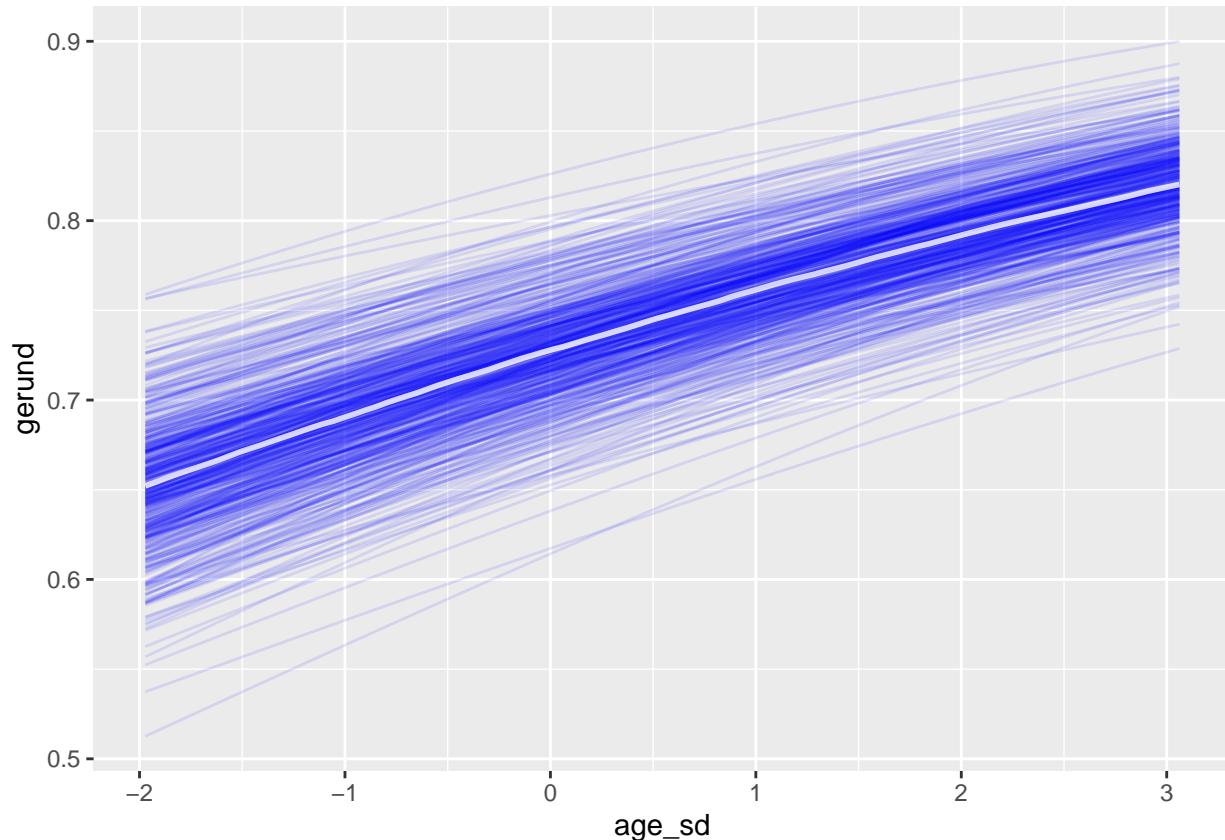
```
## Family: bernoulli
## Links: mu = logit
## Formula: gerund ~ age_sd + (1 | author)
## Data: df (Number of observations: 16629)
## Draws: 4 chains, each with iter = 4000; warmup = 1000; thin = 1;
##        total post-warmup draws = 12000
##
## Group-Level Effects:
## ~author (Number of levels: 21)
##             Estimate Est.Error 1-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
```

```

## sd(Intercept)      0.69      0.13      0.49      0.99 1.00      1521      2753
##
## Population-Level Effects:
##             Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept      0.99      0.15      0.69      1.30 1.00      1417     2264
## age_sd        0.18      0.02      0.14      0.22 1.00      7561     7128
##
## Draws were sampled using sampling(NUTS). For each parameter, Bulk_ESS
## and Tail_ESS are effective sample size measures, and Rhat is the potential
## scale reduction factor on split chains (at convergence, Rhat = 1).
# posterior predictive distribution #
conditional_effects(M1_age_author, spaghetti = TRUE, nsamples=500)

## Warning: Argument 'nsamples' is deprecated. Please use argument 'ndraws'
## instead.

```



Add WAIC:

```

# add waic for model comparison #
M1_age_author <- add_criterion(M1_age_author, 'waic', file="M1_age_author")

```

Add loo:

```

# add waic for model comparison #
M1_age_author <- add_criterion(M1_age_author, 'loo', file="M1_age_author")

```

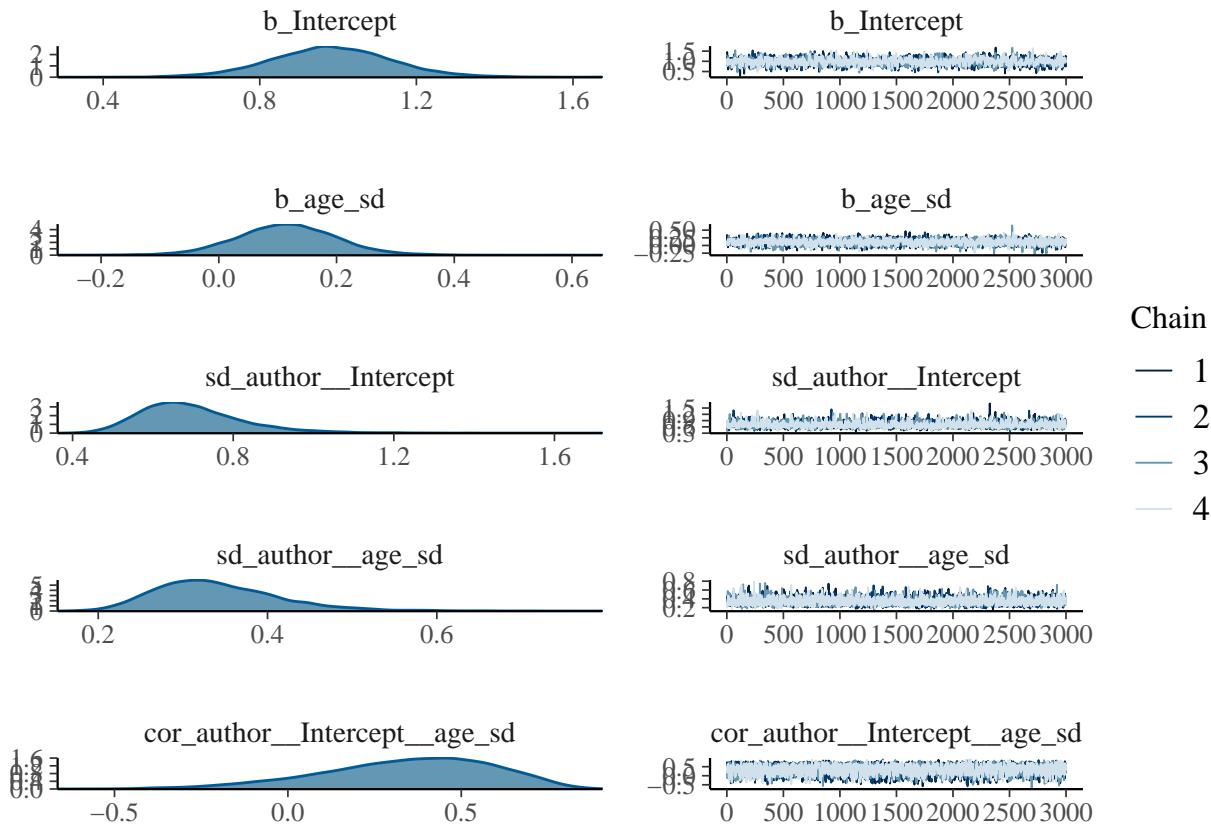
Age main effect with random author slope

Run and save model:

```
## regularizing prior for beta coefficients - helps sampling ##
M1_age_author_slope <- brm(gerund ~ age_sd + (age_sd|author), data=df, family = bernoulli(),
  chains = 4, iter = 4000, warmup = 1000, cores = 4,
  prior = c(set_prior("normal(0, 1)", "b")),
  save_model = "M1_age_author_slope.stan",
  file = "M1_age_author_slope",
  file_refit="never")
```

Plot + coefficient table:

```
# inspect trace plots for divergences - traces should be well-mixed #
plot(M1_age_author_slope)
```



```
# summary of coefficients - rhats should be close to 1 #
summary(M1_age_author_slope)
```

```
## Family: bernoulli
## Links: mu = logit
## Formula: gerund ~ age_sd + (age_sd | author)
## Data: df (Number of observations: 16629)
## Draws: 4 chains, each with iter = 4000; warmup = 1000; thin = 1;
##         total post-warmup draws = 12000
##
## Group-Level Effects:
## ~author (Number of levels: 21)
##             Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS
## sd(Intercept)     0.70      0.13     0.50     1.00 1.00    2478
## sd(age_sd)        0.34      0.07     0.22     0.51 1.00    3869
## cor(Intercept,age_sd) 0.34      0.25    -0.19     0.74 1.00    3594
```

```

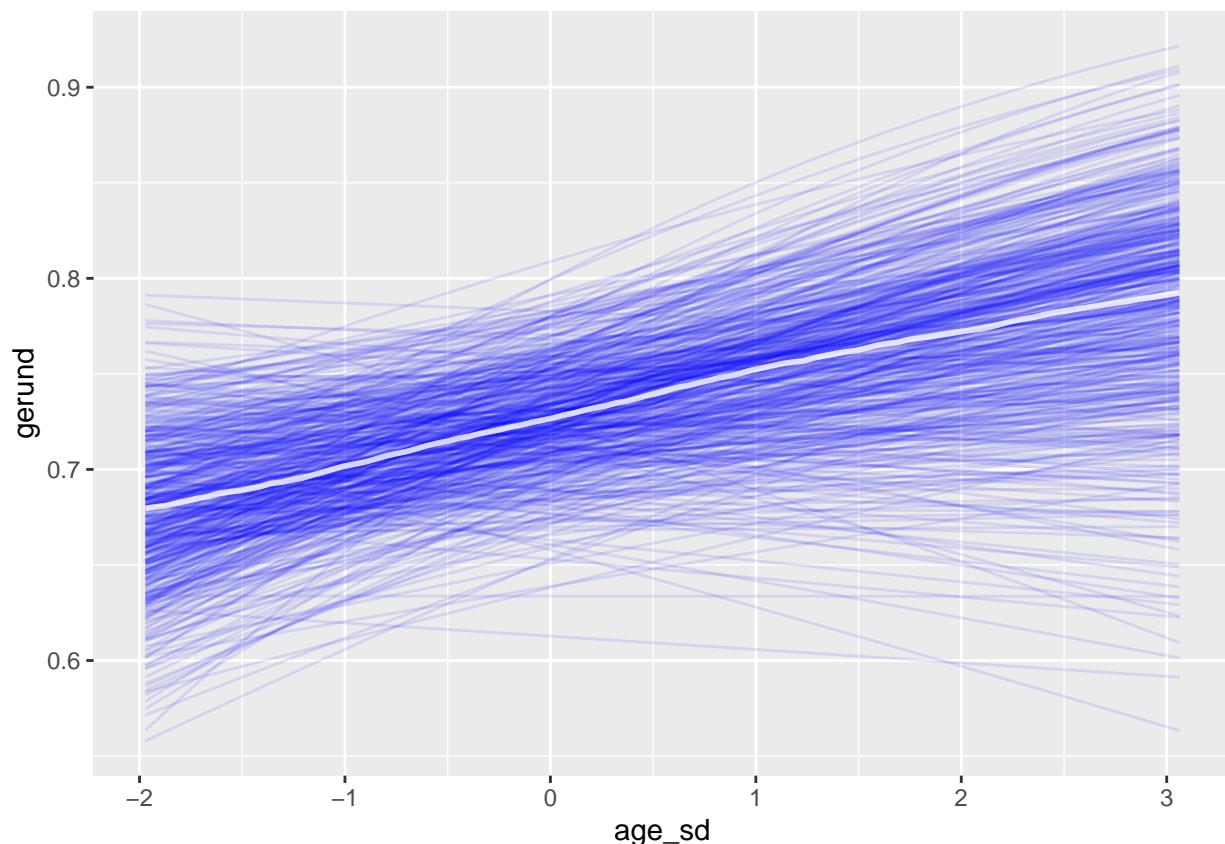
## Tail_ESS
## sd(Intercept)      4499
## sd(age_sd)        6039
## cor(Intercept,age_sd) 5428
##
## Population-Level Effects:
## Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept     0.98     0.15    0.68    1.29 1.00    1853    3379
## age_sd       0.12     0.09   -0.05    0.28 1.00    3182    4292
##
## Draws were sampled using sampling(NUTS). For each parameter, Bulk_ESS
## and Tail_ESS are effective sample size measures, and Rhat is the potential
## scale reduction factor on split chains (at convergence, Rhat = 1).
# posterior predictive distribution #
conditional_effects(M1_age_author_slope, spaghetti = TRUE, nsamples=500)

```

```

## Warning: Argument 'nsamples' is deprecated. Please use argument 'ndraws'
## instead.

```



Add WAIC:

```

# add waic for model comparison #
M1_age_author_slope <- add_criterion(M1_age_author_slope, 'waic', file="M1_age_author_slope")

```

Add loo:

```

# add waic for model comparison #
M1_age_author_slope <- add_criterion(M1_age_author_slope, 'loo', file="M1_age_author_slope")

```

Determiner models

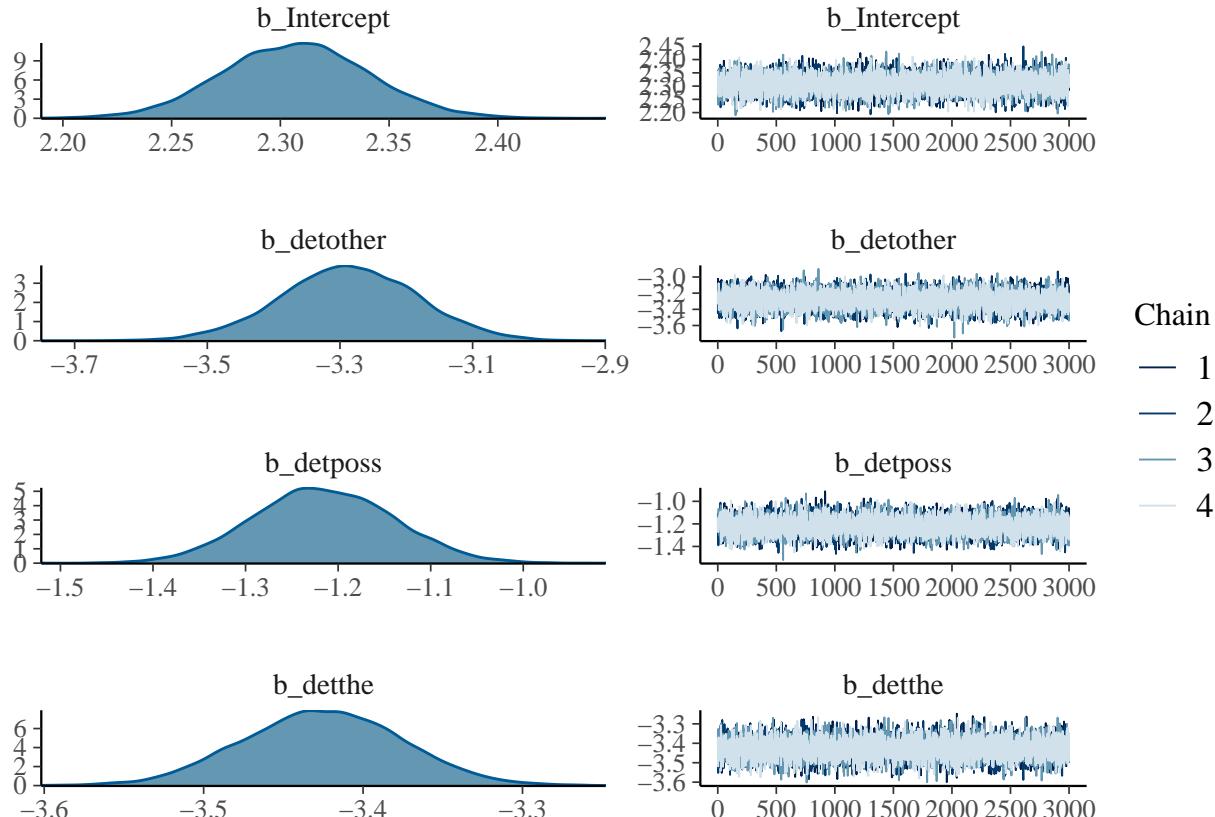
Determiner as main effect only

Run and save model:

```
## intercept + b_bare*bare + b_poss*poss + b_the*the + b_other*other ##
## regularizing prior for beta coefficients - helps sampling ##
M2_det <- brm(gerund ~ det, data=df, family = bernoulli(),
  chains = 4, iter = 4000, warmup = 1000, cores = 4,
  prior = c(set_prior("normal(0, 1)", "b")),
  save_model = "M2_det.stan",
  file = "M2_det",
  file_refit="never")
```

Plot + coefficient table:

```
# inspect trace plots for divergences - traces should be well-mixed #
plot(M2_det)
```



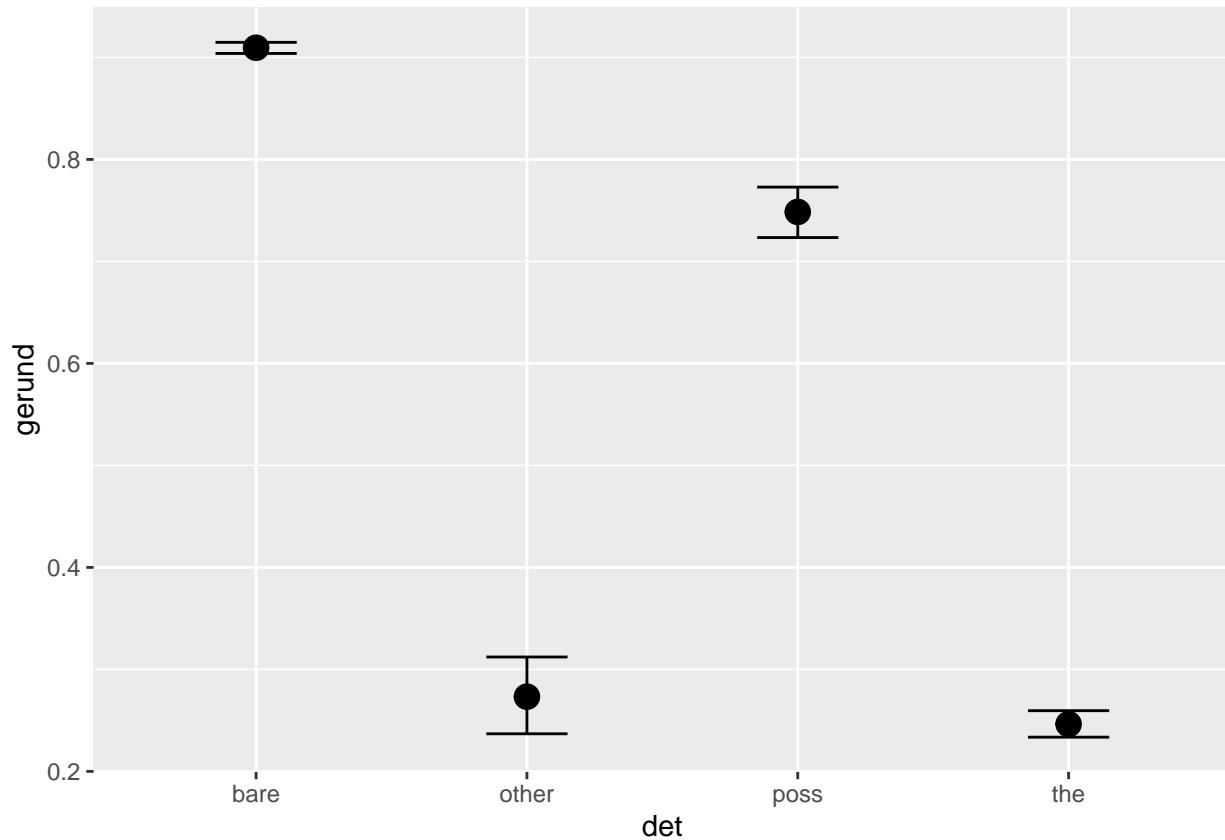
```
# summary of coefficients - rhats should be close to 1 #
summary(M2_det)
```

```
## Family: bernoulli
## Links: mu = logit
## Formula: gerund ~ det
## Data: df (Number of observations: 16629)
## Draws: 4 chains, each with iter = 4000; warmup = 1000; thin = 1;
##        total post-warmup draws = 12000
##
## Population-Level Effects:
```

```

##             Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept      2.31     0.03    2.24    2.37 1.00     8329     7916
## detother     -3.29     0.10   -3.49   -3.09 1.00    11380     8816
## detposs      -1.22     0.08   -1.36   -1.07 1.00     9955     8940
## detthe       -3.43     0.05   -3.52   -3.33 1.00    10089     9353
##
## Draws were sampled using sampling(NUTS). For each parameter, Bulk_ESS
## and Tail_ESS are effective sample size measures, and Rhat is the potential
## scale reduction factor on split chains (at convergence, Rhat = 1).
# posterior predictive distribution #
conditional_effects(M2_det)

```



Add WAIC:

```

# add waic for model comparison #
M2_det <- add_criterion(M2_det, 'waic', file="M2_det")

```

Add psis-loo:

```

# add waic for model comparison #
M2_det <- add_criterion(M2_det, 'loo', file="M2_det")

```

Determiner + author intercept

Run and save model:

```

## intercept + b_bare*bare + b_poss*poss + b_the*the + b_other*other ##
## regularizing prior for beta coefficients - helps sampling ##
M2_det_author <- brm(gerund ~ det + (1|author), data=df, family = bernoulli(),

```

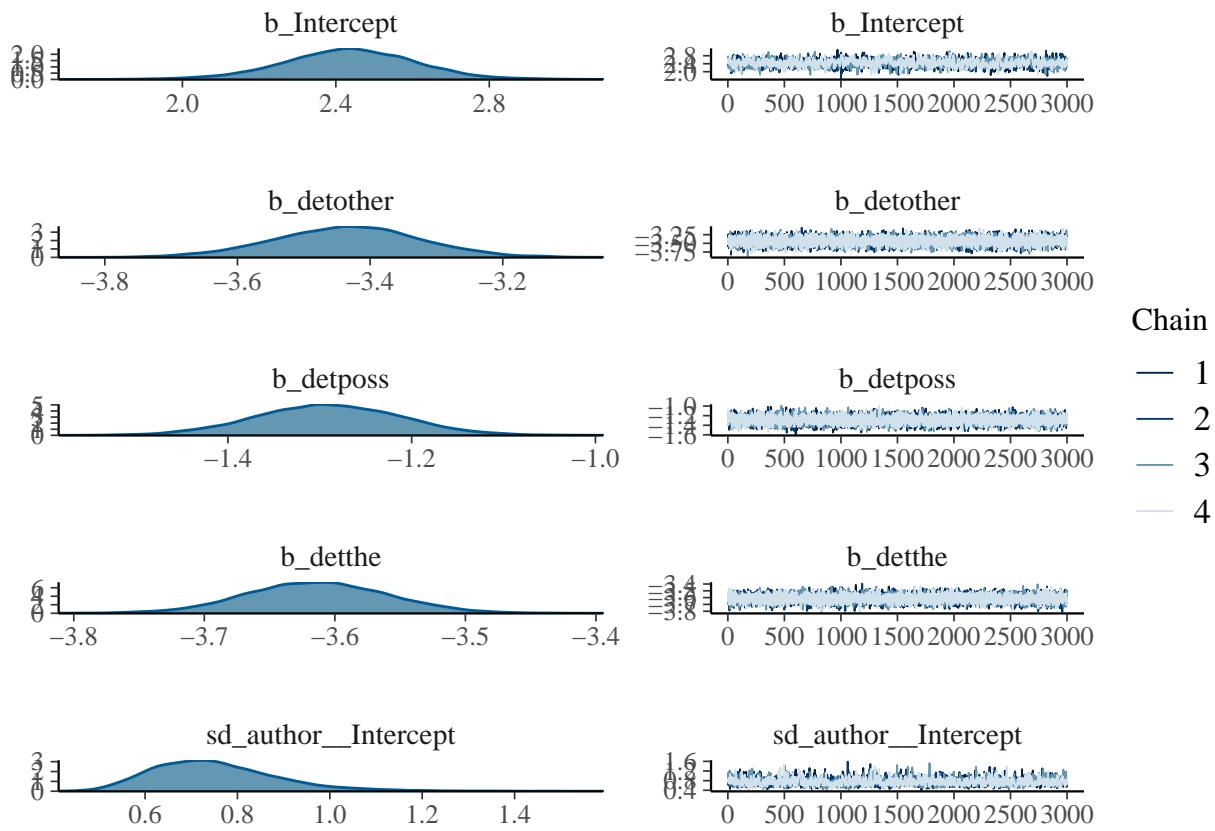
```

chains = 4, iter = 4000, warmup = 1000, cores = 4,
prior = c(set_prior("normal(0, 1)", "b")),
save_model = "M2_det_author.stan",
file = "M2_det_author",
file_refit="never")

```

Plot + coefficient table:

```
# inspect trace plots for divergences - traces should be well-mixed #
plot(M2_det_author)
```



```
# summary of coefficients - rhats should be close to 1 #
summary(M2_det_author)
```

```

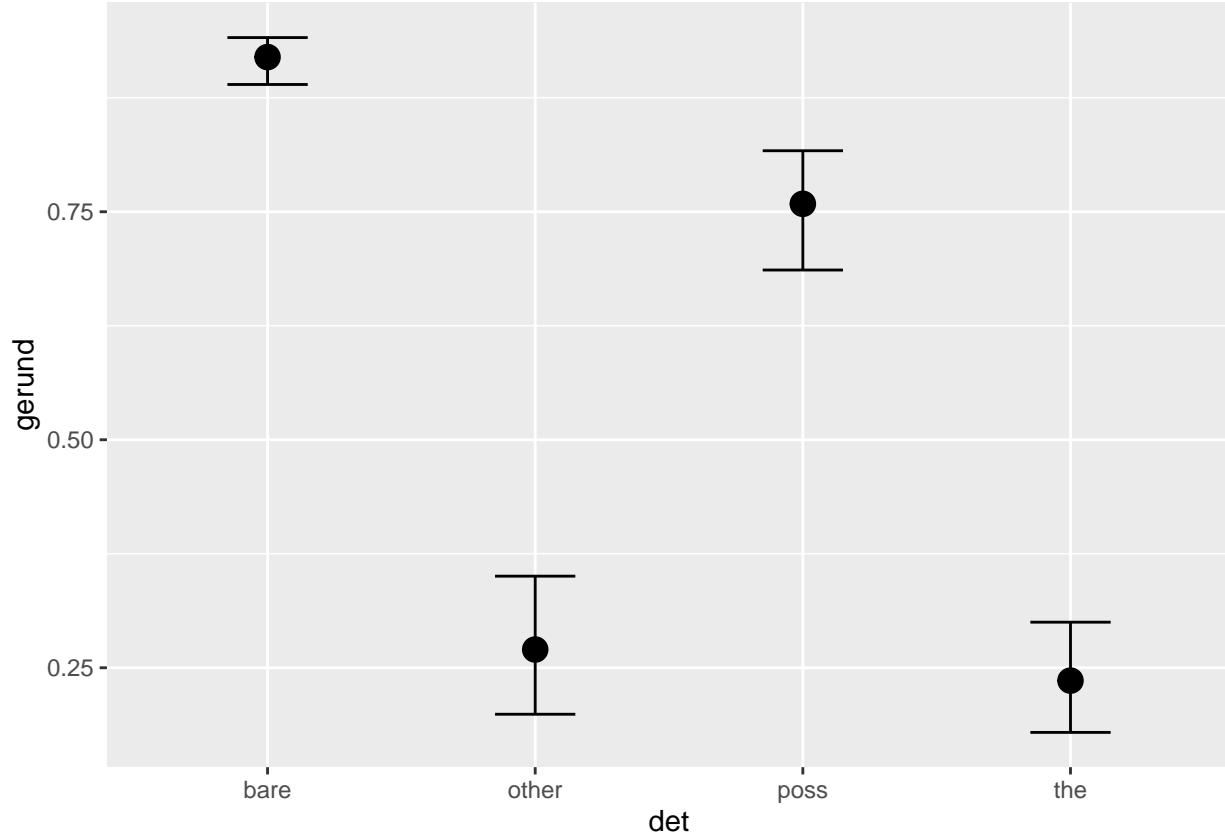
## Family: bernoulli
## Links: mu = logit
## Formula: gerund ~ det + (1 | author)
## Data: df (Number of observations: 16629)
## Draws: 4 chains, each with iter = 4000; warmup = 1000; thin = 1;
##         total post-warmup draws = 12000
##
## Group-Level Effects:
## ~author (Number of levels: 21)
##             Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sd(Intercept)    0.75      0.14     0.54     1.08 1.00     1905     2994
##
## Population-Level Effects:
##             Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept       2.44      0.17     2.09     2.77 1.00     1758     2727

```

```

## detother    -3.43      0.11     -3.66     -3.22 1.00      8677      8101
## detposs     -1.29      0.08     -1.45     -1.14 1.00      8778      7900
## detthe      -3.61      0.05     -3.72     -3.51 1.00      8758      8077
##
## Draws were sampled using sampling(NUTS). For each parameter, Bulk_ESS
## and Tail_ESS are effective sample size measures, and Rhat is the potential
## scale reduction factor on split chains (at convergence, Rhat = 1).
# posterior predictive distribution #
conditional_effects(M2_det_author)

```



Add WAIC:

```

# add waic for model comparison #
M2_det_author <- add_criterion(M2_det_author, 'waic', file="M2_det_author")

```

Add psis-loo:

```

# add waic for model comparison #
M2_det_author <- add_criterion(M2_det_author, 'loo', file="M2_det_author")

```

Determiner + author slope

Run and save model:

```

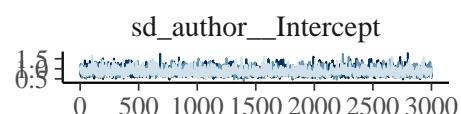
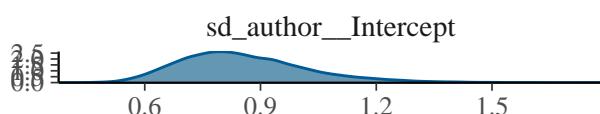
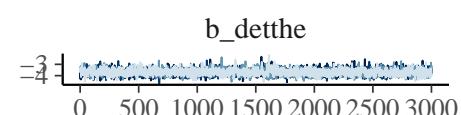
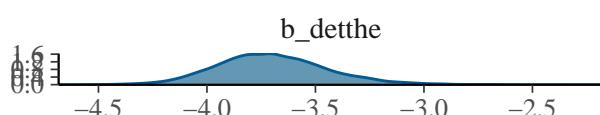
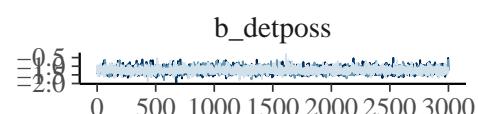
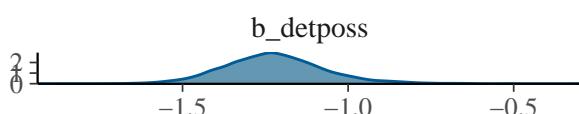
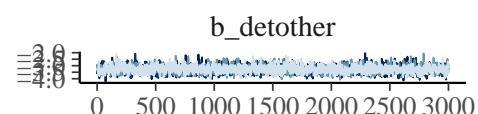
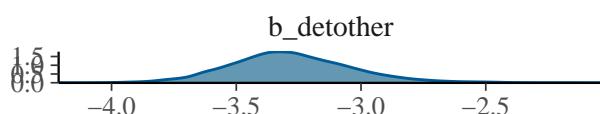
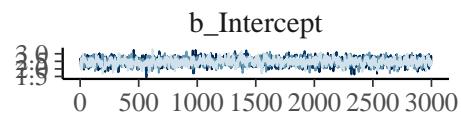
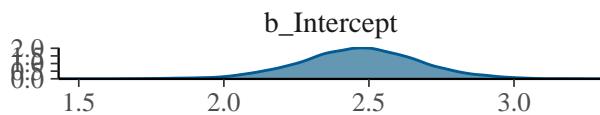
## regularizing prior for beta coefficients - helps sampling ##
M2_det_author_slope <- brm(gerund ~ det + (det|author), data=df, family = bernoulli(),
                           chains = 4, iter = 4000, warmup = 1000, cores = 4,
                           prior = c(set_prior("normal(0, 1)", "b")),
                           save_model = "M2_det_author_slope.stan",

```

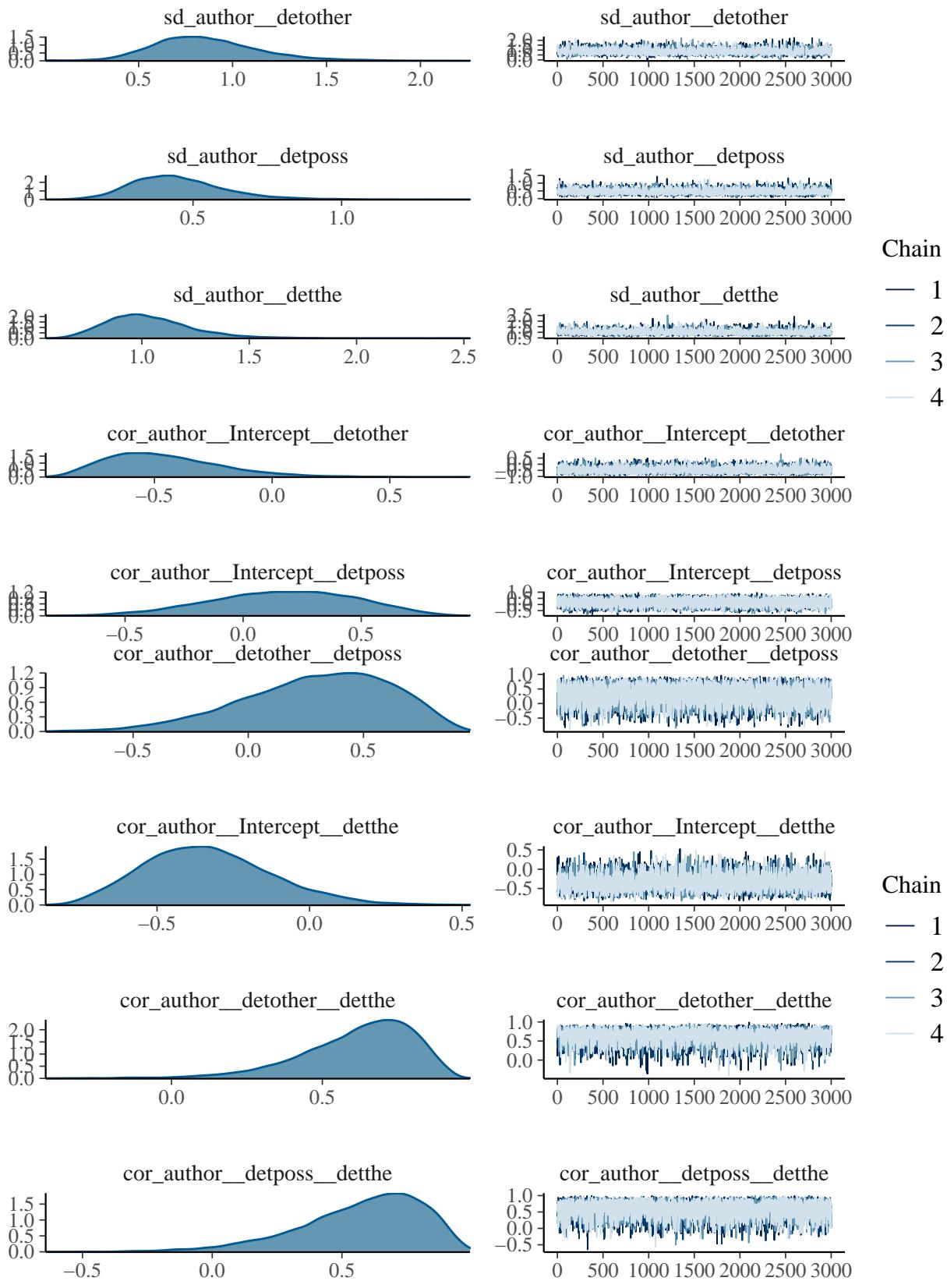
```
file = "M2_det_author_slope",  
file_refit="never")
```

Plot + coefficient table:

```
# inspect trace plots for divergences - traces should be well-mixed #  
plot(M2_det_author_slope)
```



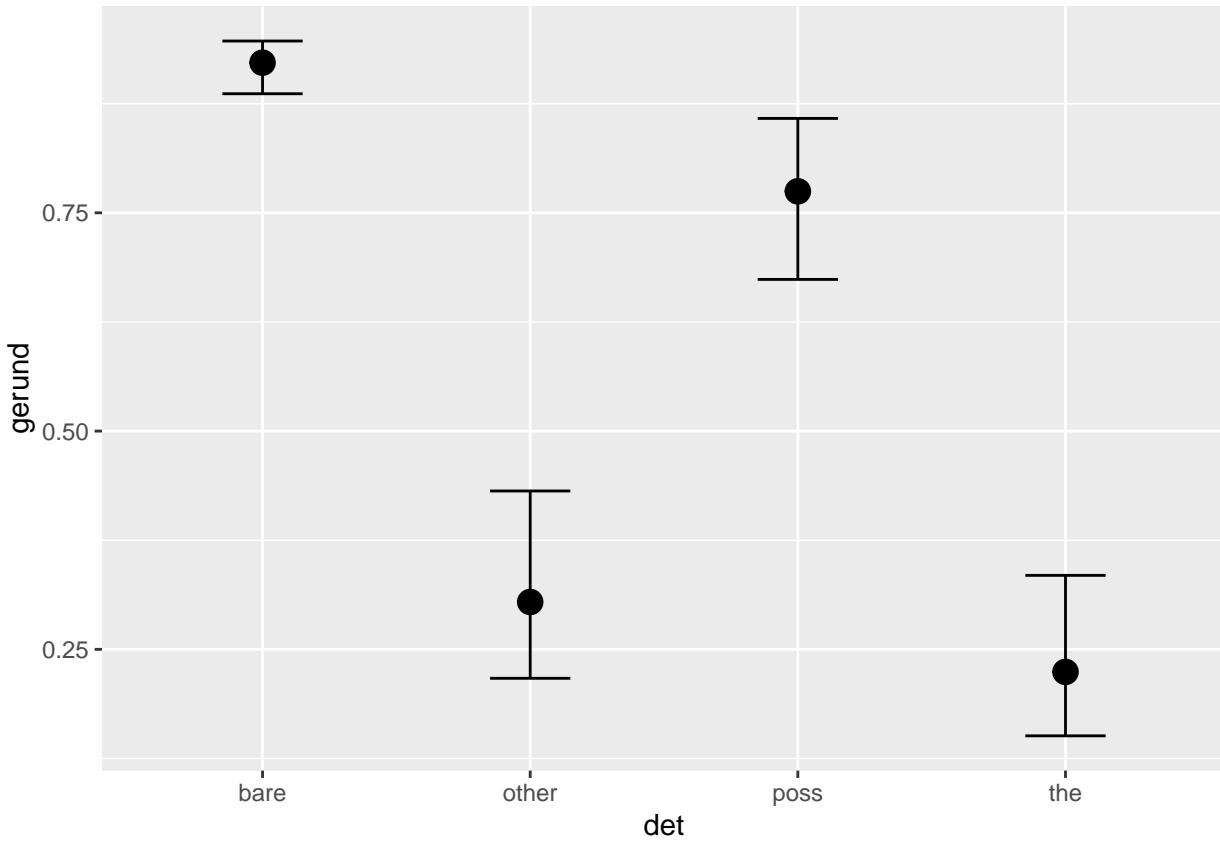
Chain
— 1
— 2
— 3
— 4



```

## Family: bernoulli
## Links: mu = logit
## Formula: gerund ~ det + (det | author)
## Data: df (Number of observations: 16629)
## Draws: 4 chains, each with iter = 4000; warmup = 1000; thin = 1;
##          total post-warmup draws = 12000
##
## Group-Level Effects:
## ~author (Number of levels: 21)
##             Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS
## sd(Intercept)     0.86    0.17    0.59    1.24 1.00   3325
## sd(detother)     0.86    0.28    0.38    1.50 1.00   3039
## sd(detposs)      0.45    0.16    0.19    0.82 1.00   5688
## sd(detthe)       1.03    0.20    0.72    1.49 1.00   4846
## cor(Intercept,detother) -0.46    0.24   -0.83    0.09 1.00   5271
## cor(Intercept,detposs)  0.17    0.30   -0.45    0.71 1.00   7376
## cor(detother,detposs)  0.30    0.32   -0.40    0.81 1.00   6252
## cor(Intercept,detthe)  -0.33    0.21   -0.69    0.11 1.00   4189
## cor(detother,detthe)  0.62    0.19    0.17    0.89 1.00   3667
## cor(detposs,detthe)   0.58    0.24    0.02    0.92 1.00   5873
##             Tail_ESS
## sd(Intercept)      5769
## sd(detother)       3130
## sd(detposs)        6764
## sd(detthe)         6308
## cor(Intercept,detother) 7342
## cor(Intercept,detposs) 8603
## cor(detother,detposs) 8124
## cor(Intercept,detthe) 6316
## cor(detother,detthe) 4796
## cor(detposs,detthe) 8009
##
## Population-Level Effects:
##             Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept      2.47    0.21    2.05    2.88 1.00   1623    2866
## detother     -3.28    0.25   -3.74   -2.75 1.00   3494    4781
## detposs      -1.22    0.15   -1.51   -0.89 1.00   5261    5429
## detthe       -3.70    0.26   -4.16   -3.15 1.00   3489    4882
##
## Draws were sampled using sampling(NUTS). For each parameter, Bulk_ESS
## and Tail_ESS are effective sample size measures, and Rhat is the potential
## scale reduction factor on split chains (at convergence, Rhat = 1).
# posterior predictive distribution #
conditional_effects(M2_det_author_slope)

```



Add WAIC:

```
# add waic for model comparison #
M2_det_author_slope <- add_criterion(M2_det_author_slope, 'waic', file="M2_det_author_slope")
```

Add psis-loo:

```
# add waic for model comparison #
M2_det_author_slope <- add_criterion(M2_det_author_slope, 'loo', file="M2_det_author_slope")
```

Full models

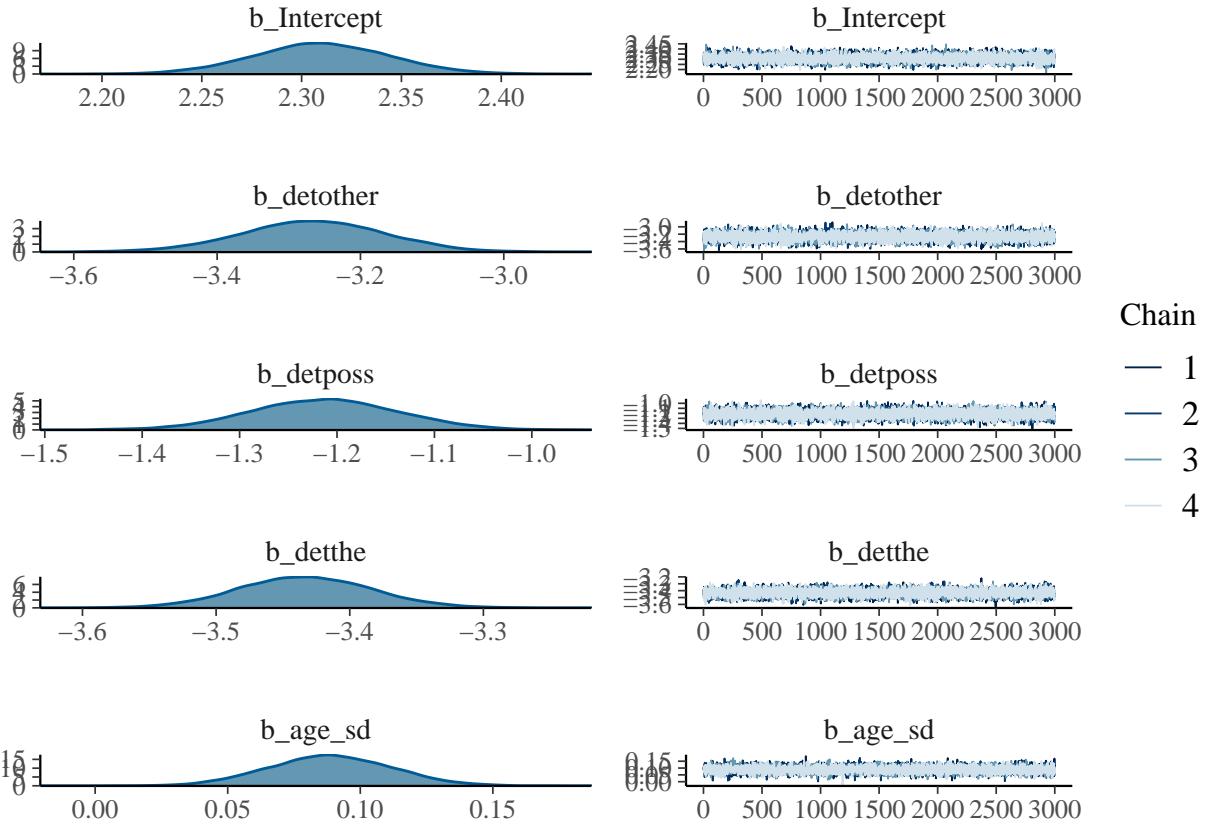
Age and Determiner as main effects only

Run and save model:

```
## regularizing prior for beta coefficients - helps sampling ##
M3_full <- brm(gerund ~ det + age_sd, data=df, family = bernoulli(),
  chains = 4, iter = 4000, warmup = 1000, cores = 4,
  prior = c(set_prior("normal(0, 1)", "b")),
  save_model = "M3_full.stan",
  file = "M3_full",
  file_refit="never")
```

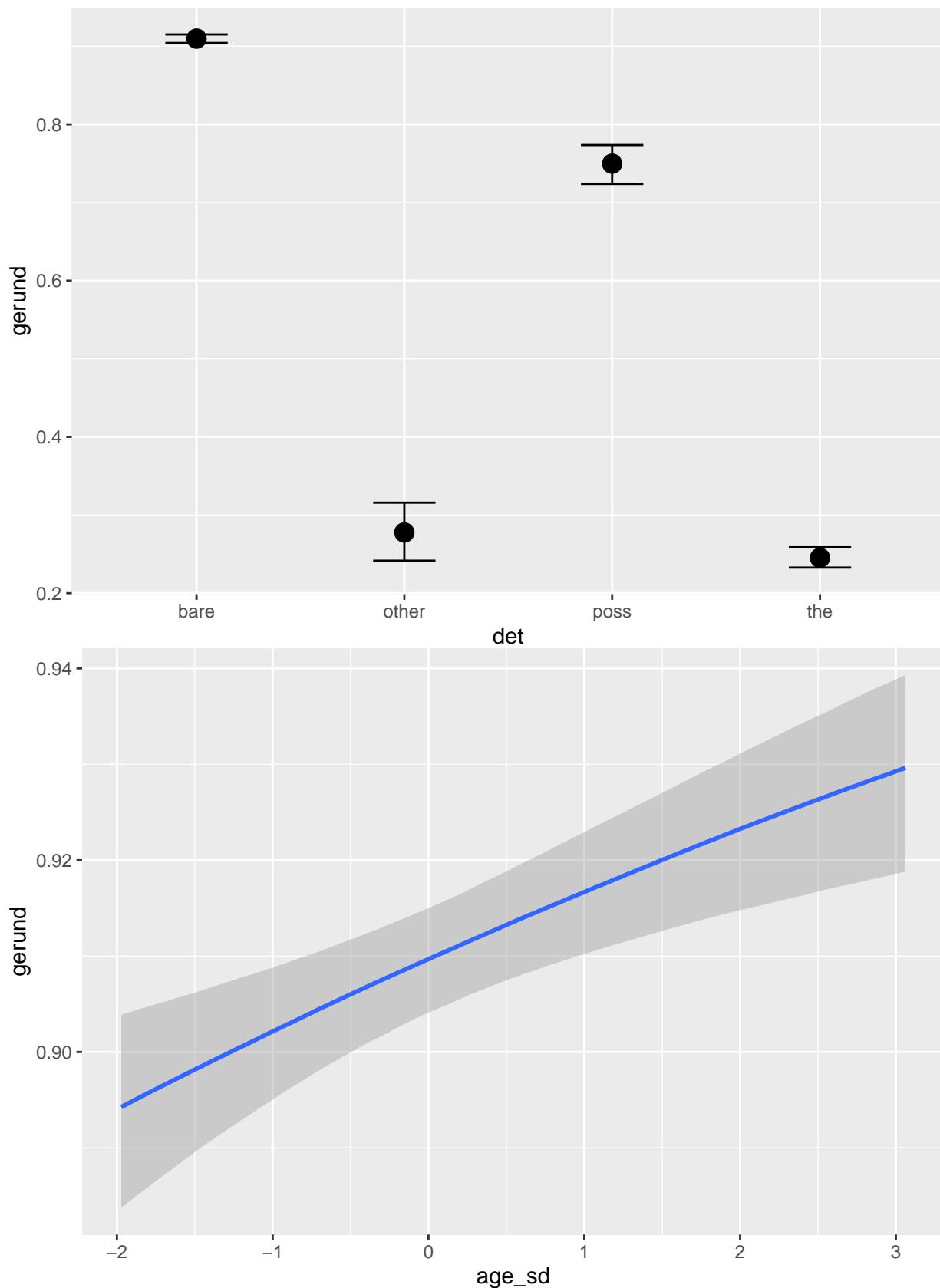
Plot + coefficient table:

```
# inspect trace plots for divergences - traces should be well-mixed #
plot(M3_full)
```



```
# summary of coefficients - rhats should be close to 1 #
summary(M3_full)
```

```
## Family: bernoulli
## Links: mu = logit
## Formula: gerund ~ det + age_sd
## Data: df (Number of observations: 16629)
## Draws: 4 chains, each with iter = 4000; warmup = 1000; thin = 1;
##         total post-warmup draws = 12000
##
## Population-Level Effects:
##             Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept     2.31      0.03    2.24    2.38 1.00    9682    9134
## detother     -3.27      0.10   -3.47   -3.07 1.00   11830    8736
## detposs     -1.21      0.08   -1.36   -1.06 1.00   11007    9381
## detthe     -3.43      0.05   -3.53   -3.34 1.00   11275    8821
## age_sd       0.09      0.02    0.04    0.13 1.00   11793    8369
##
## Draws were sampled using sampling(NUTS). For each parameter, Bulk_ESS
## and Tail_ESS are effective sample size measures, and Rhat is the potential
## scale reduction factor on split chains (at convergence, Rhat = 1).
#
# posterior predictive distribution #
conditional_effects(M3_full)
```



Add WAIC:

```
# add waic for model comparison #
M3_full <- add_criterion(M3_full, 'waic', file="M3_full")
```

Add psis-loo:

```
# add waic for model comparison #
M3_full <- add_criterion(M3_full, 'loo', file="M3_full")
```

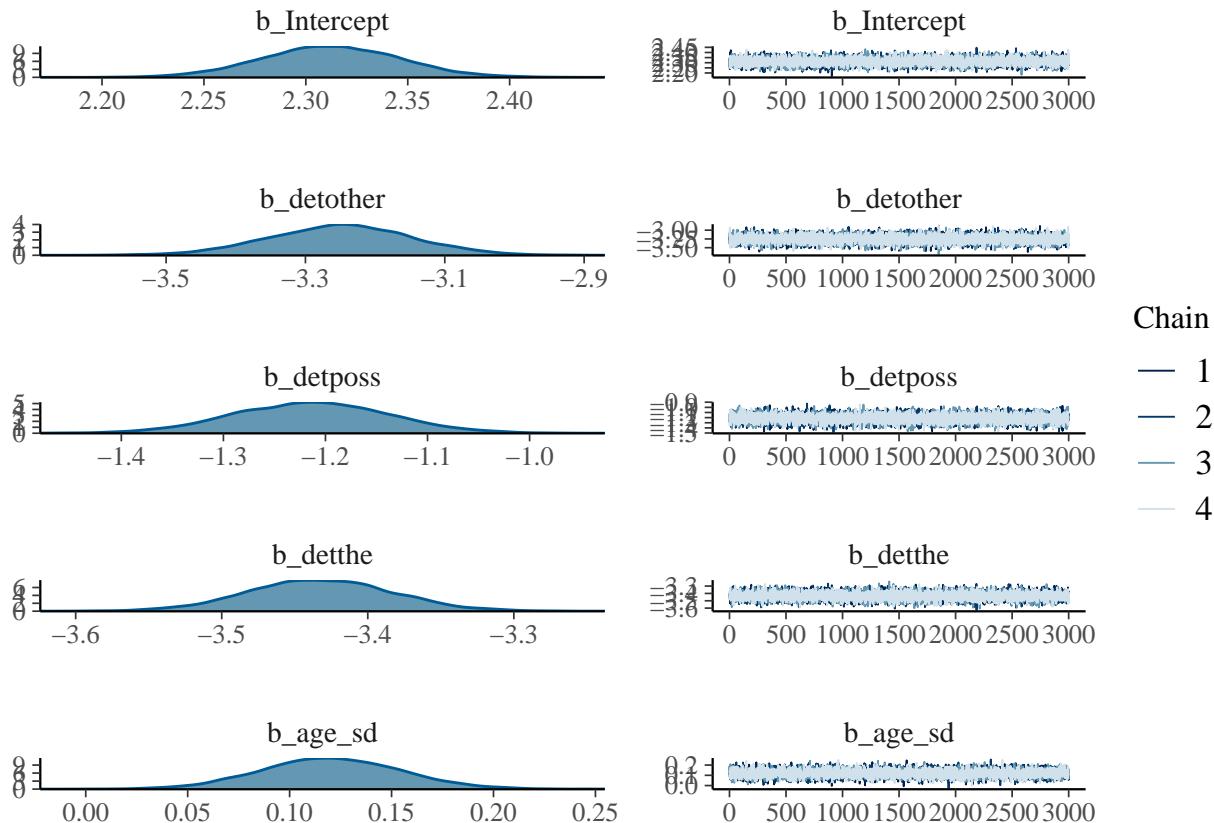
Age and Determiner as main effects only + interaction

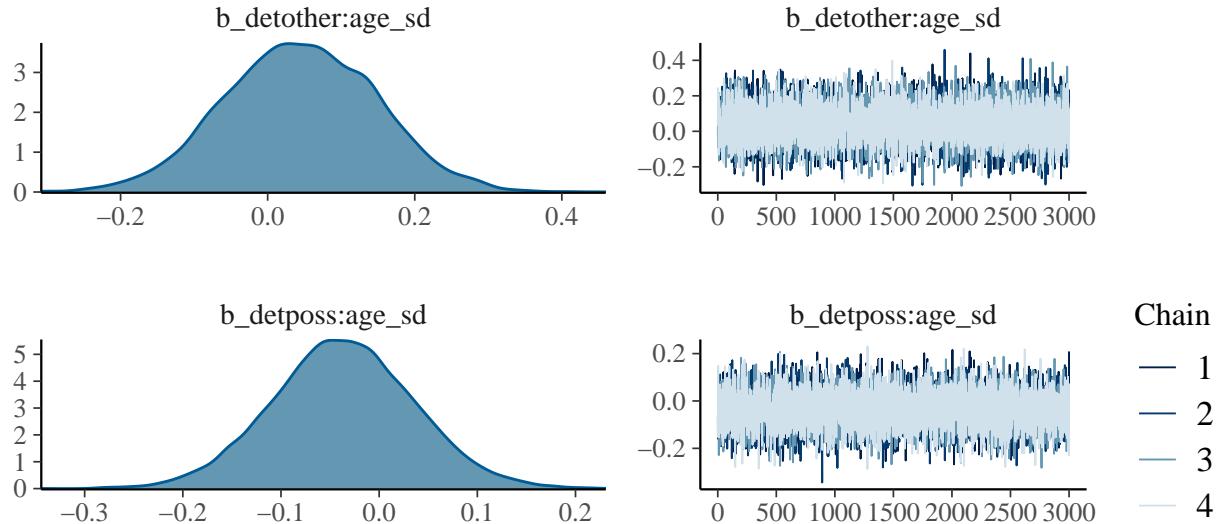
Run and save model:

```
## regularizing prior for beta coefficients - helps sampling ##
M3_full_int <- brm(gerund ~ det * age_sd, data=df, family = bernoulli(),
  chains = 4, iter = 4000, warmup = 1000, cores = 4,
  prior = c(set_prior("normal(0, 1)", "b")),
  save_model = "M3_full_int.stan",
  file = "M3_full_int",
  file_refit="never")
```

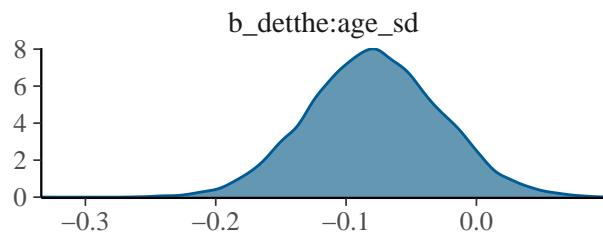
Plot + coefficient table:

```
# inspect trace plots for divergences - traces should be well-mixed #
plot(M3_full_int)
```

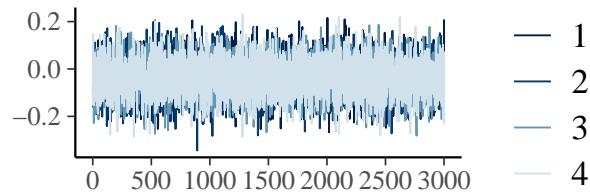




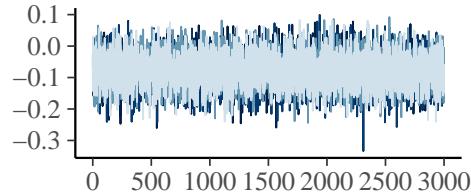
b_detthe:age_sd



b_detposs:age_sd

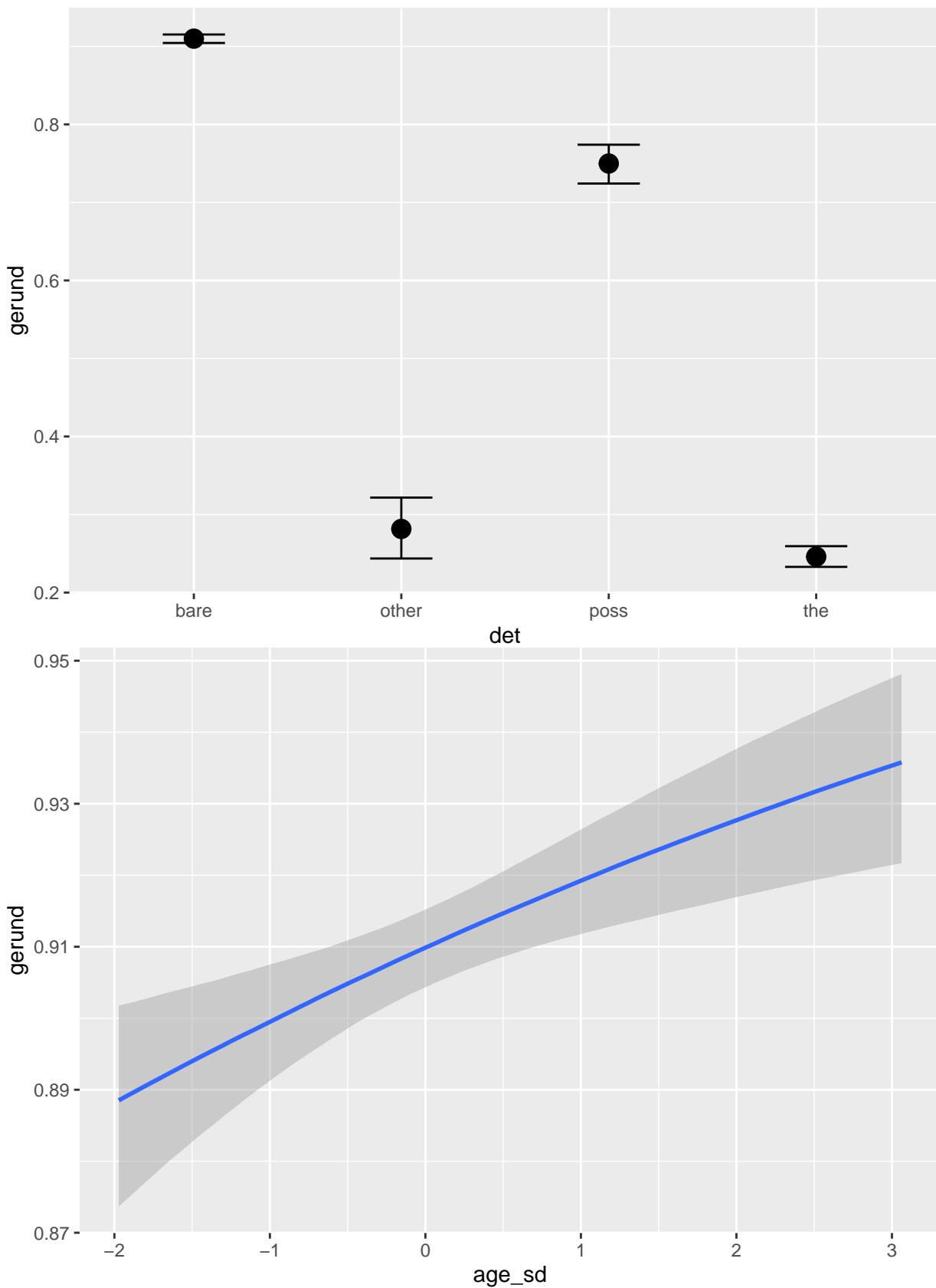


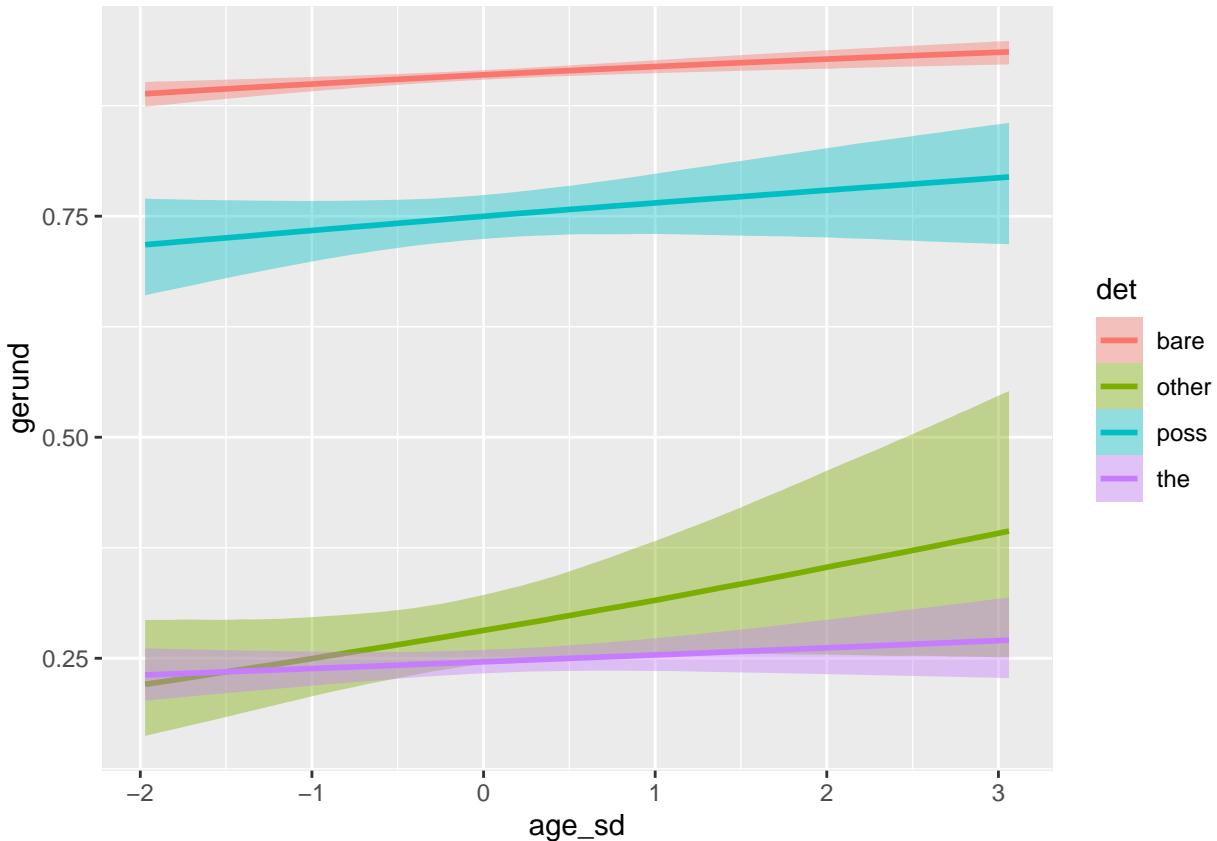
b_detthe:age_sd



```
# summary of coefficients - rhats should be close to 1 #
summary(M3_full_int)
```

```
## Family: bernoulli
## Links: mu = logit
## Formula: gerund ~ det * age_sd
## Data: df (Number of observations: 16629)
## Draws: 4 chains, each with iter = 4000; warmup = 1000; thin = 1;
##         total post-warmup draws = 12000
##
## Population-Level Effects:
##                               Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept                  2.31     0.03    2.25    2.38 1.00   10484    8974
## detother                 -3.25     0.10   -3.45   -3.05 1.00   14985    9784
## detposs                  -1.21     0.08   -1.36   -1.06 1.00   14876    9471
## detthe                   -3.43     0.05   -3.53   -3.33 1.00   12734    9989
## age_sd                    0.12     0.03    0.05    0.19 1.00    8331    8586
## detother:age_sd            0.04     0.10   -0.16    0.25 1.00   13209    9262
## detposs:age_sd             -0.04    0.07   -0.18    0.11 1.00   12703    9685
## detthe:age_sd              -0.08    0.05   -0.18    0.02 1.00    9700    9414
##
## Draws were sampled using sampling(NUTS). For each parameter, Bulk_ESS
## and Tail_ESS are effective sample size measures, and Rhat is the potential
## scale reduction factor on split chains (at convergence, Rhat = 1).
#
# posterior predictive distribution #
conditional_effects(M3_full_int)
```





Add WAIC:

```
# add waic for model comparison #
M3_full_int <- add_criterion(M3_full_int, 'waic', file="M3_full_int")
```

Add psis-loo:

```
# add waic for model comparison #
M3_full_int <- add_criterion(M3_full_int, 'loo', file="M3_full_int")
```

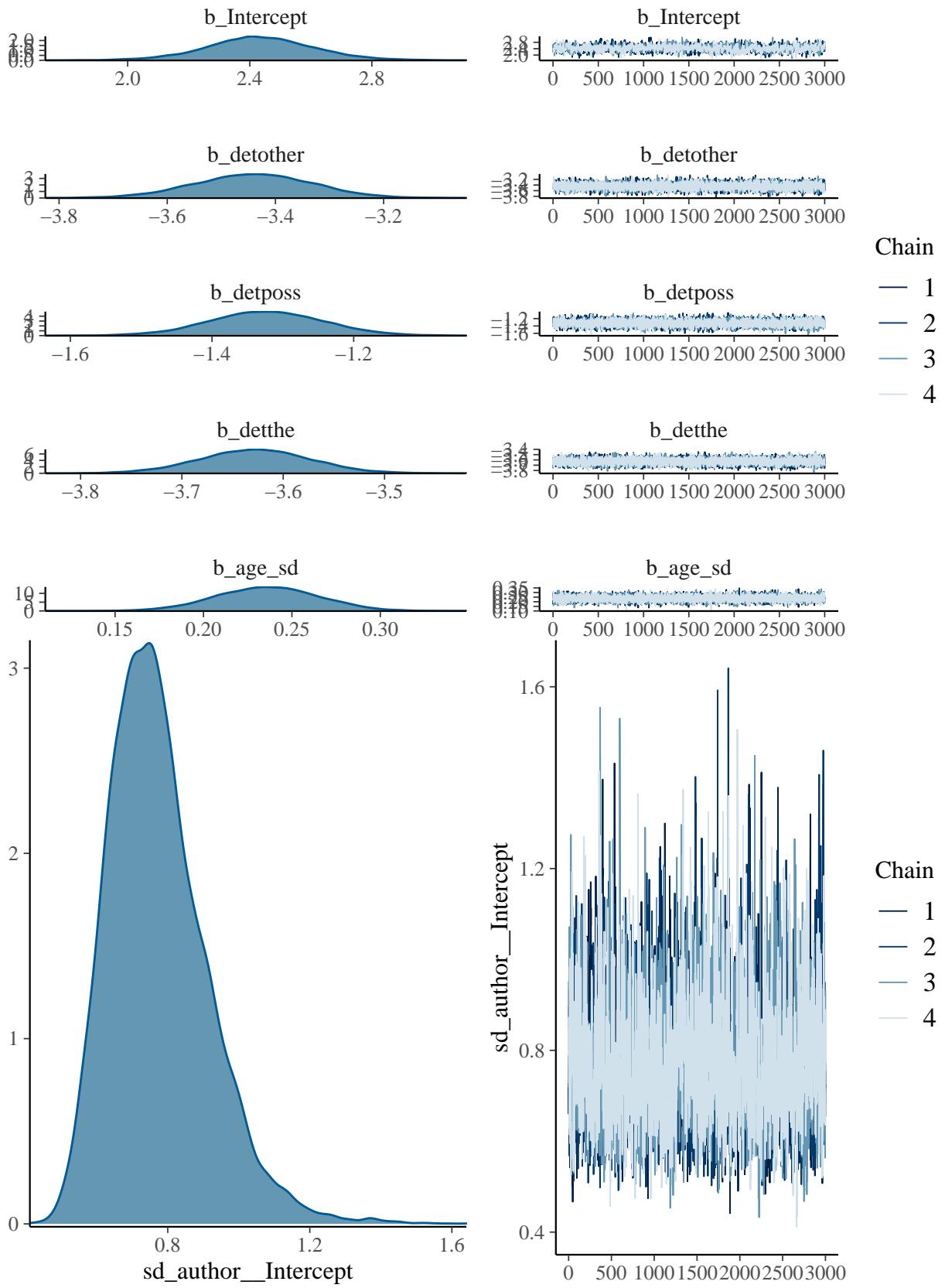
Age and Determiner + author intercept

Run and save model:

```
## intercept + b_bare*bare + b_poss*poss + b_the*the + b_other*other ##
## regularizing prior for beta coefficients - helps sampling ##
M3_full_author <- brm(gerund ~ det + age_sd + (1|author), data=df, family = bernoulli(),
  chains = 4, iter = 4000, warmup = 1000, cores = 4,
  prior = c(set_prior("normal(0, 1)", "b")),
  save_model = "M3_full_author.stan",
  file = "M3_full_author",
  file_refit="never")
```

Plot + coefficient table:

```
# inspect trace plots for divergences - traces should be well-mixed #
plot(M3_full_author)
```

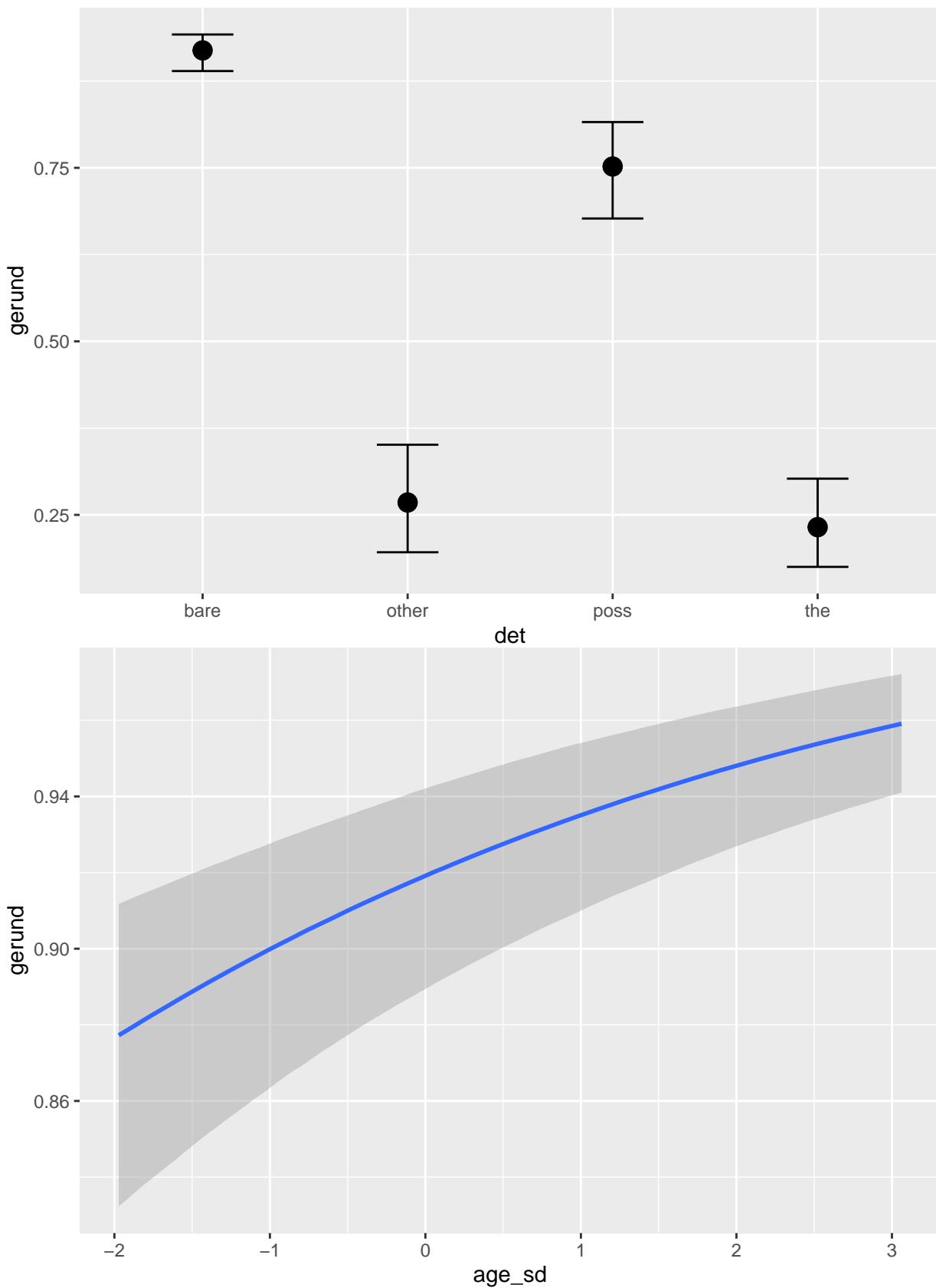


```

# summary of coefficients - rhats should be close to 1 #
summary(M3_full_author)

## Family: bernoulli
## Links: mu = logit
## Formula: gerund ~ det + age_sd + (1 | author)
## Data: df (Number of observations: 16629)
## Draws: 4 chains, each with iter = 4000; warmup = 1000; thin = 1;
##         total post-warmup draws = 12000
##
## Group-Level Effects:
## ~author (Number of levels: 21)
##             Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sd(Intercept)    0.77     0.14     0.56    1.09 1.00     1769     3677
##
## Population-Level Effects:
##             Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept      2.43     0.18     2.08    2.79 1.00     1423     2401
## detother     -3.44     0.11    -3.65   -3.23 1.00     9379     8041
## detposs      -1.32     0.08    -1.48   -1.16 1.00     9440     8255
## detthe       -3.63     0.05    -3.73   -3.52 1.00     9879     8847
## age_sd        0.24     0.03     0.18    0.29 1.00    10312     7742
##
## Draws were sampled using sampling(NUTS). For each parameter, Bulk_ESS
## and Tail_ESS are effective sample size measures, and Rhat is the potential
## scale reduction factor on split chains (at convergence, Rhat = 1).
# posterior predictive distribution #
conditional_effects(M3_full_author)

```



Add WAIC:

```
# add waic for model comparison #
M3_full_author <- add_criterion(M3_full_author, 'waic', file="M3_full_author")
```

Add loo:

```
# add waic for model comparison #
M3_full_author <- add_criterion(M3_full_author, 'loo', file="M3_full_author")
```

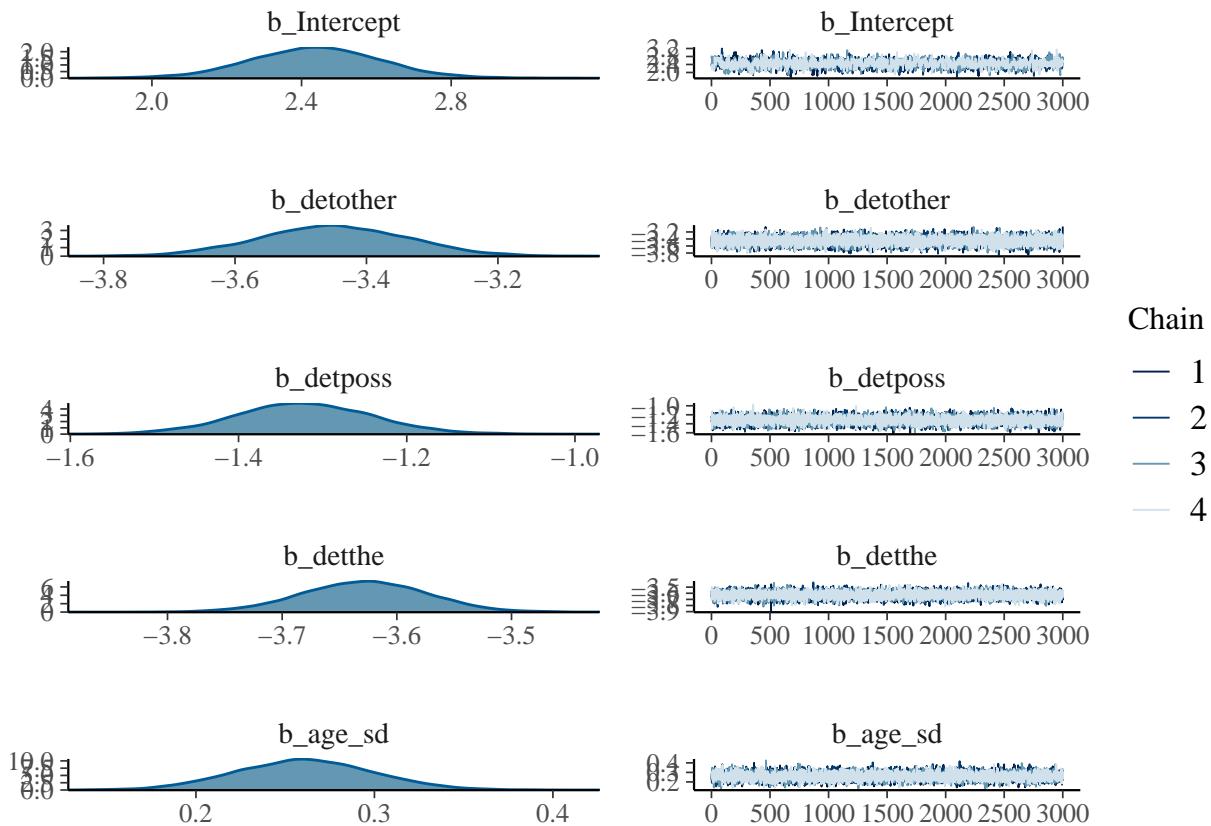
Age and Determiner Interaction + author intercept

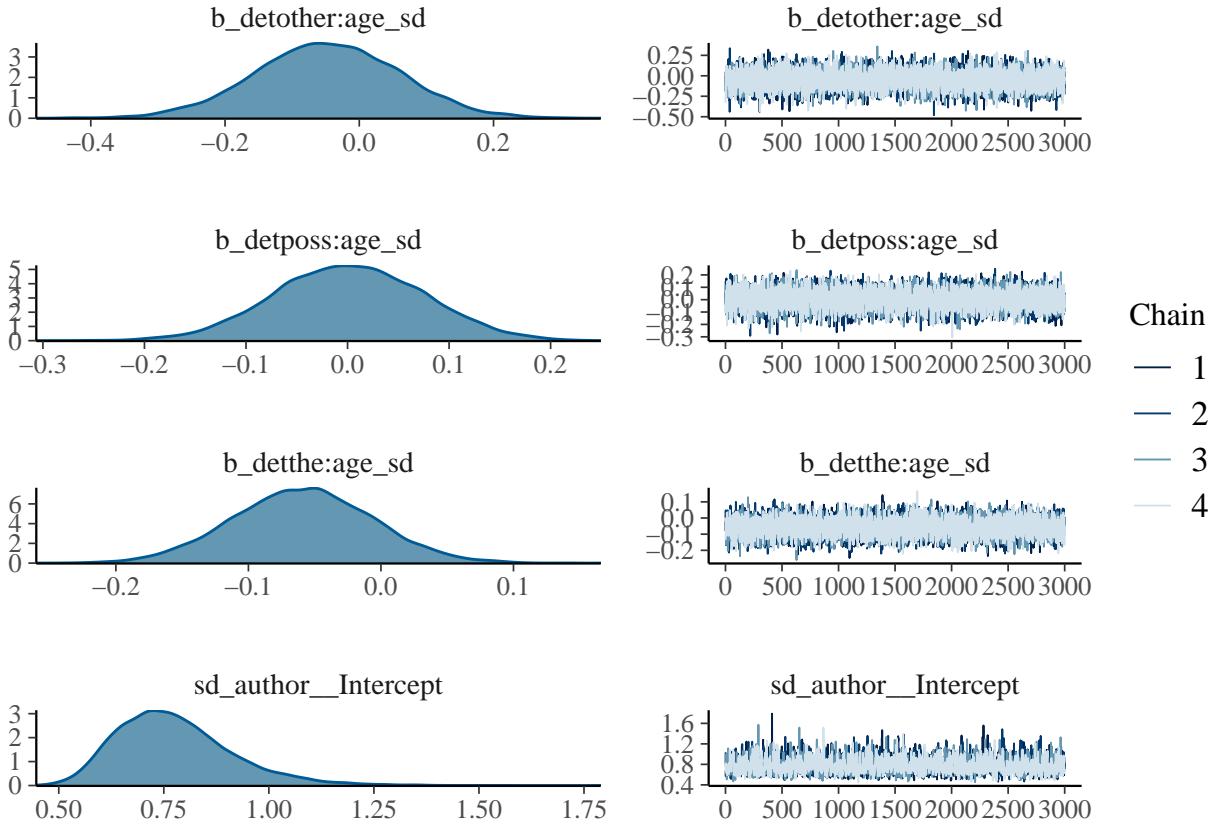
Run and save model:

```
## intercept + b_bare*bare + b_poss*poss + b_the*the + b_other*other ##
## regularizing prior for beta coefficients - helps sampling ##
M3_full_author_int <- brm(gerund ~ det*age_sd + (1|author), data=df, family = bernoulli(),
                           chains = 4, iter = 4000, warmup = 1000, cores = 4,
                           prior = c(set_prior("normal(0, 1)", "b")),
                           save_model = "M3_full_author_int.stan",
                           file = "M3_full_author_int",
                           file_refit="never")
```

Plot + coefficient table:

```
# inspect trace plots for divergences - traces should be well-mixed #
plot(M3_full_author_int)
```

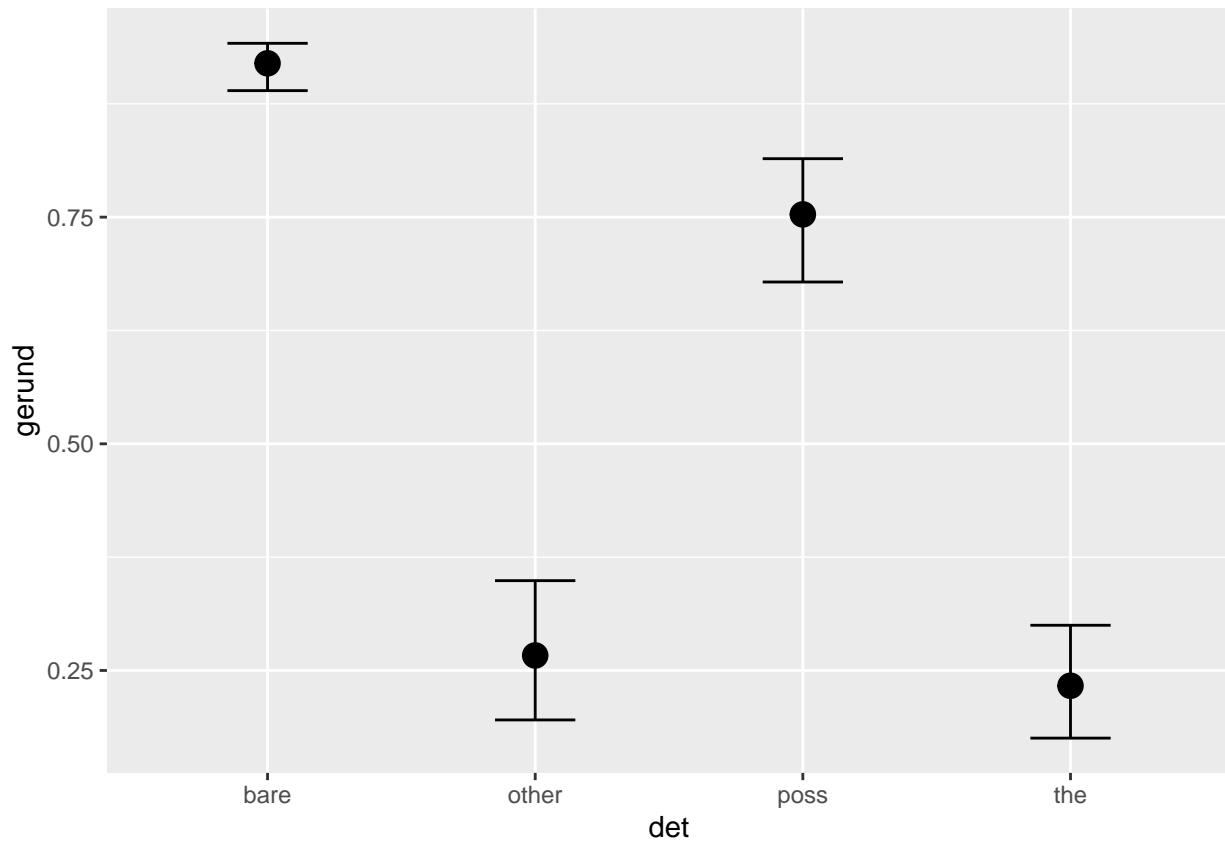


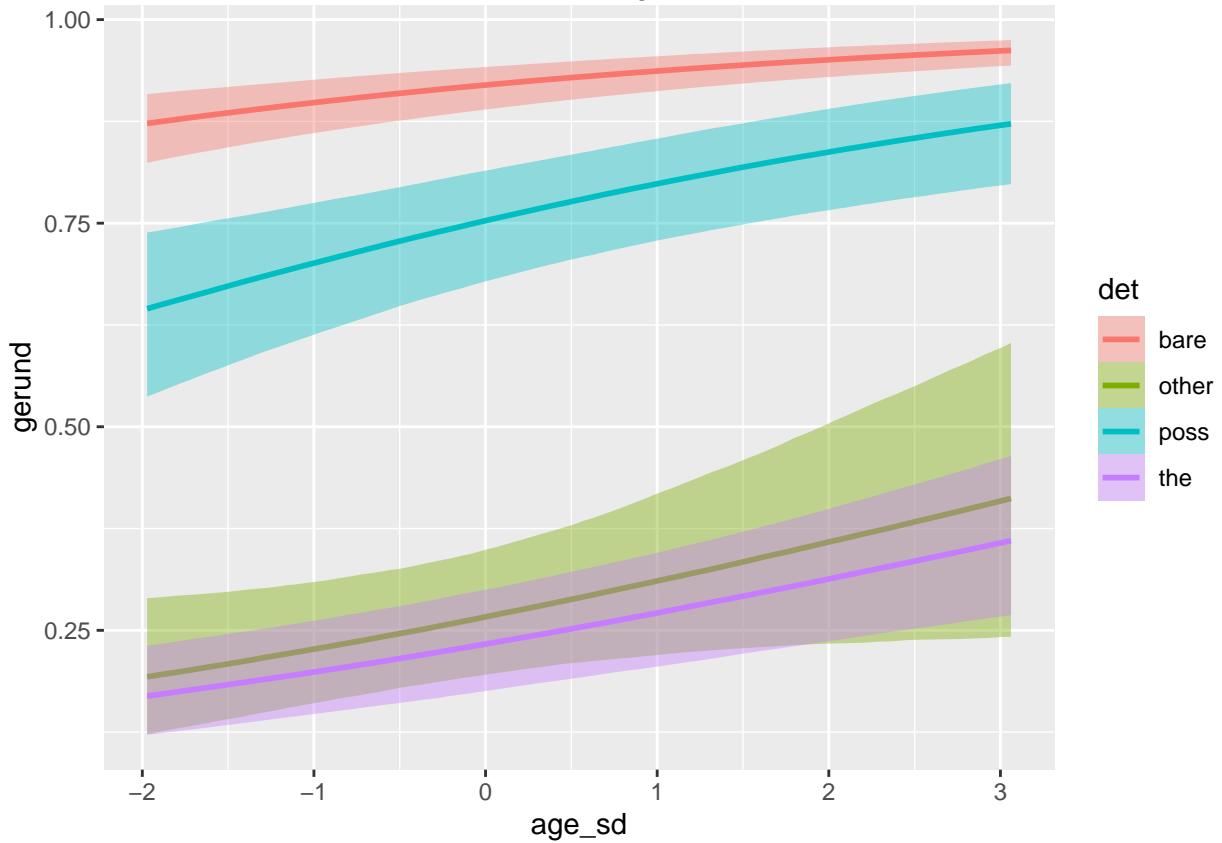
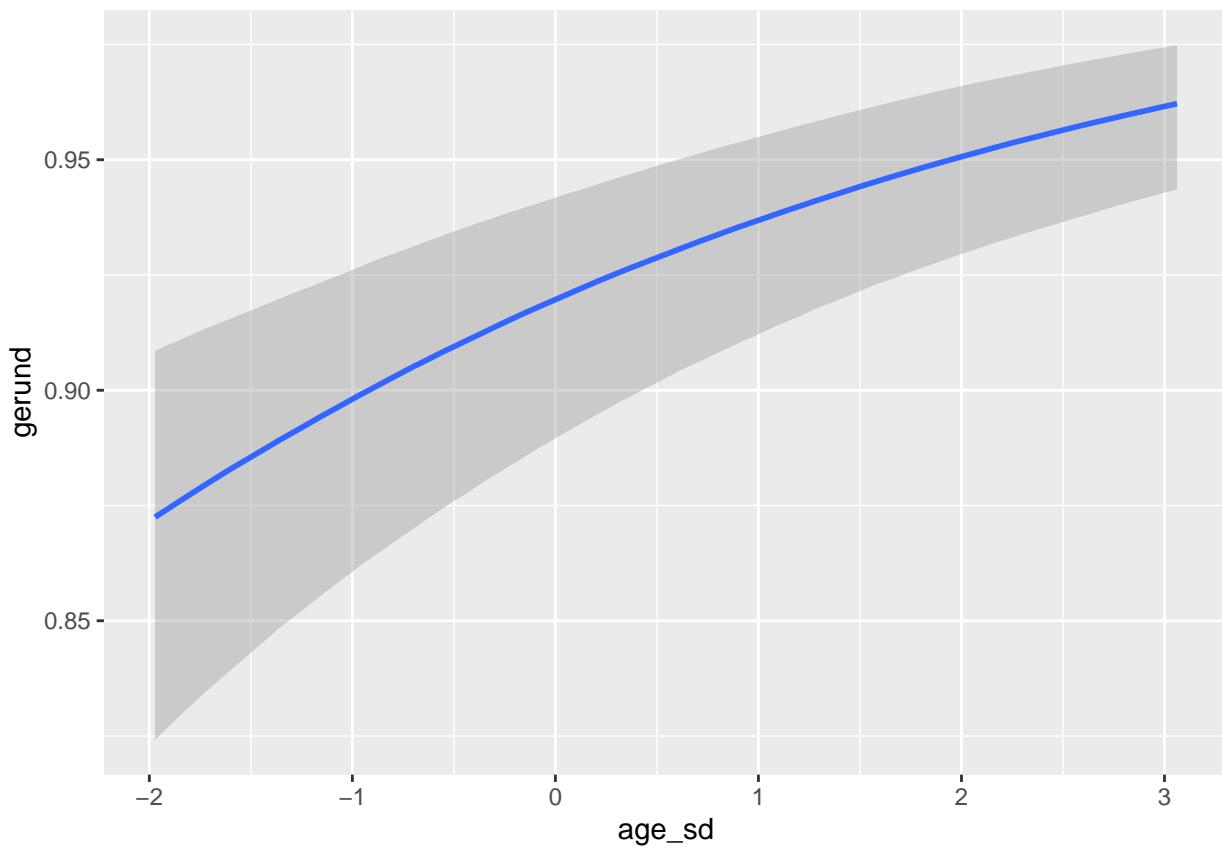


```
# summary of coefficients - rhats should be close to 1 #
summary(M3_full_author_int)
```

```
## Family: bernoulli
## Links: mu = logit
## Formula: gerund ~ det * age_sd + (1 | author)
## Data: df (Number of observations: 16629)
## Draws: 4 chains, each with iter = 4000; warmup = 1000; thin = 1;
##         total post-warmup draws = 12000
##
## Group-Level Effects:
## ~author (Number of levels: 21)
##             Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sd(Intercept)    0.78     0.14     0.56     1.09 1.00    2310    3892
##
## Population-Level Effects:
##             Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept        2.44     0.18     2.09     2.78 1.00    1672    3084
## detother       -3.45     0.11    -3.67    -3.23 1.00   11608    8811
## detposs        -1.32     0.08    -1.48    -1.16 1.00   11626    7307
## detthe         -3.63     0.05    -3.74    -3.52 1.00   11672    9451
## age_sd          0.26     0.04     0.19     0.34 1.00    8119    8855
## detother:age_sd -0.05     0.11    -0.26     0.16 1.00   10193    7474
## detposs:age_sd   0.00     0.07    -0.14     0.14 1.00   10235    9065
## detthe:age_sd   -0.06     0.05    -0.16     0.04 1.00    9149    9368
##
## Draws were sampled using sampling(NUTS). For each parameter, Bulk_ESS
## and Tail_ESS are effective sample size measures, and Rhat is the potential
```

```
## scale reduction factor on split chains (at convergence, Rhat = 1).  
# posterior predictive distribution #  
conditional_effects(M3_full_author_int)
```





Add WAIC:

```
# add waic for model comparison #
M3_full_author_int <- add_criterion(M3_full_author_int, 'waic', file="M3_full_author_int")
```

Add loo:

```
# add waic for model comparison #
M3_full_author_int <- add_criterion(M3_full_author_int, 'loo', file="M3_full_author_int")
```

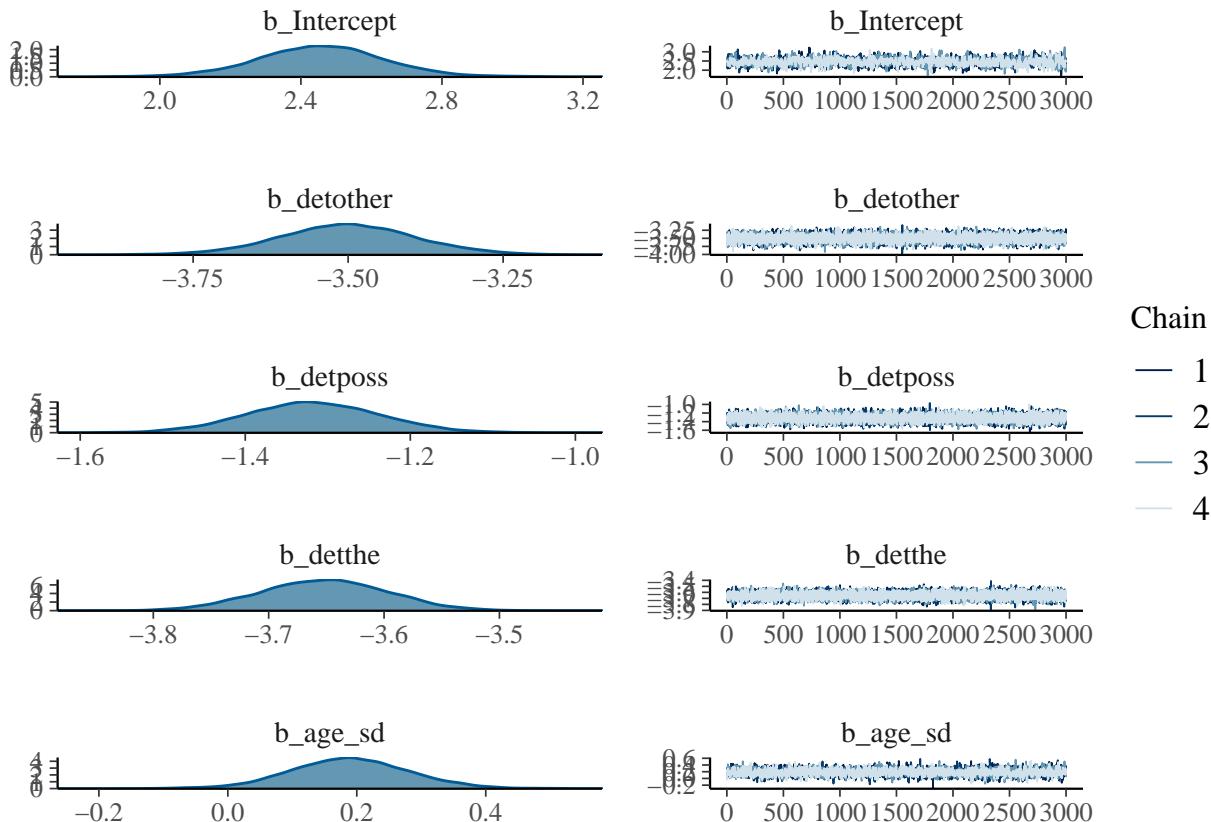
Age and Determiner + age slope

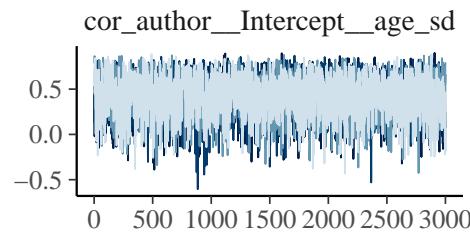
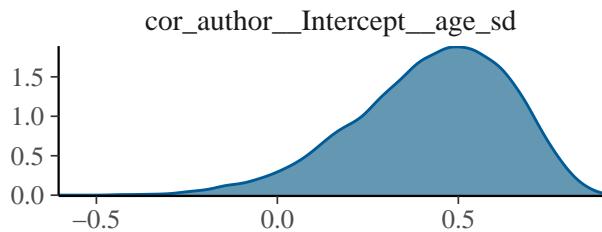
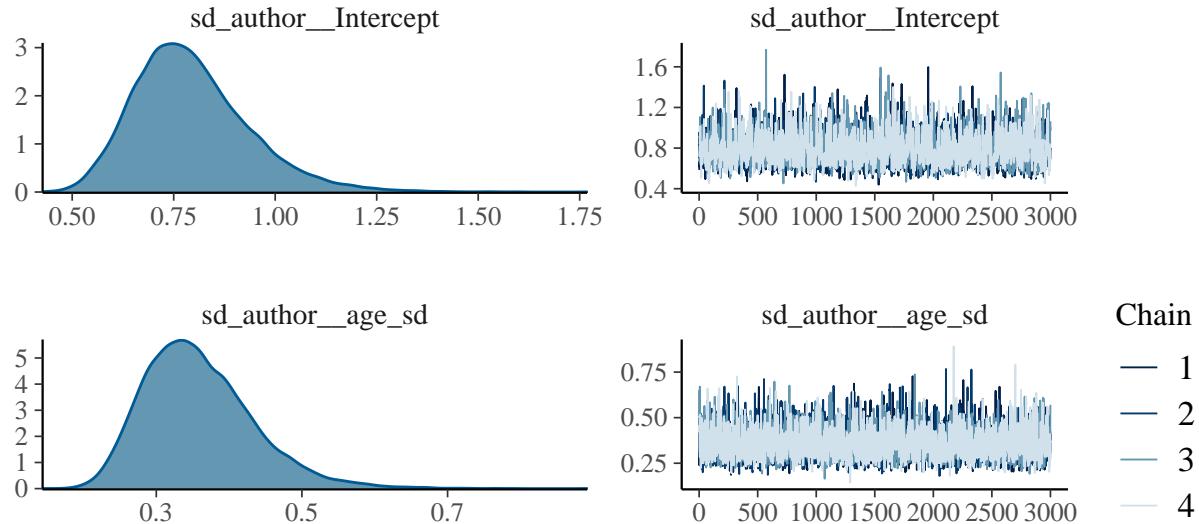
Run and save model:

```
## regularizing prior for (i) beta coefficients, (ii) lkj prior, (iii) cauchy - helps sampling ##
M3_full_author_slope_age <- brm(gerund ~ det + age_sd + (age_sd|author), data=df,
                                family = bernoulli(),
                                chains = 4, iter = 4000, warmup = 1000, cores = 4,
                                prior = c(set_prior("normal(0, 1)", "b"),
                                          set_prior("lkj(2)", "cor"),
                                          set_prior("normal(0, 5)", "Intercept"),
                                          set_prior("cauchy(0, 2)", "sd")),
                                save_model = "M3_full_author_slope_age.stan",
                                file = "M3_full_author_slope_age",
                                file_refit="never")
```

Plot + coefficient table:

```
plot(M3_full_author_slope_age)
```

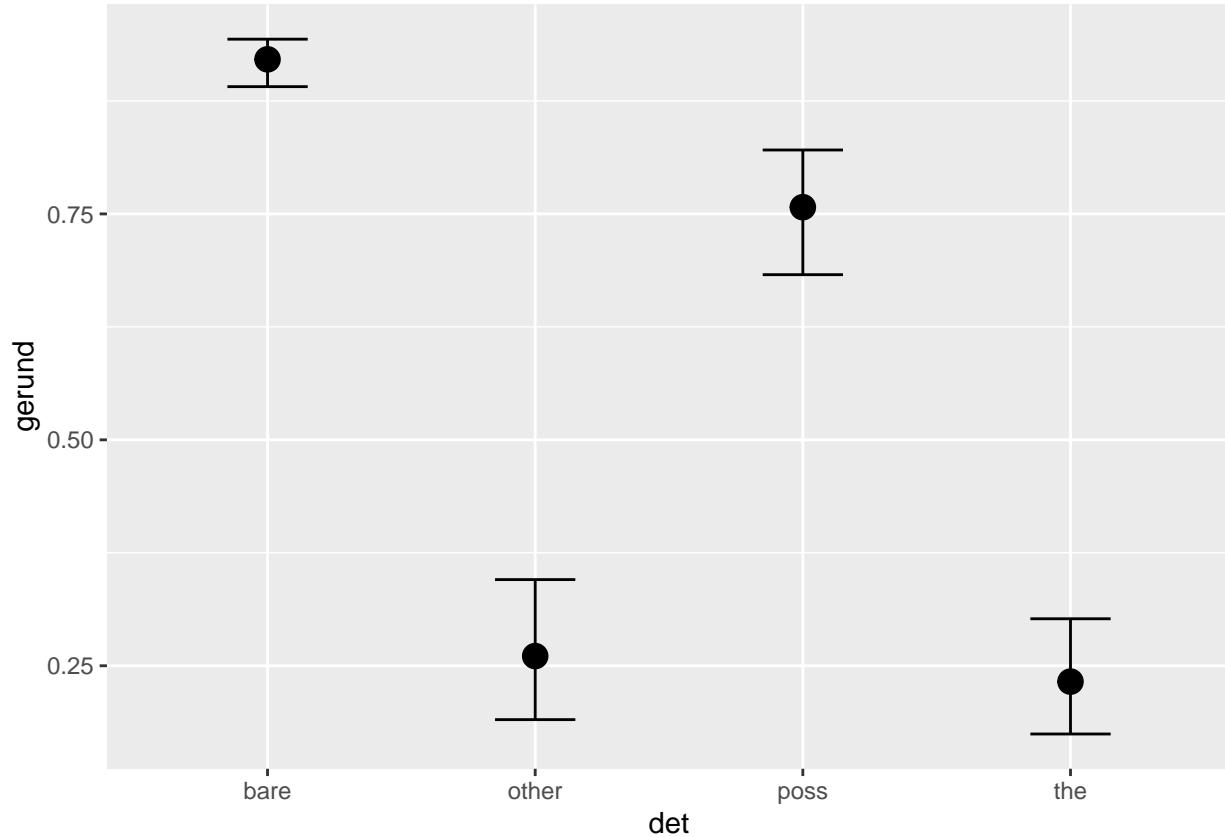


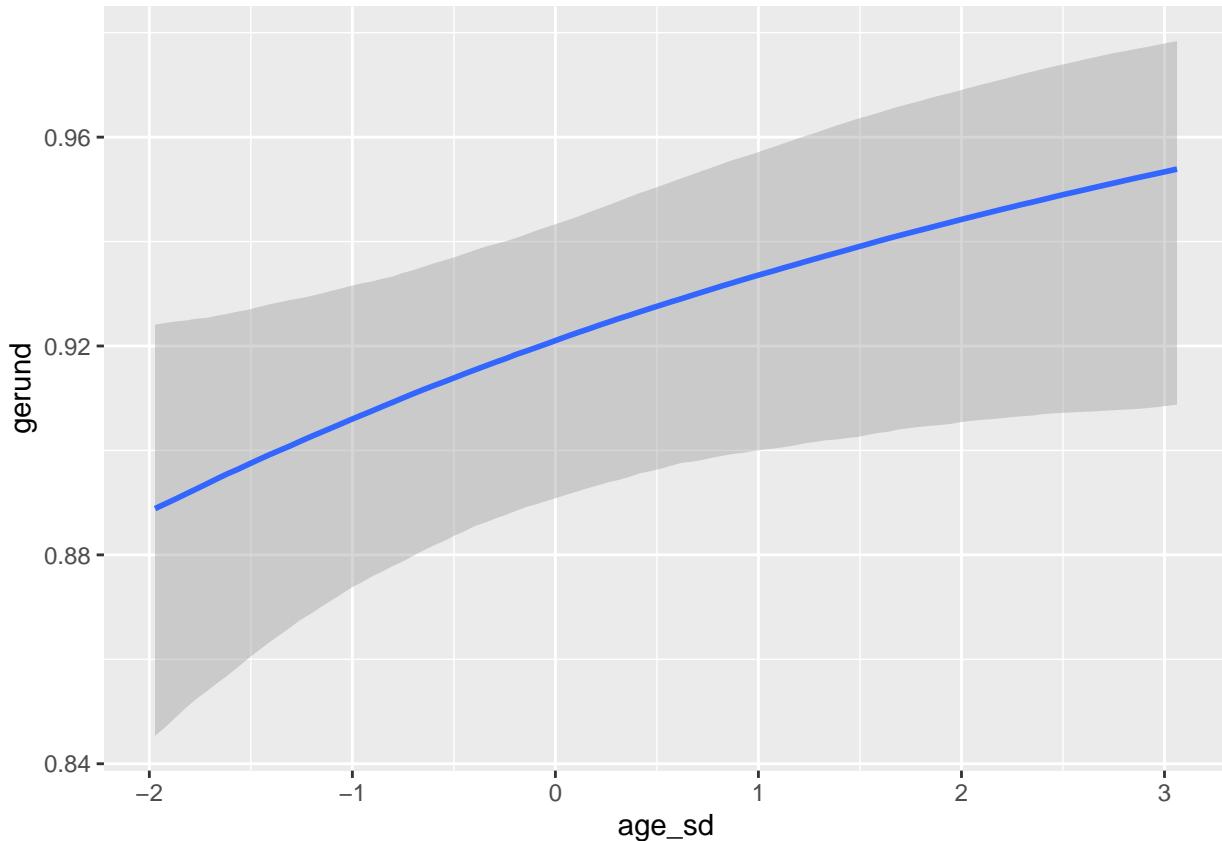


```
summary(M3_full_author_slope_age)
```

```
## Family: bernoulli
## Links: mu = logit
## Formula: gerund ~ det + age_sd + (age_sd | author)
## Data: df (Number of observations: 16629)
## Draws: 4 chains, each with iter = 4000; warmup = 1000; thin = 1;
##          total post-warmup draws = 12000
##
## Group-Level Effects:
## ~author (Number of levels: 21)
##             Estimate Est.Error 1-95% CI u-95% CI Rhat Bulk_ESS
## sd(Intercept)    0.79     0.14    0.56    1.12 1.00    2326
## sd(age_sd)      0.36     0.08    0.24    0.53 1.00    4107
## cor(Intercept,age_sd) 0.42     0.21   -0.05    0.77 1.00    3870
##                               Tail_ESS
## sd(Intercept)        4048
## sd(age_sd)          6527
## cor(Intercept,age_sd) 6040
##
## Population-Level Effects:
##             Estimate Est.Error 1-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept      2.46     0.18    2.10    2.81 1.00    1556    2545
## detother     -3.50     0.11   -3.72   -3.28 1.00   12446    9150
## detposs      -1.32     0.08   -1.48   -1.16 1.00   14131    8125
## detthe       -3.65     0.05   -3.76   -3.55 1.00   12976    9513
## age_sd        0.19     0.09    0.01    0.37 1.00    2965    5318
##
```

```
## Draws were sampled using sampling(NUTS). For each parameter, Bulk_ESS  
## and Tail_ESS are effective sample size measures, and Rhat is the potential  
## scale reduction factor on split chains (at convergence, Rhat = 1).  
conditional_effects(M3_full_author_slope_age)
```





Add WAIC:

```
M3_full_author_slope_age <- add_criterion(M3_full_author_slope_age, 'waic', file="M3_full_author_slope_a...
```

Add loo:

```
M3_full_author_slope_age <- add_criterion(M3_full_author_slope_age, 'loo', file="M3_full_author_slope_a...
```

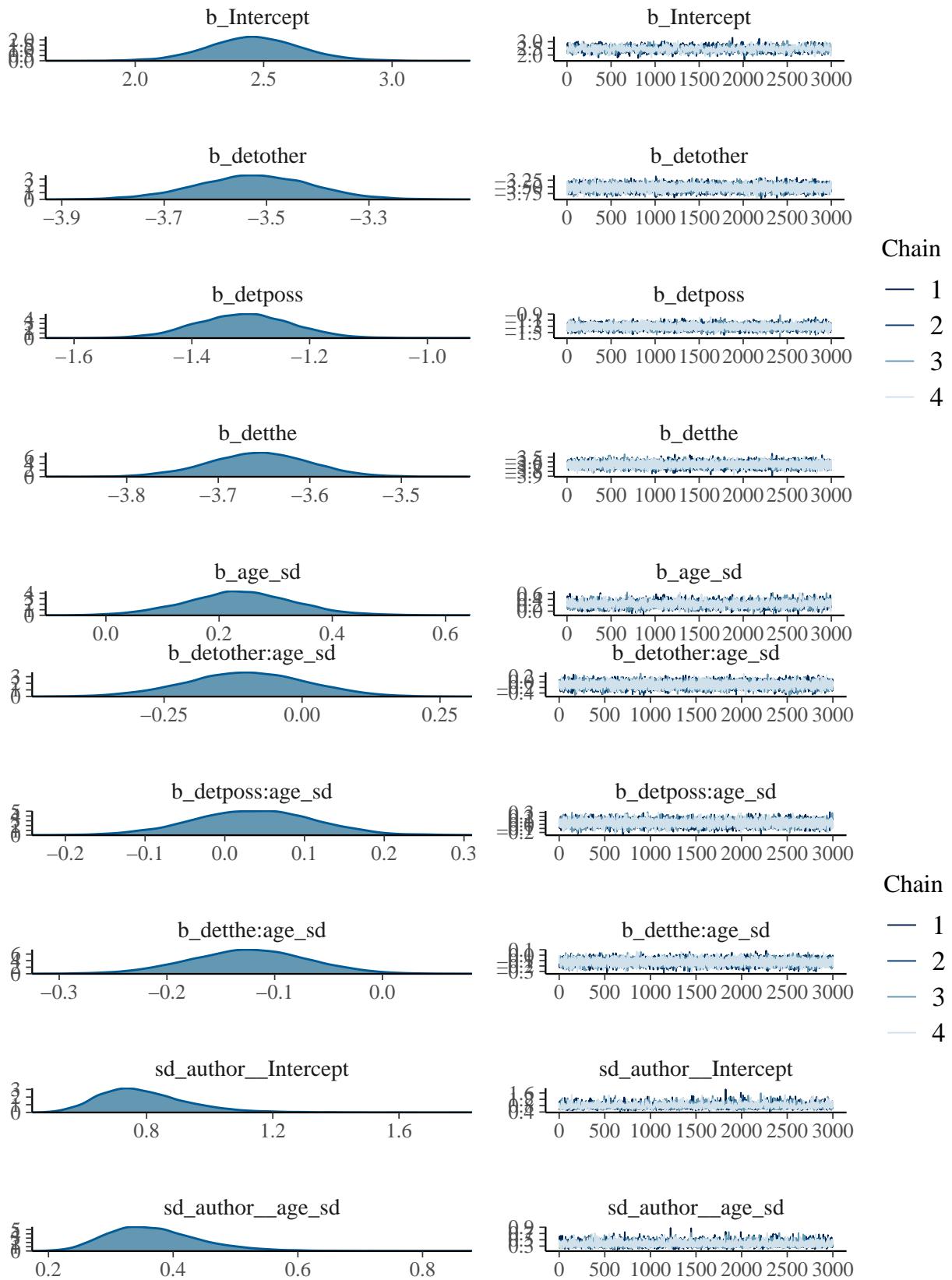
Age and Determiner Interaction + age slope

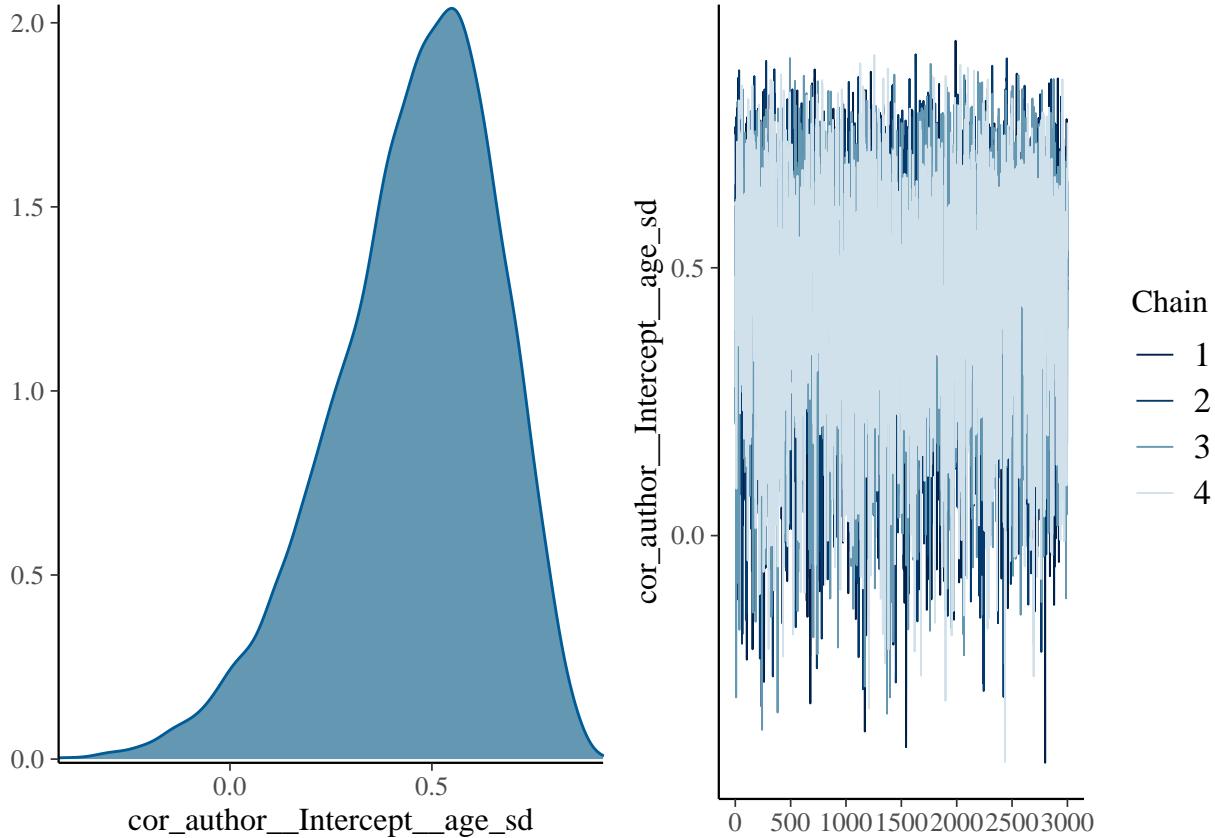
Run and save model:

```
## regularizing prior for (i) beta coefficients, (ii) lkj prior, (iii) cauchy - helps sampling ##
M3_full_author_slope_age_int <- brm(gerund ~ det*age_sd + (age_sd|author), data=df,
                                    family = bernoulli(),
                                    chains = 4, iter = 4000, warmup = 1000, cores = 4,
                                    prior = c(set_prior("normal(0, 1)", "b"),
                                              set_prior("lkj(2)", "cor"),
                                              set_prior("normal(0, 5)", "Intercept"),
                                              set_prior("cauchy(0, 2)", "sd")),
                                    save_model = "M3_full_author_slope_age_int.stan",
                                    file = "M3_full_author_slope_age_int",
                                    file_refit="never")
```

Plot + coefficient table:

```
plot(M3_full_author_slope_age_int)
```





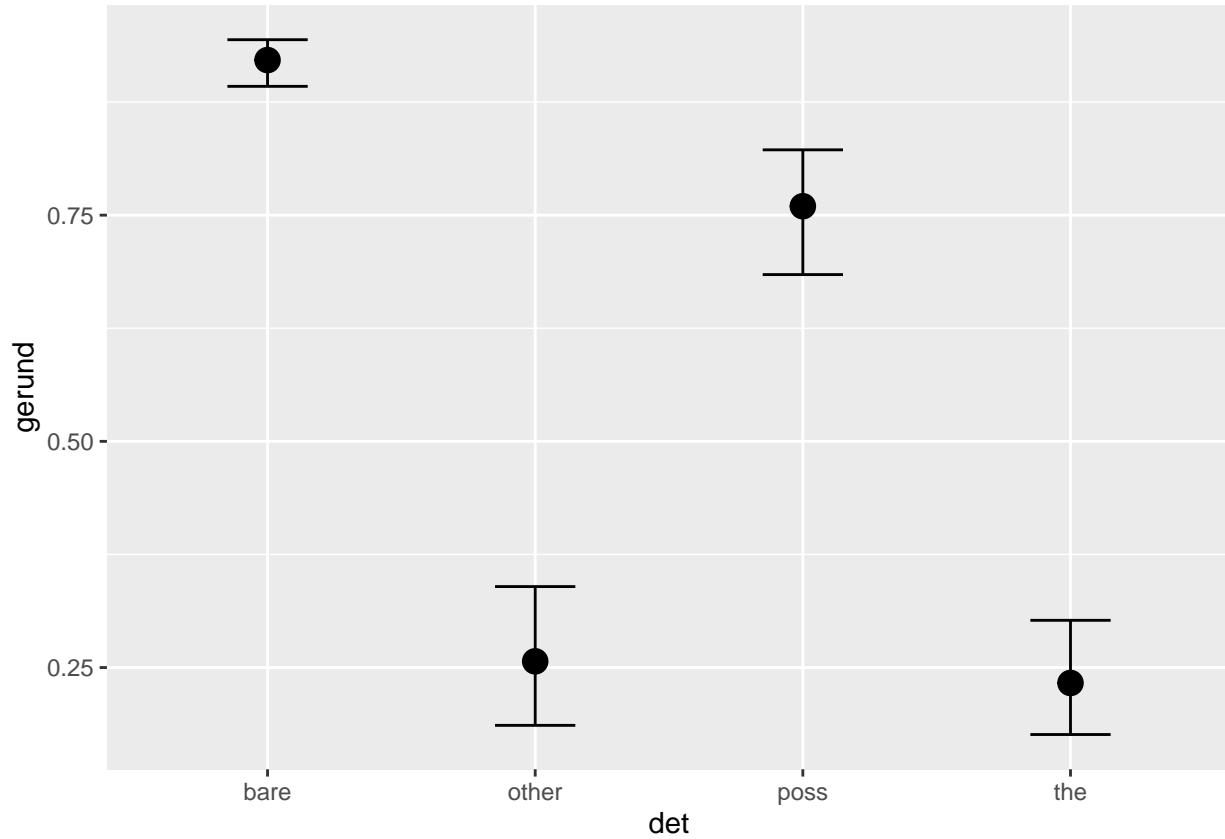
```
summary(M3_full_author_slope_age_int)
```

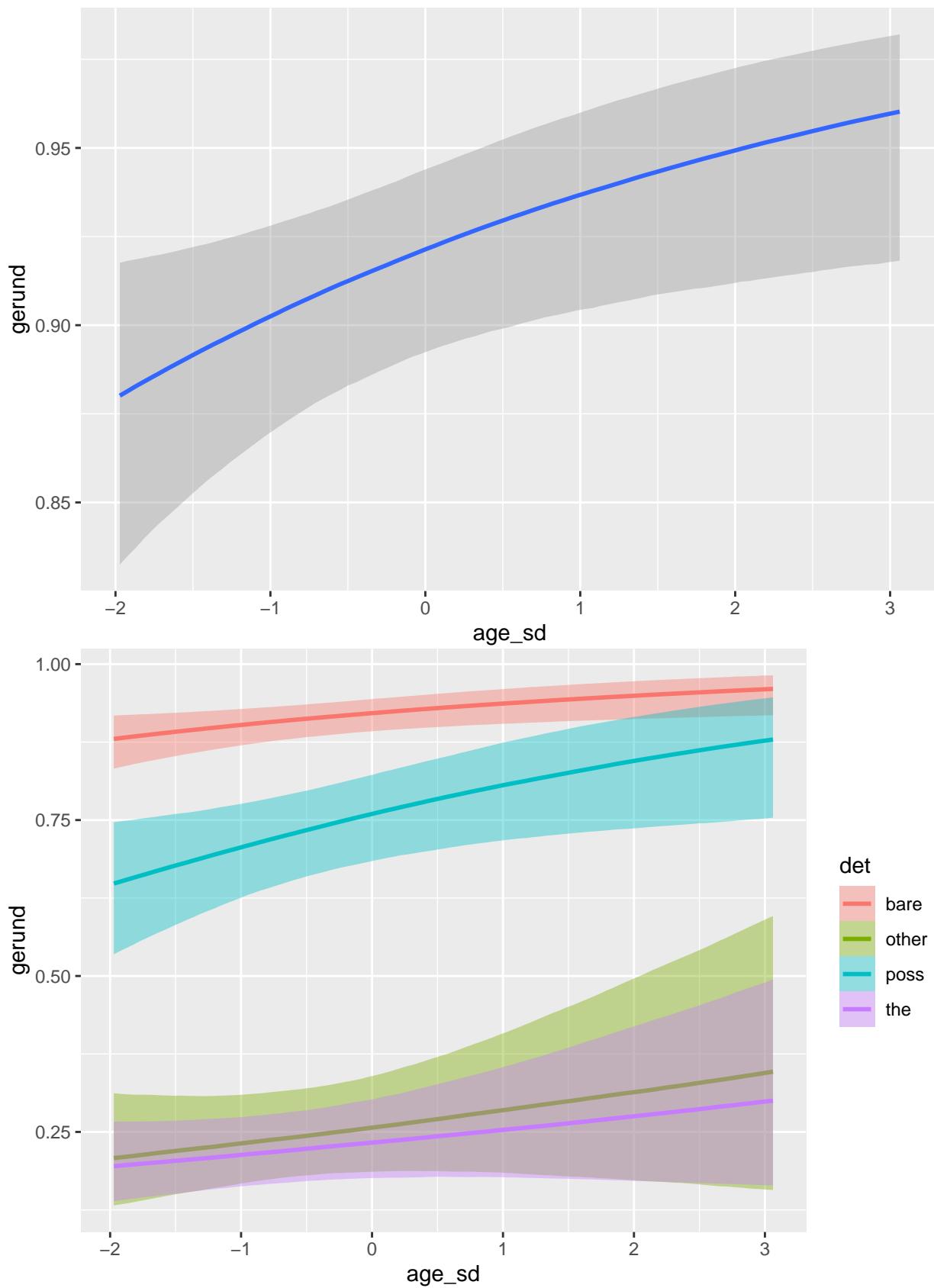
```
## Family: bernoulli
## Links: mu = logit
## Formula: gerund ~ det * age_sd + (age_sd | author)
## Data: df (Number of observations: 16629)
## Draws: 4 chains, each with iter = 4000; warmup = 1000; thin = 1;
##         total post-warmup draws = 12000
##
## Group-Level Effects:
## ~author (Number of levels: 21)
##             Estimate Est.Error 1-95% CI u-95% CI Rhat Bulk_ESS
## sd(Intercept)     0.79      0.14    0.57    1.12 1.00    2692
## sd(age_sd)       0.37      0.08    0.25    0.54 1.00    4739
## cor(Intercept,age_sd) 0.46      0.21   -0.01    0.79 1.00    4515
##                         Tail_ESS
## sd(Intercept)       4463
## sd(age_sd)          7609
## cor(Intercept,age_sd) 6859
##
## Population-Level Effects:
##             Estimate Est.Error 1-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept        2.46      0.18    2.12    2.82 1.00    1583    3194
## detother       -3.53      0.11   -3.75   -3.31 1.00    14752   9575
## detposs        -1.31      0.08   -1.47   -1.15 1.00    15500   8466
## detthe         -3.66      0.06   -3.76   -3.55 1.00    14225   7859
## age_sd          0.24      0.10    0.05    0.43 1.00    3605   5355
```

```

## detother:age_sd    -0.10      0.11     -0.31      0.11  1.00    16263    9483
## detposs:age_sd     0.04      0.08     -0.11      0.18  1.00    16128    9491
## detthe:age_sd     -0.12      0.05     -0.23     -0.02  1.00    15102    9359
##
## Draws were sampled using sampling(NUTS). For each parameter, Bulk_ESS
## and Tail_ESS are effective sample size measures, and Rhat is the potential
## scale reduction factor on split chains (at convergence, Rhat = 1).
conditional_effects(M3_full_author_slope_age_int)

```





Add WAIC:

```
M3_full_author_slope_age_int <- add_criterion(M3_full_author_slope_age_int, 'waic', file="M3_full_author
```

Add loo:

```
M3_full_author_slope_age_int <- add_criterion(M3_full_author_slope_age_int, 'loo', file="M3_full_author
```

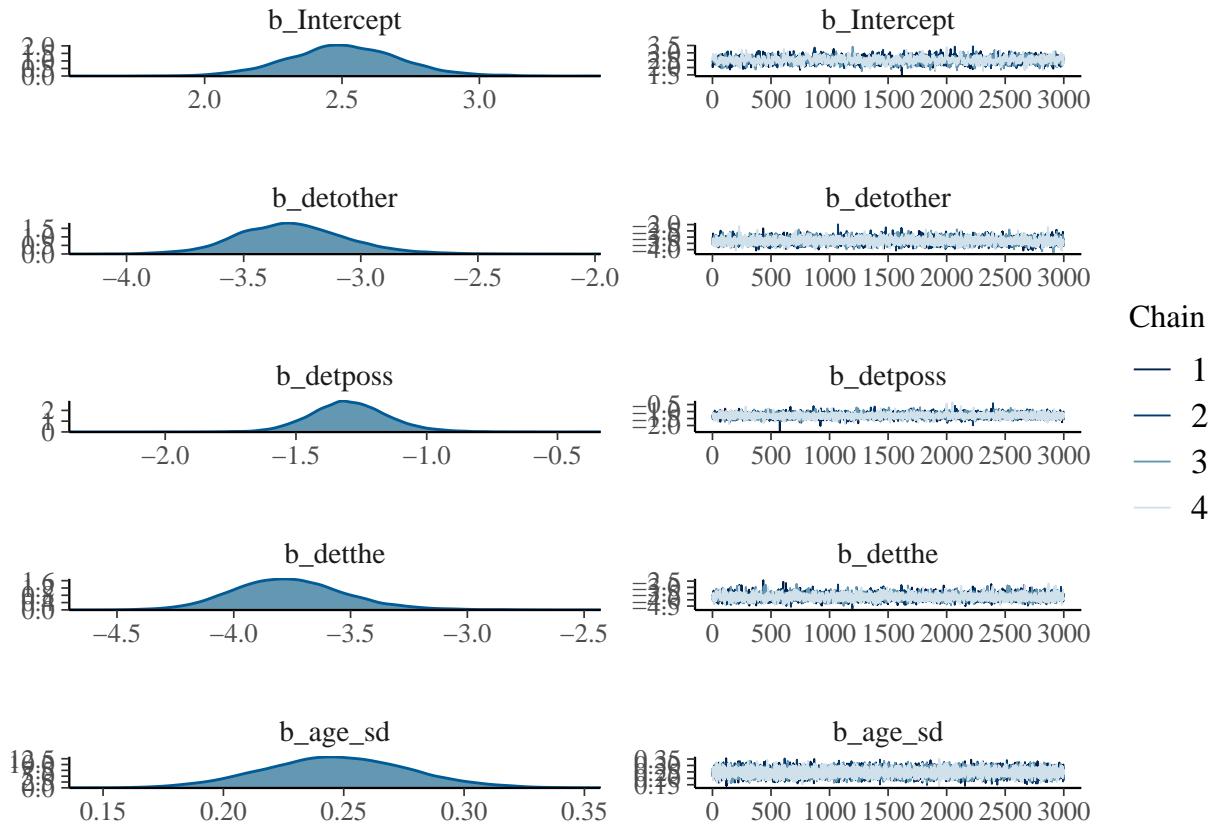
Age and Determiner + determiner slope

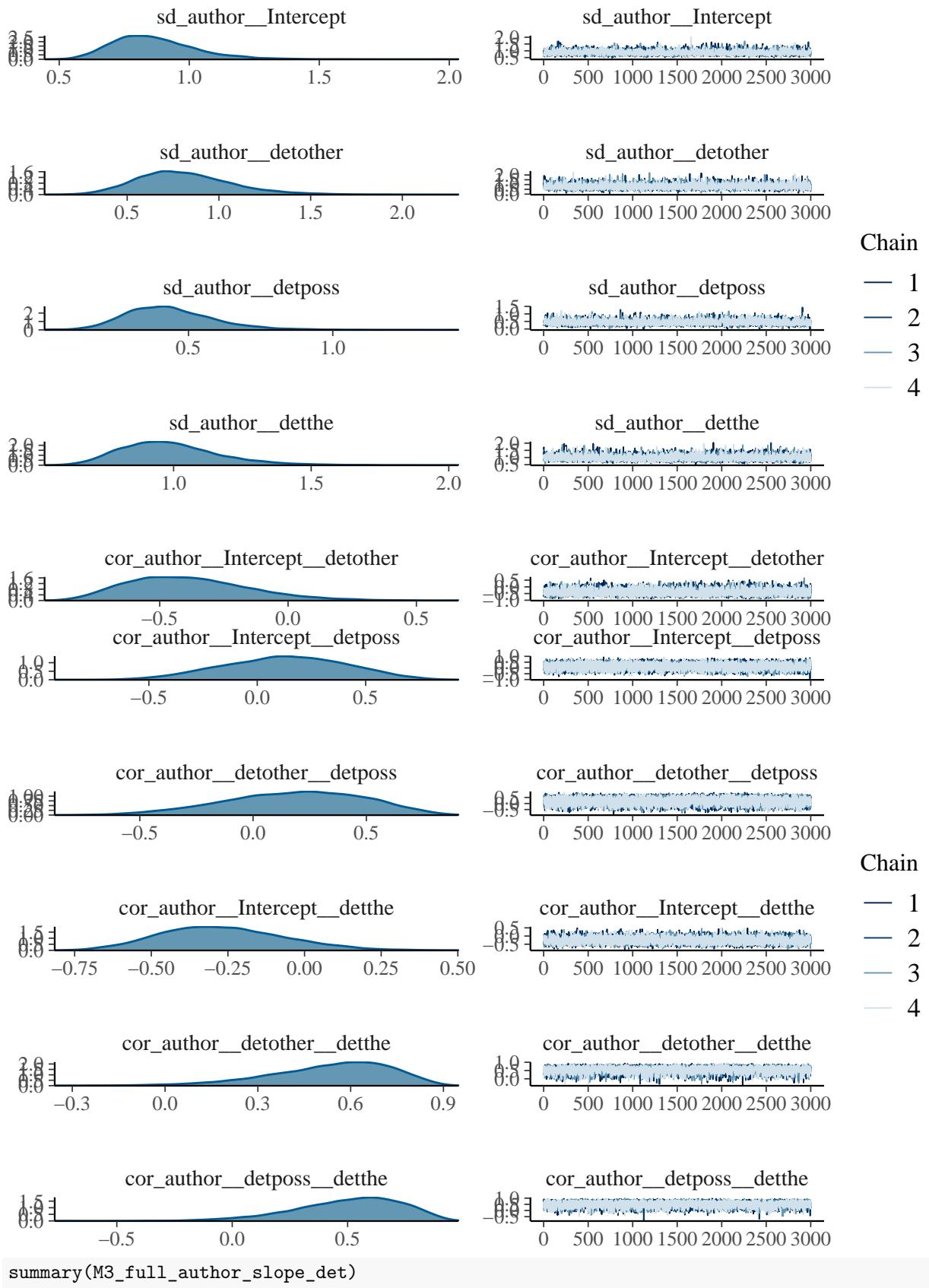
Run and save model:

```
## regularizing prior for (i) beta coefficients, (ii) lkj prior, (iii) cauchy - helps sampling ##
M3_full_author_slope_det <- brm(gerund ~ det + age_sd + (det|author), data=df,
  family = bernoulli(),
  chains = 4, iter = 4000, warmup = 1000, cores = 4,
  prior = c(set_prior("normal(0, 1)", "b"),
            set_prior("lkj(2)", "cor"),
            set_prior("normal(0, 5)", "Intercept"),
            set_prior("cauchy(0, 2)", "sd")),
  save_model = "M3_full_author_slope_det.stan",
  file = "M3_full_author_slope_det",
  file_refit="never")
```

Plot + coefficient table:

```
plot(M3_full_author_slope_det)
```

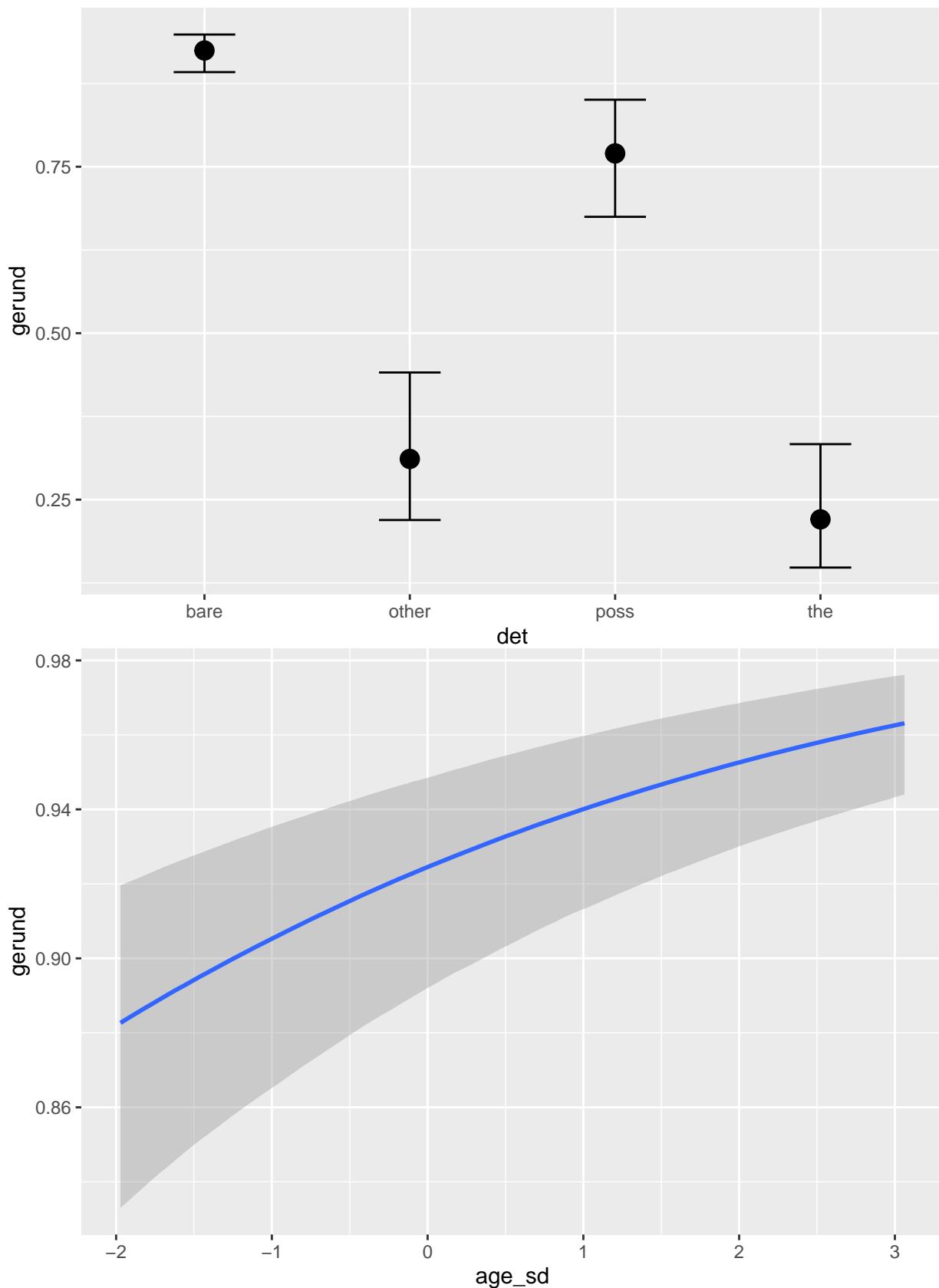




```

##  Family: bernoulli
##  Links: mu = logit
## Formula: gerund ~ det + age_sd + (det | author)
## Data: df (Number of observations: 16629)
## Draws: 4 chains, each with iter = 4000; warmup = 1000; thin = 1;
##         total post-warmup draws = 12000
##
## Group-Level Effects:
## ~author (Number of levels: 21)
##             Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS
## sd(Intercept)     0.86     0.16     0.61     1.23 1.00    3366
## sd(detother)      0.81     0.26     0.37     1.40 1.00    4563
## sd(detposs)       0.43     0.15     0.18     0.78 1.00    4523
## sd(detthe)        0.99     0.18     0.70     1.41 1.00    4795
## cor(Intercept,detother) -0.39     0.23    -0.77     0.12 1.00    6836
## cor(Intercept,detposs)   0.13     0.28    -0.42     0.65 1.00   11314
## cor(detother,detposs)   0.18     0.30    -0.44     0.72 1.00    7674
## cor(Intercept,detthe)   -0.27     0.20    -0.62     0.15 1.00    5904
## cor(detother,detthe)    0.54     0.19     0.09     0.83 1.00    4898
## cor(detposs,detthe)     0.50     0.23    -0.02     0.87 1.00    5275
##             Tail_ESS
## sd(Intercept)      6806
## sd(detother)       6275
## sd(detposs)        5278
## sd(detthe)         7310
## cor(Intercept,detother) 9195
## cor(Intercept,detposs) 9576
## cor(detother,detposs) 9410
## cor(Intercept,detthe) 7580
## cor(detother,detthe) 6981
## cor(detposs,detthe) 7635
##
## Population-Level Effects:
##             Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept      2.51     0.20     2.11     2.91 1.00    1589    3241
## detother     -3.29     0.23    -3.73    -2.80 1.00    4057    5865
## detposs      -1.29     0.15    -1.57    -0.98 1.00    6459    6708
## detthe       -3.76     0.24    -4.20    -3.25 1.00    3996    6032
## age_sd        0.25     0.03     0.19     0.31 1.00   22153    8305
##
## Draws were sampled using sampling(NUTS). For each parameter, Bulk_ESS
## and Tail_ESS are effective sample size measures, and Rhat is the potential
## scale reduction factor on split chains (at convergence, Rhat = 1).
conditional_effects(M3_full_author_slope_det)

```



Add WAIC:

```
M3_full_author_slope_det <- add_criterion(M3_full_author_slope_det, 'waic', file="M3_full_author_slope_det.waic")
```

Add loo:

```
M3_full_author_slope_det <- add_criterion(M3_full_author_slope_det, 'loo', file="M3_full_author_slope_det.loo")
```

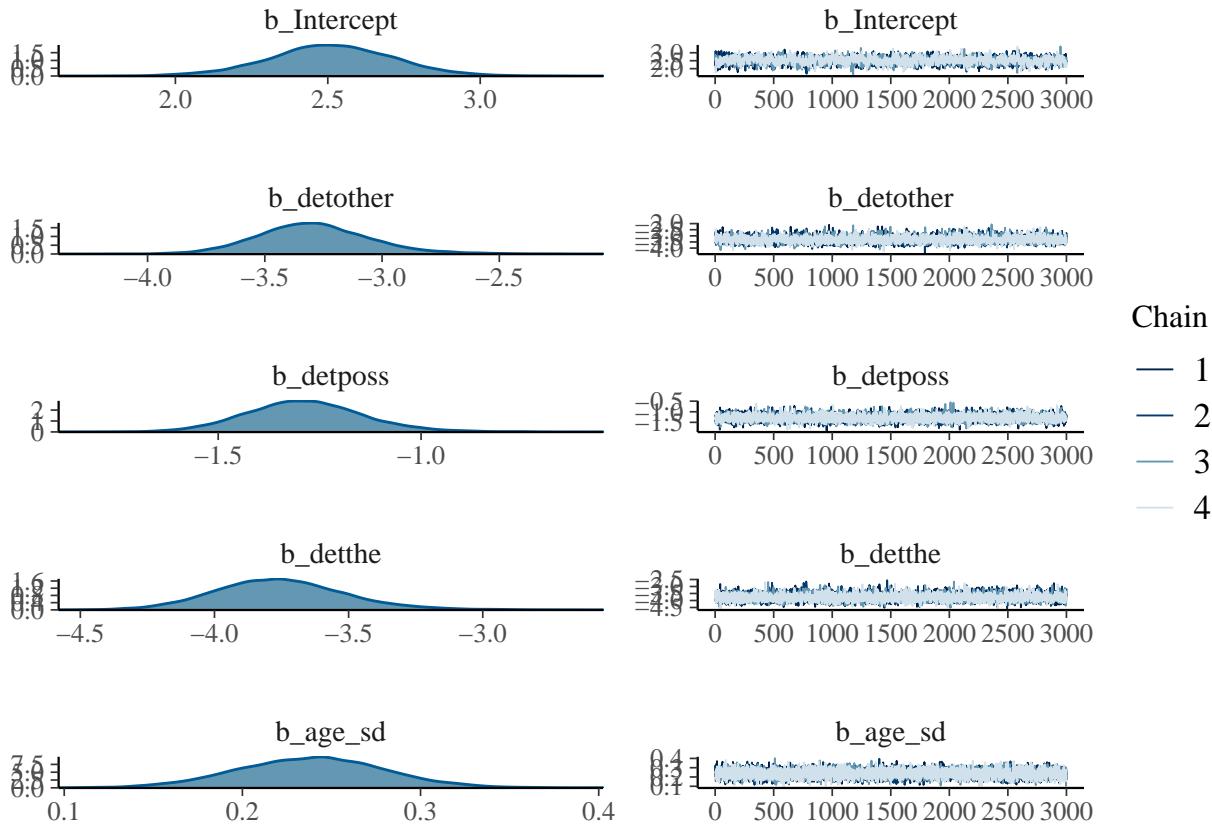
Age and Determiner Interaction + determiner slope

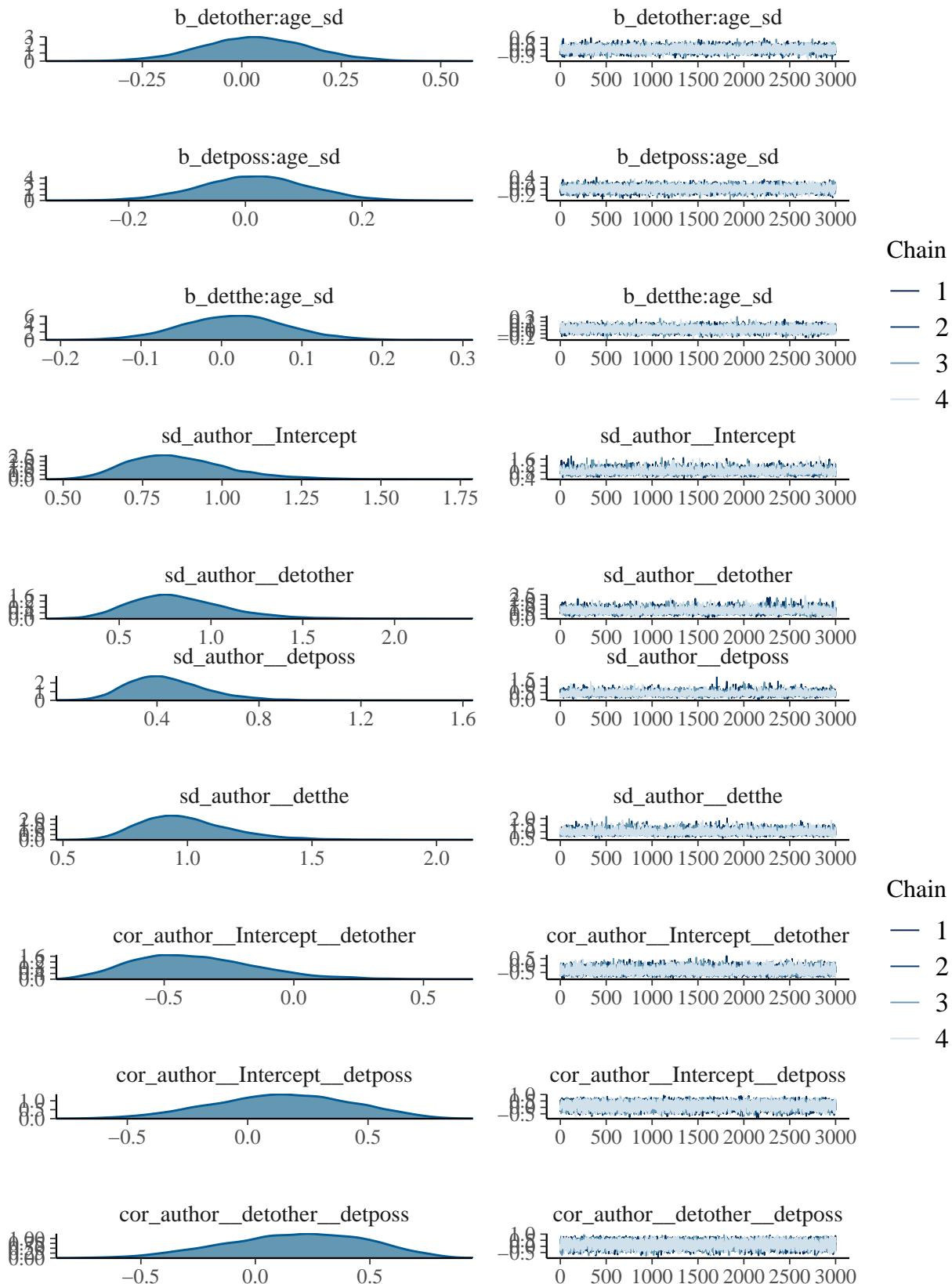
Run and save model:

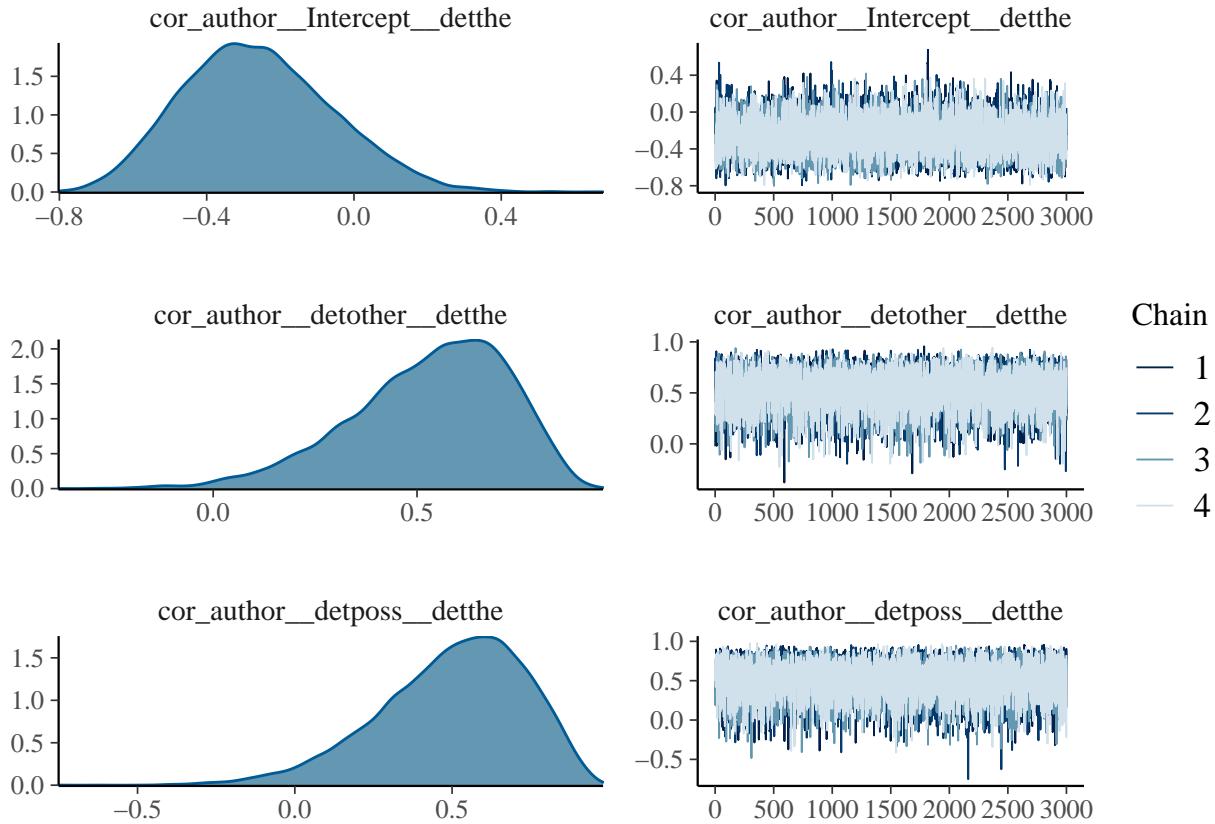
```
## regularizing prior for (i) beta coefficients, (ii) lkj prior, (iii) cauchy - helps sampling ##
M3_full_author_slope_det_int <- brm(gerund ~ det*age_sd + (det|author), data=df,
                                    family = bernoulli(),
                                    chains = 4, iter = 4000, warmup = 1000, cores = 4,
                                    prior = c(set_prior("normal(0, 1)", "b"),
                                              set_prior("lkj(2)", "cor"),
                                              set_prior("normal(0, 5)", "Intercept"),
                                              set_prior("cauchy(0, 2)", "sd")),
                                    save_model = "M3_full_author_slope_det_int.stan",
                                    file = "M3_full_author_slope_det_int",
                                    file_refit="never")
```

Plot + coefficient table:

```
plot(M3_full_author_slope_det_int)
```







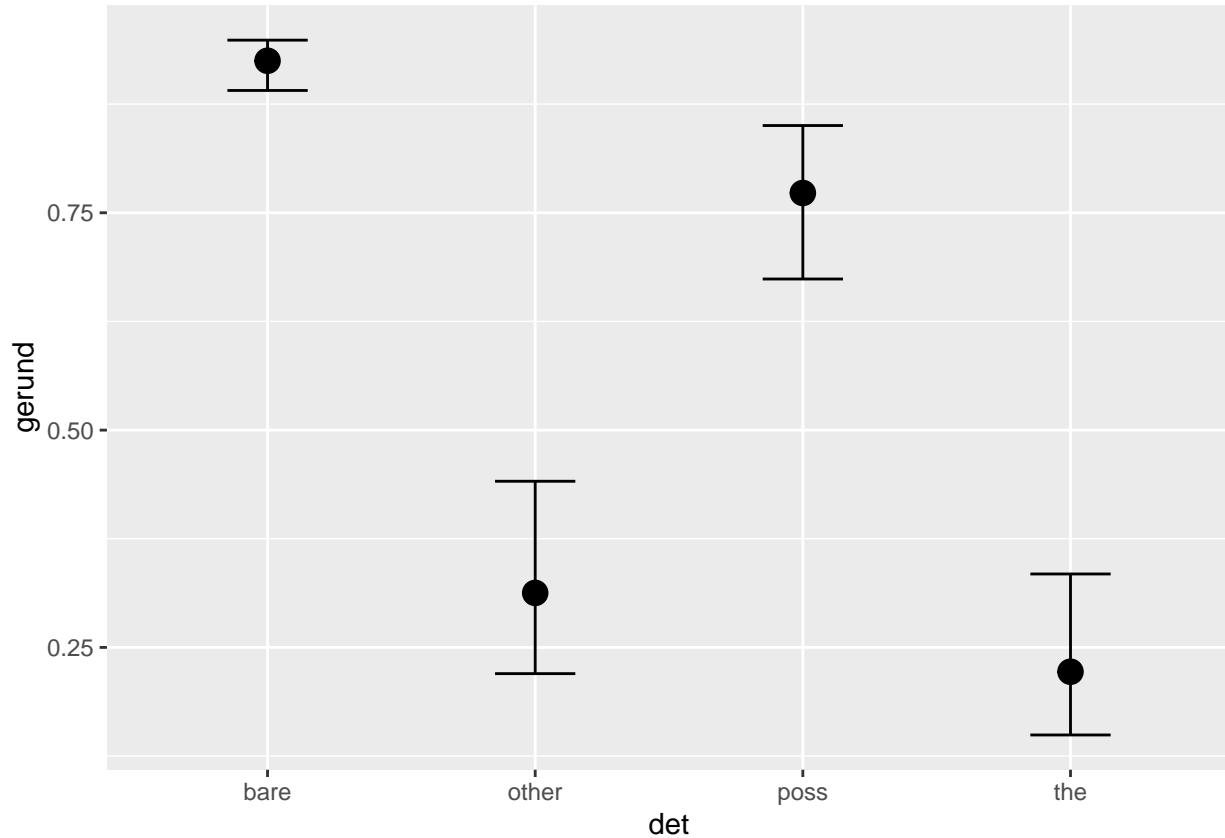
```
summary(M3_full_author_slope_det_int)
```

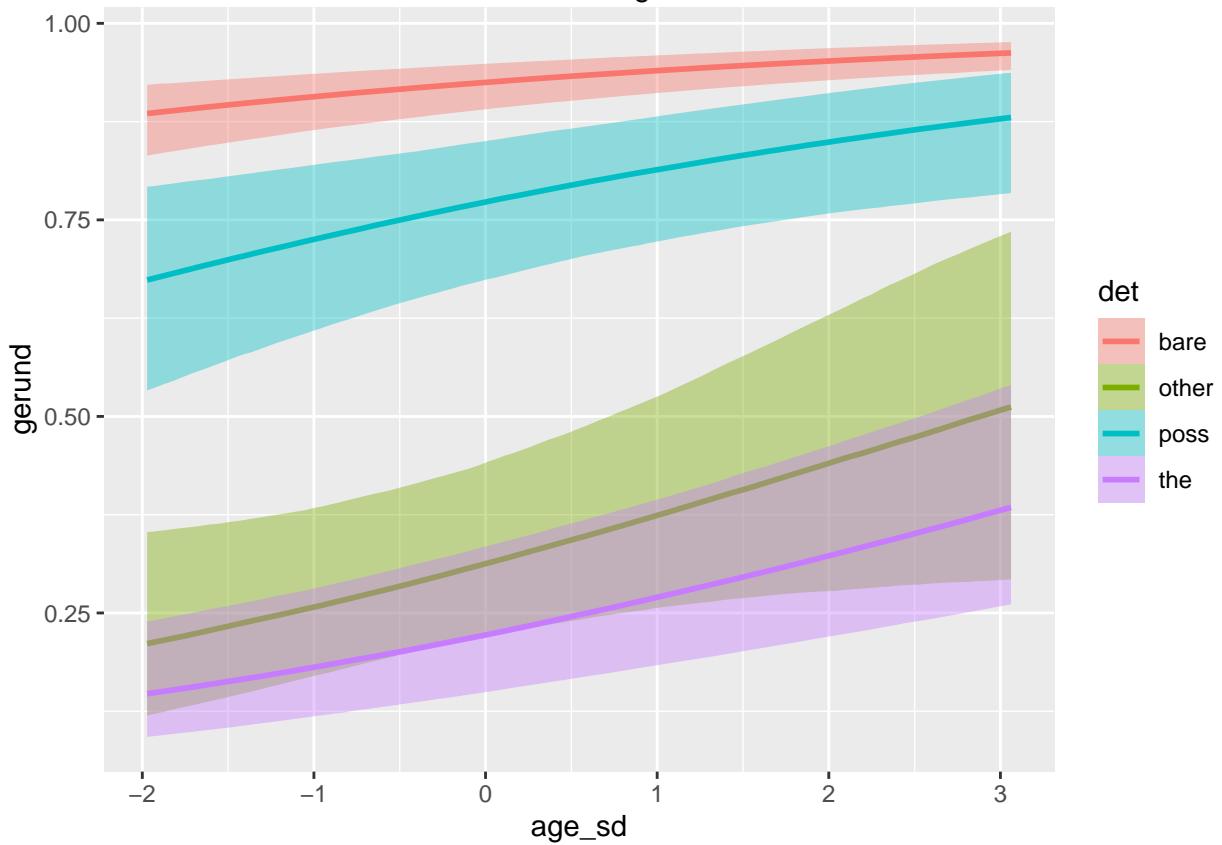
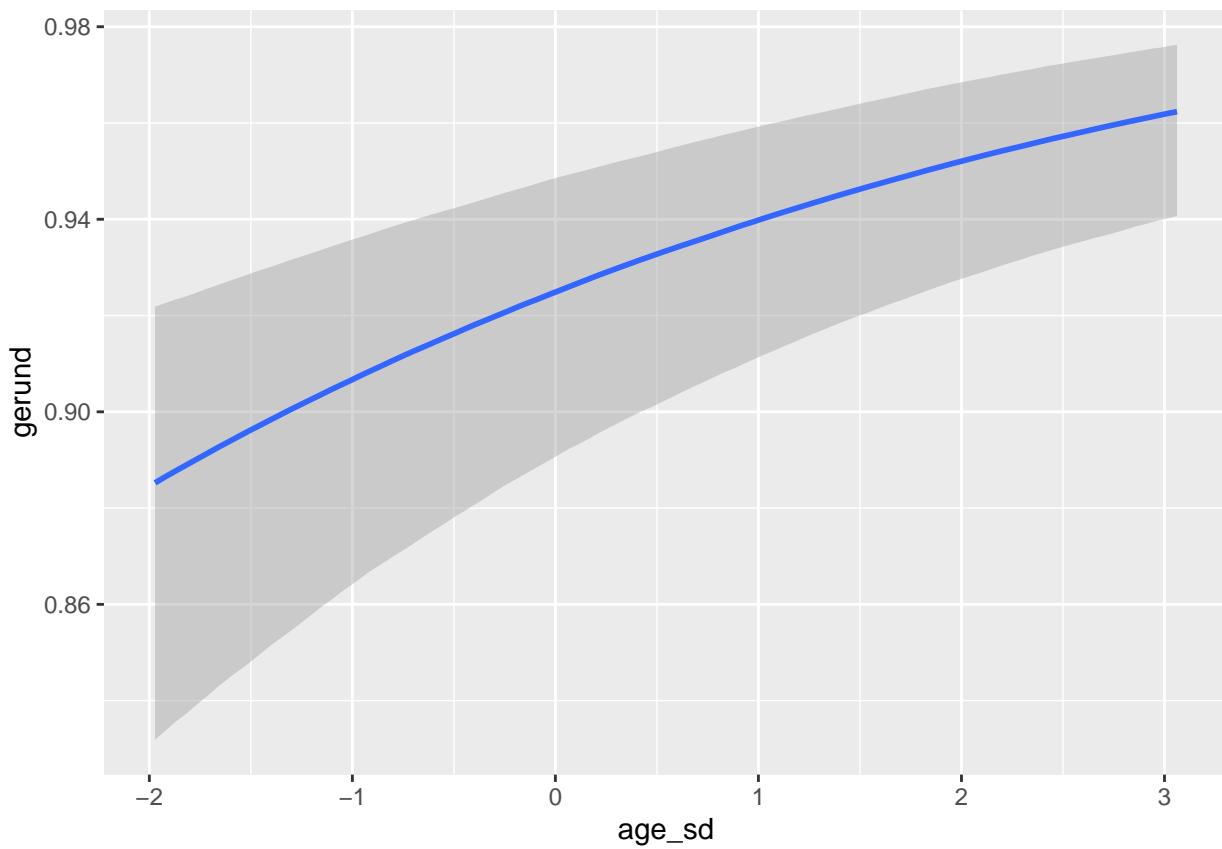
```
## Family: bernoulli
## Links: mu = logit
## Formula: gerund ~ det * age_sd + (det | author)
## Data: df (Number of observations: 16629)
## Draws: 4 chains, each with iter = 4000; warmup = 1000; thin = 1;
##          total post-warmup draws = 12000
##
## Group-Level Effects:
## ~author (Number of levels: 21)
##             Estimate Est.Error 1-95% CI u-95% CI Rhat Bulk_ESS
## sd(Intercept)    0.87     0.16    0.61    1.24 1.00   3903
## sd(detother)     0.83     0.27    0.39    1.42 1.00   4505
## sd(detposs)      0.44     0.16    0.18    0.79 1.00   5015
## sd(detthe)       0.99     0.18    0.70    1.42 1.00   5312
## cor(Intercept,detother) -0.38     0.23   -0.77    0.14 1.00   8863
## cor(Intercept,detposs)   0.14     0.28   -0.41    0.66 1.00  11092
## cor(detother,detposs)   0.18     0.30   -0.43    0.71 1.00   8259
## cor(Intercept,detthe)   -0.26     0.20   -0.62    0.16 1.00   7098
## cor(detother,detthe)    0.53     0.19    0.10    0.83 1.00   6098
## cor(detposs,detthe)     0.50     0.23   -0.02    0.86 1.00   6520
##             Tail_ESS
## sd(Intercept)    6245
## sd(detother)     6547
## sd(detposs)      5456
## sd(detthe)       7712
## cor(Intercept,detother) 8916
```

```

## cor(Intercept,detposs)      8725
## cor(detother,detposs)      10131
## cor(Intercept,detthe)       7643
## cor(detother,detthe)       7873
## cor(detposs,detthe)        8004
##
## Population-Level Effects:
##             Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept      2.51     0.21    2.10    2.91 1.00   2022    3846
## detother     -3.29     0.24   -3.73   -2.76 1.00   4760    5924
## detposs      -1.29     0.15   -1.56   -0.99 1.00   8499    9018
## detthe       -3.75     0.24   -4.20   -3.24 1.00   5559    5474
## age_sd        0.24     0.04    0.16    0.32 1.00  12706    9865
## detother:age_sd  0.03     0.13   -0.23    0.30 1.00  14167   10109
## detposs:age_sd  0.01     0.09   -0.17    0.19 1.00  12893   10435
## detthe:age_sd  0.02     0.06   -0.11    0.14 1.00  14776   9080
##
## Draws were sampled using sampling(NUTS). For each parameter, Bulk_ESS
## and Tail_ESS are effective sample size measures, and Rhat is the potential
## scale reduction factor on split chains (at convergence, Rhat = 1).
conditional_effects(M3_full_author_slope_det_int)

```





Add WAIC:

```
M3_full_author_slope_det_int <- add_criterion(M3_full_author_slope_det_int, 'waic', file="M3_full_author
```

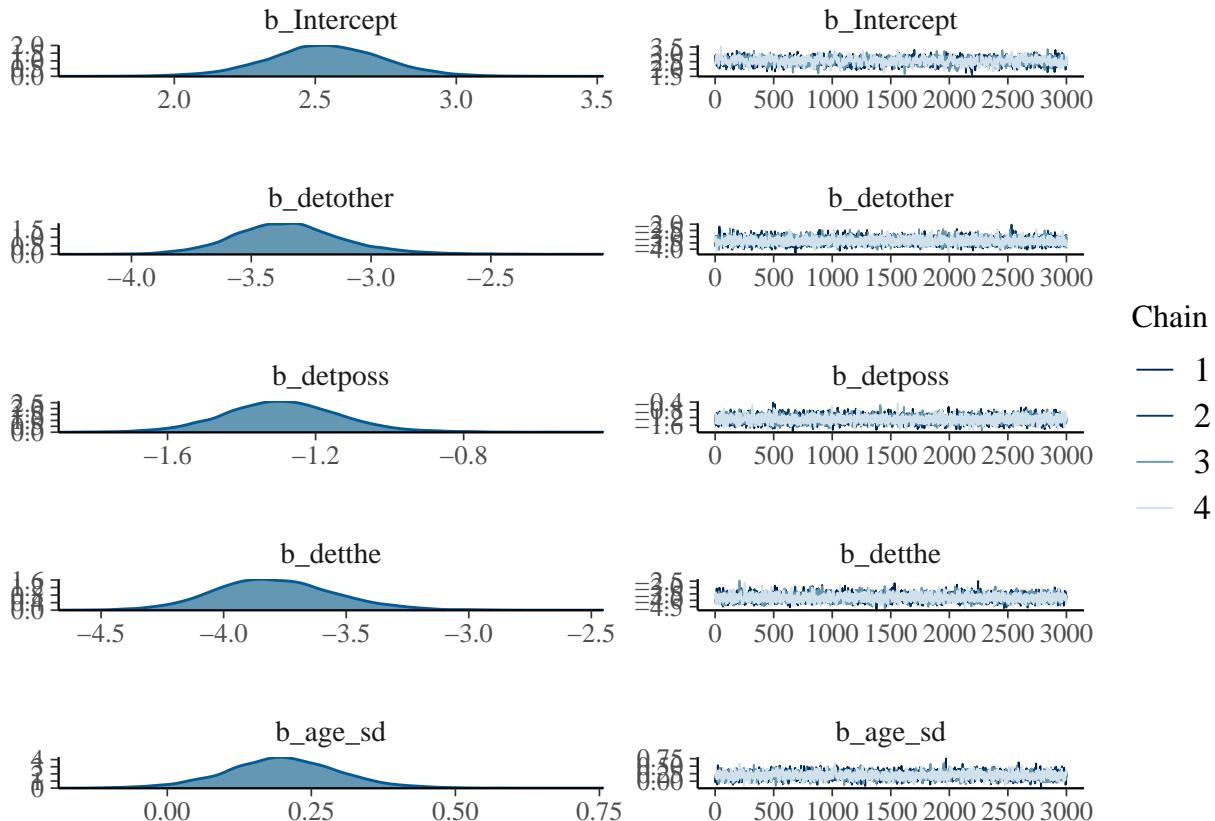
Add loo:

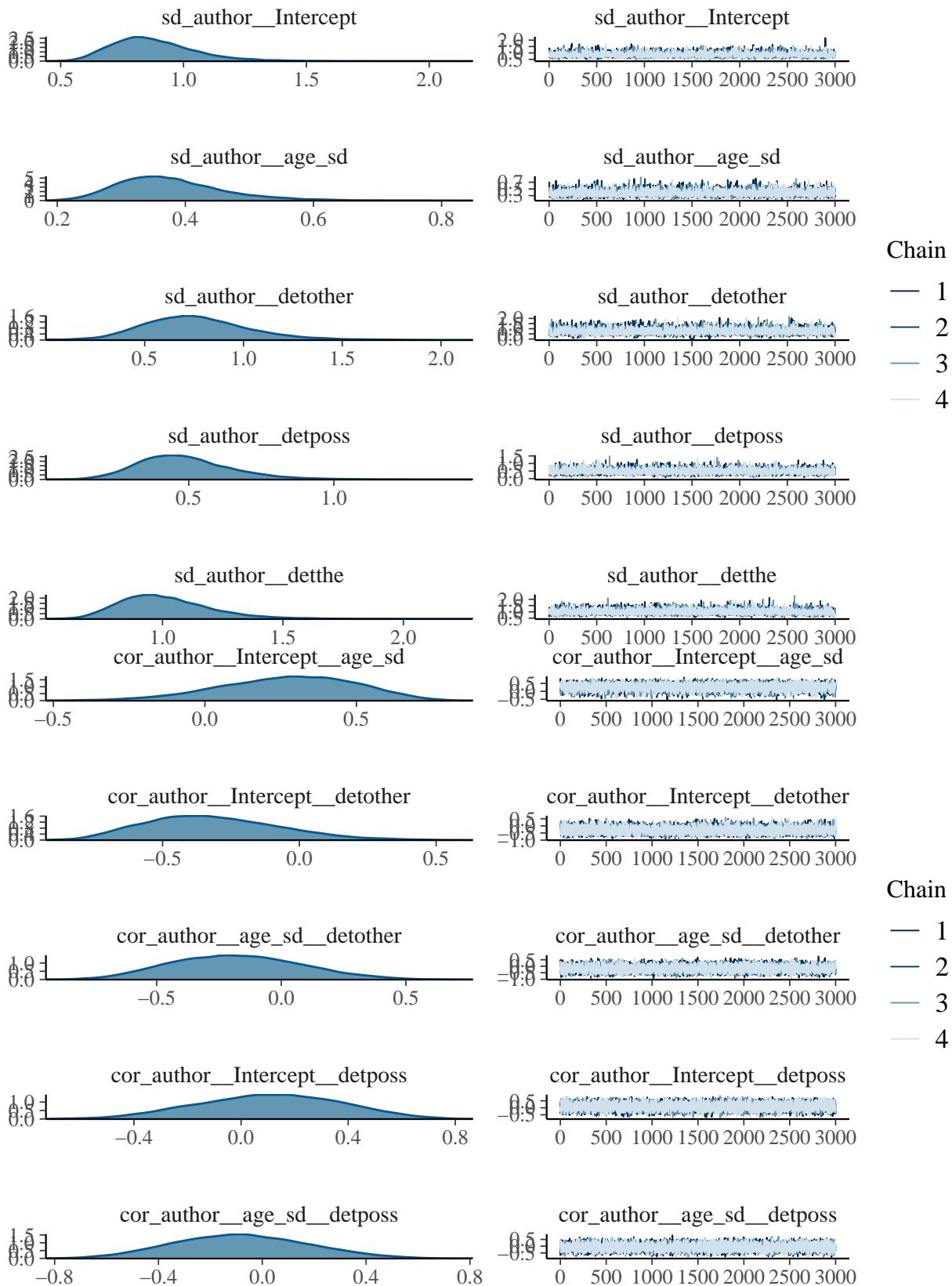
```
M3_full_author_slope_det_int <- add_criterion(M3_full_author_slope_det_int, 'loo', file="M3_full_author
```

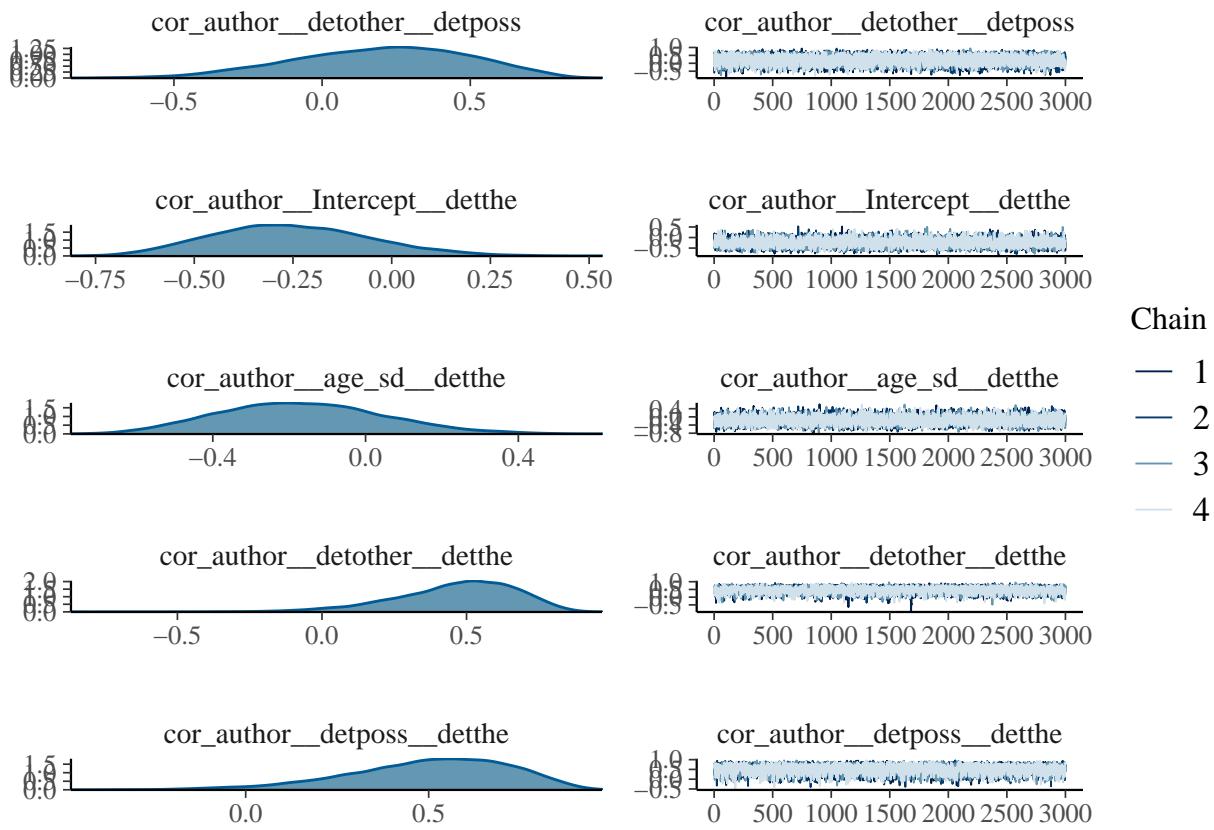
Age and Determiner + Age and determiner slope (no interaction)

```
## regularizing prior for (i) beta coefficients, (ii) lkj prior, (iii) cauchy - helps sampling ##
M3_full_author_slope_no_int <- brm(gerund ~ det + age_sd + (det+age_sd|author), data=df,
                                    family = bernoulli(),
                                    chains = 4, iter = 4000, warmup = 1000, cores = 4,
                                    prior = c(set_prior("normal(0, 1)", "b"),
                                              set_prior("lkj(2)", "cor"),
                                              set_prior("normal(0, 5)", "Intercept"),
                                              set_prior("cauchy(0, 2)", "sd")),
                                    save_model = "M3_full_author_slope_no_int.stan",
                                    file = "M3_full_author_slope_no_int",
                                    file_refit="never")
```

```
plot(M3_full_author_slope_no_int)
```







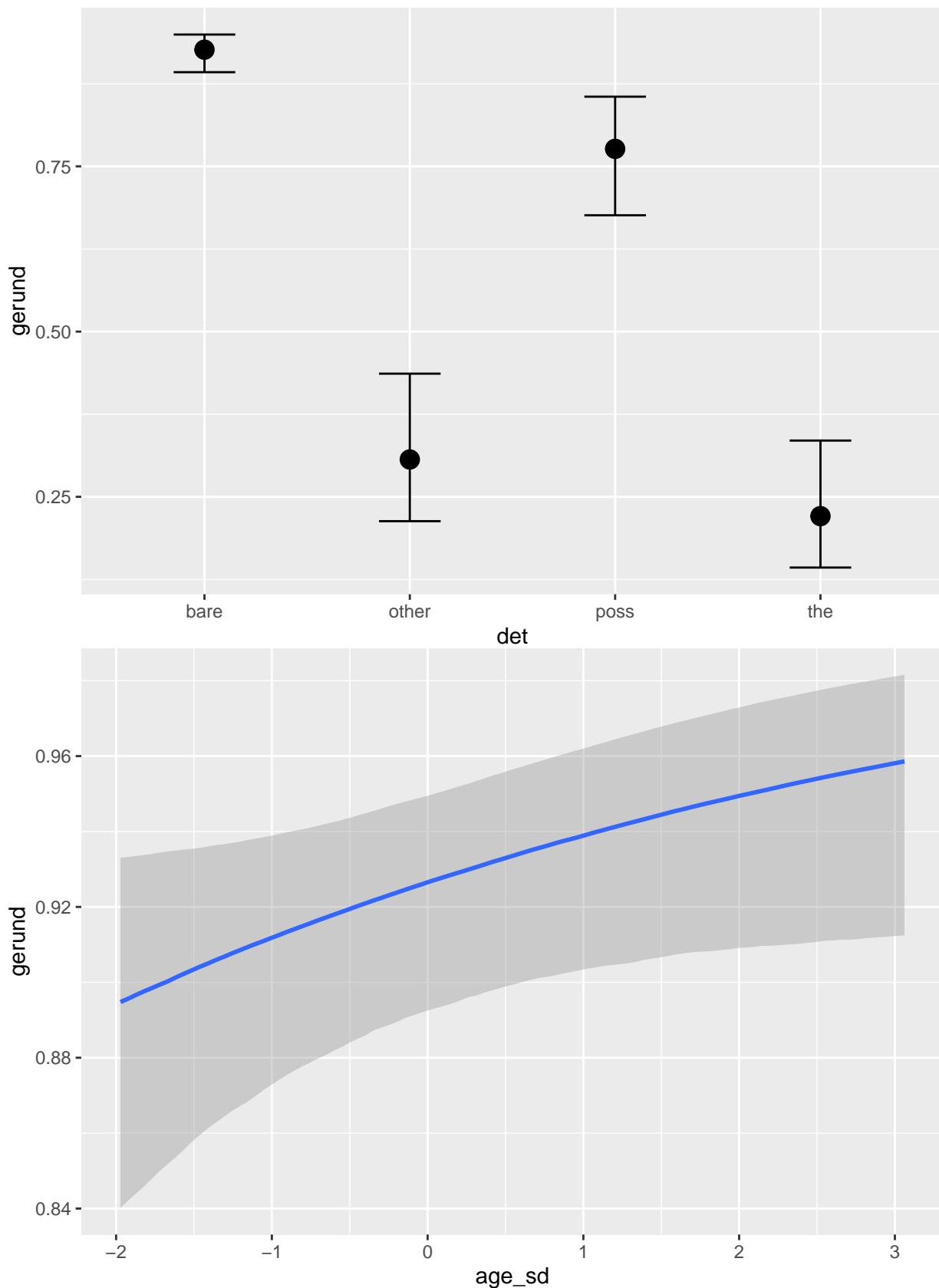
```
summary(M3_full_author_slope_no_int)
```

```
## Family: bernoulli
## Links: mu = logit
## Formula: gerund ~ det + age_sd + (age_sd + det | author)
## Data: df (Number of observations: 16629)
## Draws: 4 chains, each with iter = 4000; warmup = 1000; thin = 1;
##          total post-warmup draws = 12000
##
## Group-Level Effects:
## ~author (Number of levels: 21)
##             Estimate Est.Error 1-95% CI u-95% CI Rhat Bulk_ESS
## sd(Intercept)    0.88     0.17    0.61    1.27 1.00   3746
## sd(age_sd)      0.38     0.08    0.25    0.57 1.00   5430
## sd(detother)    0.76     0.27    0.30    1.38 1.00   3452
## sd(detposs)     0.49     0.16    0.21    0.85 1.00   4972
## sd(detthe)      1.01     0.19    0.71    1.44 1.00   5497
## cor(Intercept,age_sd) 0.27     0.22   -0.19    0.66 1.00   6848
## cor(Intercept,detother) -0.32    0.24   -0.73    0.19 1.00   8694
## cor(age_sd,detother) -0.18    0.26   -0.65    0.34 1.00   6608
## cor(Intercept,detposs) 0.11     0.26   -0.41    0.60 1.00  11540
## cor(age_sd,detposs) -0.08    0.25   -0.56    0.42 1.00   9551
## cor(detother,detposs) 0.20     0.29   -0.39    0.71 1.00   7483
## cor(Intercept,detthe) -0.25    0.20   -0.61    0.16 1.00   6340
## cor(age_sd,detthe) -0.17    0.21   -0.56    0.28 1.00   6862
## cor(detother,detthe) 0.47     0.21   -0.00    0.79 1.00   4718
## cor(detposs,detthe)  0.50     0.22   0.00    0.85 1.00   6515
## Tail_ESS
```

```

## sd(Intercept)          6940
## sd(age_sd)            7990
## sd(detother)          3632
## sd(detposs)           7063
## sd(detthe)            6803
## cor(Intercept,age_sd) 7406
## cor(Intercept,detother) 8565
## cor(age_sd,detother)  8417
## cor(Intercept,detposs) 9694
## cor(age_sd,detposs)   8790
## cor(detother,detposs) 8239
## cor(Intercept,detthe)  8038
## cor(age_sd,detthe)    8179
## cor(detother,detthe)  5689
## cor(detposs,detthe)   8918
##
## Population-Level Effects:
##             Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept      2.53     0.21    2.12    2.93 1.00    1687    3162
## detother     -3.34     0.23   -3.78   -2.84 1.00    5076    5724
## detposs      -1.29     0.16   -1.60   -0.96 1.00    6497    6826
## detthe       -3.79     0.25   -4.25   -3.28 1.00    5043    5541
## age_sd        0.20     0.10   -0.00    0.40 1.00    3662    5399
##
## Draws were sampled using sampling(NUTS). For each parameter, Bulk_ESS
## and Tail_ESS are effective sample size measures, and Rhat is the potential
## scale reduction factor on split chains (at convergence, Rhat = 1).
conditional_effects(M3_full_author_slope_no_int)

```



```
M3_full_author_slope_no_int <- add_criterion(M3_full_author_slope_no_int, 'waic', file="M3_full_author_
```

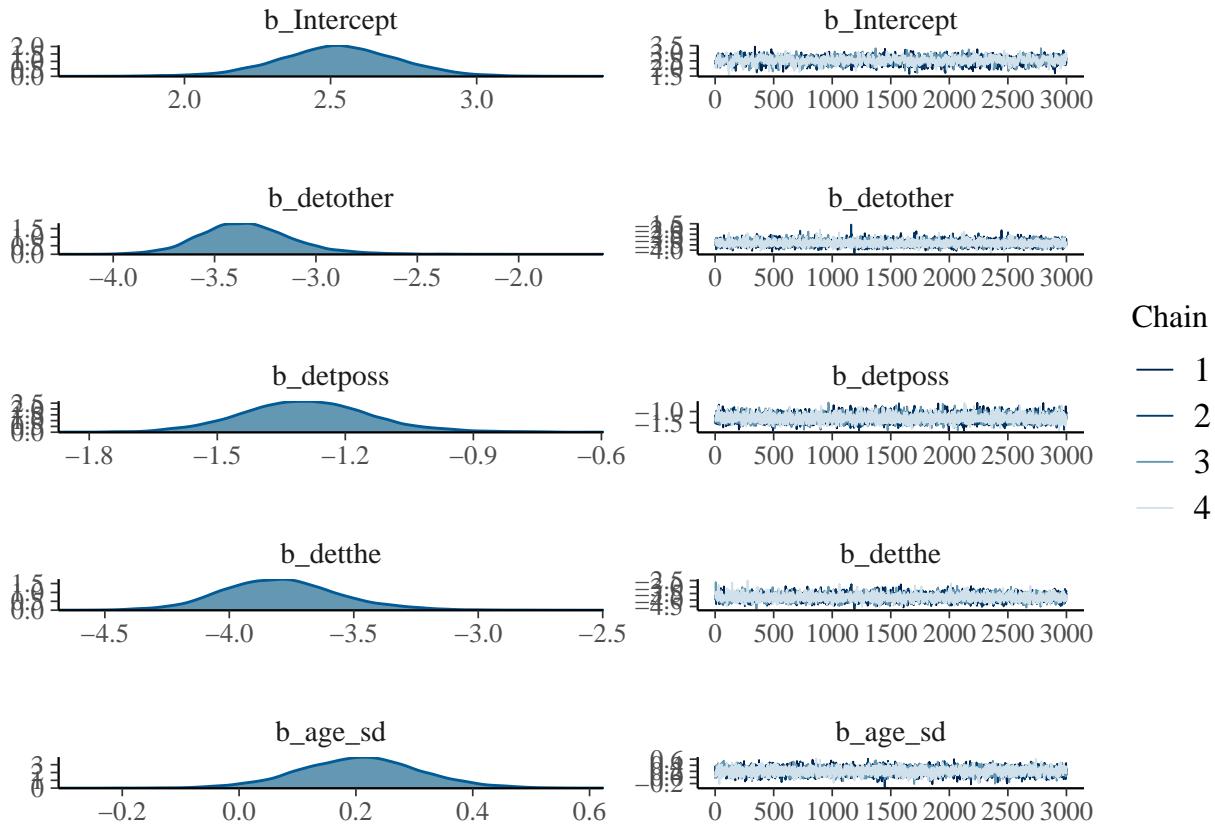
Add psis-loo:

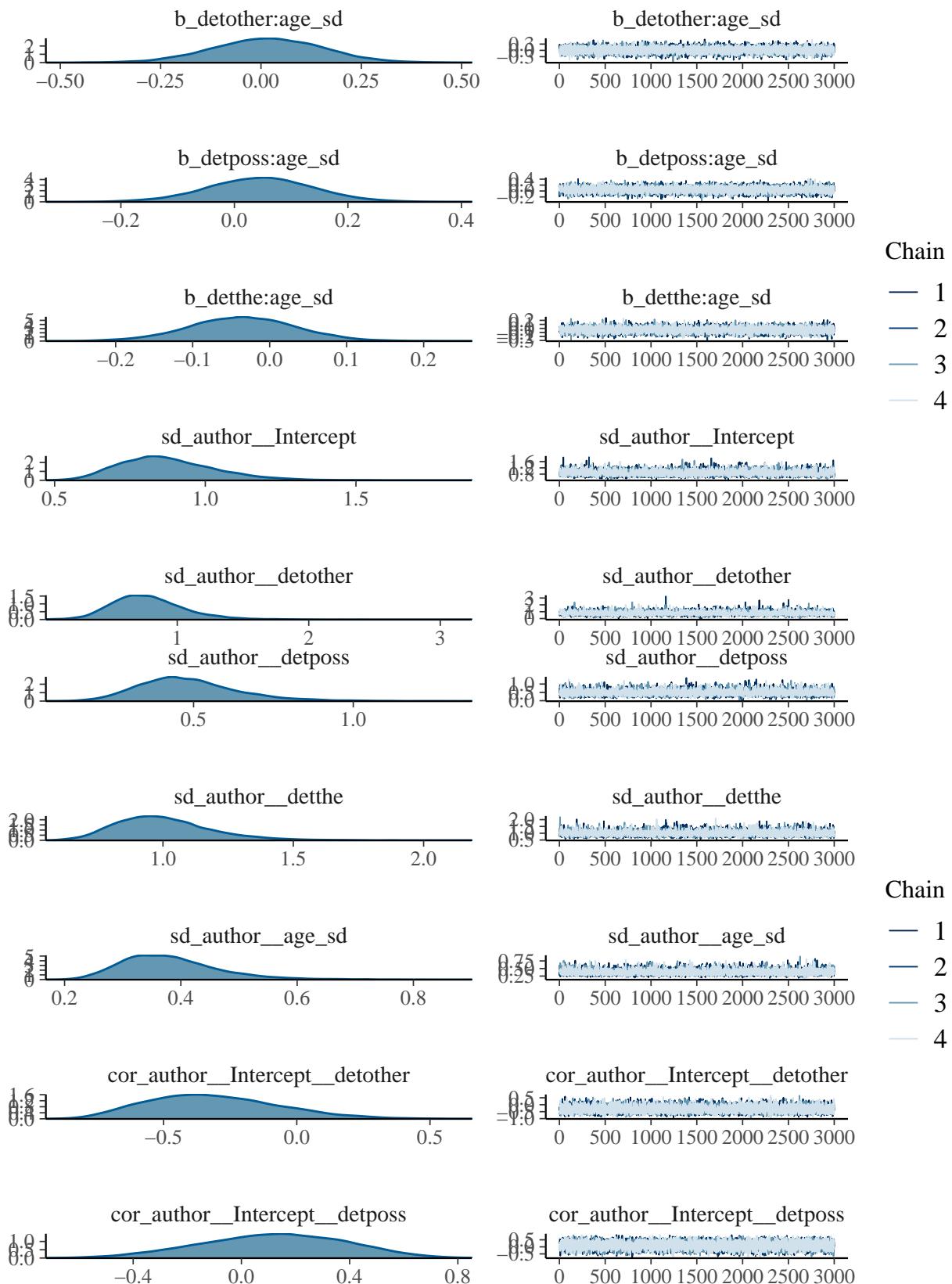
```
M3_full_author_slope_no_int <- add_criterion(M3_full_author_slope_no_int, 'loo', file="M3_full_author_s
```

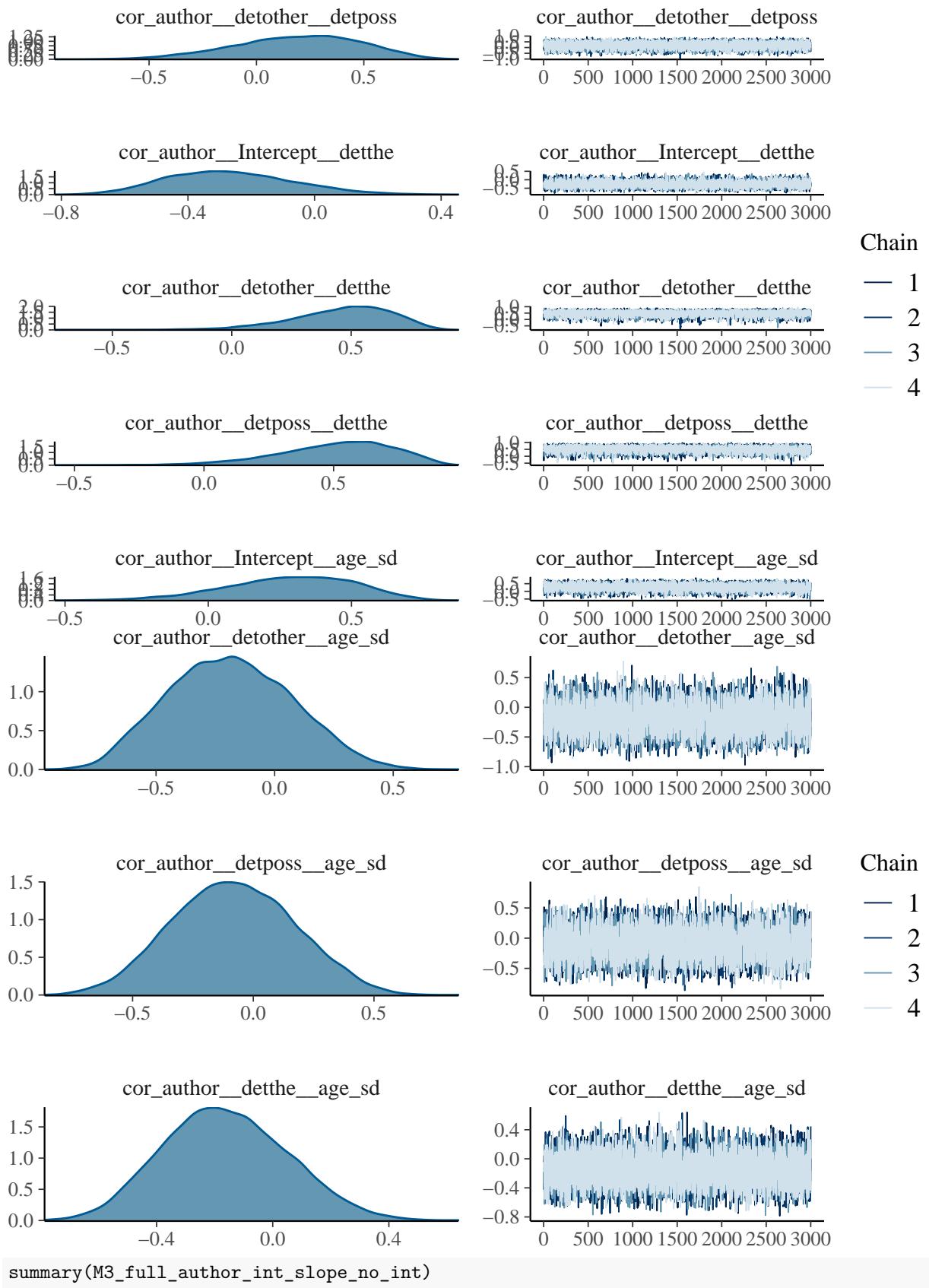
Age and Determiner + Age and determiner slope (interaction fixed effects)

```
## regularizing prior for (i) beta coefficients, (ii) lkj prior, (iii) cauchy - helps sampling ##
M3_full_author_int_slope_no_int <- brm(gerund ~ det * age_sd + (det+age_sd|author), data=df,
                                         family = bernoulli(),
                                         chains = 4, iter = 4000, warmup = 1000, cores = 4,
                                         prior = c(set_prior("normal(0, 1)", "b"),
                                                   set_prior("lkj(2)", "cor"),
                                                   set_prior("normal(0, 5)", "Intercept"),
                                                   set_prior("cauchy(0, 2)", "sd")),
                                         save_model = "M3_full_author_int_slope_no_int.stan",
                                         file = "M3_full_author_int_slope_no_int",
                                         file_refit="never")
```

```
plot(M3_full_author_int_slope_no_int)
```





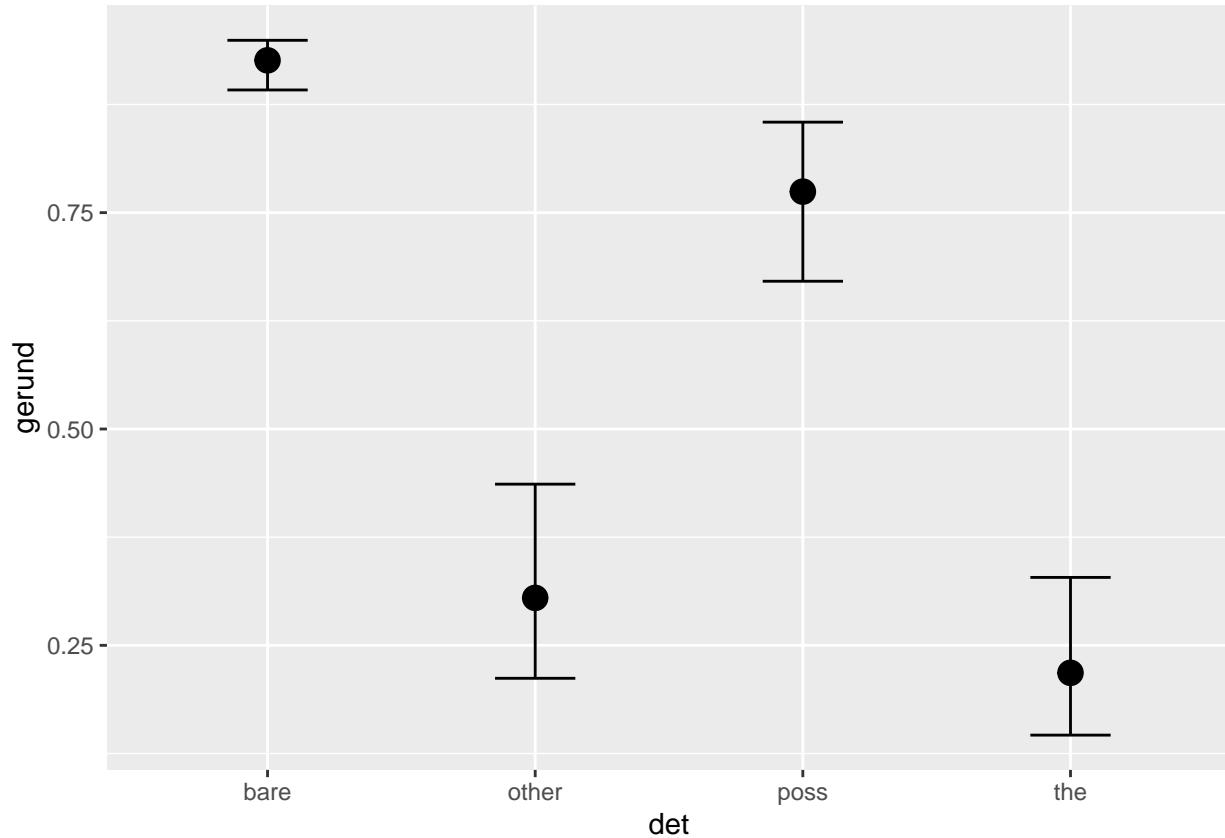


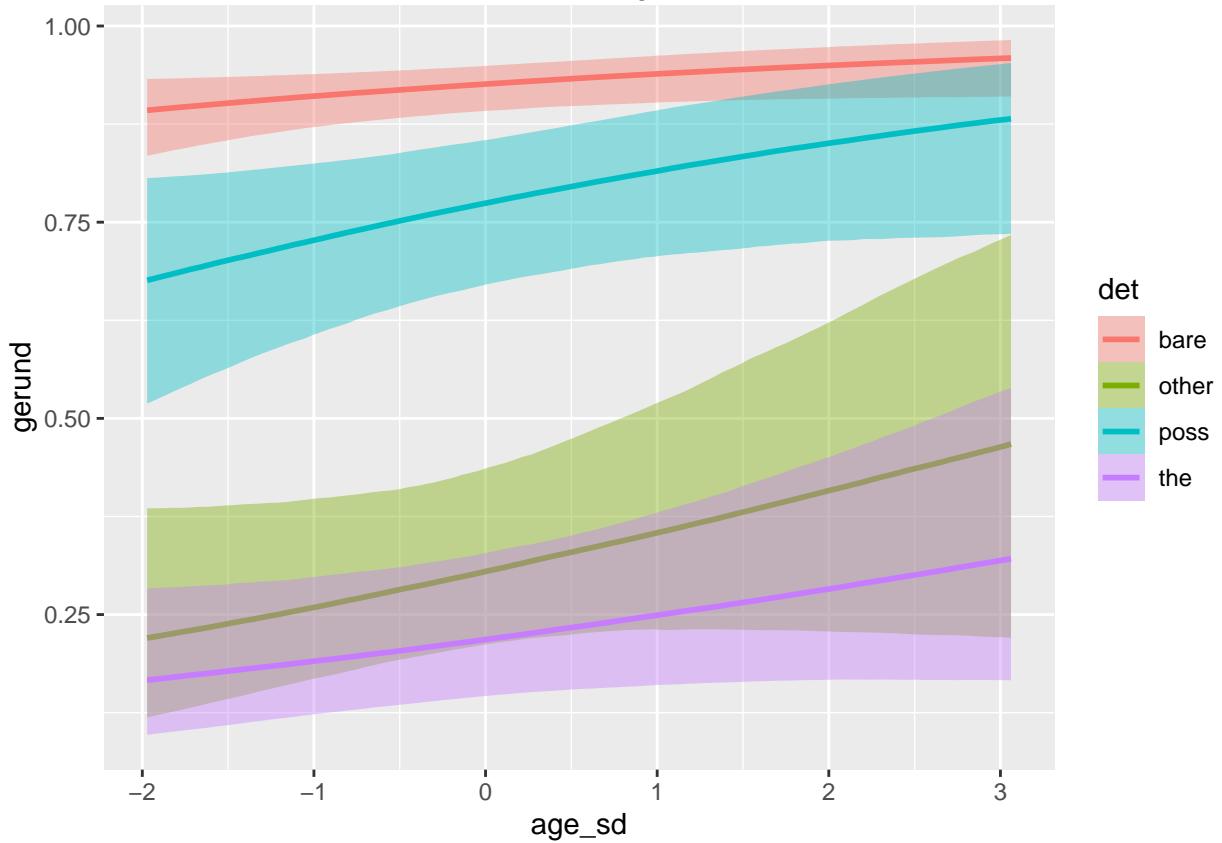
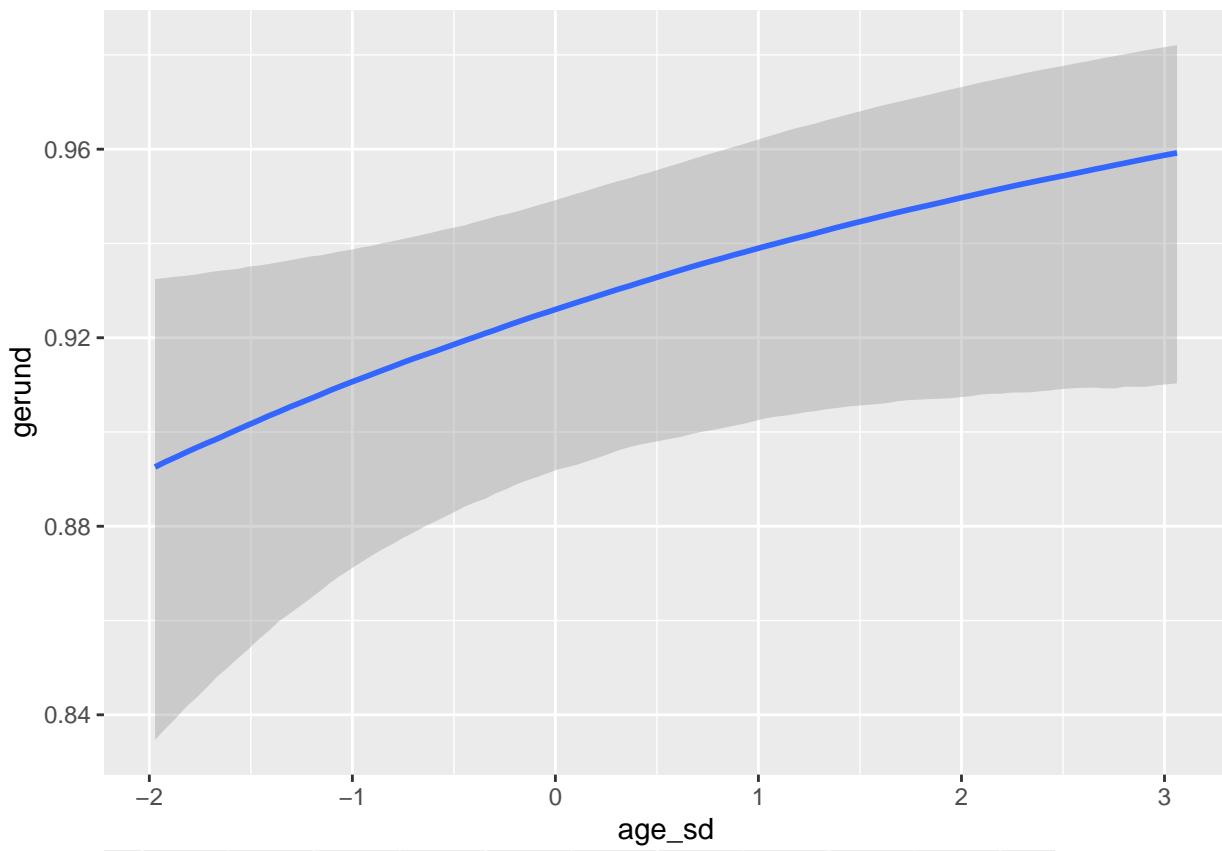
```

##  Family: bernoulli
##  Links: mu = logit
## Formula: gerund ~ det * age_sd + (det + age_sd | author)
##  Data: df (Number of observations: 16629)
##  Draws: 4 chains, each with iter = 4000; warmup = 1000; thin = 1;
##          total post-warmup draws = 12000
##
## Group-Level Effects:
## ~author (Number of levels: 21)
##                               Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS
## sd(Intercept)                0.88     0.16    0.62    1.23 1.00    4440
## sd(detother)                 0.78     0.28    0.31    1.39 1.00    3916
## sd(detposs)                  0.48     0.16    0.23    0.85 1.00    6393
## sd(detthe)                   1.00     0.18    0.71    1.42 1.00    6395
## sd(age_sd)                   0.38     0.08    0.25    0.57 1.00    7560
## cor(Intercept,detother)      -0.31     0.24   -0.72    0.21 1.00    9995
## cor(Intercept,detposs)       0.12     0.26   -0.41    0.61 1.00   11110
## cor(detother,detposs)        0.19     0.29   -0.41    0.70 1.00    7559
## cor(Intercept,detthe)        -0.27     0.20   -0.61    0.14 1.00    7476
## cor(detother,detthe)         0.46     0.21   -0.01    0.79 1.00    4918
## cor(detposs,detthe)          0.51     0.22   -0.02    0.86 1.00    6199
## cor(Intercept,age_sd)        0.29     0.22   -0.19    0.67 1.00    9438
## cor(detother,age_sd)         -0.19    0.26   -0.66    0.33 1.00    5262
## cor(detposs,age_sd)          -0.08    0.25   -0.56    0.40 1.00    6124
## cor(detthe,age_sd)           -0.16    0.21   -0.55    0.27 1.00   10823
##                               Tail_ESS
## sd(Intercept)                 7541
## sd(detother)                  4480
## sd(detposs)                   8716
## sd(detthe)                    7083
## sd(age_sd)                     8414
## cor(Intercept,detother)       8684
## cor(Intercept,detposs)        8486
## cor(detother,detposs)         9138
## cor(Intercept,detthe)         8160
## cor(detother,detthe)          5529
## cor(detposs,detthe)           7960
## cor(Intercept,age_sd)          9953
## cor(detother,age_sd)           6865
## cor(detposs,age_sd)            9032
## cor(detthe,age_sd)              10056
##
## Population-Level Effects:
##                               Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept                   2.53     0.21    2.11    2.93 1.00    1967    3431
## detother                   -3.34     0.24   -3.77   -2.83 1.00    5797    6545
## detposs                      -1.29    0.16   -1.59   -0.96 1.00    7423    8104
## detthe                      -3.79     0.24   -4.24   -3.29 1.00    5288    5645
## age_sd                       0.21     0.11   -0.00    0.42 1.00    6644    8260
## detother:age_sd                 0.02     0.14   -0.25    0.28 1.00   12361   10050
## detposs:age_sd                  0.05     0.09   -0.14    0.23 1.00   13582    9277
## detthe:age_sd                  -0.04    0.07   -0.17    0.10 1.00   18715    8758
##
## Draws were sampled using sampling(NUTS). For each parameter, Bulk_ESS

```

```
## and Tail_ESS are effective sample size measures, and Rhat is the potential
## scale reduction factor on split chains (at convergence, Rhat = 1).
conditional_effects(M3_full_author_int_slope_no_int)
```





```
M3_full_author_int_slope_no_int <- add_criterion(M3_full_author_int_slope_no_int, 'waic', file="M3_full_
```

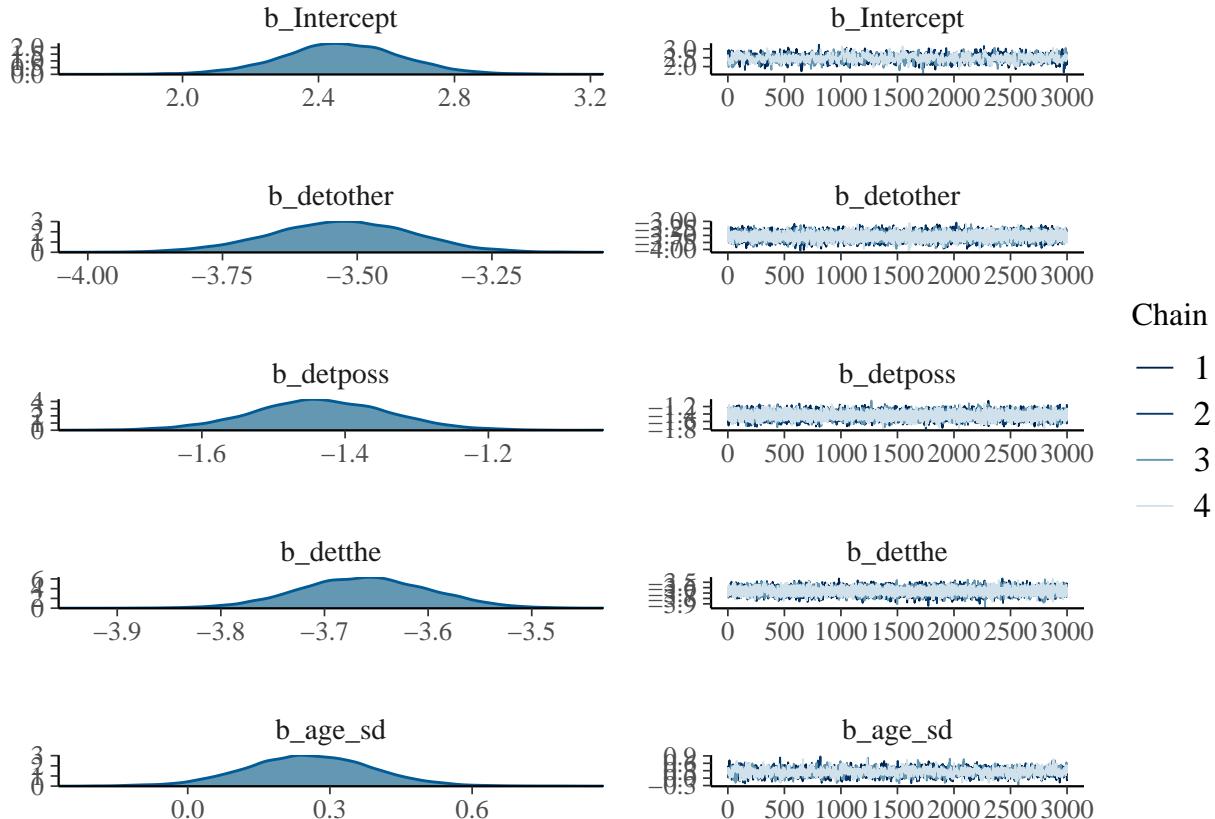
Add psis-loo:

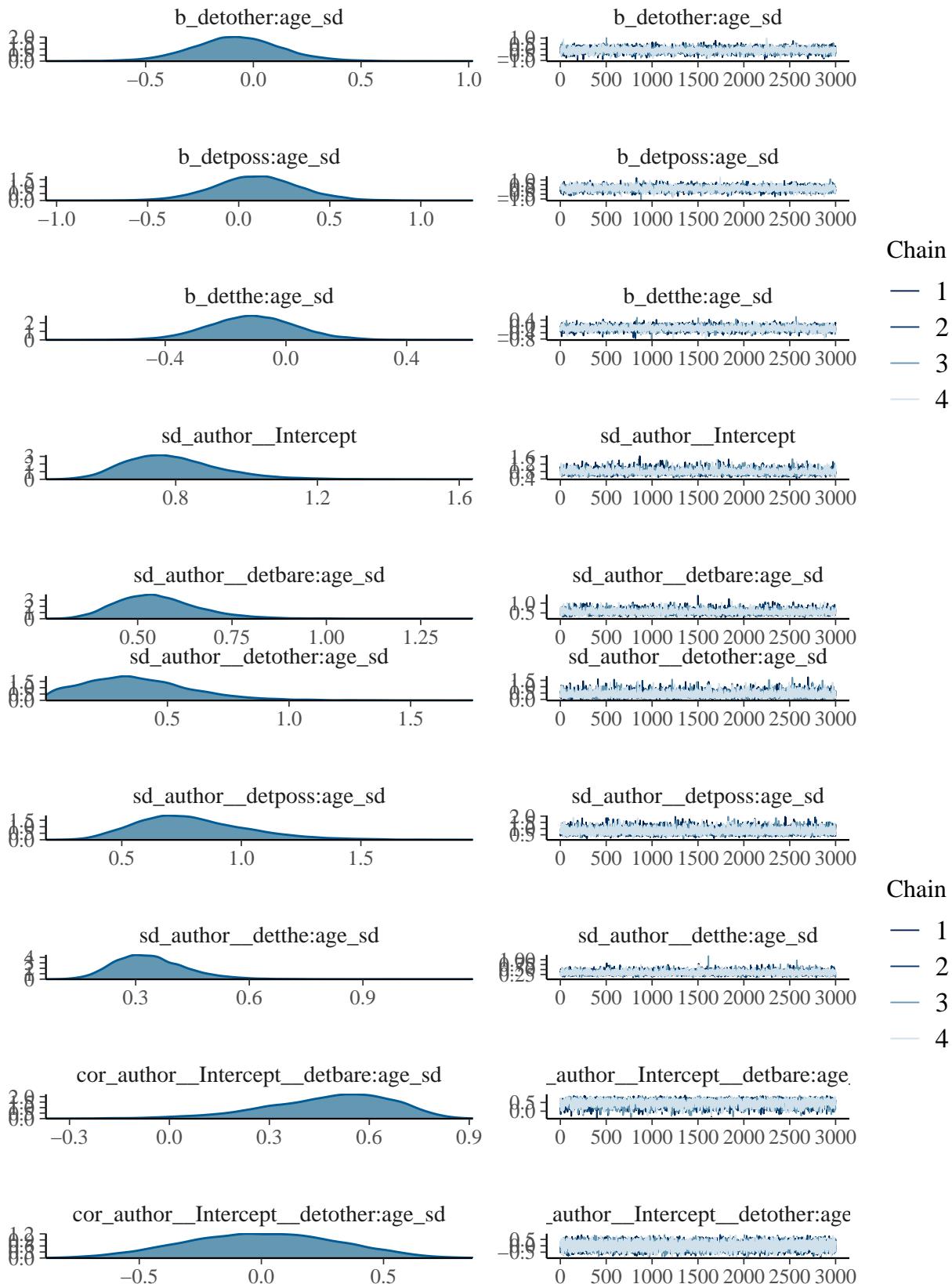
```
M3_full_author_int_slope_no_int <- add_criterion(M3_full_author_int_slope_no_int, 'loo', file="M3_full_
```

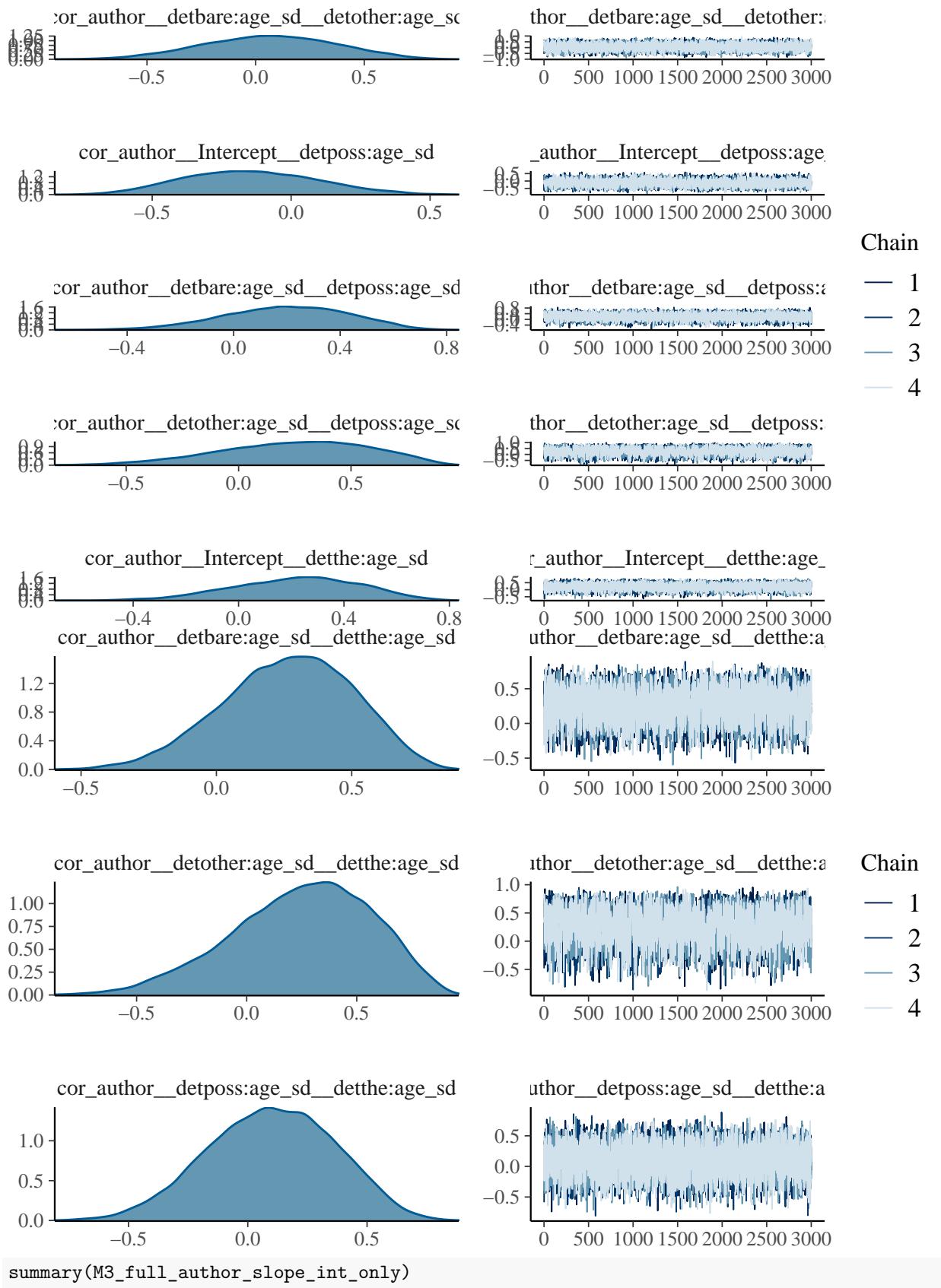
Age and Determiner + Interaction (only) slope

```
## regularizing prior for (i) beta coefficients, (ii) lkj prior, (iii) cauchy - helps sampling ##
M3_full_author_slope_int_only <- brm(gerund ~ det + age_sd + (det:age_sd|author), data=df,
                                         family = bernoulli(),
                                         chains = 4, iter = 4000, warmup = 1000, cores = 4,
                                         prior = c(set_prior("normal(0, 1)", "b"),
                                                   set_prior("lkj(2)", "cor"),
                                                   set_prior("normal(0, 5)", "Intercept"),
                                                   set_prior("cauchy(0, 2)", "sd")),
                                         save_model = "M3_full_author_slope_int_only.stan",
                                         file = "M3_full_author_slope_int_only",
                                         file_refit="never")
```

```
plot(M3_full_author_slope_int_only)
```





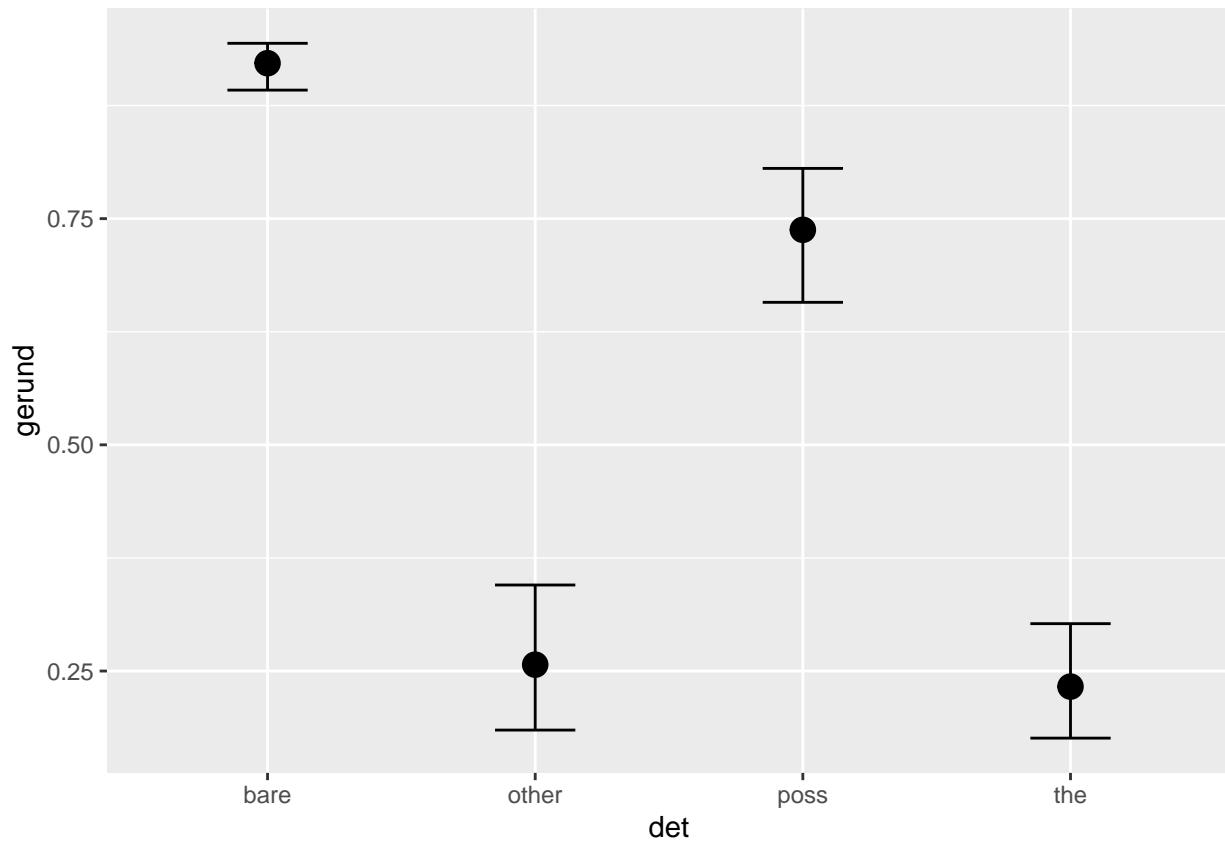


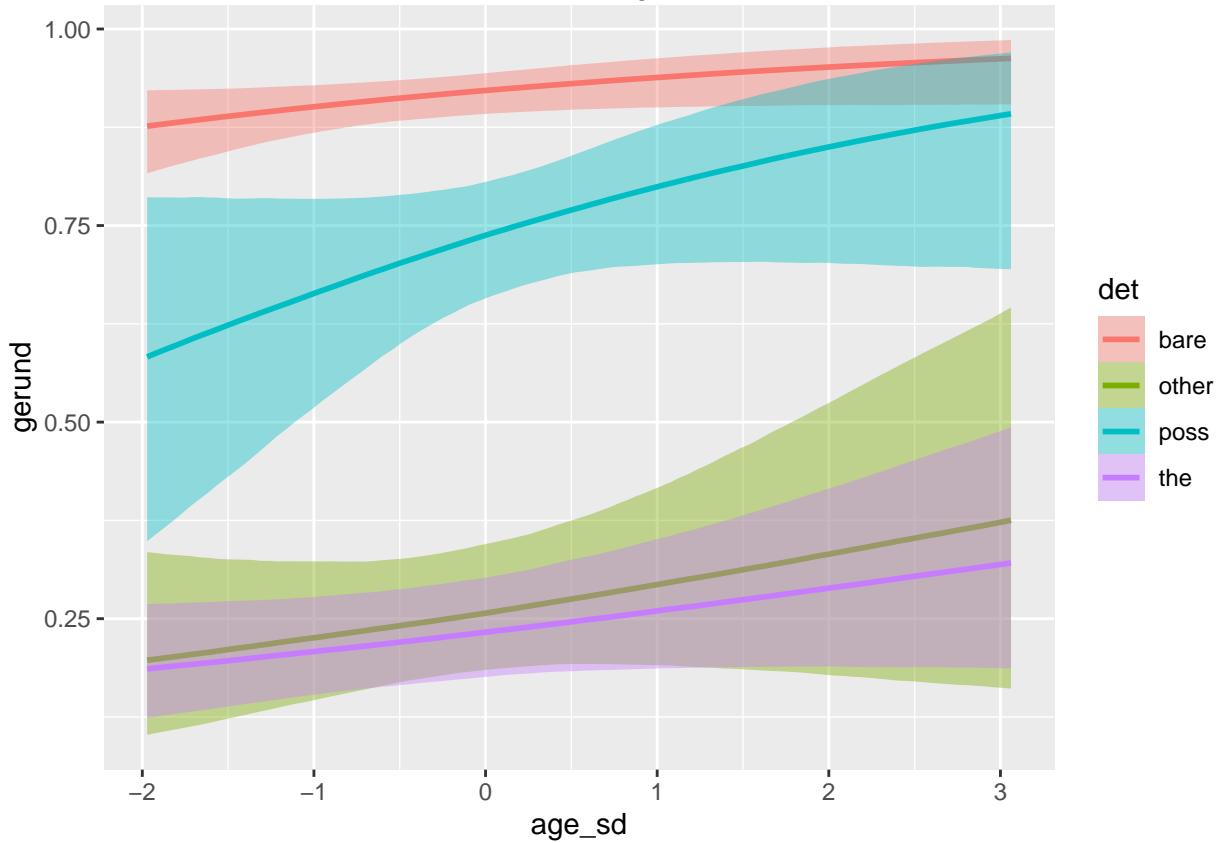
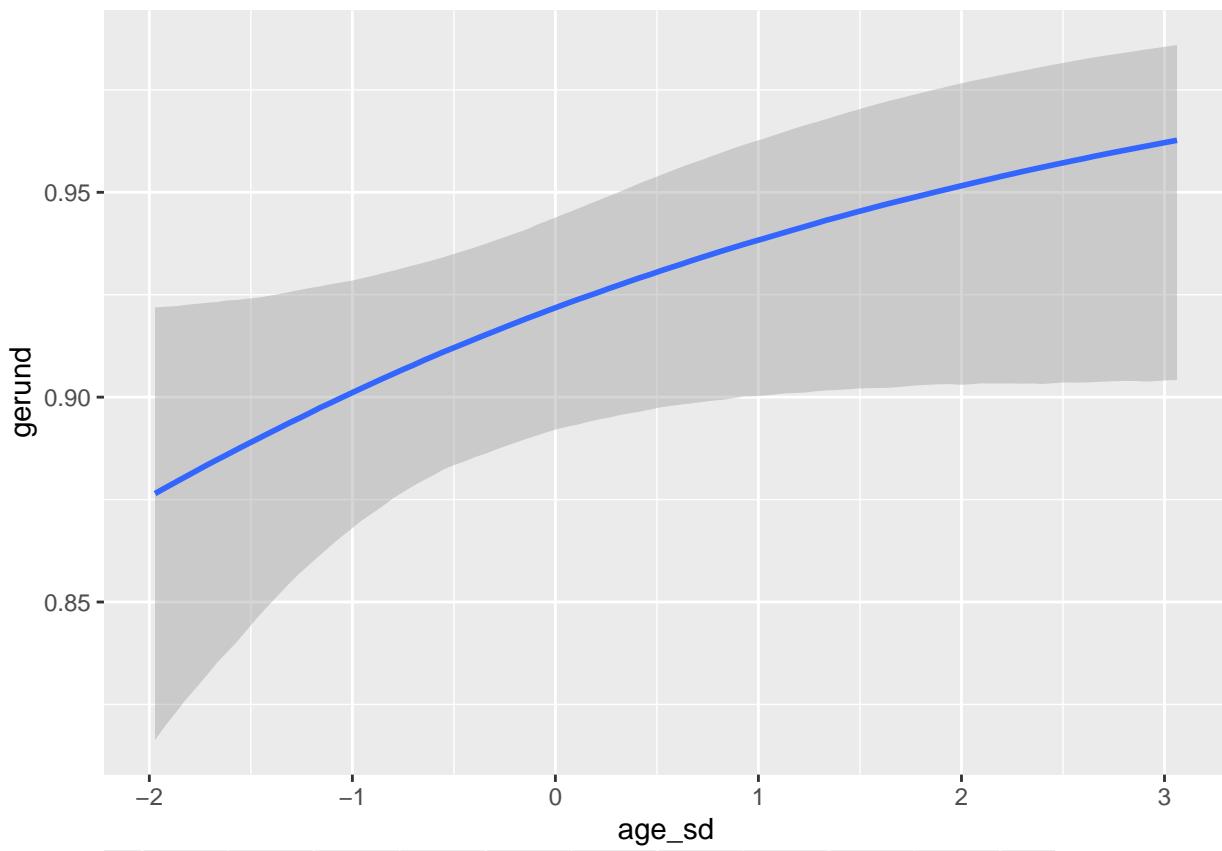
```

##  Family: bernoulli
##  Links: mu = logit
## Formula: gerund ~ det * age_sd + (det:age_sd | author)
## Data: df (Number of observations: 16629)
## Draws: 4 chains, each with iter = 4000; warmup = 1000; thin = 1;
##         total post-warmup draws = 12000
##
## Group-Level Effects:
## ~author (Number of levels: 21)
##                                         Estimate Est.Error 1-95% CI u-95% CI Rhat
## sd(Intercept)                      0.79      0.14    0.57   1.11 1.00
## sd(detbare:age_sd)                 0.55      0.11    0.37   0.81 1.00
## sd(detother:age_sd)                0.38      0.22    0.03   0.88 1.00
## sd(detposs:age_sd)                 0.80      0.24    0.42   1.34 1.00
## sd(detthe:age_sd)                  0.34      0.09    0.18   0.55 1.00
## cor(Intercept,detbare:age_sd)      0.48      0.19    0.04   0.78 1.00
## cor(Intercept,detother:age_sd)     0.00      0.30   -0.59   0.57 1.00
## cor(detbare:age_sd,detother:age_sd) 0.06      0.30   -0.53   0.63 1.00
## cor(Intercept,detposs:age_sd)      -0.15     0.24   -0.58   0.33 1.00
## cor(detbare:age_sd,detposs:age_sd) 0.20      0.23   -0.28   0.61 1.00
## cor(detother:age_sd,detposs:age_sd) 0.25      0.33   -0.44   0.80 1.00
## cor(Intercept,detthe:age_sd)       0.22      0.24   -0.27   0.64 1.00
## cor(detbare:age_sd,detthe:age_sd)  0.26      0.24   -0.23   0.69 1.00
## cor(detother:age_sd,detthe:age_sd) 0.25      0.31   -0.42   0.78 1.00
## cor(detposs:age_sd,detthe:age_sd)  0.10      0.26   -0.43   0.58 1.00
##                                         Bulk_ESS Tail_ESS
## sd(Intercept)                      2448      4129
## sd(detbare:age_sd)                 3940      7186
## sd(detother:age_sd)                2954      2741
## sd(detposs:age_sd)                 4906      6612
## sd(detthe:age_sd)                  5495      7429
## cor(Intercept,detbare:age_sd)      3403      5974
## cor(Intercept,detother:age_sd)     10636     7920
## cor(detbare:age_sd,detother:age_sd) 10081     8950
## cor(Intercept,detposs:age_sd)      6369      8010
## cor(detbare:age_sd,detposs:age_sd) 6609      7582
## cor(detother:age_sd,detposs:age_sd) 2473      4632
## cor(Intercept,detthe:age_sd)       7047      8386
## cor(detbare:age_sd,detthe:age_sd)  6768      8651
## cor(detother:age_sd,detthe:age_sd) 2817      4481
## cor(detposs:age_sd,detthe:age_sd)  6751      9059
##
## Population-Level Effects:
##                                         Estimate Est.Error 1-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept                         2.47      0.18    2.11   2.82 1.00   1213     2299
## detother                          -3.53      0.13   -3.79  -3.28 1.00   9788     8689
## detposs                           -1.43      0.10   -1.62  -1.25 1.00  12803     9381
## detthe                            -3.66      0.06   -3.78  -3.54 1.00  10623     9281
## age_sd                            0.26      0.13   -0.00   0.52 1.00   2029     3610
## detother:age_sd                  -0.08      0.21   -0.48   0.33 1.00   3412     5874
## detposs:age_sd                   0.10      0.23   -0.36   0.56 1.00   3564     5459
## detthe:age_sd                     -0.11      0.15   -0.40   0.18 1.00   2686     5184
##
## Draws were sampled using sampling(NUTS). For each parameter, Bulk_ESS

```

```
## and Tail_ESS are effective sample size measures, and Rhat is the potential
## scale reduction factor on split chains (at convergence, Rhat = 1).
conditional_effects(M3_full_author_slope_int_only)
```



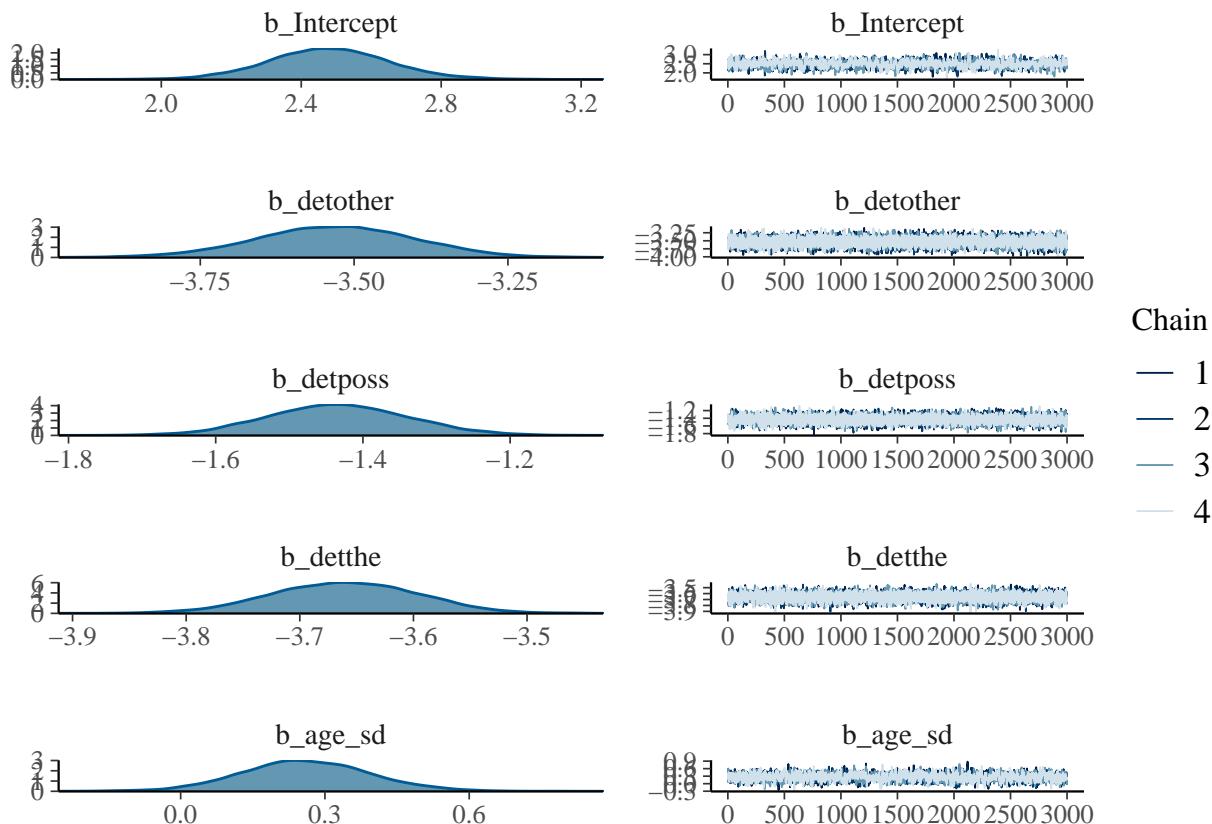


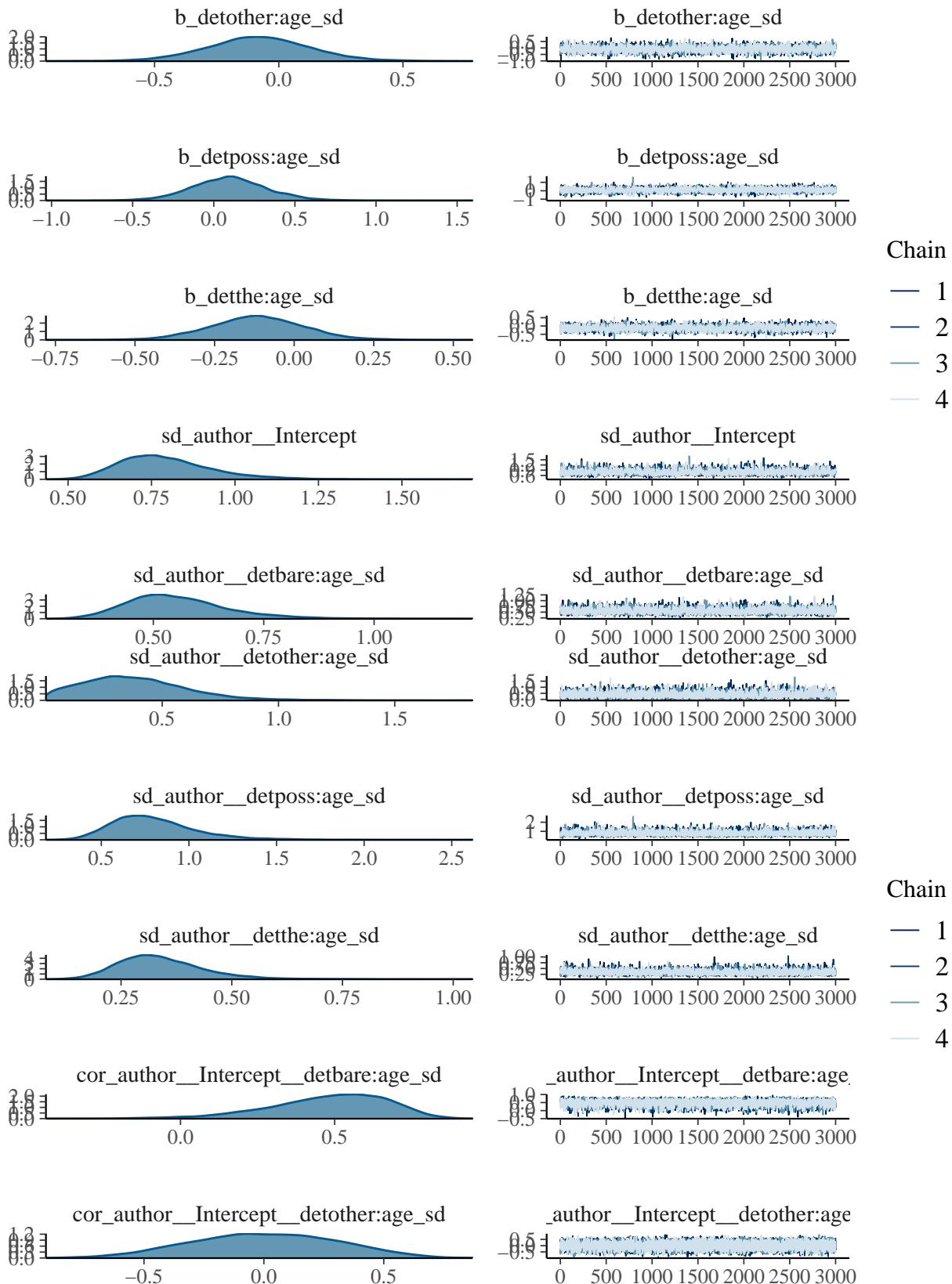
```
M3_full_author_slope_int_only <- add_criterion(M3_full_author_slope_int_only, 'waic', file="M3_full_autho
M3_full_author_slope_int_only <- add_criterion(M3_full_author_slope_int_only, 'loo', file="M3_full_autho
```

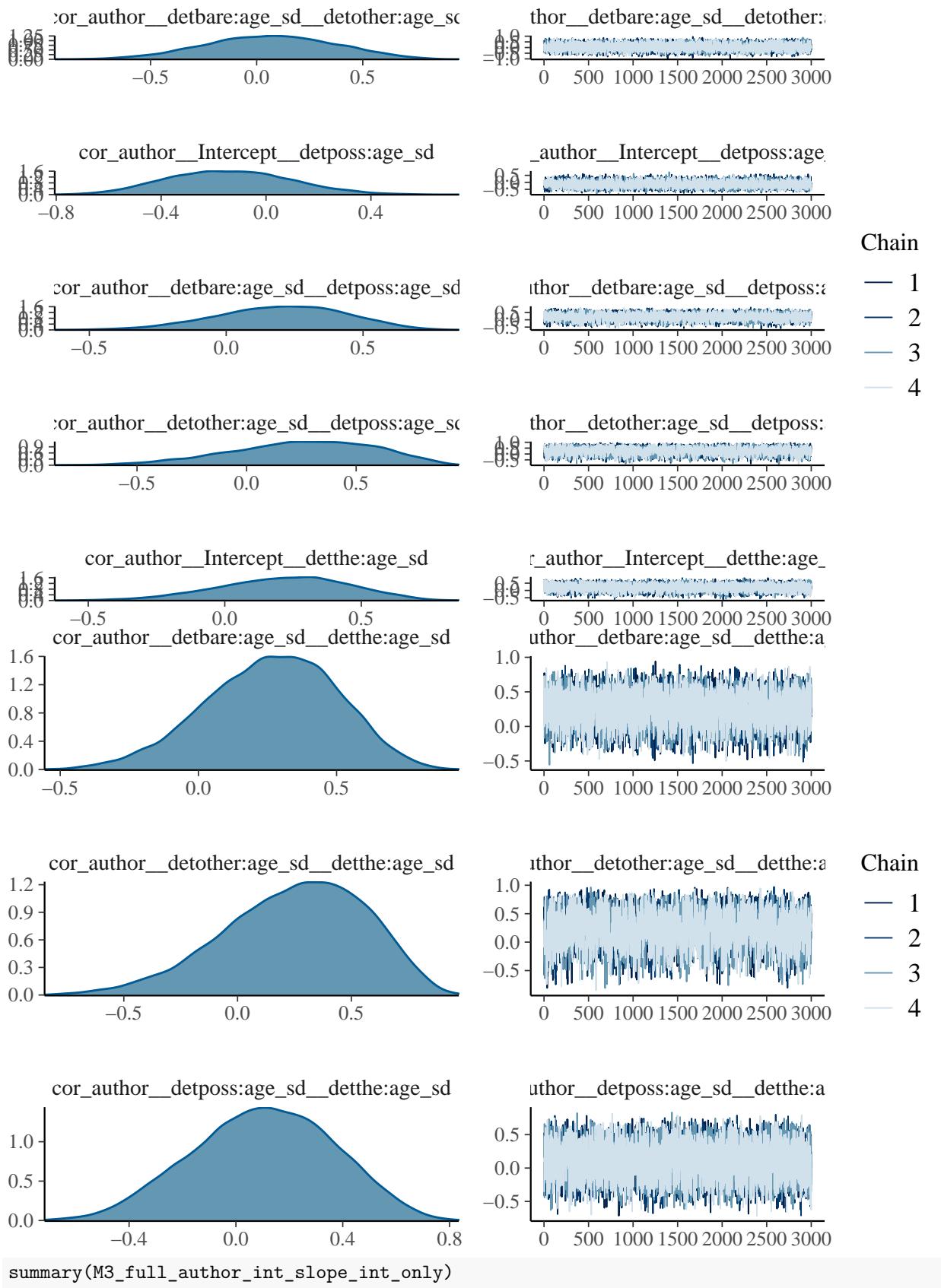
Age and Determiner Interaction + Interaction (only) slope

```
## regularizing prior for (i) beta coefficients, (ii) lkj prior, (iii) cauchy - helps sampling ##  
M3_full_author_int_slope_int_only <- brm(gerund ~ det*age_sd + (det:age_sd|author), data=df,  
family = bernoulli(),  
chains = 4, iter = 4000, warmup = 1000, cores = 4,  
prior = c(set_prior("normal(0, 1)", "b"),  
set_prior("lkj(2)", "cor"),  
set_prior("normal(0, 5)", "Intercept"),  
set_prior("cauchy(0, 2)", "sd")),  
save_model = "M3_full_author_int_slope_int_only.stan",  
file = "M3_full_author_int_slope_int_only",  
file_refit="never")
```

```
plot(M3_full_author_int_slope_int_only)
```





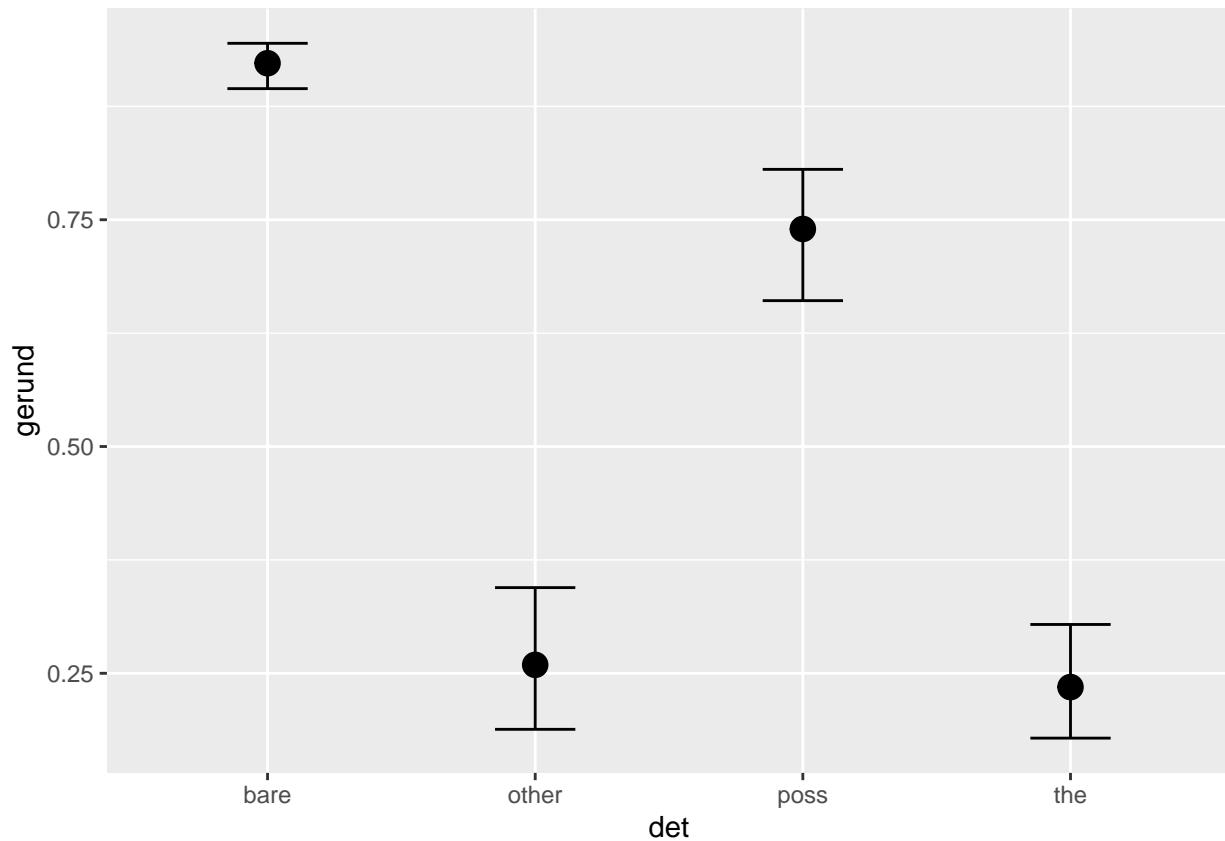


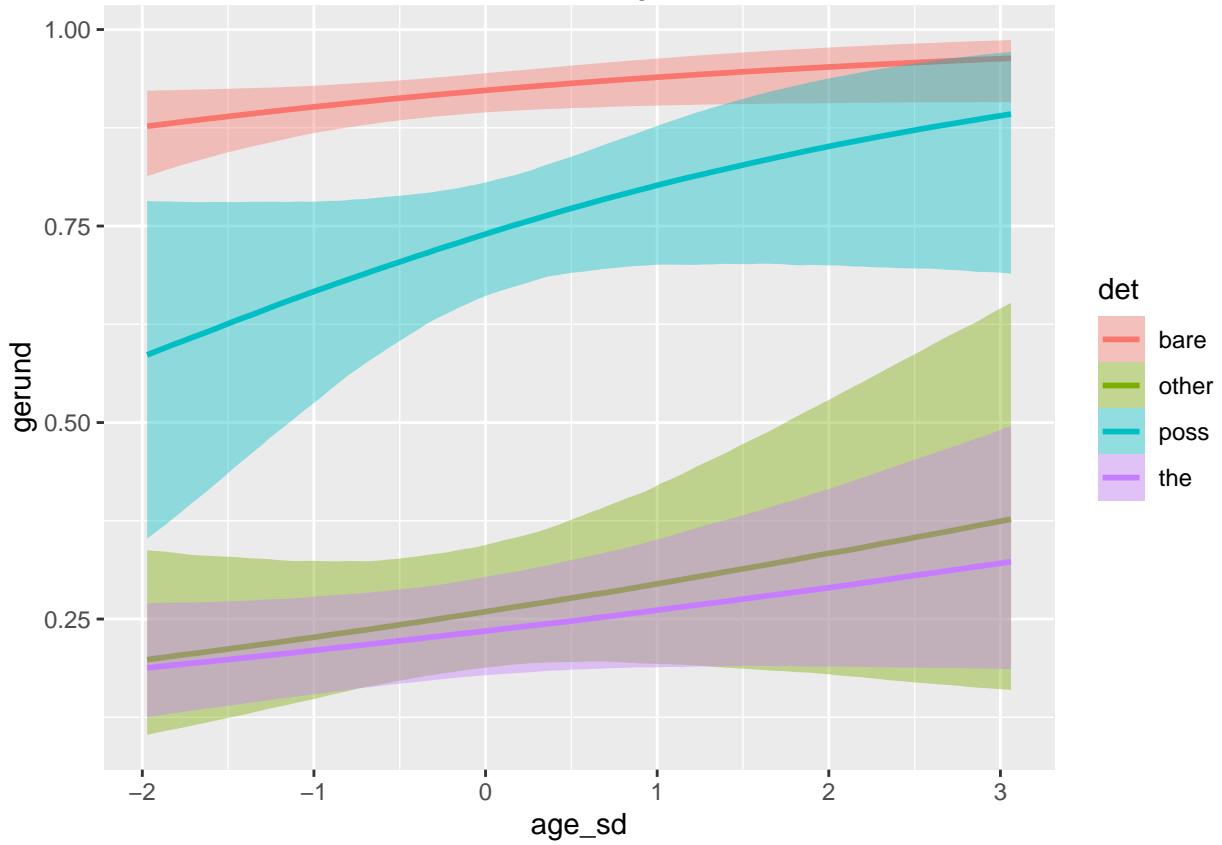
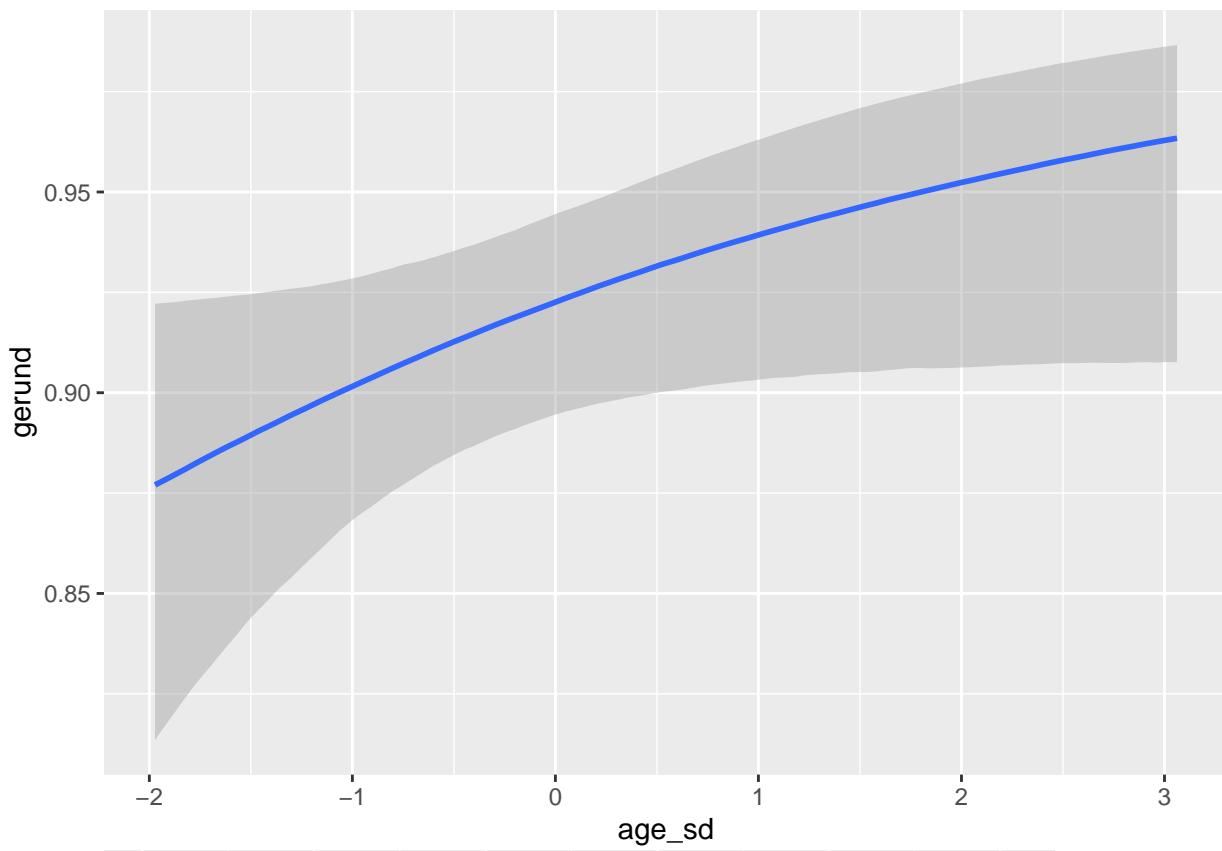
```

## Family: bernoulli
## Links: mu = logit
## Formula: gerund ~ det * age_sd + (det:age_sd | author)
## Data: df (Number of observations: 16629)
## Draws: 4 chains, each with iter = 4000; warmup = 1000; thin = 1;
##         total post-warmup draws = 12000
##
## Group-Level Effects:
## ~author (Number of levels: 21)
##                                         Estimate Est.Error 1-95% CI u-95% CI Rhat
## sd(Intercept)                      0.79      0.14    0.57    1.12 1.00
## sd(detbare:age_sd)                 0.55      0.11    0.37    0.81 1.00
## sd(detother:age_sd)                0.38      0.22    0.03    0.89 1.00
## sd(detposs:age_sd)                 0.80      0.24    0.43    1.35 1.00
## sd(detthe:age_sd)                  0.34      0.10    0.18    0.55 1.00
## cor(Intercept,detbare:age_sd)      0.48      0.19    0.05    0.78 1.00
## cor(Intercept,detother:age_sd)     0.00      0.30   -0.58    0.57 1.00
## cor(detbare:age_sd,detother:age_sd) 0.06      0.30   -0.53    0.63 1.00
## cor(Intercept,detposs:age_sd)      -0.14     0.23   -0.57    0.33 1.00
## cor(detbare:age_sd,detposs:age_sd) 0.20      0.23   -0.27    0.62 1.00
## cor(detother:age_sd,detposs:age_sd) 0.26      0.32   -0.42    0.80 1.00
## cor(Intercept,detthe:age_sd)       0.22      0.24   -0.27    0.64 1.00
## cor(detbare:age_sd,detthe:age_sd)  0.26      0.24   -0.22    0.69 1.00
## cor(detother:age_sd,detthe:age_sd) 0.25      0.31   -0.42    0.77 1.00
## cor(detposs:age_sd,detthe:age_sd)  0.10      0.26   -0.41    0.59 1.00
##                                         Bulk_ESS Tail_ESS
## sd(Intercept)                      2281      4275
## sd(detbare:age_sd)                 3944      5856
## sd(detother:age_sd)                3240      3162
## sd(detposs:age_sd)                 4961      6722
## sd(detthe:age_sd)                  5107      6605
## cor(Intercept,detbare:age_sd)      4250      6463
## cor(Intercept,detother:age_sd)     10622     8654
## cor(detbare:age_sd,detother:age_sd) 9806      8824
## cor(Intercept,detposs:age_sd)      7028      7905
## cor(detbare:age_sd,detposs:age_sd) 6226      8268
## cor(detother:age_sd,detposs:age_sd) 2979      5316
## cor(Intercept,detthe:age_sd)       8515      8940
## cor(detbare:age_sd,detthe:age_sd)  6585      7321
## cor(detother:age_sd,detthe:age_sd) 2548      3857
## cor(detposs:age_sd,detthe:age_sd)  8245      9717
##
## Population-Level Effects:
##                                         Estimate Est.Error 1-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept                         2.48      0.18    2.14    2.83 1.00    1530    3008
## detother                          -3.53      0.13   -3.79   -3.28 1.00   10230   9466
## detposs                           -1.43      0.10   -1.62   -1.24 1.00   11619   8813
## detthe                            -3.66      0.06   -3.79   -3.54 1.00   11019   9647
## age_sd                            0.26      0.13   -0.00    0.53 1.00    2166    4148
## detother:age_sd                  -0.08      0.21   -0.49    0.33 1.00    3466    5789
## detposs:age_sd                   0.10      0.23   -0.35    0.56 1.00    3206    5316
## detthe:age_sd                    -0.12      0.15   -0.40    0.17 1.00    2938    4861
##
## Draws were sampled using sampling(NUTS). For each parameter, Bulk_ESS

```

```
## and Tail_ESS are effective sample size measures, and Rhat is the potential
## scale reduction factor on split chains (at convergence, Rhat = 1).
conditional_effects(M3_full_author_int_slope_int_only)
```





Add WAIC:

```
M3_full_author_int_slope_int_only <- add_criterion(M3_full_author_int_slope_int_only, 'waic', file="M3_f
```

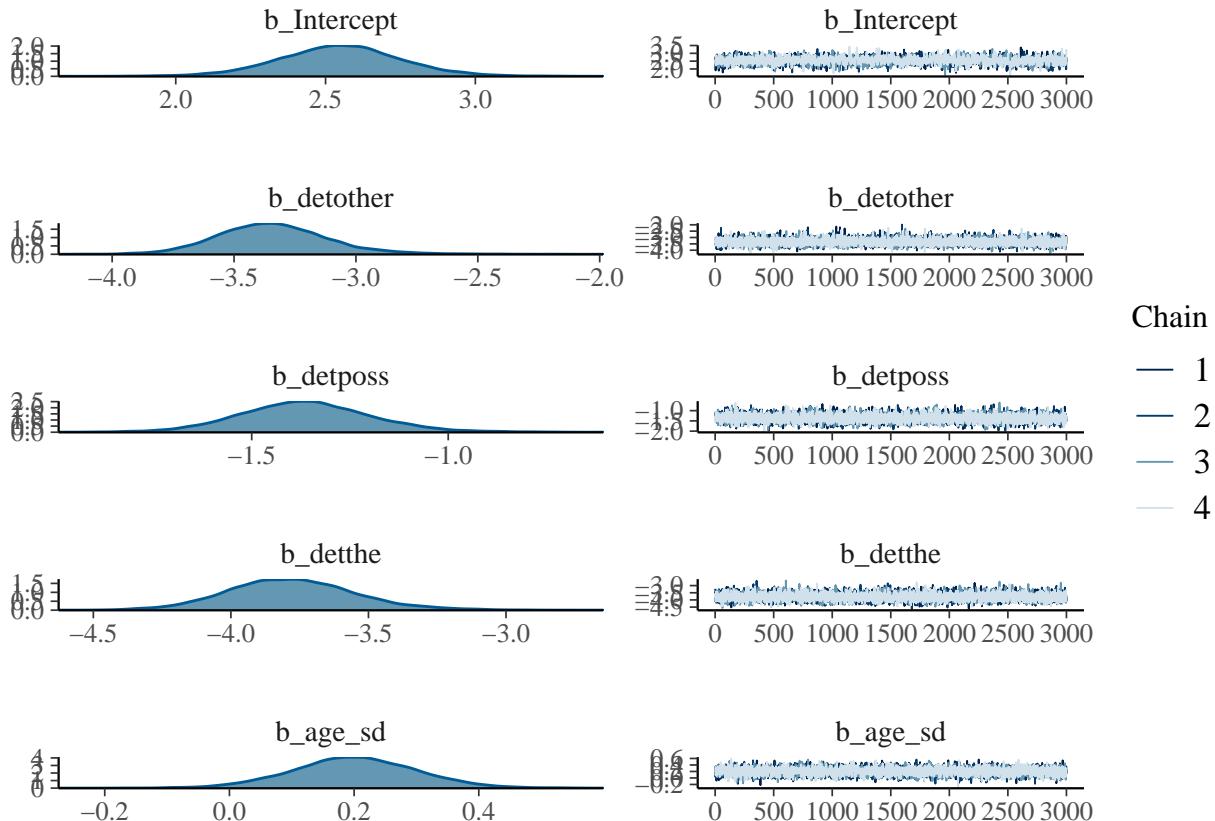
Add psis-loo:

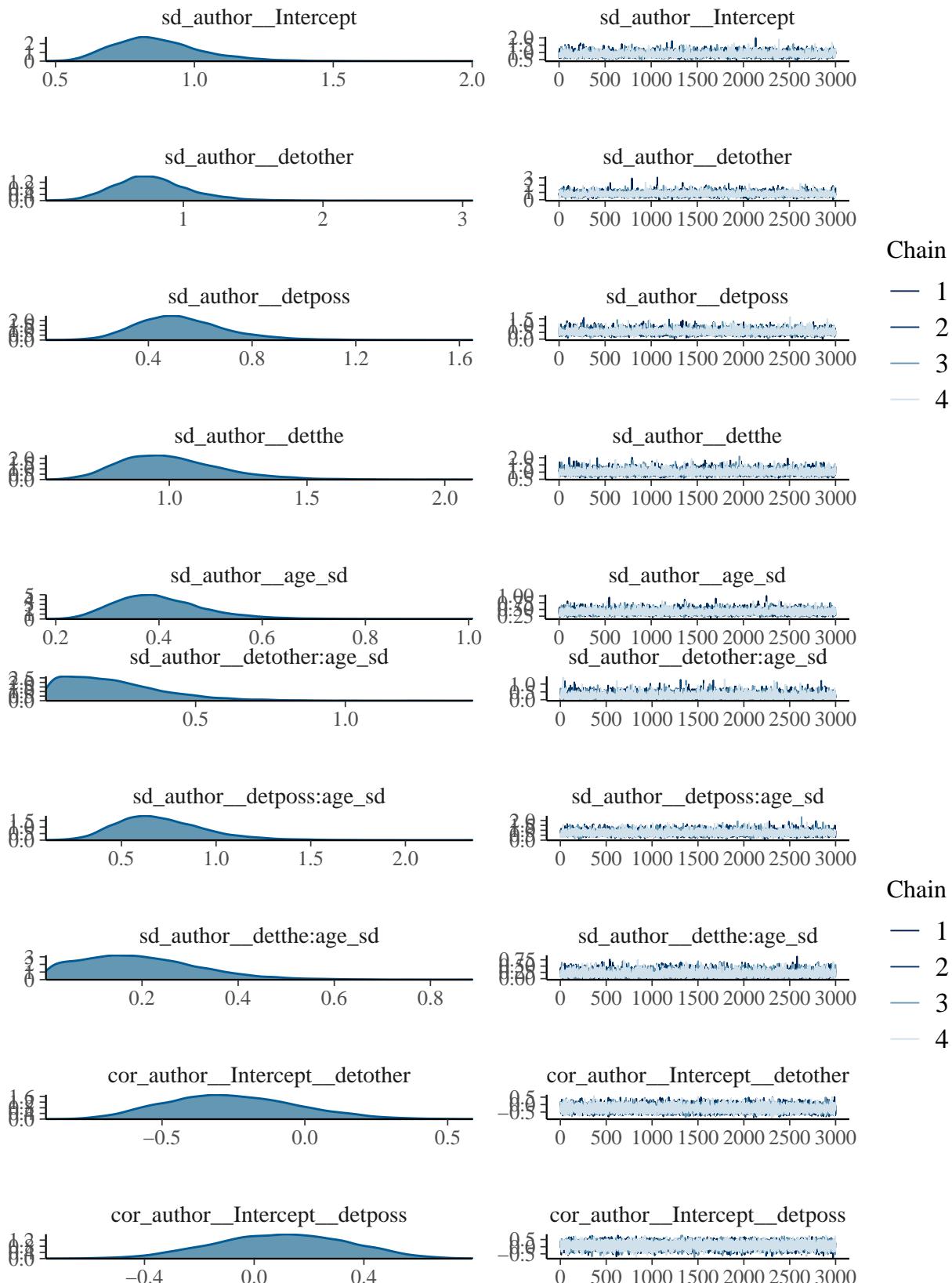
```
M3_full_author_int_slope_int_only <- add_criterion(M3_full_author_int_slope_int_only, 'loo', file="M3_f
```

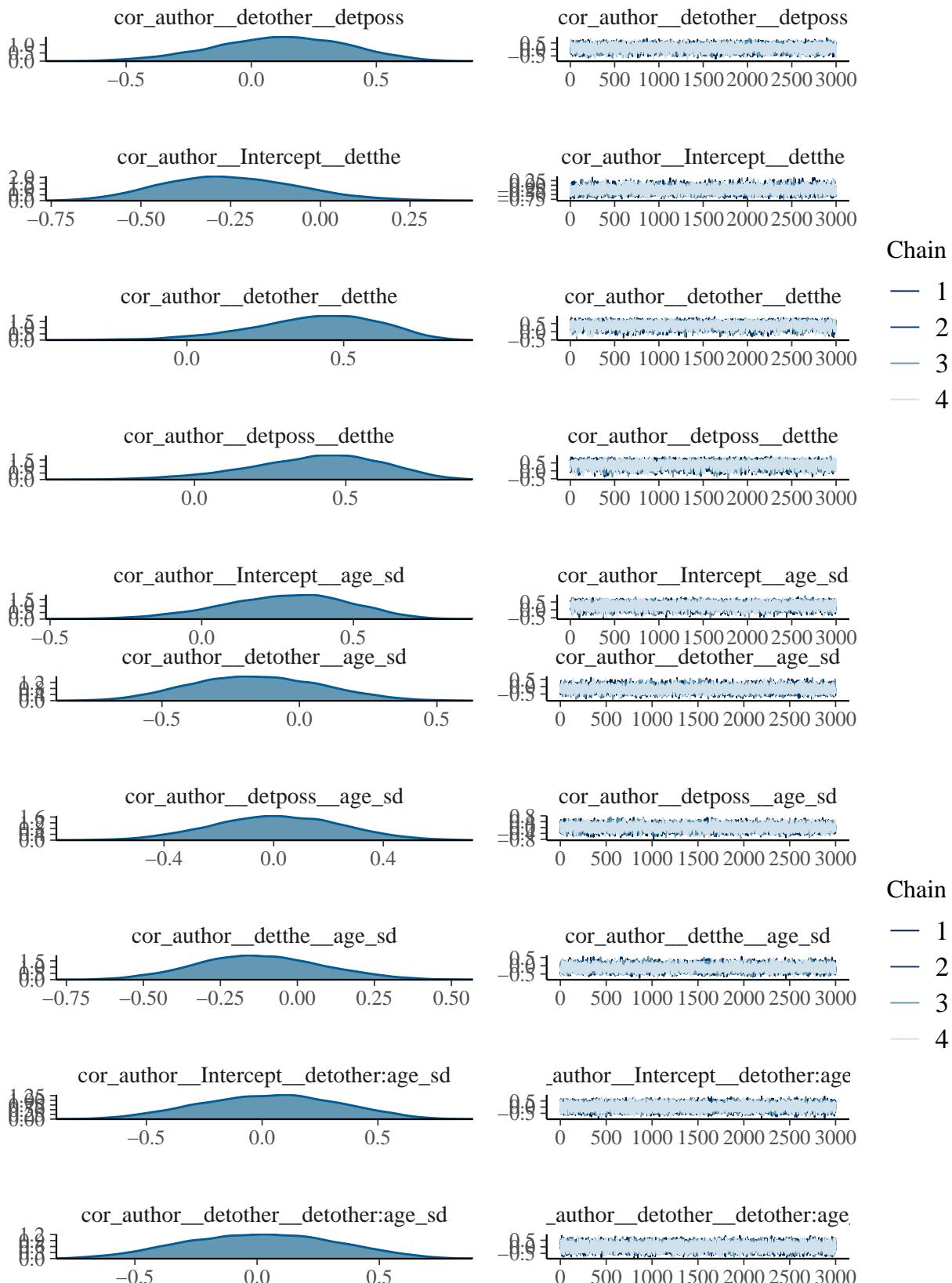
Age and Determiner + Interaction slope

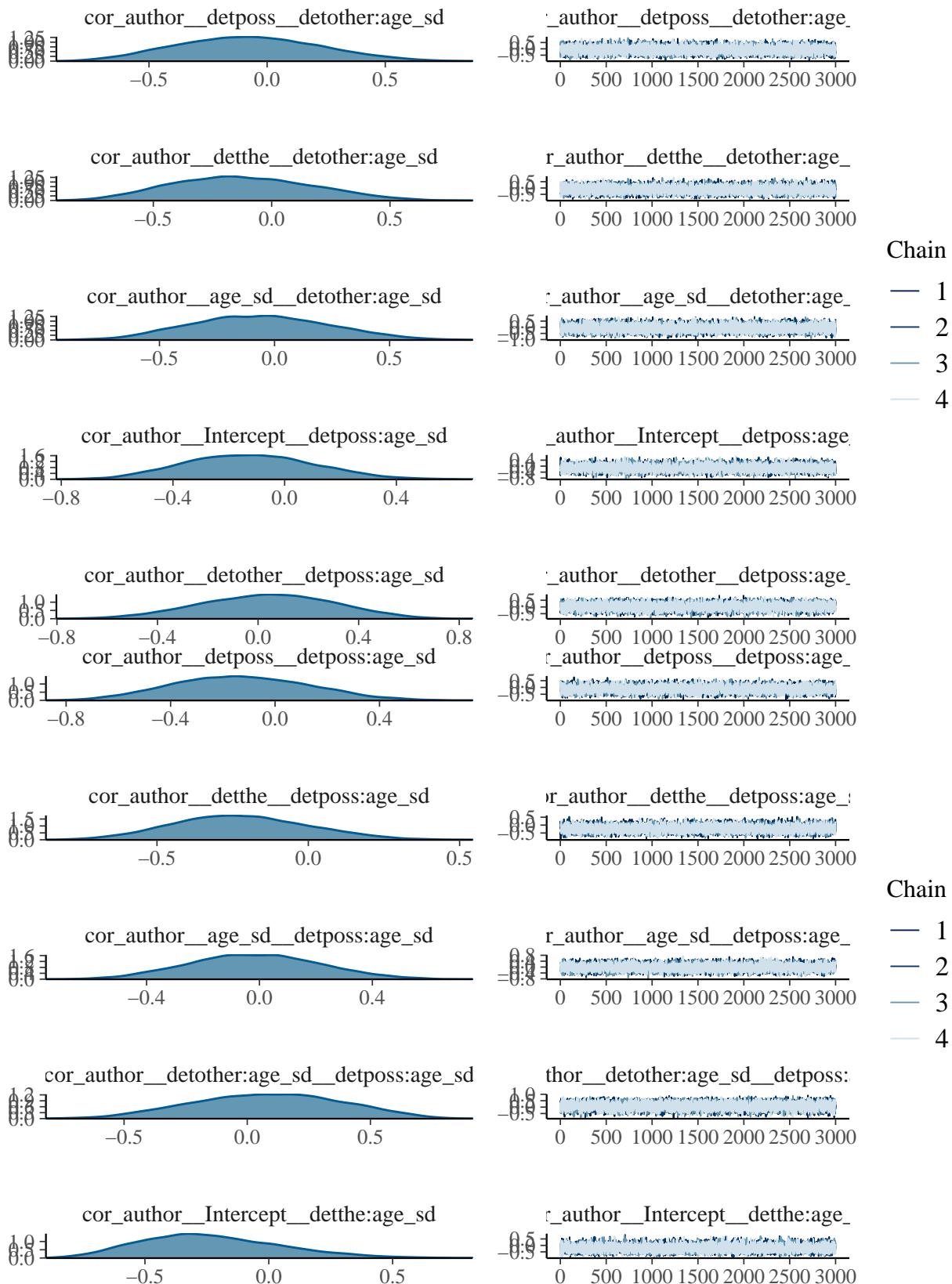
```
## regularizing prior for (i) beta coefficients, (ii) lkj prior, (iii) cauchy - helps sampling ##
M3_full_author_slope_int <- brm(gerund ~ det + age_sd + (det*age_sd|author), data=df,
                                family = bernoulli(),
                                chains = 4, iter = 4000, warmup = 1000, cores = 4,
                                prior = c(set_prior("normal(0, 1)", "b"),
                                          set_prior("lkj(2)", "cor"),
                                          set_prior("normal(0, 5)", "Intercept"),
                                          set_prior("cauchy(0, 2)", "sd")),
                                save_model = "M3_full_author_slope_int.stan",
                                file = "M3_full_author_slope_int",
                                file_refit="never")
```

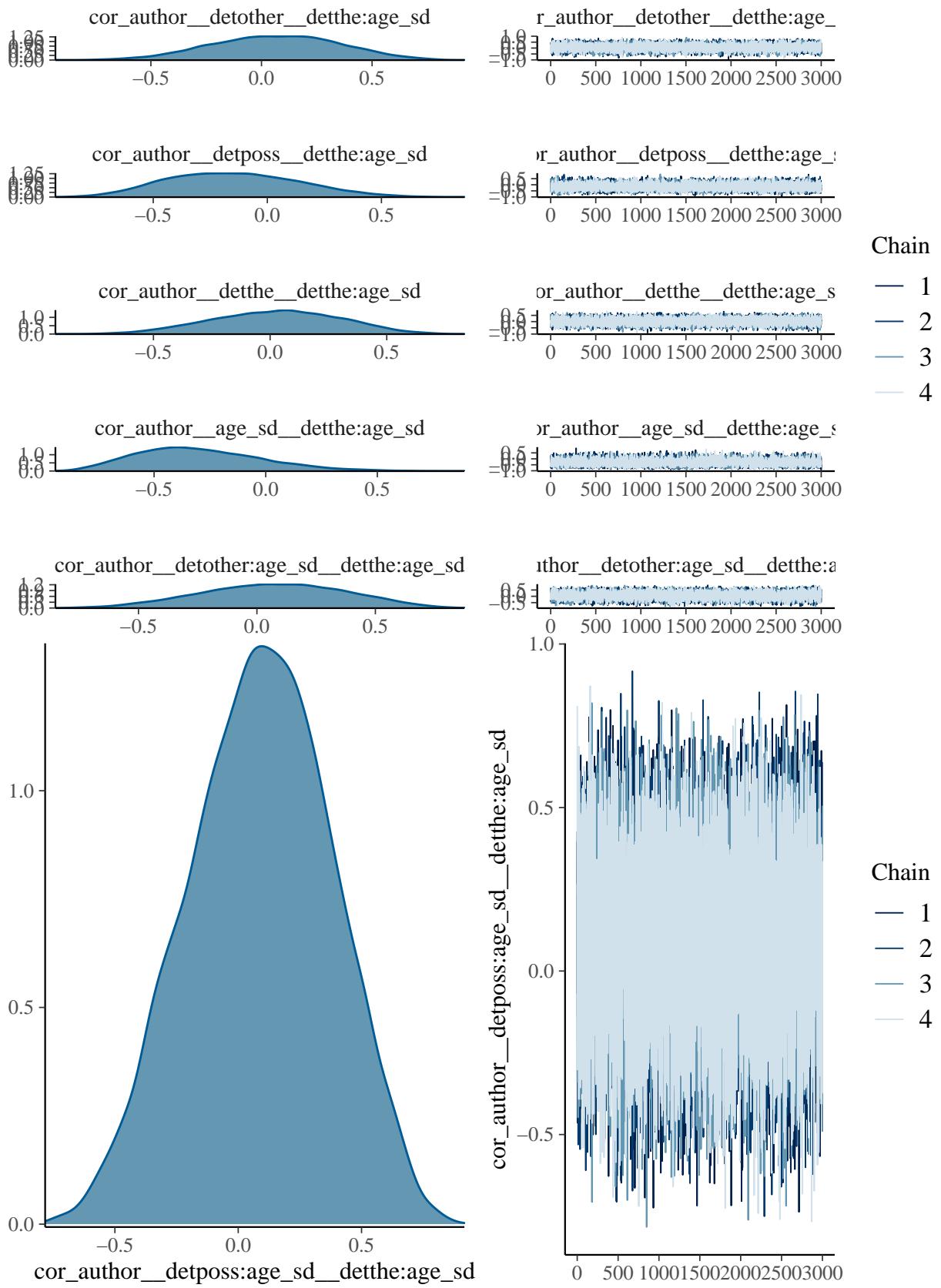
```
plot(M3_full_author_slope_int)
```











```

summary(M3_full_author_slope_int)

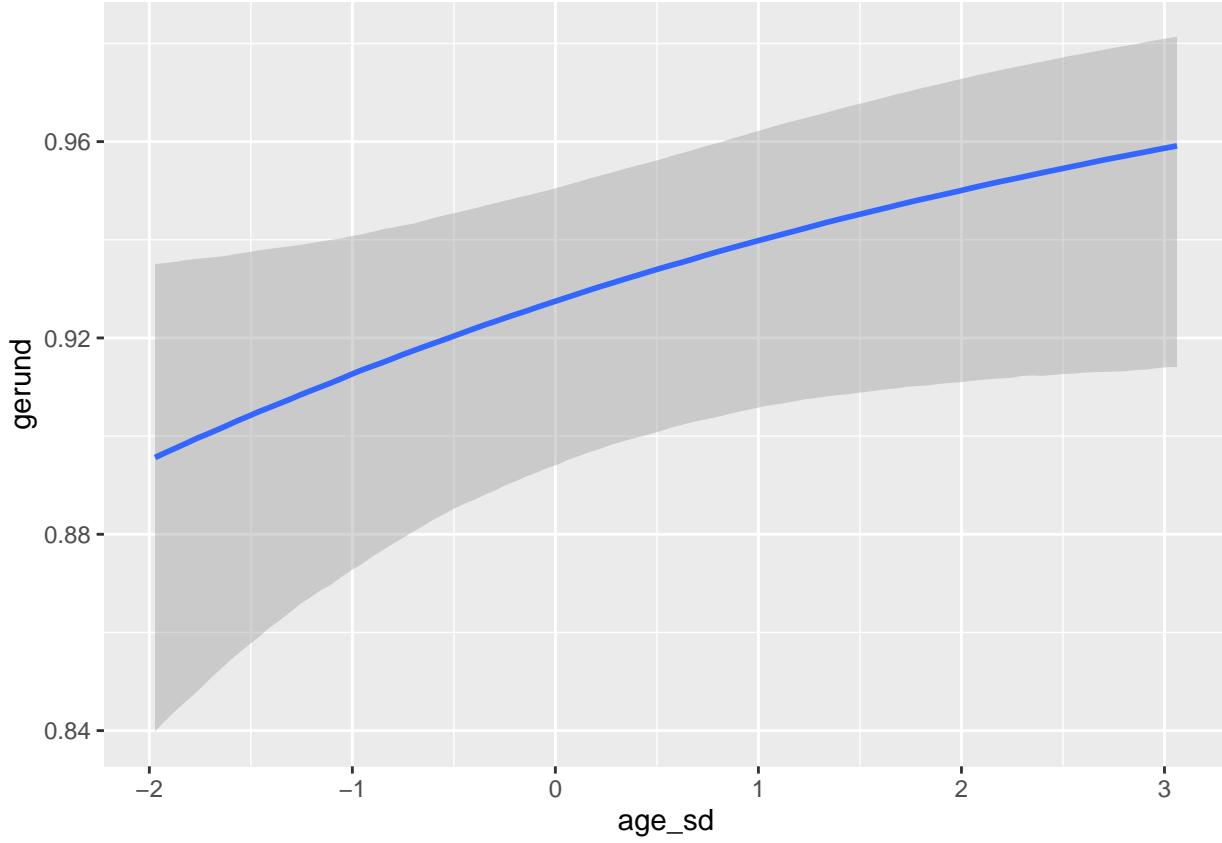
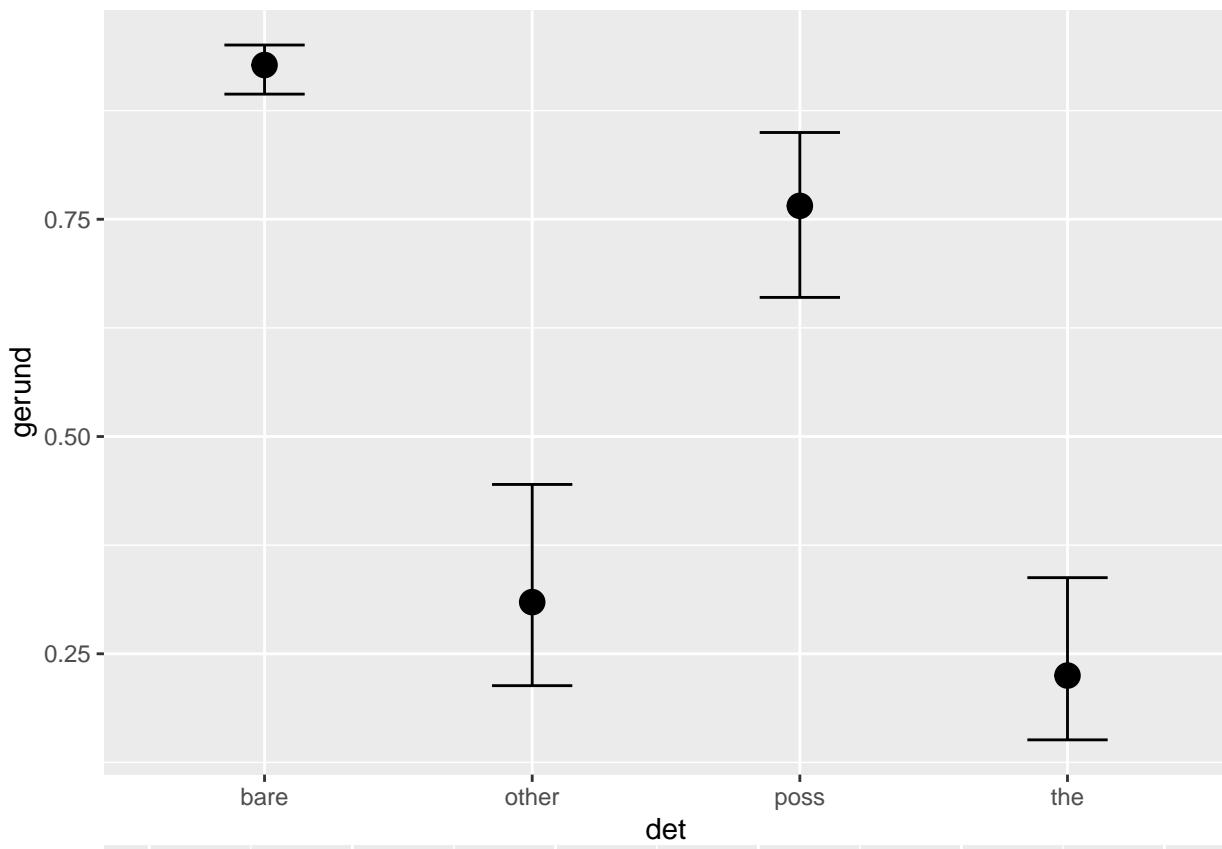
##  Family: bernoulli
##  Links: mu = logit
## Formula: gerund ~ det + age_sd + (det * age_sd | author)
##   Data: df (Number of observations: 16629)
##   Draws: 4 chains, each with iter = 4000; warmup = 1000; thin = 1;
##          total post-warmup draws = 12000
##
## Group-Level Effects:
## ~author (Number of levels: 21)
##                               Estimate Est.Error 1-95% CI u-95% CI Rhat
## sd(Intercept)                0.87     0.16    0.61    1.24 1.00
## sd(detother)                 0.78     0.28    0.31    1.38 1.00
## sd(detposs)                  0.53     0.18    0.24    0.93 1.00
## sd(detthe)                   1.01     0.19    0.71    1.43 1.00
## sd(age_sd)                   0.40     0.09    0.26    0.60 1.00
## sd(detother:age_sd)          0.23     0.17    0.01    0.63 1.00
## sd(detposs:age_sd)           0.71     0.24    0.33    1.26 1.00
## sd(detthe:age_sd)            0.20     0.12    0.01    0.47 1.00
## cor(Intercept,detother)      -0.26     0.23   -0.66    0.21 1.00
## cor(Intercept,detposs)       0.10     0.24   -0.37    0.55 1.00
## cor(detother,detposs)        0.12     0.26   -0.41    0.60 1.00
## cor(Intercept,detthe)        -0.25     0.19   -0.59    0.14 1.00
## cor(detother,detthe)         0.41     0.20   -0.03    0.75 1.00
## cor(detposs,detthe)          0.40     0.22   -0.07    0.77 1.00
## cor(Intercept,age_sd)        0.27     0.21   -0.16    0.65 1.00
## cor(detother,age_sd)         -0.16     0.23   -0.59    0.31 1.00
## cor(detposs,age_sd)          0.01     0.23   -0.43    0.46 1.00
## cor(detthe,age_sd)           -0.12     0.20   -0.50    0.28 1.00
## cor(Intercept,detother:age_sd) 0.03     0.29   -0.54    0.58 1.00
## cor(detother,detother:age_sd) 0.01     0.30   -0.56    0.58 1.00
## cor(detposs,detother:age_sd) -0.08     0.30   -0.63    0.51 1.00
## cor(detthe,detother:age_sd)  -0.12     0.29   -0.65    0.46 1.00
## cor(age_sd,detother:age_sd) -0.06     0.29   -0.61    0.52 1.00
## cor(Intercept,detposs:age_sd) -0.13     0.23   -0.55    0.33 1.00
## cor(detother,detposs:age_sd)  0.04     0.26   -0.48    0.53 1.00
## cor(detposs,detposs:age_sd)  -0.13     0.26   -0.61    0.38 1.00
## cor(detthe,detposs:age_sd)  -0.22     0.22   -0.63    0.22 1.00
## cor(age_sd,detposs:age_sd) -0.02     0.23   -0.45    0.43 1.00
## cor(detother:age_sd,detposs:age_sd) 0.08     0.30   -0.49    0.63 1.00
## cor(Intercept,detthe:age_sd) -0.23     0.28   -0.70    0.36 1.00
## cor(detother,detthe:age_sd)  0.07     0.28   -0.49    0.60 1.00
## cor(detposs,detthe:age_sd) -0.15     0.28   -0.66    0.42 1.00
## cor(detthe,detthe:age_sd)  0.03     0.27   -0.51    0.53 1.00
## cor(age_sd,detthe:age_sd) -0.30     0.28   -0.76    0.30 1.00
## cor(detother:age_sd,detthe:age_sd) 0.07     0.30   -0.52    0.63 1.00
## cor(detposs:age_sd,detthe:age_sd) 0.09     0.28   -0.47    0.62 1.00
##                               Bulk_ESS Tail_ESS
## sd(Intercept)                4905     7318
## sd(detother)                 4463     5155
## sd(detposs)                  5986     6481
## sd(detthe)                   6484     7903
## sd(age_sd)                   8227     9195

```

```

## sd(detother:age_sd)           6833   6958
## sd(detposs:age_sd)            6449   8298
## sd(detthe:age_sd)             4674   6005
## cor(Intercept,detother)       11279  9228
## cor(Intercept,detposs)         14299  9771
## cor(detother,detposs)         10595  10474
## cor(Intercept,detthe)          8553   8617
## cor(detother,detthe)          5484   5982
## cor(detposs,detthe)           6152   7756
## cor(Intercept,age_sd)          12376  9802
## cor(detother,age_sd)           7140   7841
## cor(detposs,age_sd)            7339   9293
## cor(detthe,age_sd)             11566  10253
## cor(Intercept,detother:age_sd) 24766  9409
## cor(detother,detother:age_sd) 19180  9063
## cor(detposs,detother:age_sd) 16612  9255
## cor(detthe,detother:age_sd) 15780  9335
## cor(age_sd,detother:age_sd) 17042  9296
## cor(Intercept,detposs:age_sd) 13040  10107
## cor(detother,detposs:age_sd) 8949   9648
## cor(detposs,detposs:age_sd) 8225   8832
## cor(detthe,detposs:age_sd) 12589  10117
## cor(age_sd,detposs:age_sd) 12926  10505
## cor(detother:age_sd,detposs:age_sd) 6543   8468
## cor(Intercept,detthe:age_sd) 14728  9095
## cor(detother,detthe:age_sd) 16698  10170
## cor(detposs,detthe:age_sd) 13633  9624
## cor(detthe,detthe:age_sd) 18490  10520
## cor(age_sd,detthe:age_sd) 9960   8964
## cor(detother:age_sd,detthe:age_sd) 9210   10281
## cor(detposs:age_sd,detthe:age_sd) 12962  9605
##
## Population-Level Effects:
##               Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept     2.55      0.21    2.13    2.96 1.00    2493   3975
## detother    -3.34      0.23   -3.76   -2.85 1.00    7129   7481
## detposs     -1.36      0.17   -1.68   -1.02 1.00    9762   9023
## detthe      -3.78      0.23   -4.22   -3.28 1.00    6108   6988
## age_sd       0.20      0.10    0.00    0.40 1.00    8120   8764
##
## Draws were sampled using sampling(NUTS). For each parameter, Bulk_ESS
## and Tail_ESS are effective sample size measures, and Rhat is the potential
## scale reduction factor on split chains (at convergence, Rhat = 1).
conditional_effects(M3_full_author_slope_int)

```

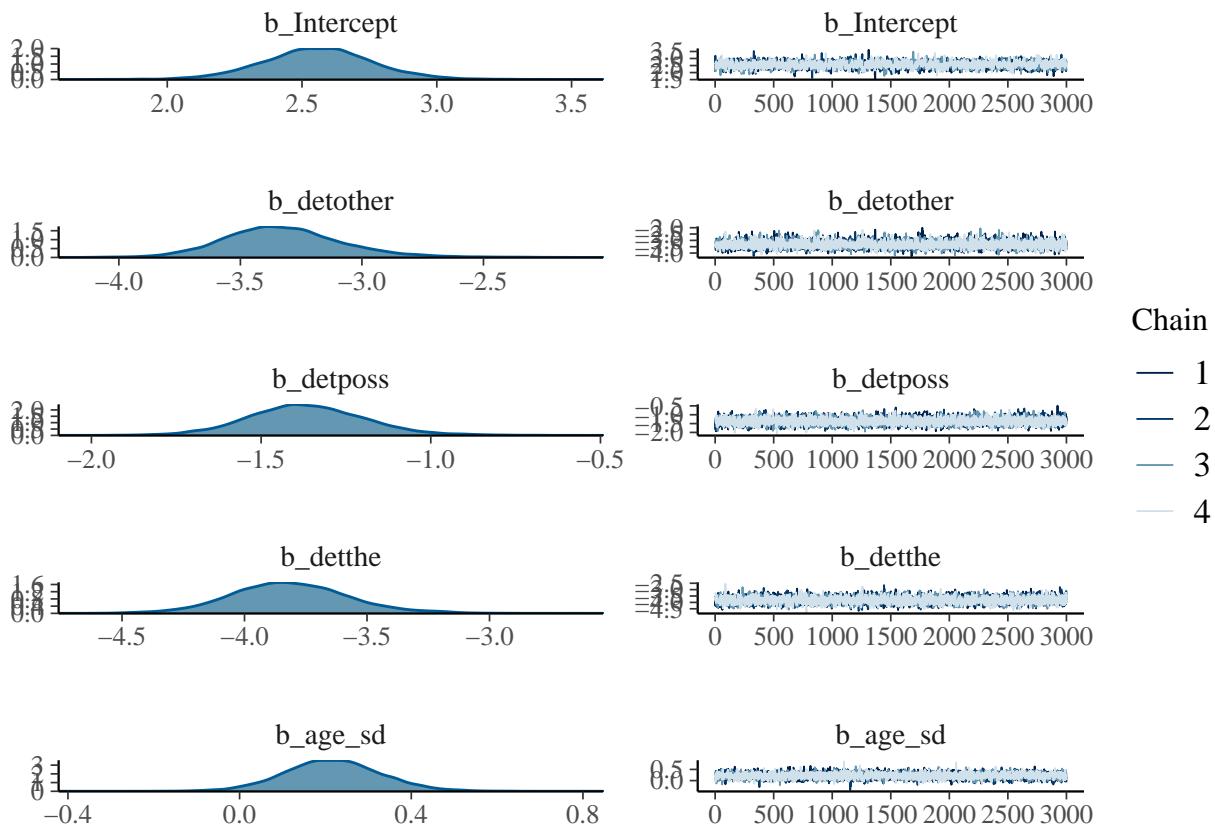


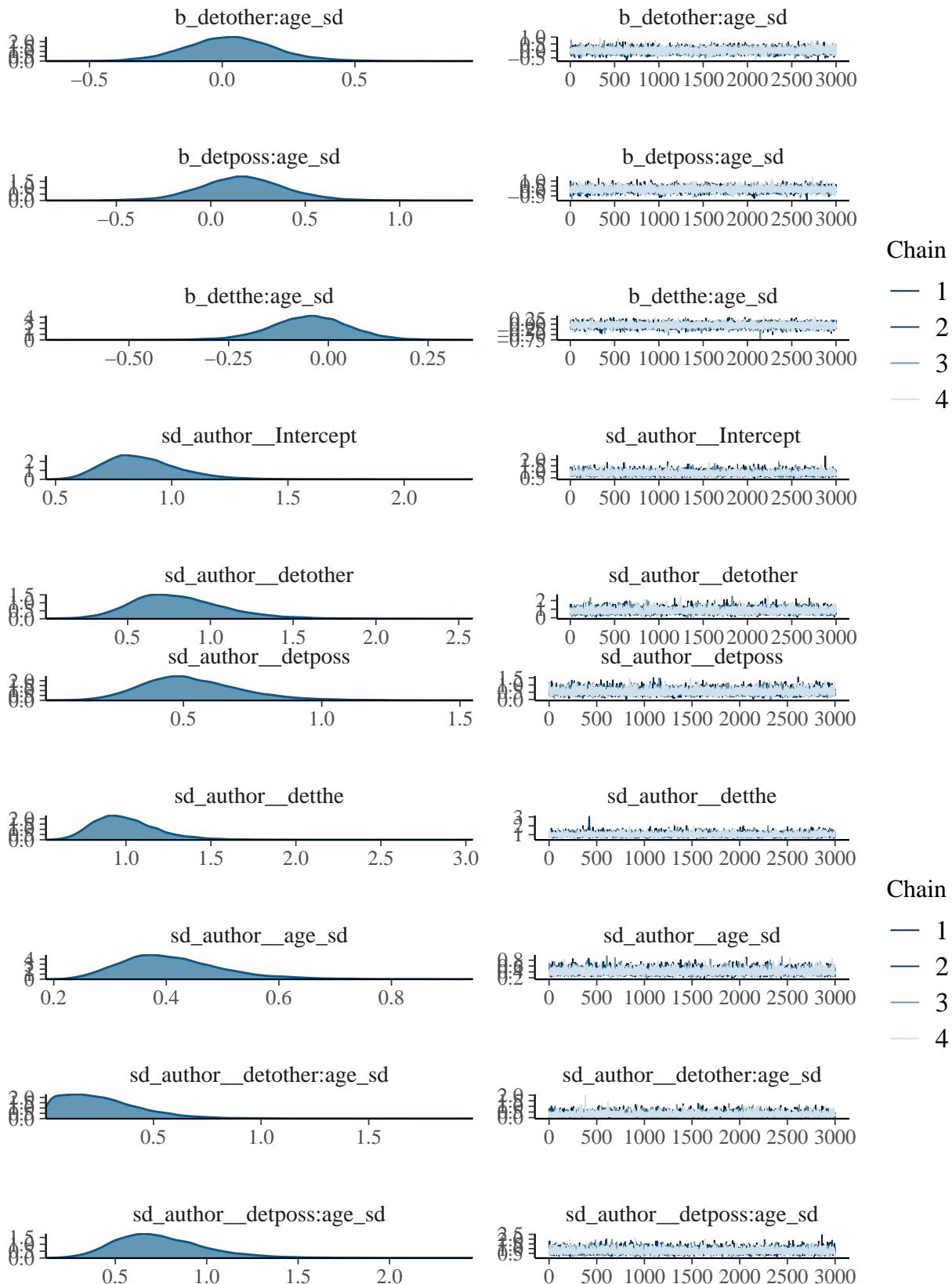
```
M3_full_author_slope_int <- add_criterion(M3_full_author_slope_int, 'waic', file="M3_full_author_slope_int.waic")
M3_full_author_slope_int <- add_criterion(M3_full_author_slope_int, 'loo', file="M3_full_author_slope_int.loo")
```

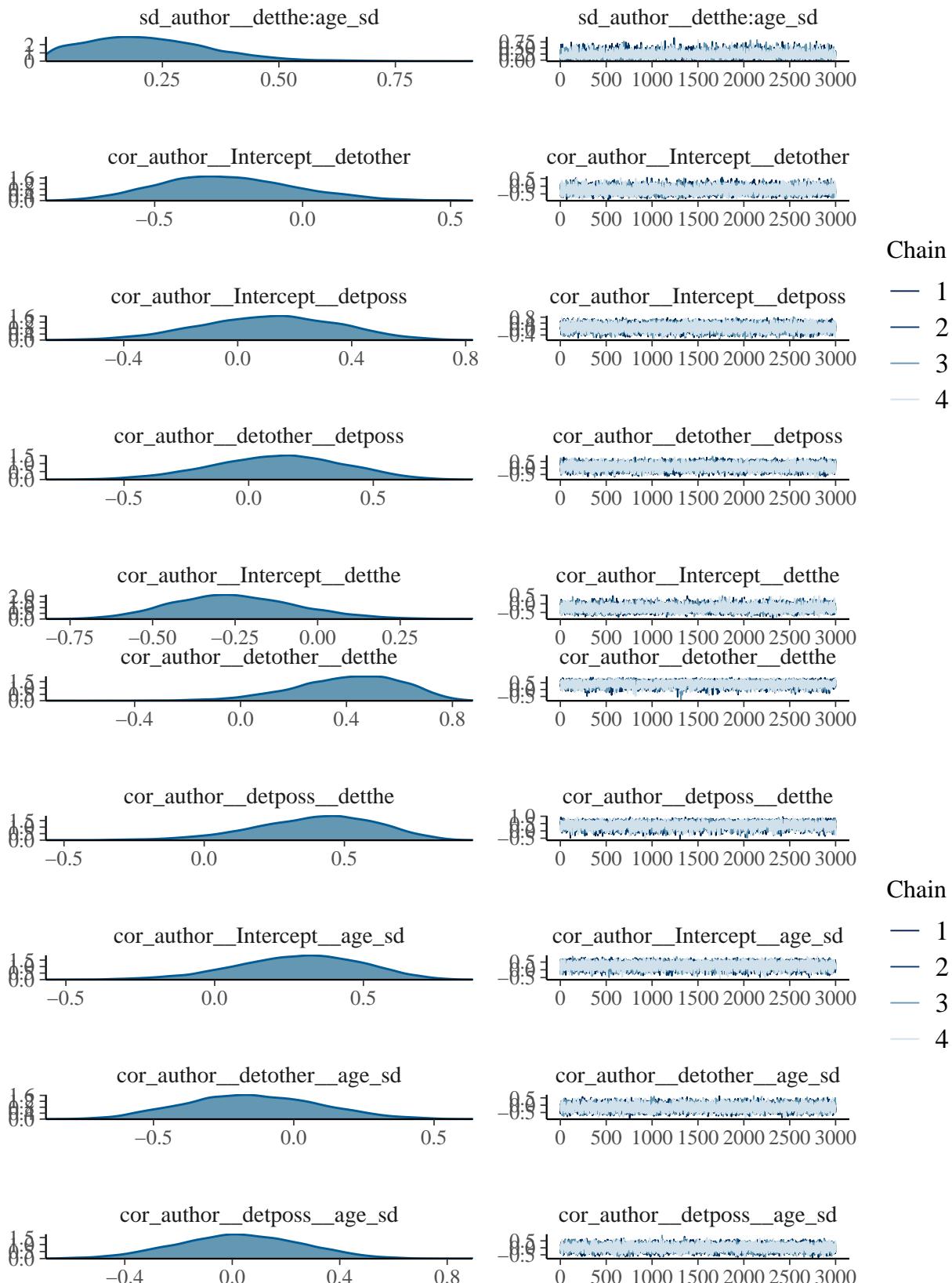
Age and Determiner Interaction + Interaction slope

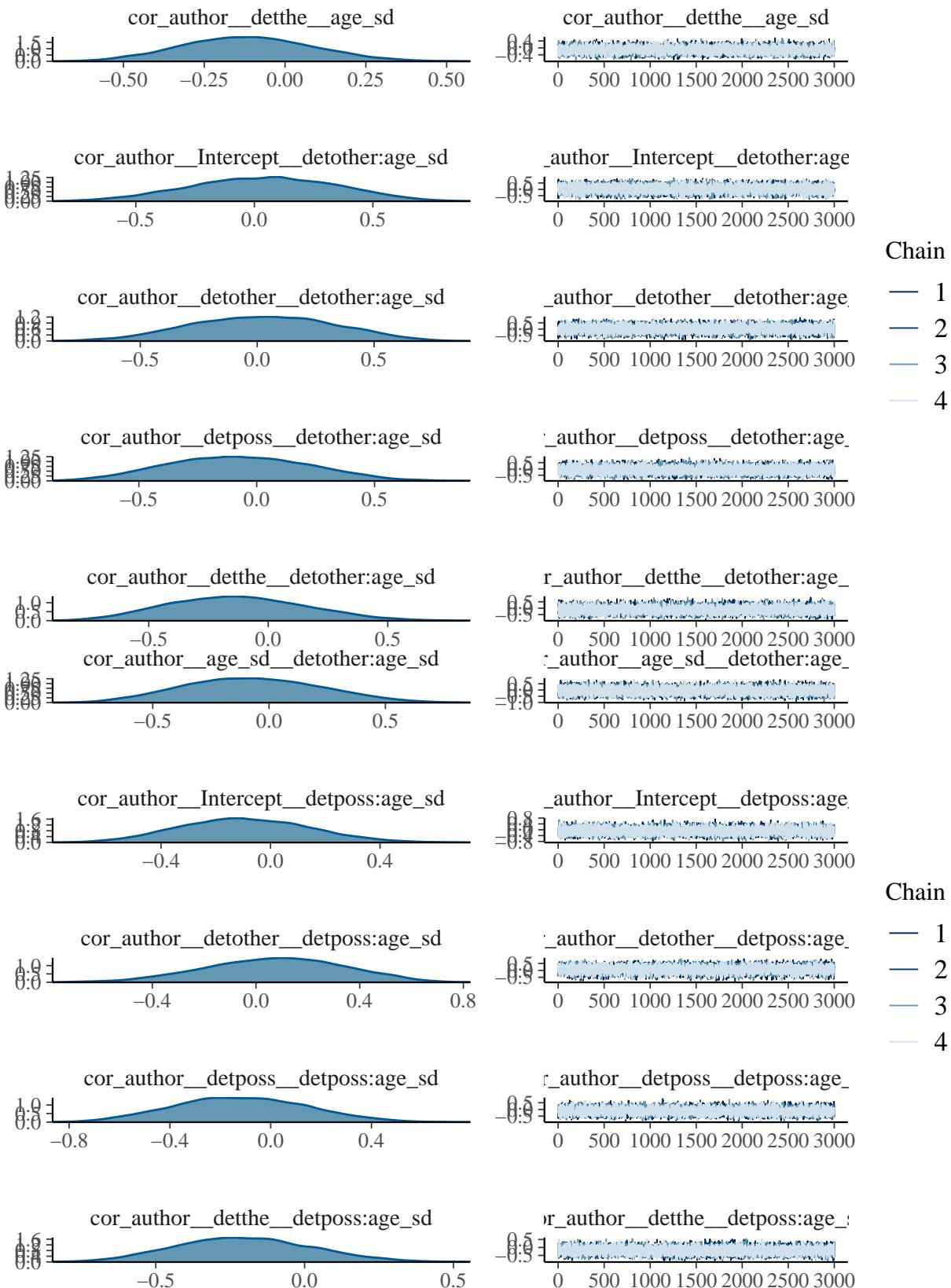
```
## regularizing prior for (i) beta coefficients, (ii) lkj prior, (iii) cauchy - helps sampling ##  
M3_full_author_int_slope_int <- brm(gerund ~ det * age_sd + (det*age_sd|author),  
  data=df, family = bernoulli(),  
  chains = 4, iter = 4000, warmup = 1000, cores = 4,  
  prior = c(set_prior("normal(0, 1)", "b"),  
  set_prior("lkj(2)", "cor"),  
  set_prior("normal(0, 5)", "Intercept"),  
  set_prior("cauchy(0, 2)", "sd")),  
  save_model = "M3_full_author_int_slope_int.stan",  
  file = "M3_full_author_int_slope_int",  
  file_refit="never")
```

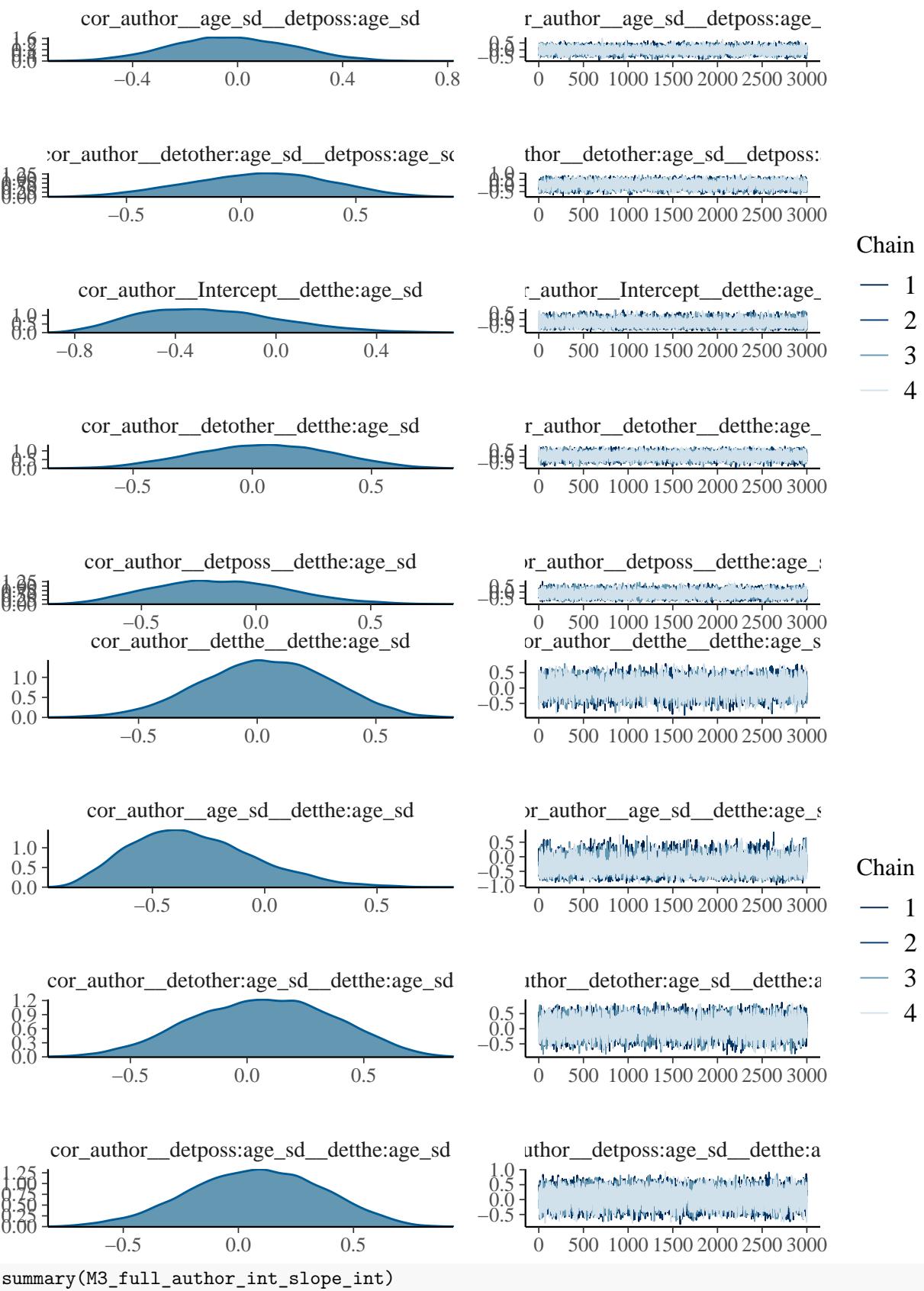
```
plot(M3_full_author_int_slope_int)
```











```

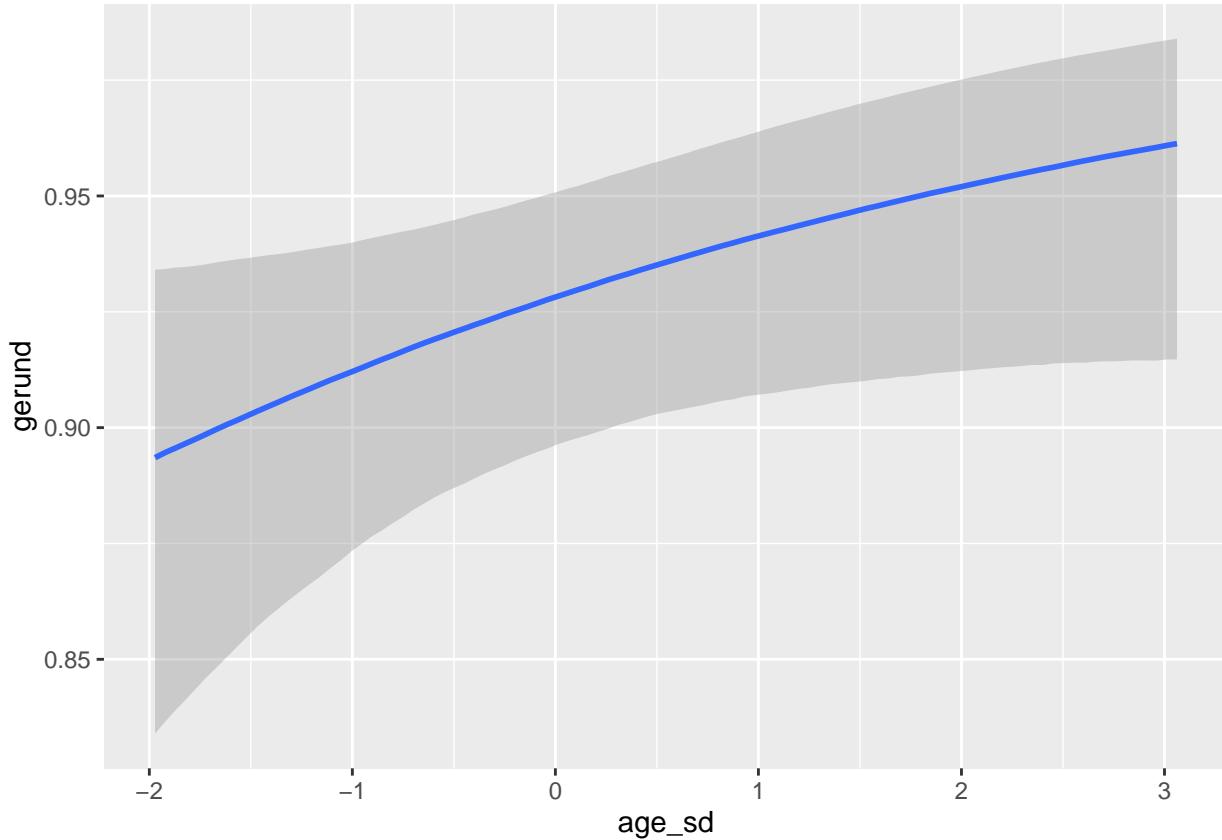
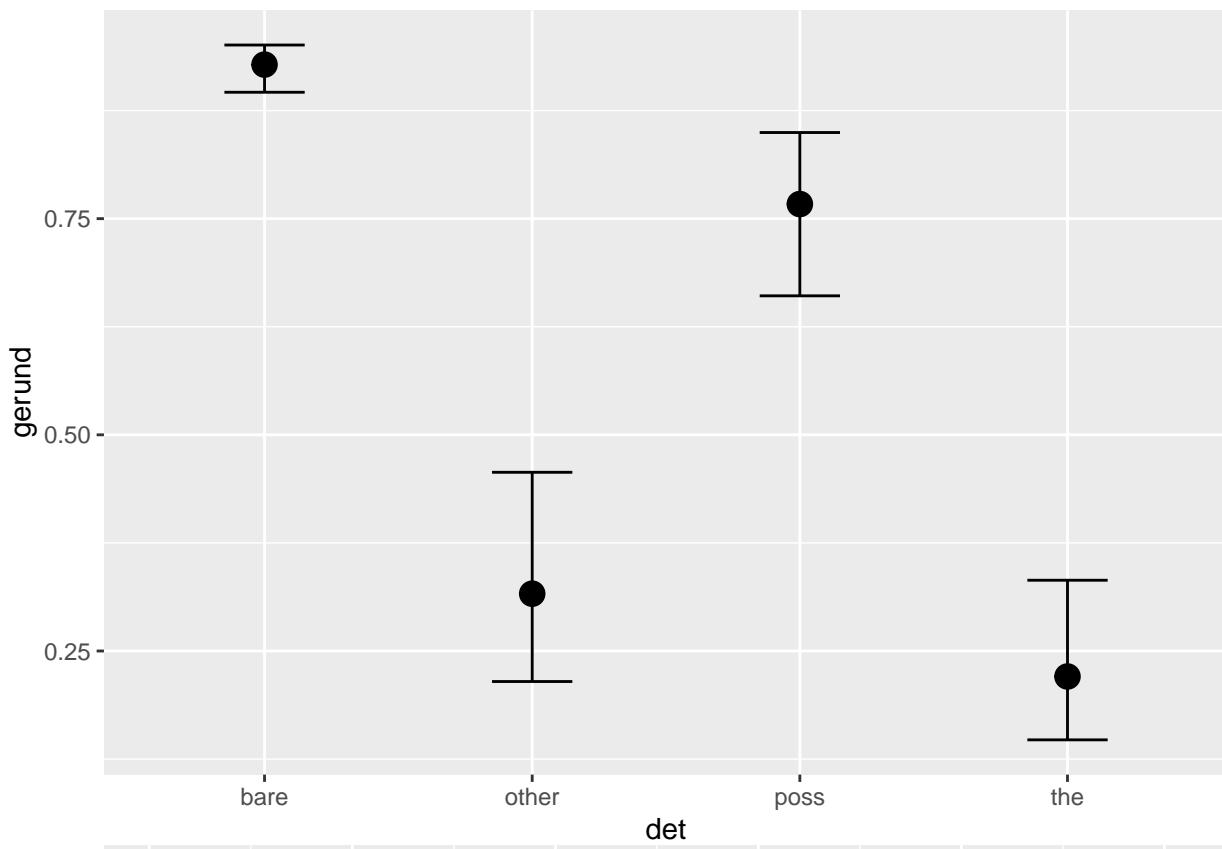
##  Family: bernoulli
##  Links: mu = logit
## Formula: gerund ~ det * age_sd + (det * age_sd | author)
## Data: df (Number of observations: 16629)
## Draws: 4 chains, each with iter = 4000; warmup = 1000; thin = 1;
##         total post-warmup draws = 12000
##
## Group-Level Effects:
## ~author (Number of levels: 21)
##                               Estimate Est.Error 1-95% CI u-95% CI Rhat
## sd(Intercept)                0.87     0.16    0.62    1.24 1.00
## sd(detother)                 0.81     0.28    0.34    1.43 1.00
## sd(detposs)                  0.53     0.18    0.23    0.95 1.00
## sd(detthe)                   1.00     0.19    0.70    1.43 1.00
## sd(age_sd)                   0.41     0.09    0.27    0.62 1.00
## sd(detother:age_sd)          0.26     0.19    0.01    0.70 1.00
## sd(detposs:age_sd)           0.75     0.25    0.35    1.31 1.00
## sd(detthe:age_sd)            0.22     0.13    0.02    0.51 1.00
## cor(Intercept,detother)      -0.25    0.23   -0.66    0.22 1.00
## cor(Intercept,detposs)        0.11     0.24   -0.37    0.56 1.00
## cor(detother,detposs)        0.12     0.26   -0.41    0.60 1.00
## cor(Intercept,detthe)        -0.25    0.19   -0.59    0.14 1.00
## cor(detother,detthe)         0.41     0.20   -0.03    0.74 1.00
## cor(detposs,detthe)          0.40     0.22   -0.07    0.77 1.00
## cor(Intercept,age_sd)        0.28     0.21   -0.16    0.66 1.00
## cor(detother,age_sd)         -0.15    0.24   -0.58    0.32 1.00
## cor(detposs,age_sd)          0.03     0.23   -0.42    0.46 1.00
## cor(detthe,age_sd)           -0.12    0.20   -0.49    0.28 1.00
## cor(Intercept,detother:age_sd) 0.04     0.30   -0.55    0.60 1.00
## cor(detother,detother:age_sd) 0.02     0.30   -0.55    0.59 1.00
## cor(detposs,detother:age_sd) -0.08     0.29   -0.63    0.49 1.00
## cor(detthe,detother:age_sd) -0.13     0.28   -0.65    0.43 1.00
## cor(age_sd,detother:age_sd) -0.07     0.29   -0.61    0.50 1.00
## cor(Intercept,detposs:age_sd) -0.09     0.23   -0.53    0.37 1.00
## cor(detother,detposs:age_sd)  0.07     0.26   -0.45    0.56 1.00
## cor(detposs,detposs:age_sd) -0.12     0.26   -0.61    0.39 1.00
## cor(detthe,detposs:age_sd) -0.20     0.22   -0.62    0.25 1.00
## cor(age_sd,detposs:age_sd) -0.02     0.23   -0.45    0.42 1.00
## cor(detother:age_sd,detposs:age_sd) 0.08     0.30   -0.51    0.62 1.00
## cor(Intercept,detthe:age_sd) -0.26     0.28   -0.72    0.34 1.00
## cor(detother,detthe:age_sd)  0.05     0.28   -0.50    0.58 1.00
## cor(detposs,detthe:age_sd) -0.15     0.29   -0.67    0.44 1.00
## cor(detthe,detthe:age_sd)  0.04     0.27   -0.49    0.54 1.00
## cor(age_sd,detthe:age_sd) -0.31     0.27   -0.77    0.29 1.00
## cor(detother:age_sd,detthe:age_sd) 0.07     0.30   -0.51    0.62 1.00
## cor(detposs:age_sd,detthe:age_sd) 0.08     0.28   -0.49    0.61 1.00
##                               Bulk_ESS Tail_ESS
## sd(Intercept)                4269     5966
## sd(detother)                 3550     3780
## sd(detposs)                  5777     6201
## sd(detthe)                   4887     6502
## sd(age_sd)                   7063     8127
## sd(detother:age_sd)          5753     6449
## sd(detposs:age_sd)           6793     8398

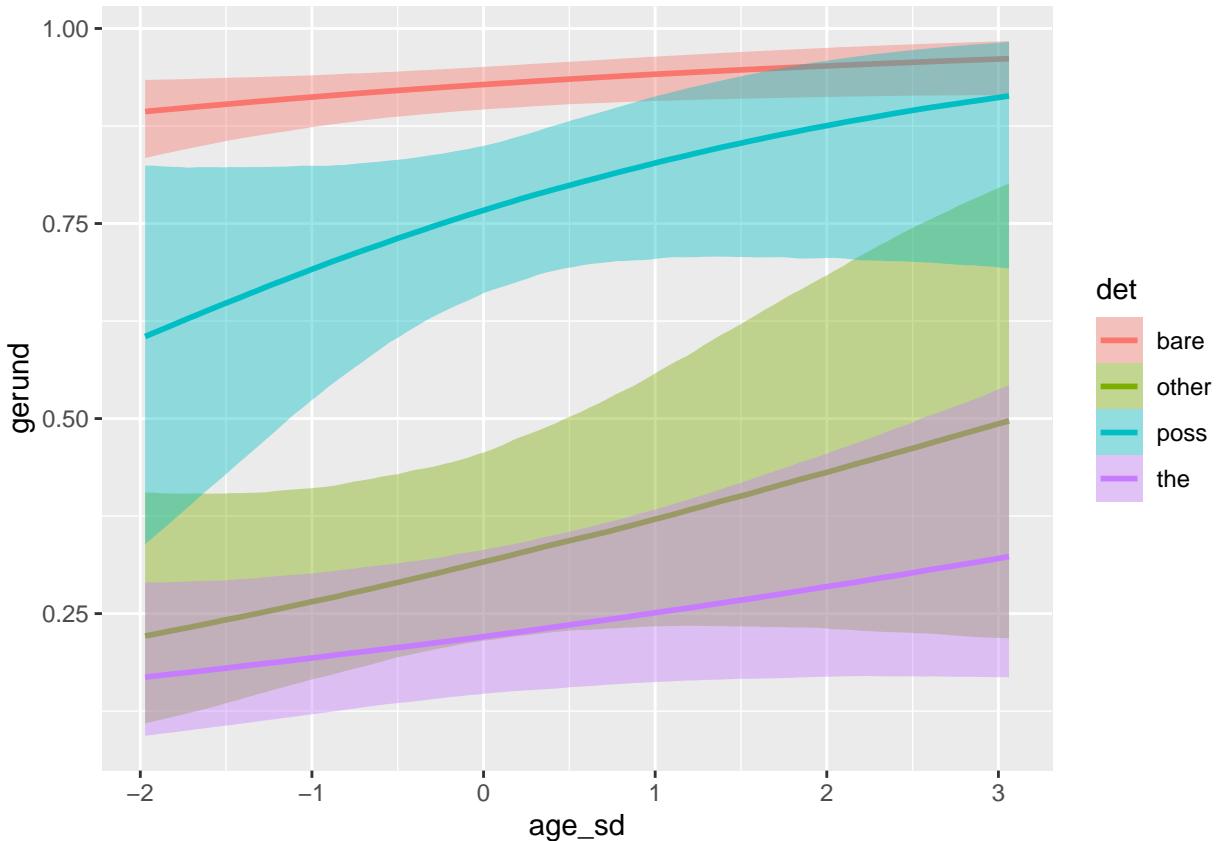
```

```

## sd(detthe:age_sd)           4437    5817
## cor(Intercept,detother)     10655   9216
## cor(Intercept,detposs)      13004   9719
## cor(detother,detposs)       8822    8776
## cor(Intercept,detthe)        8050    8423
## cor(detother,detthe)        5050    5196
## cor(detposs,detthe)         5676    7882
## cor(Intercept,age_sd)       10440   9553
## cor(detother,age_sd)        6572    8011
## cor(detposs,age_sd)         6870    9122
## cor(detthe,age_sd)          9779    9566
## cor(Intercept,detother:age_sd) 23834   8792
## cor(detother,detother:age_sd) 17259   8669
## cor(detposs,detother:age_sd) 16071   9608
## cor(detthe,detother:age_sd) 15420   9299
## cor(age_sd,detother:age_sd) 16477   9124
## cor(Intercept,detposs:age_sd) 14601   9700
## cor(detother,detposs:age_sd) 7960    8548
## cor(detposs,detposs:age_sd) 8091    8602
## cor(detthe,detposs:age_sd) 11749   10235
## cor(age_sd,detposs:age_sd) 12144   9399
## cor(detother:age_sd,detposs:age_sd) 5980   9147
## cor(Intercept,detthe:age_sd) 14775   9671
## cor(detother,detthe:age_sd) 15157   9689
## cor(detposs,detthe:age_sd) 13247   10007
## cor(detthe,detthe:age_sd) 15917   9381
## cor(age_sd,detthe:age_sd) 11070   9200
## cor(detother:age_sd,detthe:age_sd) 9145   9608
## cor(detposs:age_sd,detthe:age_sd) 11634   10774
##
## Population-Level Effects:
##               Estimate Est.Error 1-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept      2.56     0.20    2.16    2.96 1.00    2376   4201
## detother     -3.32     0.25   -3.77   -2.78 1.00    5440   6310
## detposs      -1.36     0.17   -1.70   -1.01 1.00    7038   8185
## detthe       -3.81     0.24   -4.27   -3.31 1.00    4504   5796
## age_sd        0.22     0.11   -0.00    0.44 1.00    5679   7164
## detother:age_sd 0.03     0.17   -0.29    0.37 1.00   10801   8770
## detposs:age_sd 0.17     0.23   -0.28    0.63 1.00    8784   8702
## detthe:age_sd -0.05     0.10   -0.25    0.15 1.00    8902   7997
##
## Draws were sampled using sampling(NUTS). For each parameter, Bulk_ESS
## and Tail_ESS are effective sample size measures, and Rhat is the potential
## scale reduction factor on split chains (at convergence, Rhat = 1).
conditional_effects(M3_full_author_int_slope_int)

```





```
M3_full_author_int_slope_int <- add_criterion(M3_full_author_int_slope_int, 'waic', file="M3_full_author_int_slope_int.waic")
M3_full_author_int_slope_int <- add_criterion(M3_full_author_int_slope_int, 'loo', file="M3_full_author_int_slope_int.loo")
```

model comparison

```
w <- loo_compare(base, base_author, M1_age, M1_age_author, M1_age_author_slope, M2_det, M2_det_author, M2_det_slope)
```

All models: WAIC

```
## Warning: Not all models have the same y variable. ('yhash' attributes do not
## match)
```

```
print(w, simplify = FALSE)
```

	elpd_diff	se_diff	elpd_waic	se_elpd_waic
## M3_full_author_slope_int	0.0	0.0	-5905.1	78.4
## M3_full_author_int_slope_int	-1.2	111.3	-5906.3	78.5
## M3_full_author_slope_no_int	-9.9	4.7	-5915.0	78.4
## M3_full_author_int_slope_no_int	-12.3	4.8	-5917.4	78.4
## M3_full_author_slope_det	-61.4	111.3	-5966.5	78.5
## M3_full_author_slope_det_int	-64.0	111.4	-5969.1	78.5
## M2_det_author_slope	-96.4	111.6	-6001.5	78.8
## M3_full_author_slope_int_only	-115.0	111.9	-6020.1	79.2
## M3_full_author_int_slope_int_only	-115.2	15.0	-6020.3	79.2
## M3_full_author_slope_age_int	-142.5	111.8	-6047.6	79.1
## M3_full_author_slope_age	-143.4	111.8	-6048.5	79.1
## M3_full_author	-197.6	112.0	-6102.7	79.3

```

## M3_full_author_int      -199.6    112.0 -6104.7    79.3
## M2_det_author          -231.2    112.3 -6136.3    79.7
## M3_full                 -621.8    112.2 -6526.9    79.2
## M3_full_int             -623.3     34.4 -6528.3    79.2
## M2_det                  -628.5    112.2 -6533.5    79.3
## M1_age_author_slope     -3523.2    97.9 -9428.2    59.0
## M1_age_author            -3587.4    74.2 -9492.5    58.1
## base_author              -3621.1    74.2 -9526.2    57.9
## M1_age                   -4055.1    94.8 -9960.2    53.2
## base                      -4059.0    94.7 -9964.1    53.1
##
## p_waic   se_p_waic waic      se_waic
## M3_full_author_slope_int 91.6      2.5  11810.2   156.9
## M3_full_author_int_slope_int 94.8      2.6  11812.7   156.9
## M3_full_author_slope_no_int 73.3      1.8  11830.0   156.7
## M3_full_author_int_slope_no_int 76.0      1.9  11834.8   156.8
## M3_full_author_slope_det 58.9      1.5  11932.9   157.0
## M3_full_author_slope_det_int 61.7      1.6  11938.3   157.0
## M2_det_author_slope      57.0      1.5  12003.0   157.6
## M3_full_author_slope_int_only 65.8      1.8  12040.2   158.4
## M3_full_author_int_slope_int_only 66.0      1.8  12040.5   158.4
## M3_full_author_slope_age_int 38.3      0.8  12095.2   158.2
## M3_full_author_slope_age 35.4      0.7  12096.9   158.1
## M3_full_author            22.7      0.4  12205.4   158.7
## M3_full_author_int        25.4      0.5  12209.4   158.7
## M2_det_author              21.6      0.4  12272.6   159.3
## M3_full                   4.9       0.1  13053.7   158.4
## M3_full_int                7.7       0.2  13056.7   158.5
## M2_det                     4.0       0.1  13067.1   158.5
## M1_age_author_slope        37.3      0.6  18856.5   118.0
## M1_age_author              21.4      0.3  18984.9   116.3
## base_author                 20.4      0.3  19052.3   115.8
## M1_age                     2.0       0.0  19920.3   106.4
## base                       1.0       0.0  19928.3   106.3
round(model_weights(base, base_author, M1_age, M1_age_author, M1_age_author_slope, M2_det, M2_det_author))

##                                base           base_author
##                                0.000000      0.000000
##                                M1_age         M1_age_author
##                                0.000000      0.000000
##                                M1_age_author_slope      M2_det
##                                0.000000      0.000000
##                                M2_det_author          M2_det_author_slope
##                                0.000000      0.000000
##                                M3_full           M3_full_int
##                                0.000000      0.000000
##                                M3_full_author        M3_full_author_int
##                                0.000000      0.000000
##                                M3_full_author_slope_age M3_full_author_slope_age_int
##                                0.000000      0.000000
##                                M3_full_author_slope_det M3_full_author_slope_no_int
##                                0.000000      0.000039
## M3_full_author_int_slope_no_int M3_full_author_slope_det_int
##                                0.000004      0.000000
## M3_full_author_int_slope_int_only M3_full_author_slope_int_only
```

```

##          0.000000          0.000000
##      M3_full_author_slope_int    M3_full_author_int_slope_int
##          0.776493          0.223465

w_10 <- loo_compare(M2_det_author_slope, M3_full_author_slope_age_int, M3_full_author_slope_det, M3_full_

```

Top 10

```

## Warning: Not all models have the same y variable. ('yhash' attributes do not
## match)

print(w_10, simplify = FALSE)

```

	elpd_diff	se_diff	elpd_waic	se_elpd_waic
## M3_full_author_slope_int	0.0	0.0	-5905.1	78.4
## M3_full_author_int_slope_int	-1.2	111.3	-5906.3	78.5
## M3_full_author_slope_no_int	-9.9	4.7	-5915.0	78.4
## M3_full_author_int_slope_no_int	-12.3	4.8	-5917.4	78.4
## M3_full_author_slope_det	-61.4	111.3	-5966.5	78.5
## M3_full_author_slope_det_int	-64.0	111.4	-5969.1	78.5
## M2_det_author_slope	-96.4	111.6	-6001.5	78.8
## M3_full_author_slope_int_only	-115.0	111.9	-6020.1	79.2
## M3_full_author_int_slope_int_only	-115.2	15.0	-6020.3	79.2
## M3_full_author_slope_age_int	-142.5	111.8	-6047.6	79.1
	p_waic	se_p_waic	waic	se_waic
## M3_full_author_slope_int	91.6	2.5	11810.2	156.9
## M3_full_author_int_slope_int	94.8	2.6	11812.7	156.9
## M3_full_author_slope_no_int	73.3	1.8	11830.0	156.7
## M3_full_author_int_slope_no_int	76.0	1.9	11834.8	156.8
## M3_full_author_slope_det	58.9	1.5	11932.9	157.0
## M3_full_author_slope_det_int	61.7	1.6	11938.3	157.0
## M2_det_author_slope	57.0	1.5	12003.0	157.6
## M3_full_author_slope_int_only	65.8	1.8	12040.2	158.4
## M3_full_author_int_slope_int_only	66.0	1.8	12040.5	158.4
## M3_full_author_slope_age_int	38.3	0.8	12095.2	158.2

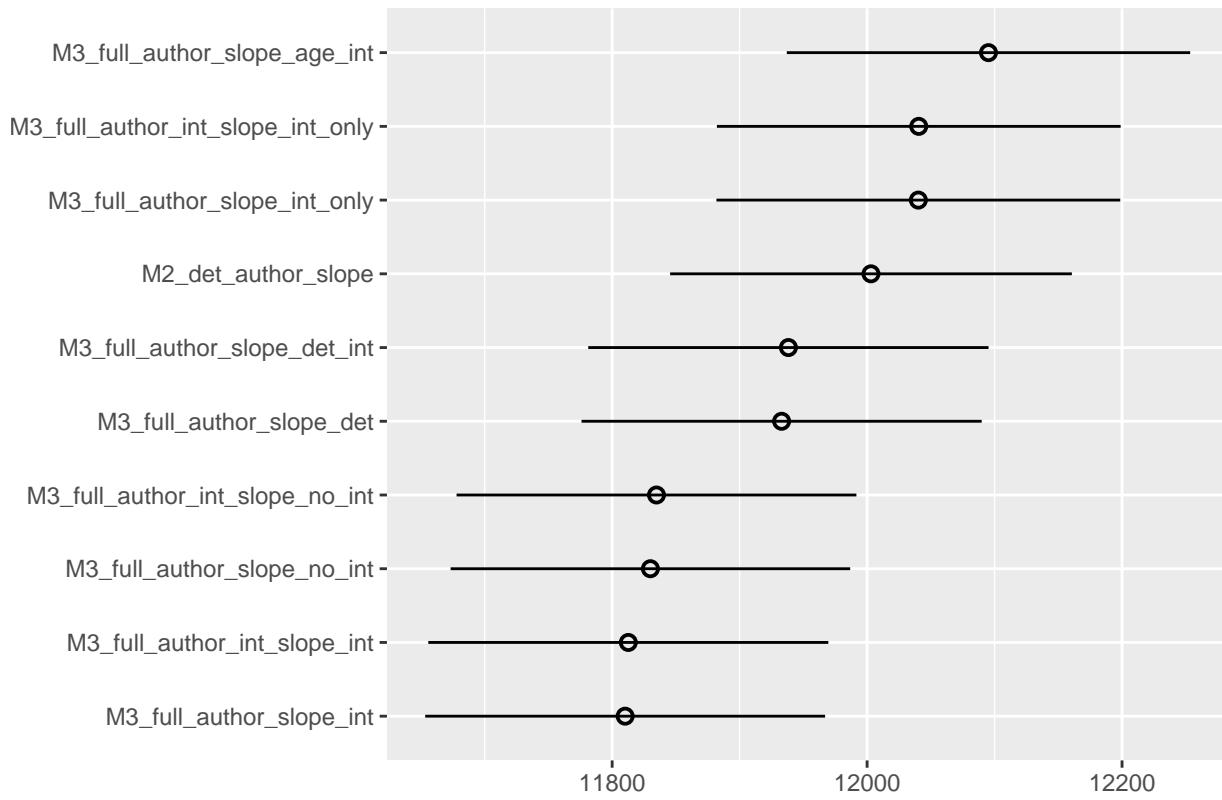
```

w_10[, 7:8] %>%
  data.frame() %>%
  rownames_to_column(var = "model_name") %>%

  ggplot(aes(x = reorder(model_name, waic),
             y = waic,
             ymin = waic - se_waic,
             ymax = waic + se_waic)) +
  geom_pointrange(shape = 21) +
  coord_flip() +
  labs(x = NULL, y = NULL,
       title = "WAIC comparison top 10")

```

WAIC comparison top 10



```
1 <- loo_compare(base, base_author, M1_age, M1_age_author, M1_age_author_slope, M2_det, M2_det_author, M2_det_slope)
```

All models: PSIS-LOO

```
## Warning: Not all models have the same y variable. ('yhash' attributes do not
## match)
print(1, simplify = FALSE)

##                                     elpd_diff se_diff elpd_loo se_elpd_loo
## M3_full_author_slope_int          0.0     0.0 -5905.4    78.4
## M3_full_author_int_slope_int     -1.3    111.3 -5906.7    78.5
## M3_full_author_slope_no_int      -9.7     4.7 -5915.1    78.4
## M3_full_author_int_slope_no_int -12.1     4.8 -5917.5    78.4
## M3_full_author_slope_det        -61.2    111.3 -5966.6    78.5
## M3_full_author_slope_det_int    -63.9    111.4 -5969.2    78.5
## M2_det_author_slope             -96.2    111.6 -6001.6    78.8
## M3_full_author_slope_int_only   -114.8   111.9 -6020.2    79.2
## M3_full_author_int_slope_int_only -115.0   15.0 -6020.4    79.2
## M3_full_author_slope_age_int    -142.2   111.8 -6047.6    79.1
## M3_full_author_slope_age        -143.1   111.8 -6048.5    79.1
## M3_full_author                 -197.3   112.0 -6102.7    79.3
## M3_full_author_int              -199.3   112.0 -6104.7    79.3
## M2_det_author                  -230.9   112.3 -6136.3    79.7
## M3_full                        -621.5   112.2 -6526.9    79.2
## M3_full_int                     -623.0    34.4 -6528.4    79.2
## M2_det                         -628.2   112.2 -6533.6    79.3
```

```

## M1_age_author_slope      -3522.9      97.9 -9428.3      59.0
## M1_age_author      -3587.1      74.2 -9492.5      58.1
## base_author      -3620.8      74.2 -9526.2      57.9
## M1_age      -4054.8      94.8 -9960.2      53.2
## base      -4058.7      94.7 -9964.1      53.1
##          p_loo    se_p_loo   looic   se_looic
## M3_full_author_slope_int      91.9       2.5 11810.8     156.9
## M3_full_author_int_slope_int      95.2       2.6 11813.4     156.9
## M3_full_author_slope_no_int      73.4       1.8 11830.2     156.7
## M3_full_author_int_slope_no_int      76.1       1.9 11835.0     156.8
## M3_full_author_slope_det      59.0       1.5 11933.1     157.0
## M3_full_author_slope_det_int      61.8       1.6 11938.5     157.0
## M2_det_author_slope      57.1       1.5 12003.2     157.6
## M3_full_author_slope_int_only      65.9       1.8 12040.5     158.4
## M3_full_author_int_slope_int_only      66.2       1.8 12040.8     158.4
## M3_full_author_slope_age_int      38.4       0.8 12095.3     158.2
## M3_full_author_slope_age      35.5       0.7 12096.9     158.1
## M3_full_author      22.7       0.4 12205.4     158.7
## M3_full_author_int      25.4       0.5 12209.4     158.7
## M2_det_author      21.6       0.4 12272.6     159.3
## M3_full      4.9       0.1 13053.7     158.4
## M3_full_int      7.8       0.2 13056.7     158.5
## M2_det      4.0       0.1 13067.1     158.5
## M1_age_author_slope      37.3       0.6 18856.5     118.0
## M1_age_author      21.5       0.3 18985.0     116.3
## base_author      20.4       0.3 19052.3     115.8
## M1_age      2.0       0.0 19920.3     106.4
## base      1.0       0.0 19928.3     106.3

round(model_weights(base, base_author, M1_age, M1_age_author, M1_age_author_slope, M2_det, M2_det_author))

##          base      base_author
##          0.000000      0.000000
##          M1_age      M1_age_author
##          0.000000      0.000000
##          M1_age_author_slope      M2_det
##          0.000000      0.000000
##          M2_det_author      M2_det_author_slope
##          0.000000      0.000000
##          M3_full      M3_full_int
##          0.000000      0.000000
##          M3_full_author      M3_full_author_int
##          0.000000      0.000000
##          M3_full_author_slope_age      M3_full_author_slope_age_int
##          0.000000      0.000000
##          M3_full_author_slope_det      M3_full_author_slope_no_int
##          0.000000      0.000047
##          M3_full_author_int_slope_no_int      M3_full_author_slope_det_int
##          0.000004      0.000000
##          M3_full_author_int_slope_int_only      M3_full_author_slope_int_only
##          0.000000      0.000000
##          M3_full_author_slope_int      M3_full_author_int_slope_int
##          0.784664      0.215285

```

```

l_10 <- loo_compare(M2_det_author_slope, M3_full_author_slope_age_int, M3_full_author_slope_det, M3_full_
Top 10

## Warning: Not all models have the same y variable. ('yhash' attributes do not
## match)

print(l_10, simplify = FALSE)

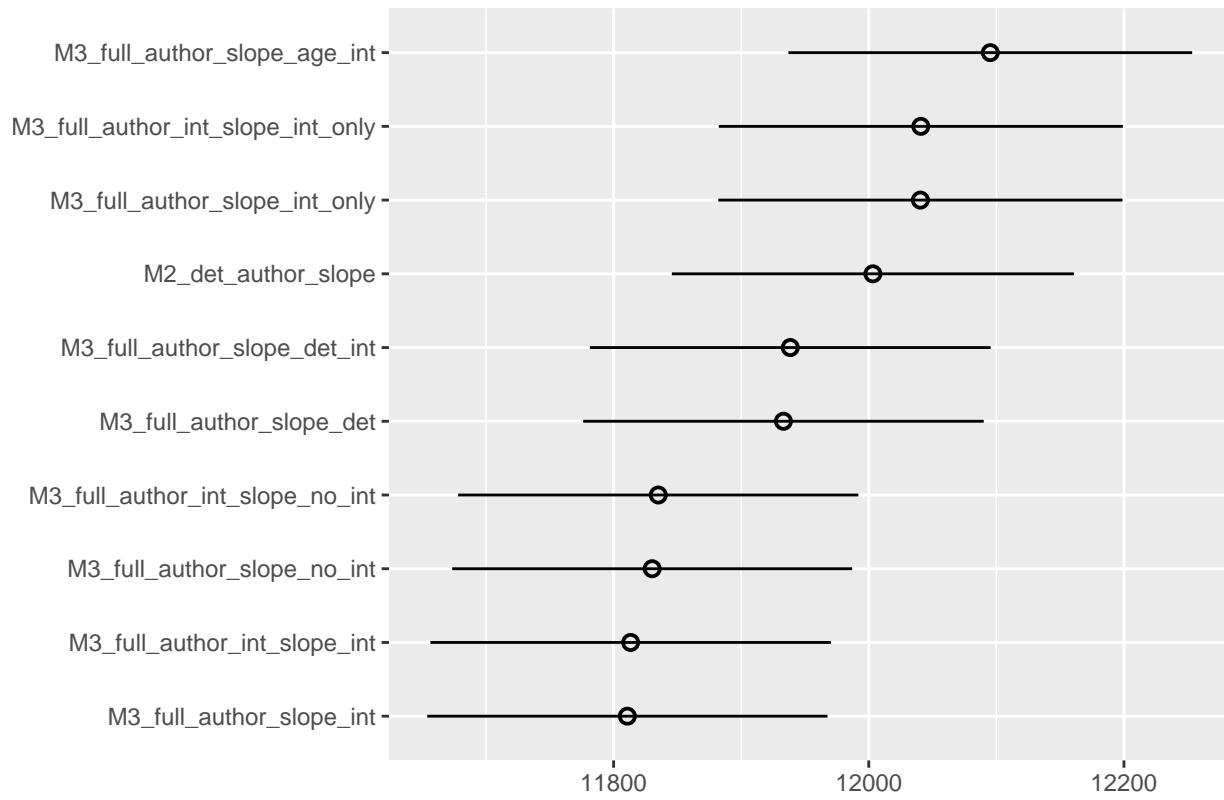
##                                     elpd_diff se_diff elpd_loo se_elpd_loo
## M3_full_author_slope_int          0.0      0.0 -5905.4    78.4
## M3_full_author_int_slope_int     -1.3     111.3 -5906.7    78.5
## M3_full_author_slope_no_int      -9.7      4.7 -5915.1    78.4
## M3_full_author_int_slope_no_int -12.1      4.8 -5917.5    78.4
## M3_full_author_slope_det        -61.2     111.3 -5966.6    78.5
## M3_full_author_slope_det_int    -63.9     111.4 -5969.2    78.5
## M2_det_author_slope             -96.2     111.6 -6001.6    78.8
## M3_full_author_slope_int_only   -114.8     111.9 -6020.2    79.2
## M3_full_author_int_slope_int_only -115.0      15.0 -6020.4    79.2
## M3_full_author_slope_age_int    -142.2     111.8 -6047.6    79.1
##                                     p_loo    se_p_loo looic    se_looic
## M3_full_author_slope_int         91.9      2.5 11810.8   156.9
## M3_full_author_int_slope_int    95.2      2.6 11813.4   156.9
## M3_full_author_slope_no_int     73.4      1.8 11830.2   156.7
## M3_full_author_int_slope_no_int 76.1      1.9 11835.0   156.8
## M3_full_author_slope_det       59.0      1.5 11933.1   157.0
## M3_full_author_slope_det_int   61.8      1.6 11938.5   157.0
## M2_det_author_slope            57.1      1.5 12003.2   157.6
## M3_full_author_slope_int_only   65.9      1.8 12040.5   158.4
## M3_full_author_int_slope_int_only 66.2      1.8 12040.8   158.4
## M3_full_author_slope_age_int   38.4      0.8 12095.3   158.2

l_10[, 7:8] %>%
  data.frame() %>%
  rownames_to_column(var = "model_name") %>%

  ggplot(aes(x = reorder(model_name, looic),
             y = looic,
             ymin = looic - se_looic,
             ymax = looic + se_looic)) +
  geom_pointrange(shape = 21) +
  coord_flip() +
  labs(x = NULL, y = NULL,
       title = "LOO comparison top 10")

```

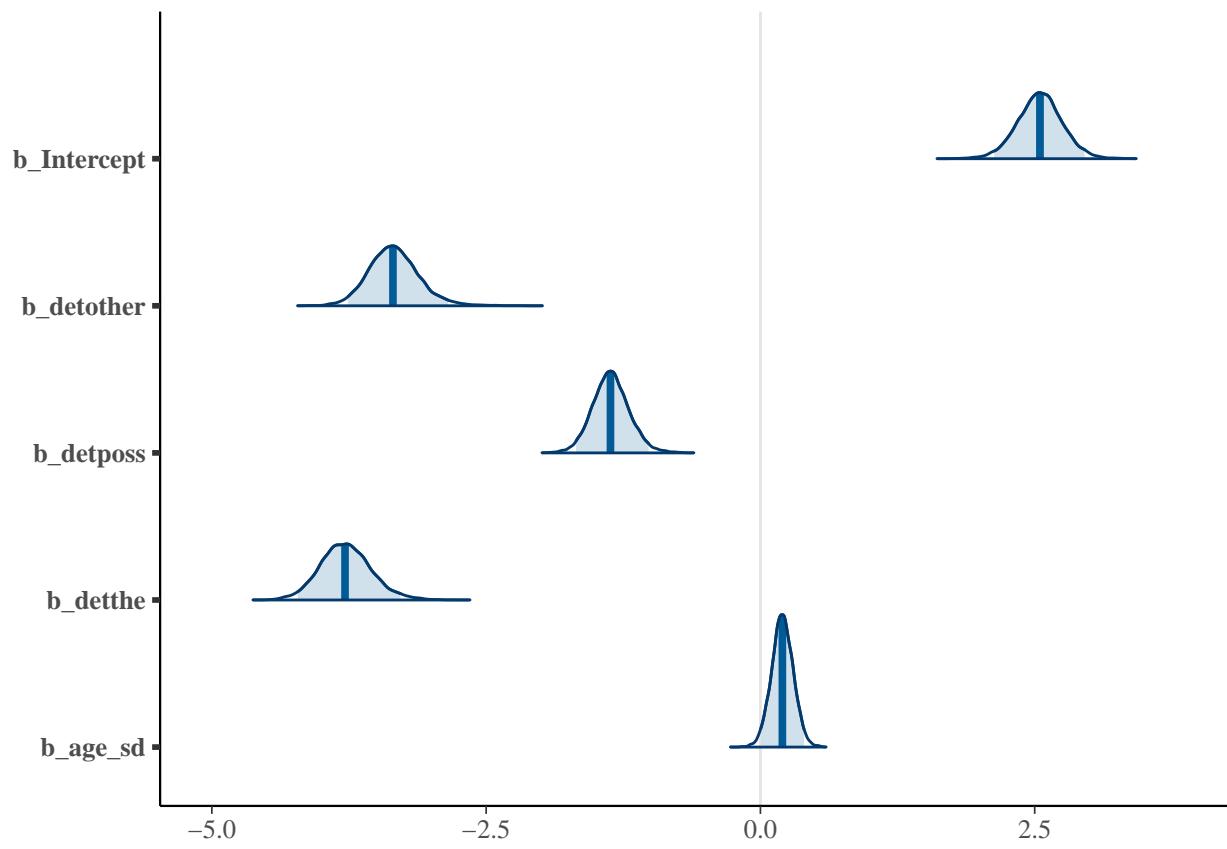
LOO comparison top 10



Examine selected model

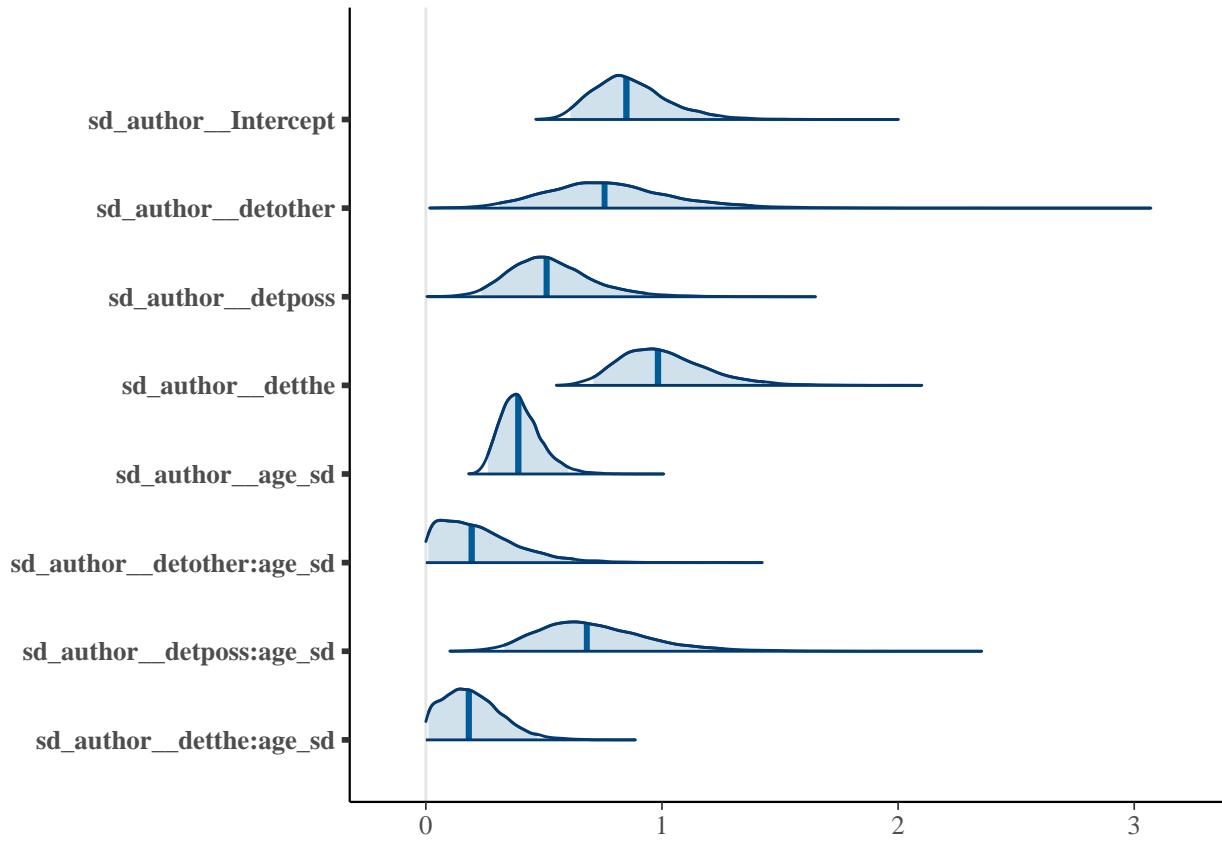
Plot population-level effects:

```
mcmc_plot(M3_full_author_slope_int,
           type = "areas",
           variable = "^b_",
           regex = TRUE,
           prob = 0.95)
```



Plot group-level standard deviation:

```
mcmc_plot(M3_full_author_slope_int,  
          type = "areas",  
          variable = "^sd_",  
          regex = TRUE,  
          prob = 0.95)
```



Create df with posterior predictive probabilities:

```
#adjust 'probs' for other interval range (e.g. c(0.05, 0.95), c(0.025, 0.975))
X <- cbind(df[, c("det", "age_sd", "author")], fitted(M3_full_author_slope_int, probs=c(0.025,0.975))[, names(X) <- c("det", "age", "author", "gerund", "lower", "upper")]
```

Function to examine interaction of age with specific determiner per author:

```
pick <- function(author, category) {
  XX = X[(X$det == category) & (X$author == author),]
  return(rbind(unique(XX[(XX$age == min(XX$age)),]), unique(XX[(XX$age == max(XX$age)),])))
}
```

```
#examine posterior prob per authors; CI at 95%
pick("1 Peter Heylyn (1599-1662)", "poss")
```

	det	age	author	gerund	lower	upper
##	6752	poss -1.092925	1 Peter Heylyn (1599-1662)	0.2415925	0.06816365	0.4769192
##	7463	poss 1.224108	1 Peter Heylyn (1599-1662)	0.8641593	0.69823105	0.9690665

```
pick("2 William Prynne (1600-1669)", "poss")
```

	det	age	author	gerund	lower
##	10425	poss -1.572311	2 William Prynne (1600-1669)	0.09751107	0.02046372
##	11404	poss 1.623597	2 William Prynne (1600-1669)	0.88549711	0.71937906
##		upper			
##	10425	0.2401751			
##	11404	0.9751599			

```

pick("2 William Prynne (1600-1669)", "bare")

##      det      age             author   gerund    lower    upper
## 10399 bare -1.572311 2 William Prynne (1600-1669) 0.6958632 0.6244635 0.7643514
## 11401 bare  1.623597 2 William Prynne (1600-1669) 0.9643023 0.9382541 0.9819451
pick("2 William Prynne (1600-1669)", "the")

##      det      age             author   gerund    lower
## 1     the -1.572311 2 William Prynne (1600-1669) 0.01057951 0.00316715
## 11370 the  1.463801 2 William Prynne (1600-1669) 0.11376265 0.04842769
##      upper
## 1     0.02268646
## 11370 0.21327564

pick("5 Jeremy Taylor (1613-1167)", "bare")

##      det      age             author   gerund    lower    upper
## 13972 bare -1.3326182 5 Jeremy Taylor (1613-1167) 0.9151528 0.8684709 0.9491573
## 14295 bare  0.4251313 5 Jeremy Taylor (1613-1167) 0.9532121 0.9255453 0.9747910
pick("9 George Fox (1624-1691)", "poss")

##      det      age             author   gerund    lower    upper
## 5516 poss -1.332618 9 George Fox (1624-1691) 0.4113615 0.1614344 0.6827054
## 6095 poss  1.623597 9 George Fox (1624-1691) 0.7595809 0.5408924 0.9184287
pick("9 George Fox (1624-1691)", "bare")

##      det      age             author   gerund    lower    upper
## 5517 bare -1.332618 9 George Fox (1624-1691) 0.8883482 0.8341642 0.9327542
## 6075 bare  1.463801 9 George Fox (1624-1691) 0.7516574 0.6706917 0.8211978
pick("10 Robert Boyle (1627-1691)", "bare")

##      det      age             author   gerund    lower    upper
## 3366 bare -1.971800 10 Robert Boyle (1627-1691) 0.9451027 0.9066852 0.9715119
## 3812 bare  1.383904 10 Robert Boyle (1627-1691) 0.9832167 0.9660943 0.9942868
pick("12 John Bunyan (1628-1688)", "bare")

##      det      age             author   gerund    lower    upper
## 2606 bare -1.412516 12 John Bunyan (1628-1688) 0.8622754 0.8064378 0.9091374
## 3322 bare  1.144211 12 John Bunyan (1628-1688) 0.6131756 0.5183070 0.7031037
pick("12 John Bunyan (1628-1688)", "poss")

##      det      age             author   gerund    lower    upper
## 2610 poss -1.412516 12 John Bunyan (1628-1688) 0.6738717 0.4728195 0.8410038
## 3337 poss  1.144211 12 John Bunyan (1628-1688) 0.2615458 0.1400004 0.4091648
pick("16 Daniel Whitby (1638-1726)", "bare")

##      det      age             author   gerund    lower    upper
## 14698 bare -1.412516 16 Daniel Whitby (1638-1726) 0.7878408 0.7389275 0.8312322
## 16613 bare  2.582369 16 Daniel Whitby (1638-1726) 0.9523981 0.9326729 0.9687420
pick("16 Daniel Whitby (1638-1726)", "the")

##      det      age             author   gerund    lower    upper

```

```

## 14700 the -1.412516 16 Daniel Whitby (1638-1726) 0.198923 0.1464508 0.2628553
## 16628 the 2.582369 16 Daniel Whitby (1638-1726) 0.488626 0.3836037 0.5904474
pick("17 Mather Increase (1639-1723)", "bare")

##      det      age             author   gerund    lower    upper
## 8653 bare -1.97180 17 Mather Increase (1639-1723) 0.8778553 0.8054046 0.9312755
## 9476 bare  2.90196 17 Mather Increase (1639-1723) 0.9711200 0.9469979 0.9868612
pick("20 Gilbert Burnet (1643-1715)", "bare")

##      det      age             author   gerund    lower    upper
## 268 bare -1.252720 20 Gilbert Burnet (1643-1715) 0.8962111 0.8626350 0.9232427
## 2598 bare  1.064313 20 Gilbert Burnet (1643-1715) 0.9703819 0.9564771 0.9818842
#examine posterior prob per authors; CI at 89%
pick("9 George Fox (1624-1691)", "poss")

##      det      age             author   gerund    lower    upper
## 5516 poss -1.332618 9 George Fox (1624-1691) 0.4113615 0.1614344 0.6827054
## 6095 poss  1.623597 9 George Fox (1624-1691) 0.7595809 0.5408924 0.9184287
pick("9 George Fox (1624-1691)", "bare")

##      det      age             author   gerund    lower    upper
## 5517 bare -1.332618 9 George Fox (1624-1691) 0.8883482 0.8341642 0.9327542
## 6075 bare  1.463801 9 George Fox (1624-1691) 0.7516574 0.6706917 0.8211978
#examine posterior prob per authors; CI at 97.5%
pick("1 Peter Heylyn (1599-1662)", "poss")

##      det      age             author   gerund    lower    upper
## 6752 poss -1.092925 1 Peter Heylyn (1599-1662) 0.2415925 0.06816365 0.4769192
## 7463 poss  1.224108 1 Peter Heylyn (1599-1662) 0.8641593 0.69823105 0.9690665
pick("2 William Prynne (1600-1669)", "poss")

##      det      age             author   gerund    lower    upper
## 10425 poss -1.572311 2 William Prynne (1600-1669) 0.09751107 0.02046372
## 11404 poss  1.623597 2 William Prynne (1600-1669) 0.88549711 0.71937906
##      upper
## 10425 0.2401751
## 11404 0.9751599
pick("2 William Prynne (1600-1669)", "bare")

##      det      age             author   gerund    lower    upper
## 10399 bare -1.572311 2 William Prynne (1600-1669) 0.6958632 0.6244635 0.7643514
## 11401 bare  1.623597 2 William Prynne (1600-1669) 0.9643023 0.9382541 0.9819451
pick("20 Gilbert Burnet (1643-1715)", "bare")

##      det      age             author   gerund    lower    upper
## 268 bare -1.252720 20 Gilbert Burnet (1643-1715) 0.8962111 0.8626350 0.9232427
## 2598 bare  1.064313 20 Gilbert Burnet (1643-1715) 0.9703819 0.9564771 0.9818842

```

To create Figure 3:

```

last_char <- function(string) {
  substr(string, nchar(string), nchar(string))
}

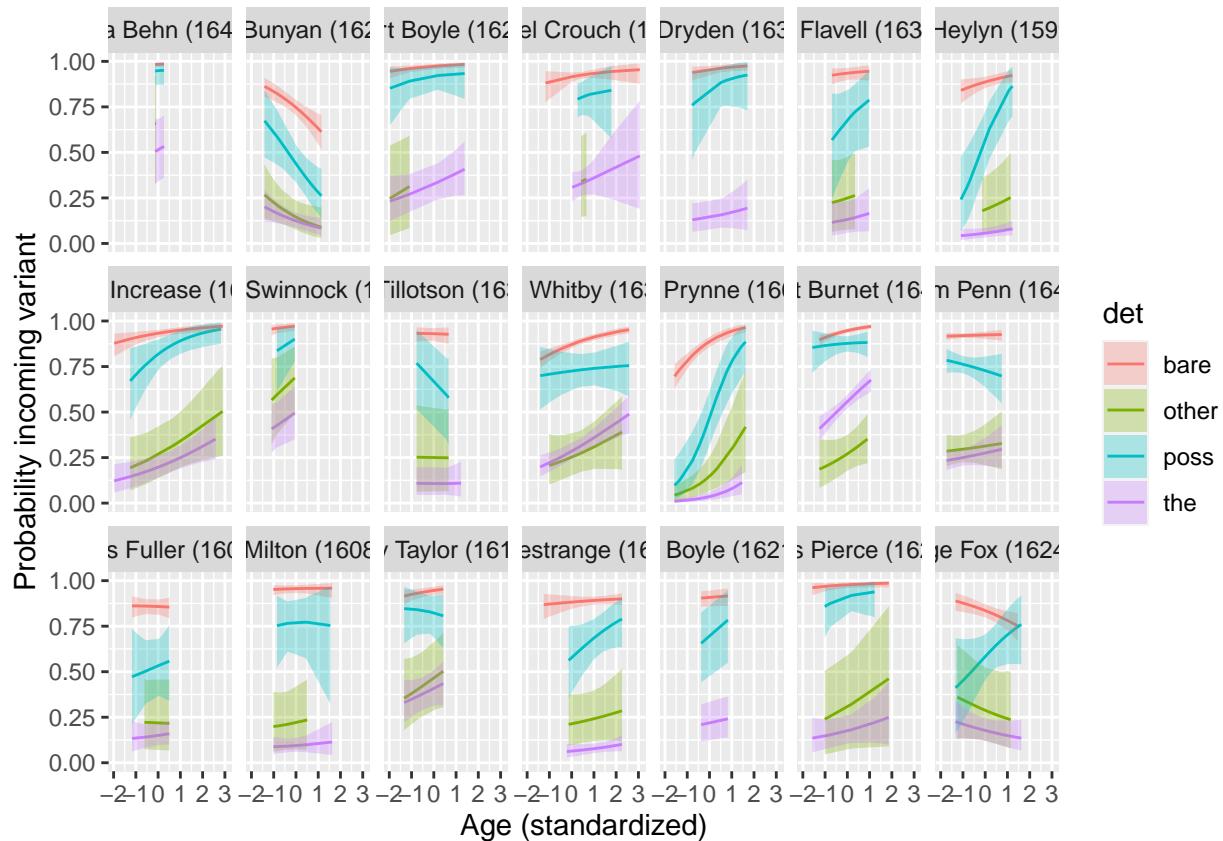
```

```

authors <- as.character(unique(df$author))
id <- order(sapply(authors, function(i) paste(last_char(i), substr(i, 1, 1))))
authors <- authors[id]
X$author <- factor(X$author, levels = authors)

ggplot(X, aes(x=age, hue=det, color=det)) +
  geom_line(aes(y=gerund)) +
  facet_wrap(~author, nrow=3) +
  geom_ribbon(aes(ymin=lower, ymax=upper, fill=det), colour = NA, alpha=0.3) +
  # geom_line(aes(y=lower), lty=2) +
  # geom_line(aes(y=upper), lty=2) +
  ylab("Probability incoming variant") + xlab("Age (standardized)")

```



Further exploration: age slopes

Incarceration

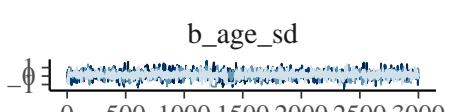
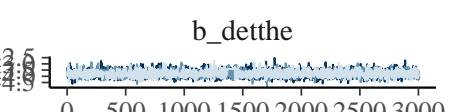
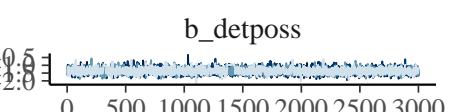
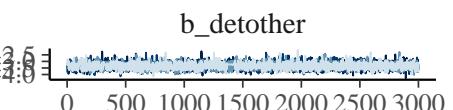
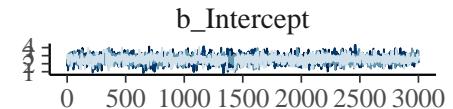
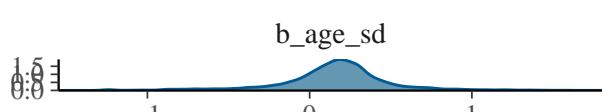
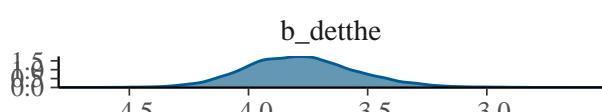
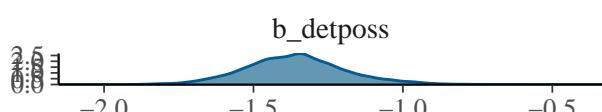
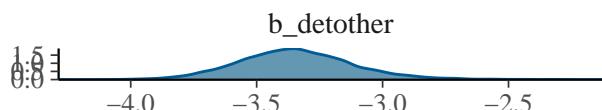
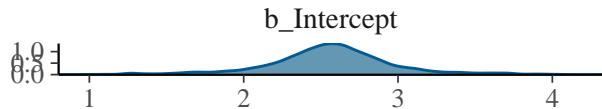
```

M4_inc_s <- brm(gerund ~ det + age_sd + (age_sd|incarcerated) + (det*age_sd|author), data=df,
                  family = bernoulli(),
                  chains = 4, iter = 4000, warmup = 1000, cores = 4,
                  prior = c(set_prior("normal(0, 1)", "b"),
                            set_prior("lkj(2)", "cor"),
                            set_prior("normal(0, 5)", "Intercept"),
                            set_prior("cauchy(0, 2)", "sd")),
                  control = list(max_treedepth = 12, adapt_delta = 1),
                  save_model = "M4_inc_s.stan",

```

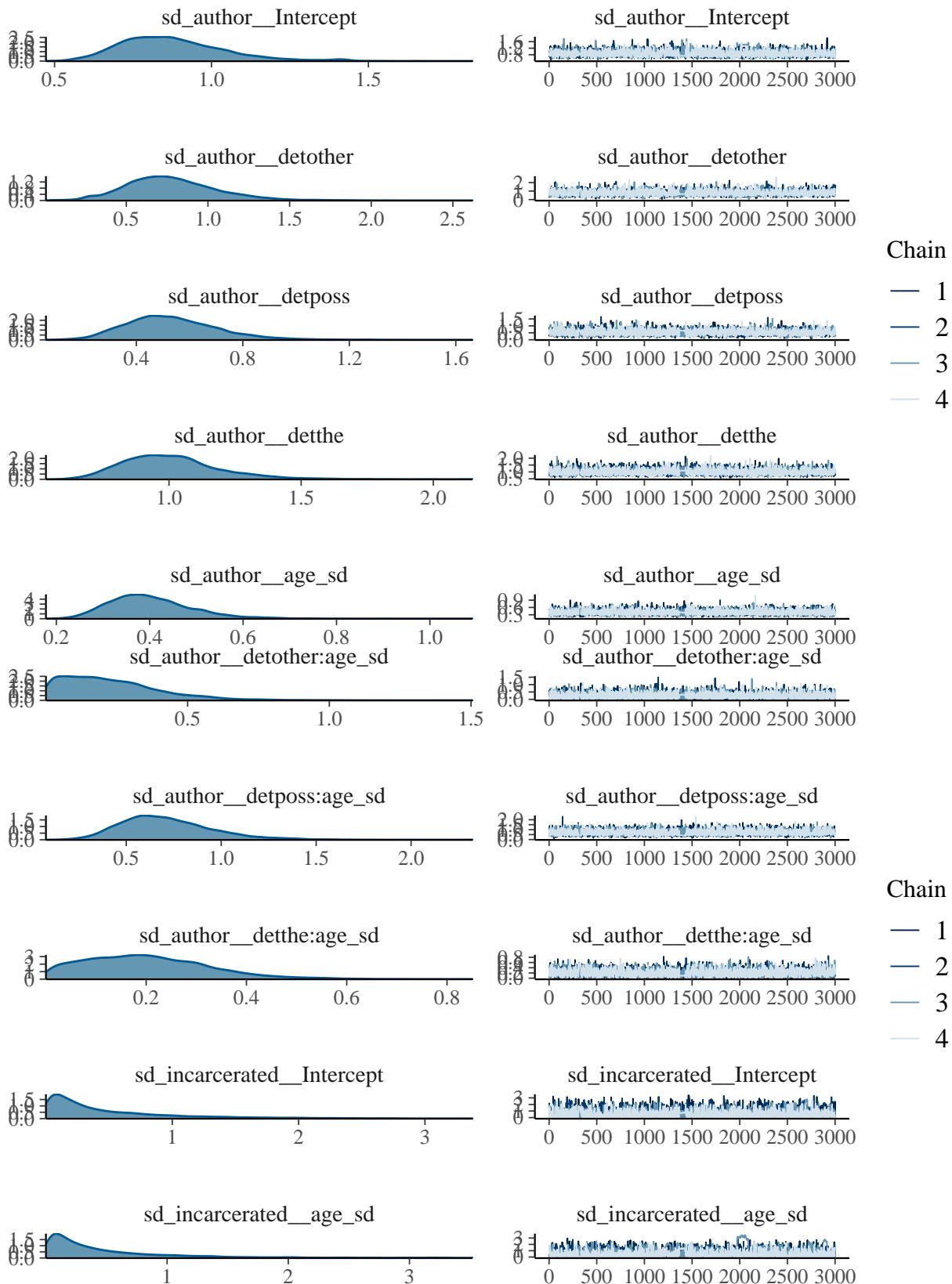
```
file = "M4_inc_s",
file_refit="never")
```

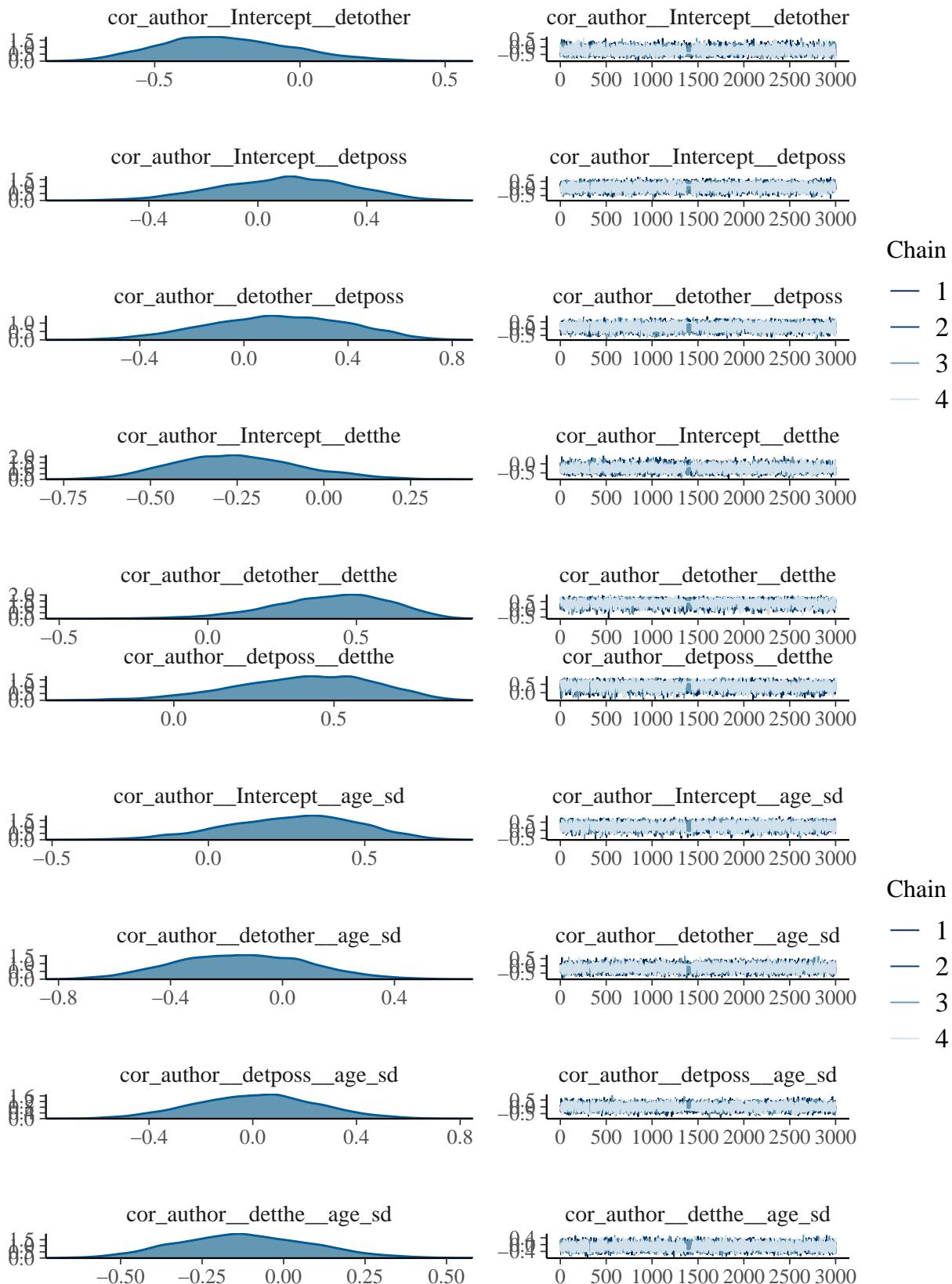
```
plot(M4_inc_s)
```

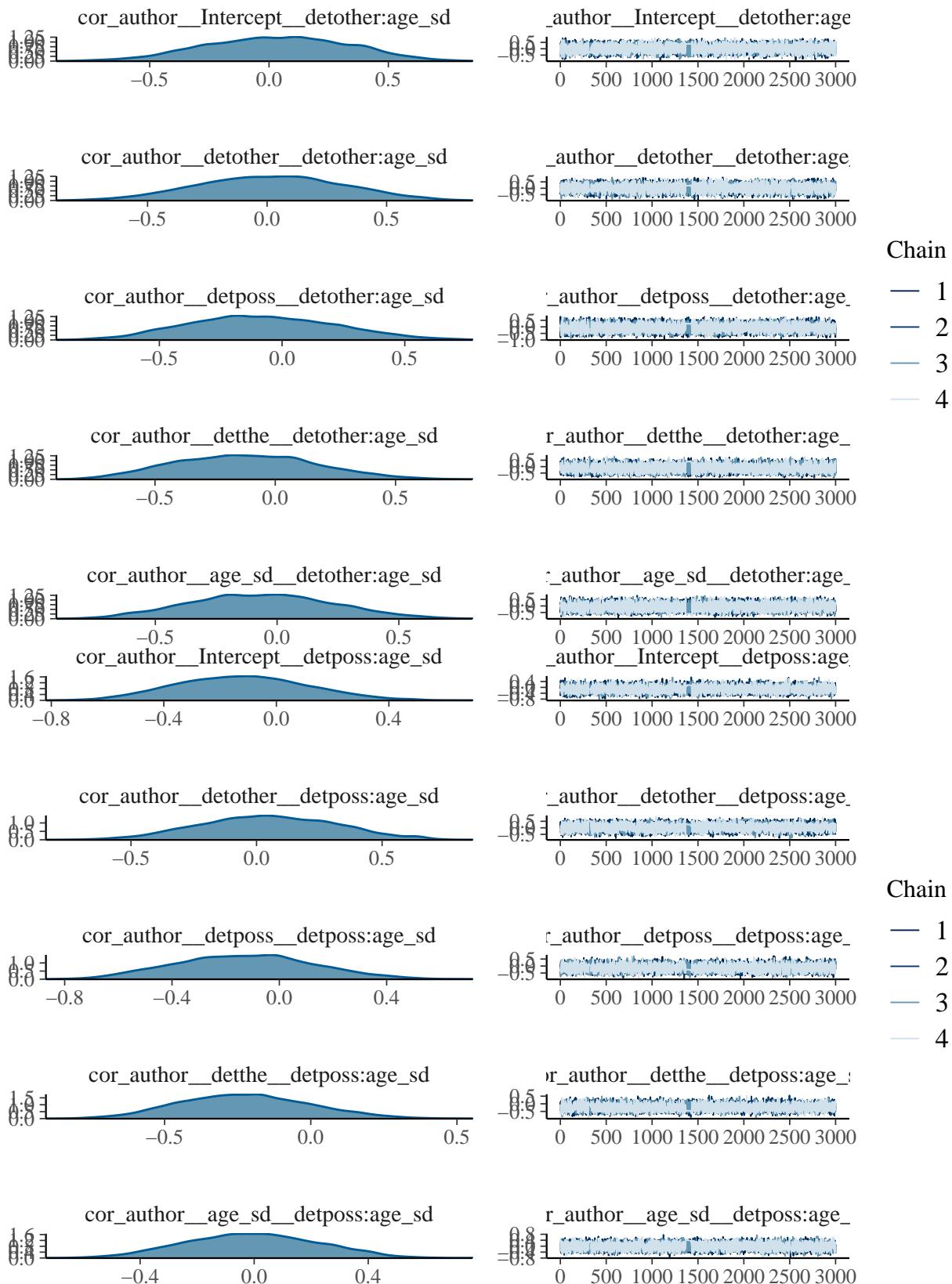


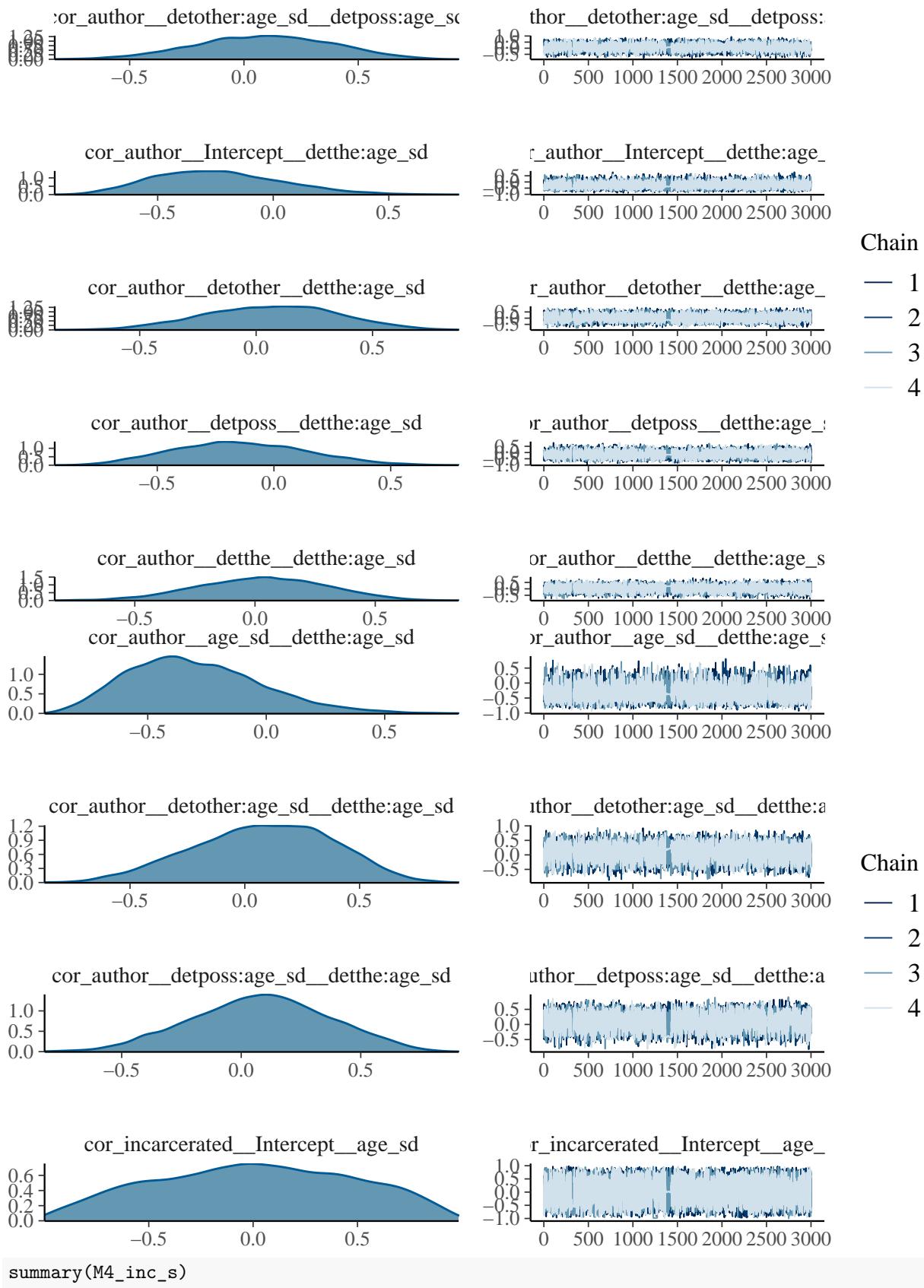
Chain

- 1
- 2
- 3
- 4









```

## Warning: There were 1312 divergent transitions after warmup.
## Increasing adapt_delta above 0.8 may help. See http://mc-stan.org/misc/
## warnings.html#divergent-transitions-after-warmup

## Family: bernoulli
## Links: mu = logit
## Formula: gerund ~ det + age_sd + (age_sd | incarcerated) + (det * age_sd | author)
## Data: df (Number of observations: 16629)
## Draws: 4 chains, each with iter = 4000; warmup = 1000; thin = 1;
##         total post-warmup draws = 12000
##
## Group-Level Effects:
## ~author (Number of levels: 21)
##                                         Estimate Est.Error 1-95% CI u-95% CI Rhat
## sd(Intercept)                      0.88      0.17    0.61     1.28 1.00
## sd(detother)                      0.78      0.28    0.28     1.38 1.00
## sd(detposs)                        0.53      0.18    0.25     0.93 1.00
## sd(detthe)                         1.01      0.18    0.71     1.42 1.00
## sd(age_sd)                         0.40      0.09    0.26     0.60 1.00
## sd(detother:age_sd)                0.23      0.17    0.01     0.63 1.00
## sd(detposs:age_sd)                 0.71      0.24    0.33     1.27 1.00
## sd(detthe:age_sd)                  0.20      0.12    0.01     0.48 1.00
## cor(Intercept,detother)            -0.25      0.22   -0.65     0.22 1.00
## cor(Intercept,detposs)              0.10      0.24   -0.38     0.53 1.00
## cor(detother,detposs)              0.13      0.26   -0.39     0.60 1.00
## cor(Intercept,detthe)              -0.25      0.18   -0.58     0.13 1.00
## cor(detother,detthe)               0.41      0.20   -0.03     0.74 1.00
## cor(detposs,detthe)                0.40      0.22   -0.06     0.77 1.00
## cor(Intercept,age_sd)              0.27      0.21   -0.16     0.64 1.00
## cor(detother,age_sd)               -0.14      0.23   -0.58     0.32 1.00
## cor(detposs,age_sd)                0.01      0.23   -0.44     0.46 1.00
## cor(detthe,age_sd)                 -0.12      0.20   -0.49     0.29 1.00
## cor(Intercept,detother:age_sd)     0.03      0.30   -0.54     0.59 1.00
## cor(detother,detother:age_sd)     0.02      0.30   -0.56     0.59 1.00
## cor(detposs,detother:age_sd)      -0.08      0.29   -0.62     0.50 1.00
## cor(detthe,detother:age_sd)       -0.12      0.29   -0.65     0.45 1.00
## cor(age_sd,detother:age_sd)       -0.06      0.29   -0.61     0.50 1.00
## cor(Intercept,detposs:age_sd)     -0.12      0.23   -0.55     0.34 1.00
## cor(detother,detposs:age_sd)      0.05      0.27   -0.47     0.57 1.00
## cor(detposs,detposs:age_sd)       -0.13      0.25   -0.60     0.38 1.00
## cor(detthe,detposs:age_sd)        -0.22      0.22   -0.63     0.22 1.00
## cor(age_sd,detposs:age_sd)        -0.01      0.23   -0.44     0.42 1.00
## cor(detother:age_sd,detposs:age_sd) 0.09      0.29   -0.49     0.64 1.00
## cor(Intercept,detthe:age_sd)      -0.24      0.27   -0.71     0.34 1.00
## cor(detother,detthe:age_sd)       0.07      0.28   -0.49     0.60 1.00
## cor(detposs,detthe:age_sd)        -0.14      0.28   -0.65     0.42 1.00
## cor(detthe,detthe:age_sd)         0.03      0.26   -0.50     0.53 1.00
## cor(age_sd,detthe:age_sd)         -0.30      0.28   -0.76     0.31 1.00
## cor(detother:age_sd,detthe:age_sd) 0.08      0.30   -0.52     0.62 1.00
## cor(detposs:age_sd,detthe:age_sd)  0.08      0.28   -0.47     0.62 1.00
##
##                                         Bulk_ESS Tail_ESS
## sd(Intercept)                      1409      515
## sd(detother)                       1360      419
## sd(detposs)                        3704     7105

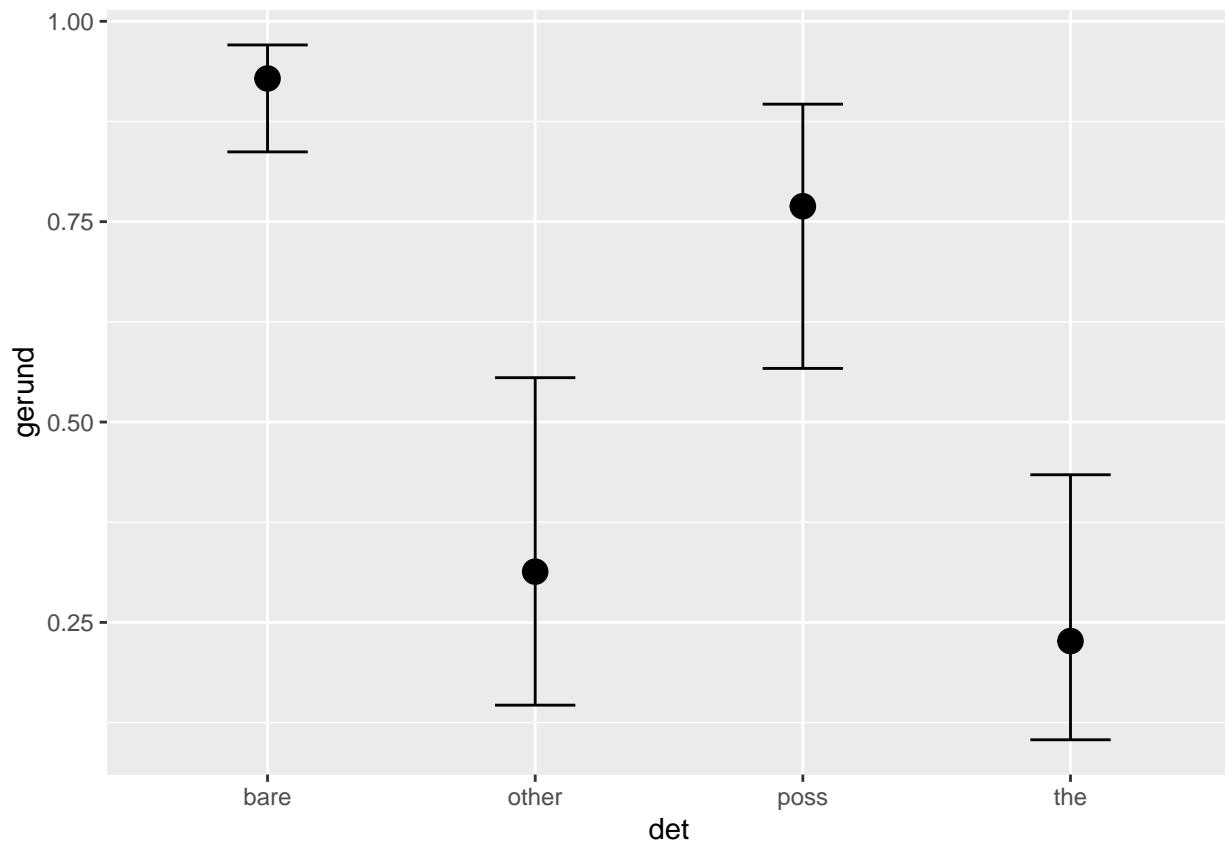
```

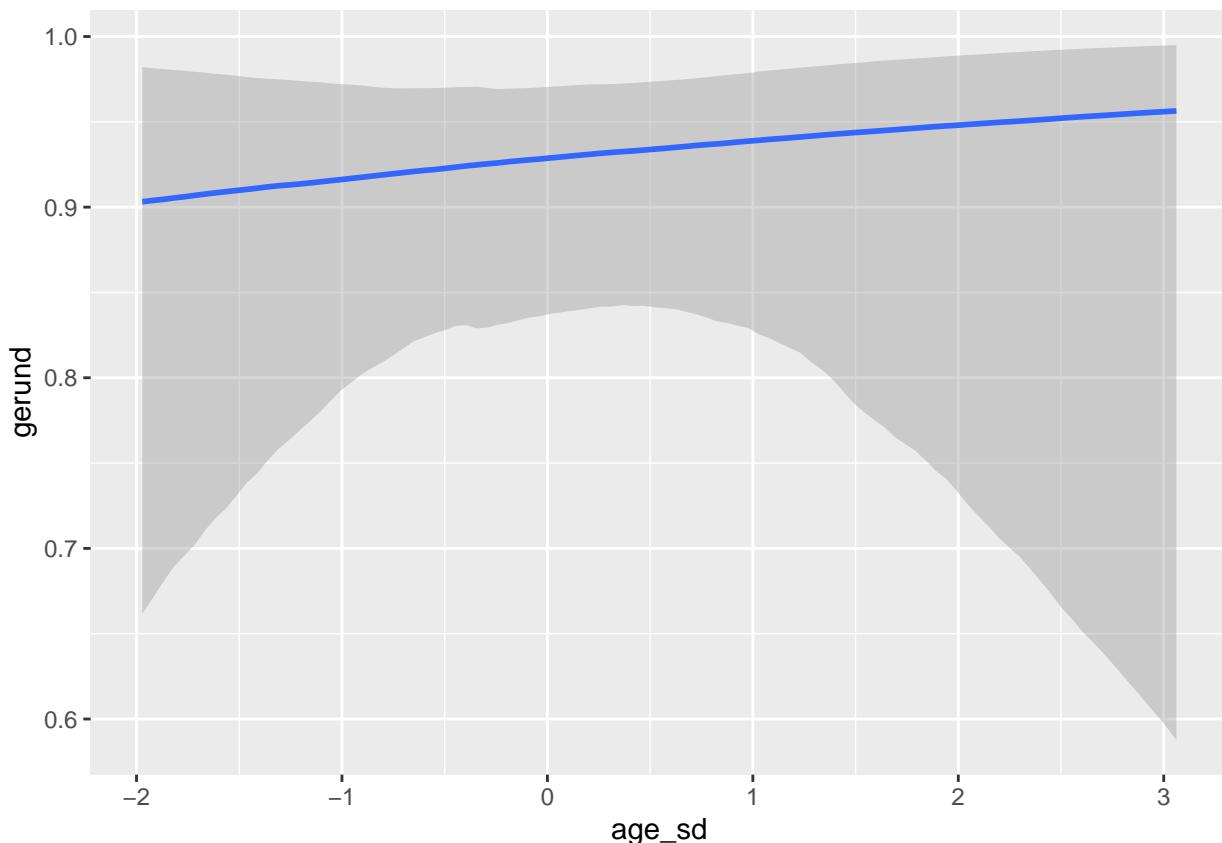
```

## sd(detthe) 4709 6683
## sd(age_sd) 4007 5552
## sd(detother:age_sd) 1650 510
## sd(detposs:age_sd) 3863 6004
## sd(detthe:age_sd) 3270 4517
## cor(Intercept,detother) 5775 6964
## cor(Intercept,detposs) 8967 7599
## cor(detother,detposs) 2452 767
## cor(Intercept,detthe) 5502 7316
## cor(detother,detthe) 3741 5024
## cor(detposs,detthe) 3996 4097
## cor(Intercept,age_sd) 2689 1523
## cor(detother,age_sd) 5008 7041
## cor(detposs,age_sd) 3598 4528
## cor(detthe,age_sd) 4729 4539
## cor(Intercept,detother:age_sd) 5823 7937
## cor(detother,detother:age_sd) 8611 3703
## cor(detposs,detother:age_sd) 7876 6830
## cor(detthe,detother:age_sd) 6628 2371
## cor(age_sd,detother:age_sd) 5288 1488
## cor(Intercept,detposs:age_sd) 7906 7018
## cor(detother,detposs:age_sd) 1659 478
## cor(detposs,detposs:age_sd) 5365 7270
## cor(detthe,detposs:age_sd) 5594 6388
## cor(age_sd,detposs:age_sd) 3540 1574
## cor(detother:age_sd,detposs:age_sd) 5104 7553
## cor(Intercept,detthe:age_sd) 6925 5576
## cor(detother,detthe:age_sd) 8895 8369
## cor(detposs,detthe:age_sd) 5324 5360
## cor(detthe,detthe:age_sd) 10088 5827
## cor(age_sd,detthe:age_sd) 5754 5639
## cor(detother:age_sd,detthe:age_sd) 7035 7809
## cor(detposs:age_sd,detthe:age_sd) 6202 4550
##
## ~incarcerated (Number of levels: 2)
## Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS
## sd(Intercept) 0.48 0.54 0.01 2.01 1.00 3648
## sd(age_sd) 0.48 0.56 0.01 2.08 1.01 1111
## cor(Intercept,age_sd) 0.01 0.47 -0.85 0.84 1.00 5048
## Tail_ESS
## sd(Intercept) 3166
## sd(age_sd) 444
## cor(Intercept,age_sd) 2459
##
## Population-Level Effects:
## Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept 2.56 0.41 1.64 3.49 1.00 1573 1088
## detother -3.35 0.23 -3.77 -2.86 1.00 4412 3664
## detposs -1.36 0.17 -1.68 -1.00 1.00 3813 1538
## detthe -3.78 0.24 -4.21 -3.29 1.00 3443 2662
## age_sd 0.15 0.34 -0.71 0.87 1.00 1814 728
##
## Draws were sampled using sampling(NUTS). For each parameter, Bulk_ESS
## and Tail_ESS are effective sample size measures, and Rhat is the potential

```

```
## scale reduction factor on split chains (at convergence, Rhat = 1).  
conditional_effects(M4_inc_s)
```



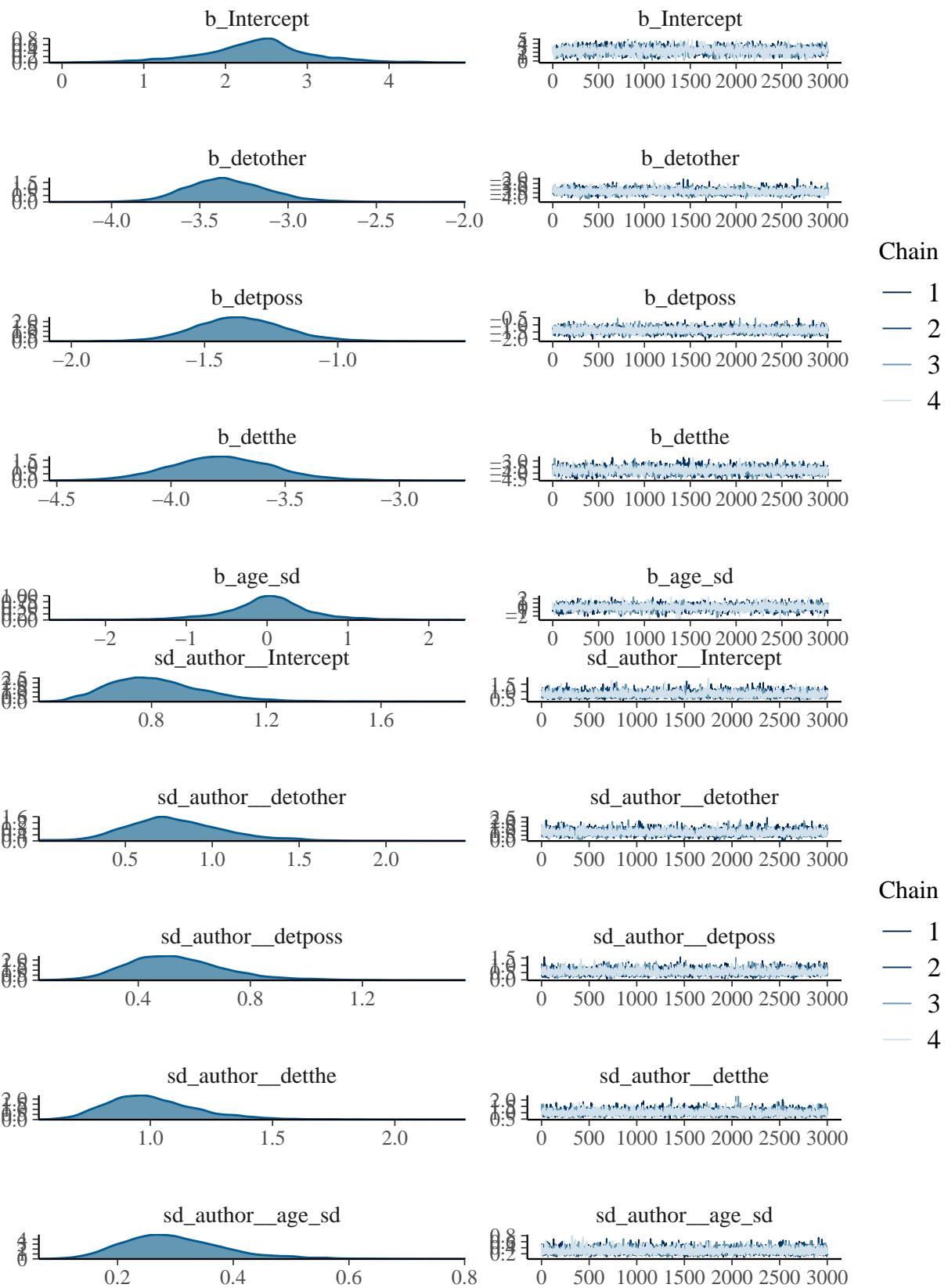


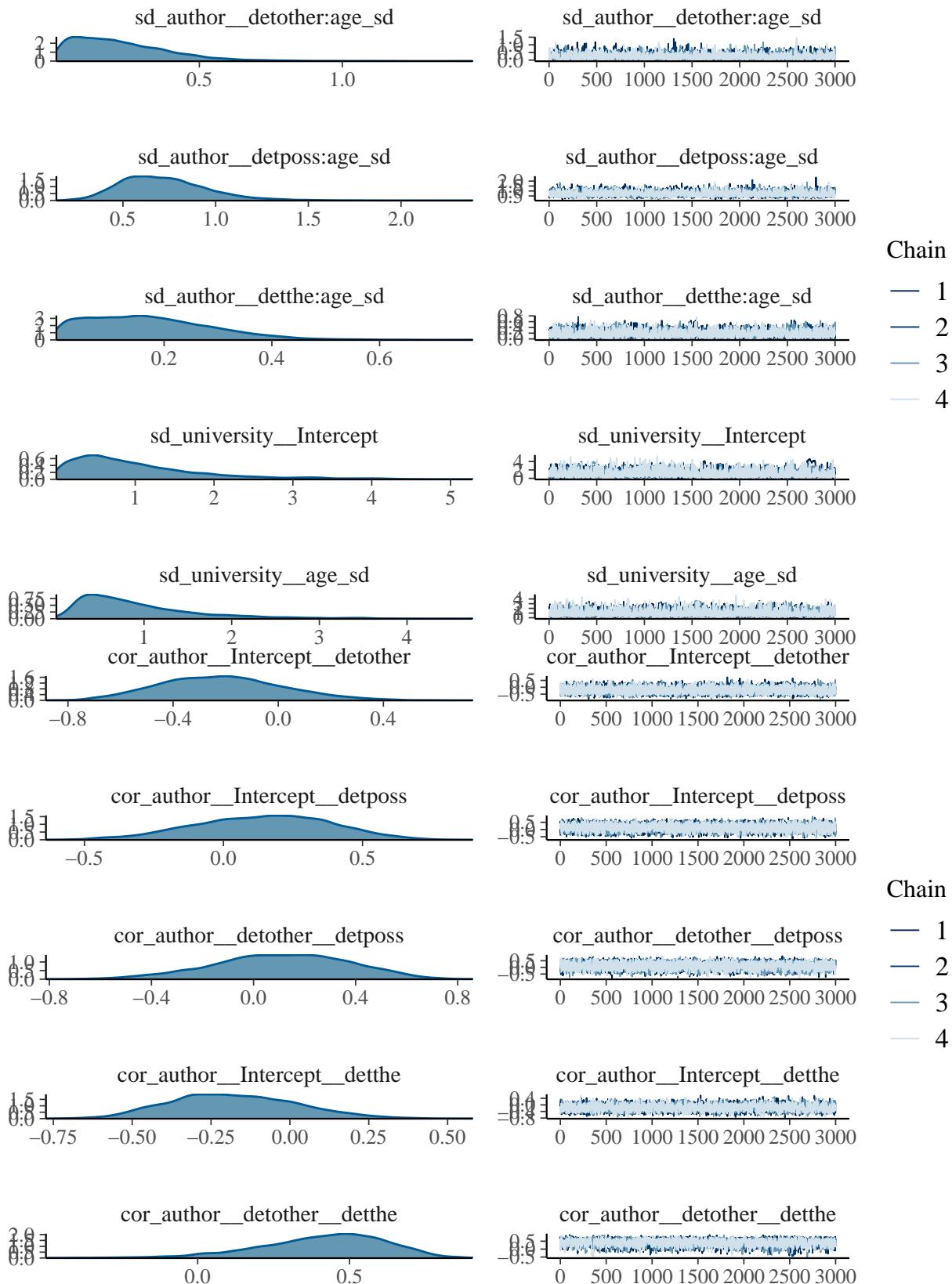
```
M4_inc_s <- add_criterion(M4_inc_s, 'waic', file="M4_inc_s")
M4_inc_s <- add_criterion(M4_inc_s, 'loo', file="M4_inc_s")
```

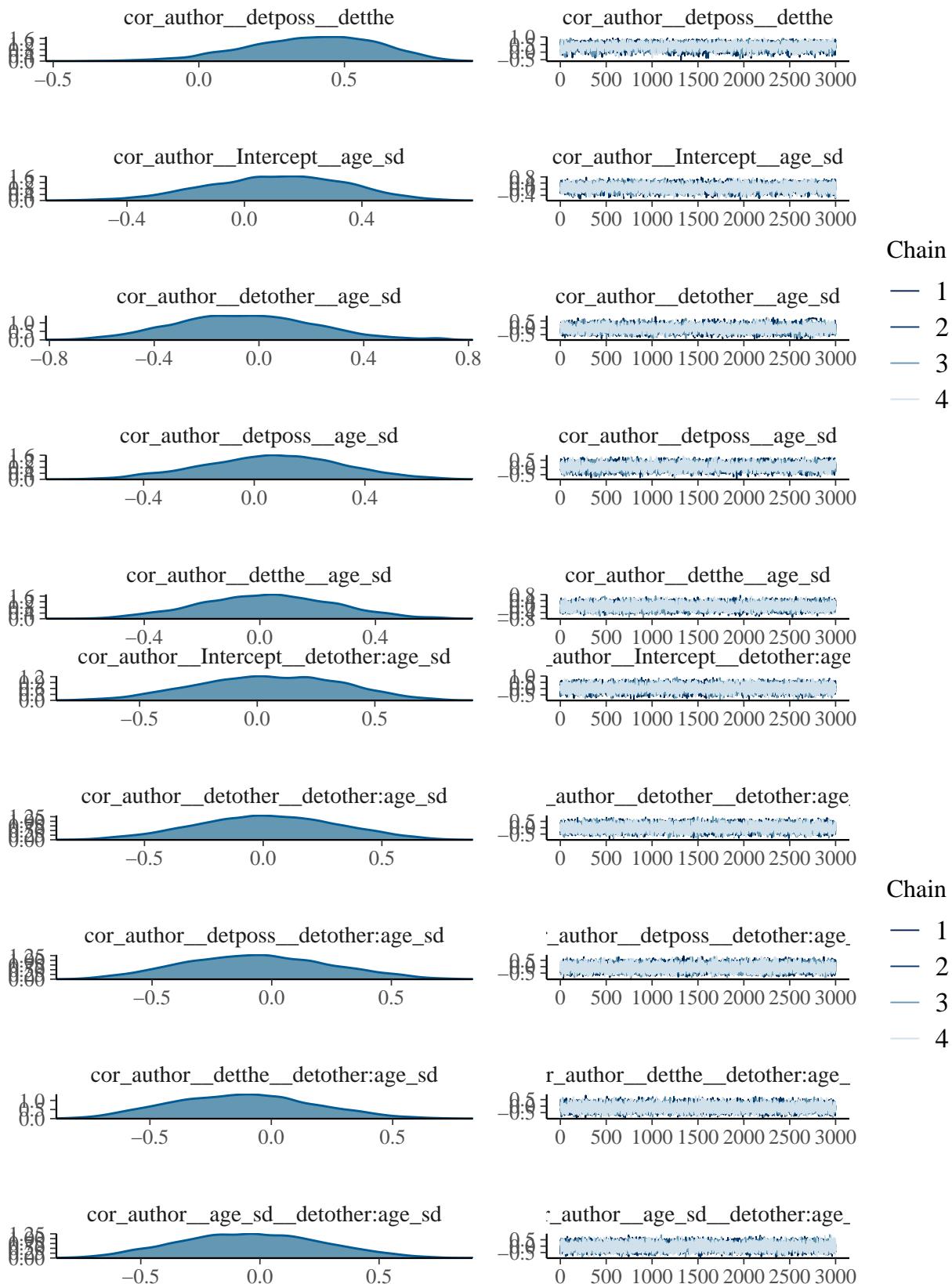
University

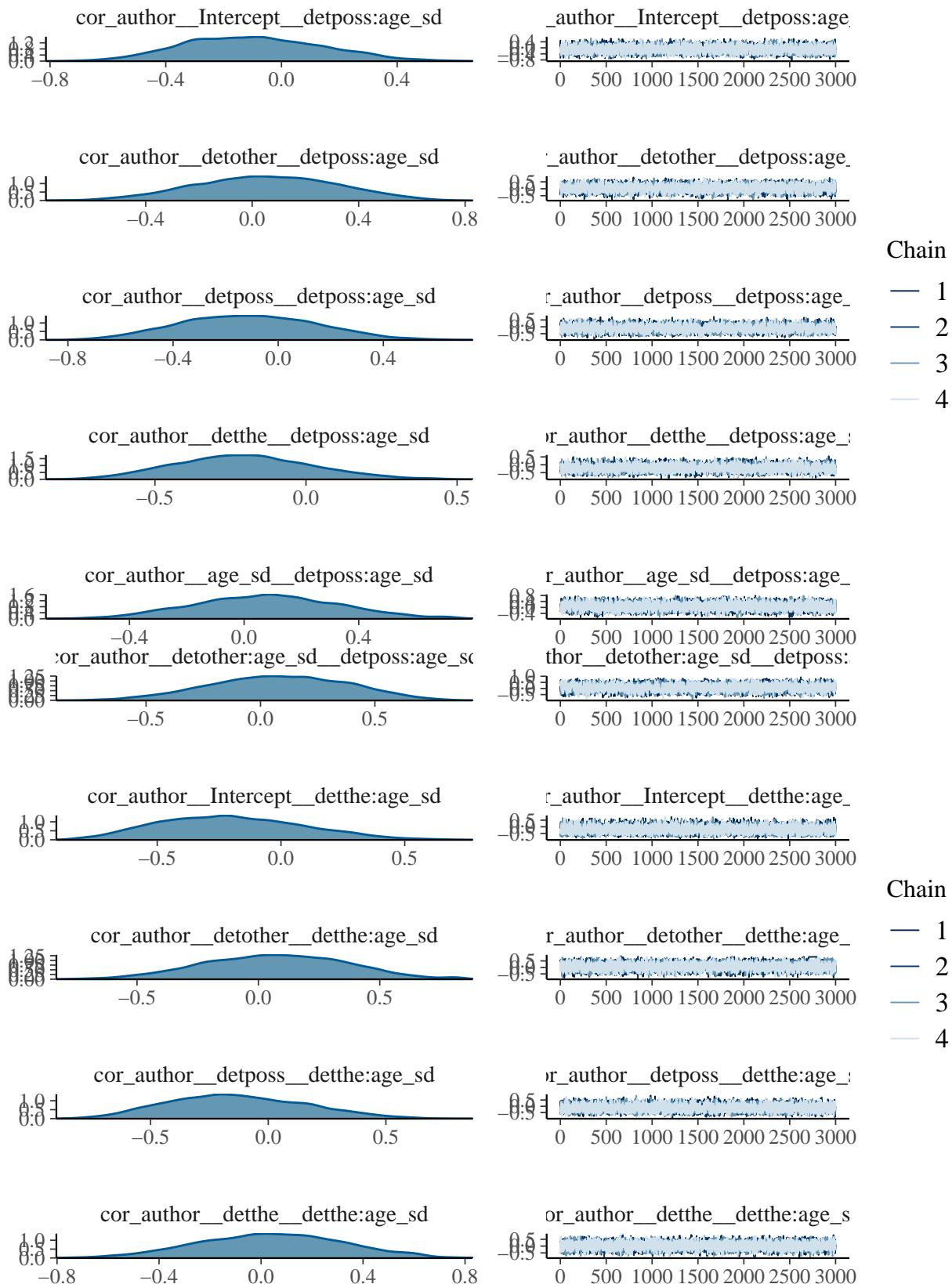
```
M4_uni_s <- brm(gerund ~ det + age_sd + (age_sd|university) + (det*age_sd|author), data=df,
family = bernoulli(),
chains = 4, iter = 4000, warmup = 1000, cores = 4,
prior = c(set_prior("normal(0, 1)", "b"),
          set_prior("lkj(2)", "cor"),
          set_prior("normal(0, 5)", "Intercept"),
          set_prior("cauchy(0, 2)", "sd")),
control = list(max_treedepth = 12),
save_model = "M4_uni_s.stan",
file = "M4_uni_s",
file_refit="never")
```

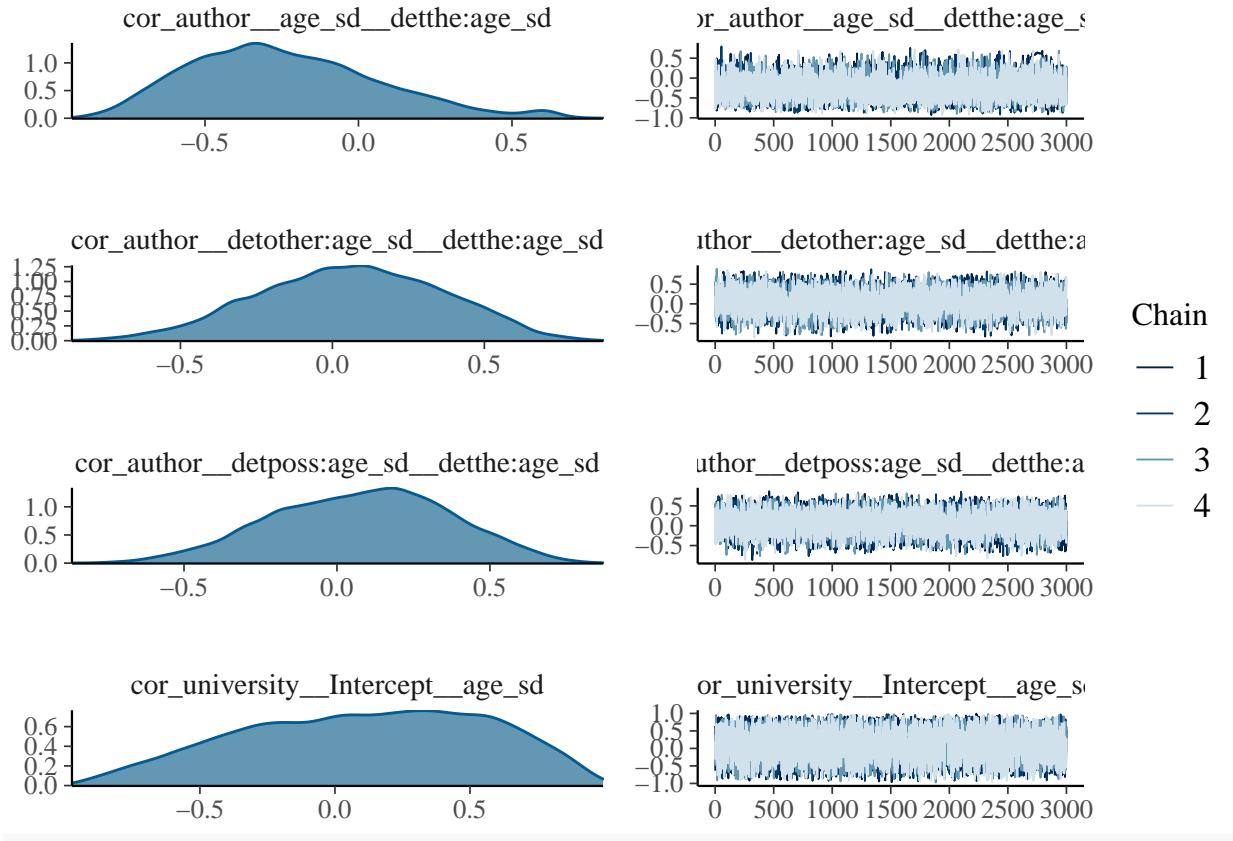
```
plot(M4_uni_s)
```











```
summary(M4_uni_s)
```

```
## Warning: There were 1374 divergent transitions after warmup.
## Increasing adapt_delta above 0.8 may help. See http://mc-stan.org/misc/
## warnings.html#divergent-transitions-after-warmup

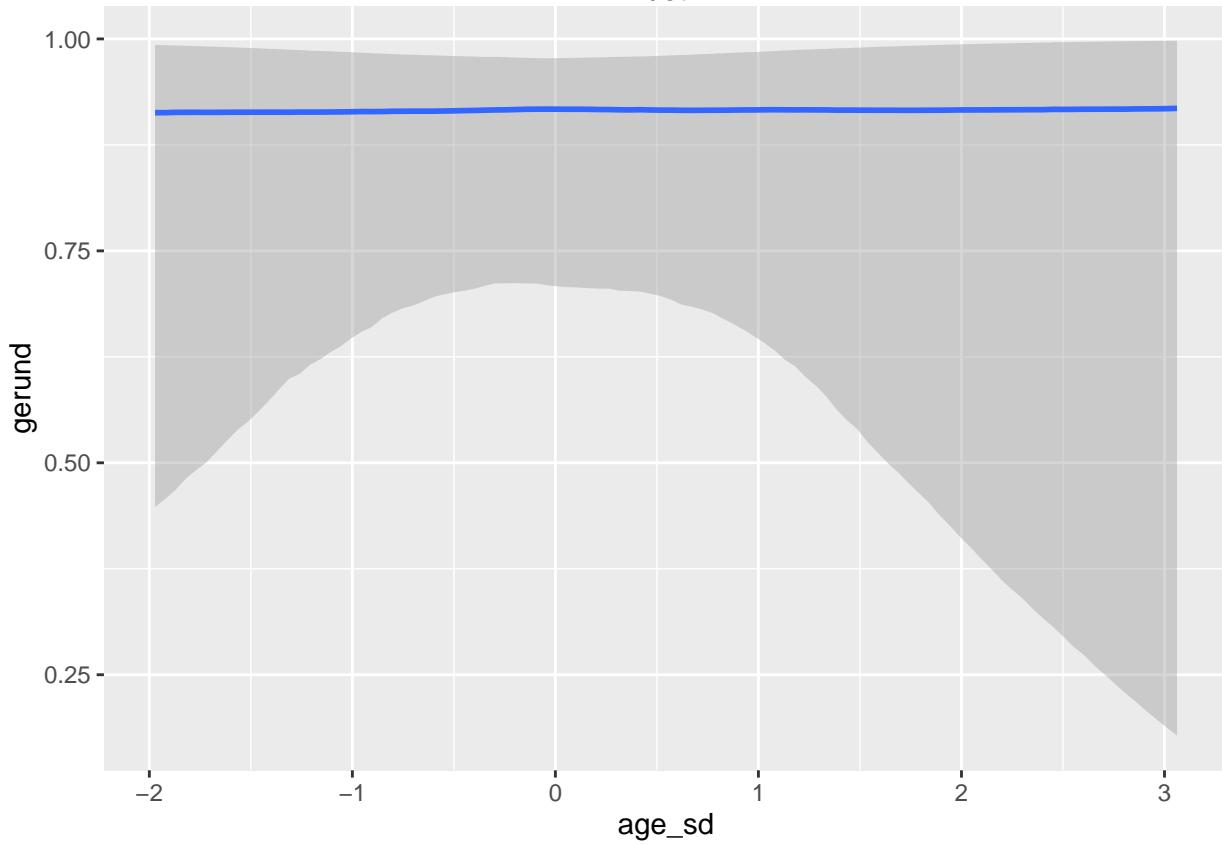
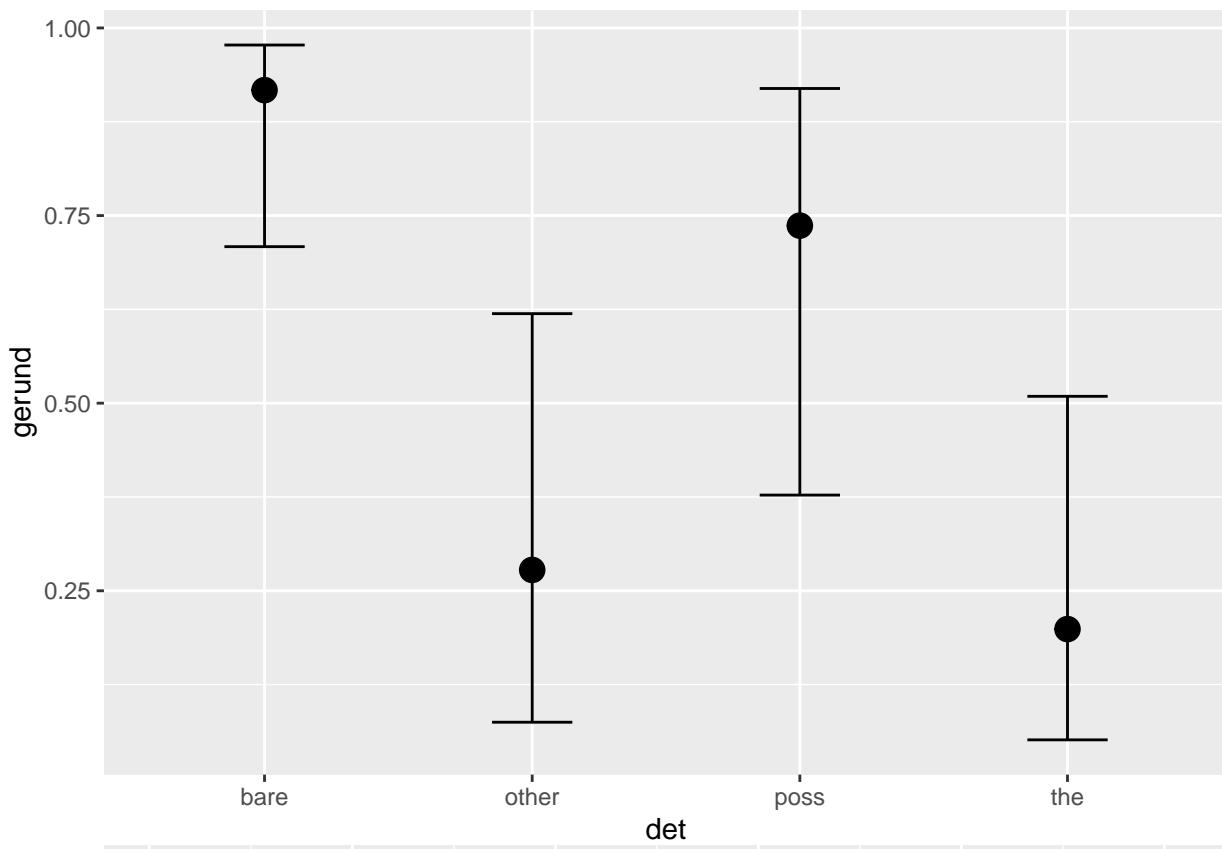
## Family: bernoulli
##   Links: mu = logit
## Formula: gerund ~ det + age_sd + (age_sd | university) + (det * age_sd | author)
##   Data: df (Number of observations: 16629)
##   Draws: 4 chains, each with iter = 4000; warmup = 1000; thin = 1;
##          total post-warmup draws = 12000
##
## Group-Level Effects:
## ~author (Number of levels: 21)
##                               Estimate Est.Error 1-95% CI u-95% CI Rhat
## sd(Intercept)                0.82     0.16    0.54    1.19 1.00
## sd(detother)                 0.79     0.29    0.29    1.45 1.00
## sd(detposs)                  0.54     0.18    0.24    0.94 1.00
## sd(detthe)                   1.01     0.19    0.71    1.43 1.00
## sd(age_sd)                   0.30     0.09    0.15    0.50 1.00
## sd(detother:age_sd)          0.23     0.17    0.01    0.63 1.00
## sd(detposs:age_sd)           0.72     0.23    0.35    1.26 1.00
## sd(detthe:age_sd)            0.17     0.11    0.01    0.43 1.00
## cor(Intercept,detother)      -0.21    0.23   -0.63    0.27 1.00
## cor(Intercept,detposs)        0.14     0.24   -0.34    0.59 1.00
## cor(detother,detposs)        0.11     0.26   -0.42    0.58 1.00
## cor(Intercept,detthe)         -0.18    0.20   -0.53    0.23 1.00
```

## cor(detother,detthe)	0.41	0.21	-0.04	0.75	1.00
## cor(detposs,detthe)	0.39	0.22	-0.08	0.77	1.00
## cor(Intercept,age_sd)	0.11	0.23	-0.36	0.54	1.00
## cor(detother,age_sd)	-0.05	0.26	-0.55	0.49	1.00
## cor(detposs,age_sd)	0.07	0.25	-0.42	0.54	1.00
## cor(detthe,age_sd)	0.03	0.23	-0.41	0.47	1.00
## cor(Intercept,detother:age_sd)	0.05	0.30	-0.53	0.61	1.00
## cor(detother,detother:age_sd)	0.02	0.29	-0.55	0.57	1.00
## cor(detposs,detother:age_sd)	-0.06	0.30	-0.62	0.53	1.00
## cor(detthe,detother:age_sd)	-0.12	0.29	-0.64	0.45	1.00
## cor(age_sd,detother:age_sd)	-0.04	0.30	-0.59	0.54	1.00
## cor(Intercept,detposs:age_sd)	-0.10	0.24	-0.53	0.37	1.00
## cor(detother,detposs:age_sd)	0.05	0.26	-0.46	0.55	1.00
## cor(detposs,detposs:age_sd)	-0.11	0.26	-0.59	0.39	1.00
## cor(detthe,detposs:age_sd)	-0.21	0.22	-0.62	0.26	1.00
## cor(age_sd,detposs:age_sd)	0.08	0.25	-0.40	0.58	1.00
## cor(detother:age_sd,detposs:age_sd)	0.08	0.30	-0.50	0.63	1.00
## cor(Intercept,detthe:age_sd)	-0.20	0.29	-0.70	0.38	1.00
## cor(detother,detthe:age_sd)	0.07	0.29	-0.49	0.63	1.00
## cor(detposs,detthe:age_sd)	-0.13	0.29	-0.64	0.45	1.00
## cor(detthe,detthe:age_sd)	0.04	0.28	-0.51	0.58	1.00
## cor(age_sd,detthe:age_sd)	-0.24	0.31	-0.74	0.46	1.00
## cor(detother:age_sd,detthe:age_sd)	0.06	0.30	-0.53	0.61	1.00
## cor(detposs:age_sd,detthe:age_sd)	0.08	0.29	-0.49	0.61	1.00
##		Bulk_ESS	Tail_ESS		
## sd(Intercept)	1429	795			
## sd(detother)	1301	765			
## sd(detposs)	3360	5507			
## sd(detthe)	2371	2633			
## sd(age_sd)	2586	740			
## sd(detother:age_sd)	3456	3709			
## sd(detposs:age_sd)	3543	4732			
## sd(detthe:age_sd)	1957	804			
## cor(Intercept,detother)	4208	3015			
## cor(Intercept,detposs)	4429	3709			
## cor(detother,detposs)	4601	3408			
## cor(Intercept,detthe)	3283	5708			
## cor(detother,detthe)	1973	2371			
## cor(detposs,detthe)	2547	4989			
## cor(Intercept,age_sd)	4842	7664			
## cor(detother,age_sd)	1592	761			
## cor(detposs,age_sd)	2891	1299			
## cor(detthe,age_sd)	2555	743			
## cor(Intercept,detother:age_sd)	7167	5905			
## cor(detother,detother:age_sd)	9608	7462			
## cor(detposs,detother:age_sd)	4407	1820			
## cor(detthe,detother:age_sd)	9100	7992			
## cor(age_sd,detother:age_sd)	6741	4582			
## cor(Intercept,detposs:age_sd)	4690	7766			
## cor(detother,detposs:age_sd)	4333	4765			
## cor(detposs,detposs:age_sd)	3514	6560			
## cor(detthe,detposs:age_sd)	3824	1362			
## cor(age_sd,detposs:age_sd)	1783	1087			
## cor(detother:age_sd,detposs:age_sd)	3259	5570			

```

## cor(Intercept,detthe:age_sd)           3709    3163
## cor(detother,detthe:age_sd)          1945     902
## cor(detposs,detthe:age_sd)          3689    2855
## cor(detthe,detthe:age_sd)           2513     615
## cor(age_sd,detthe:age_sd)           1618     569
## cor(detother:age_sd,detthe:age_sd)  4312    5251
## cor(detposs:age_sd,detthe:age_sd)  6182    8064
##
## ~university (Number of levels: 2)
##                               Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS
## sd(Intercept)             1.03      0.85    0.05    3.36 1.00    1091
## sd(age_sd)                0.92      0.67    0.14    2.75 1.00    1841
## cor(Intercept,age_sd)     0.11      0.44   -0.75    0.85 1.00    5088
##                               Tail_ESS
## sd(Intercept)              544
## sd(age_sd)                 1350
## cor(Intercept,age_sd)      5900
##
## Population-Level Effects:
##                               Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept      2.37      0.68    0.89    3.76 1.00    2131    1765
## detother     -3.34      0.23   -3.76   -2.85 1.00    2898    4786
## detposs      -1.36      0.17   -1.68   -1.01 1.00    4226    5072
## detthe       -3.77      0.23   -4.22   -3.29 1.00    2489    4332
## age_sd        0.01      0.55   -1.18    1.16 1.00    2773    1303
##
## Draws were sampled using sampling(NUTS). For each parameter, Bulk_ESS
## and Tail_ESS are effective sample size measures, and Rhat is the potential
## scale reduction factor on split chains (at convergence, Rhat = 1).
conditional_effects(M4_uni_s)

```



```
M4_uni_s <- add_criterion(M4_uni_s, 'waic', file="M4_uni_s")
M4_uni_s <- add_criterion(M4_uni_s, 'loo', file="M4_uni_s")
```

Generation

```
M_gen <- brm(gerund ~ det + age_sd*generation + (age_sd*det|author), data=df,
             family = bernoulli(),
             chains = 4, iter = 4000, warmup = 1000, cores = 4,
             prior = c(set_prior("normal(0, 1)", "b"),
                       set_prior("normal(0, 5)", "Intercept"),
                       set_prior("lkj(2)", "cor"),
                       set_prior("cauchy(0, 2)", "sd")
                     ),
             save_model = "M_gen.stan",
             file = "M_gen",
             file_refit="never")

M_gen <- add_criterion(M_gen, 'waic', file="M_gen")
M_gen <- add_criterion(M_gen, 'loo', file="M_gen")

M_gen_1 <- brm(gerund ~ det + age_sd + generation + (age_sd*det|author), data=df,
                family = bernoulli(),
                chains = 4, iter = 4000, warmup = 1000, cores = 4,
                prior = c(set_prior("normal(0, 1)", "b"),
                          set_prior("normal(0, 5)", "Intercept"),
                          set_prior("lkj(2)", "cor"),
                          set_prior("cauchy(0, 2)", "sd")
                        ),
                save_model = "M_gen_1.stan",
                file = "M_gen_1",
                file_refit="never")

M_gen_1 <- add_criterion(M_gen_1, 'waic', file="M_gen")

## Warning:
## 2 (0.0%) p_waic estimates greater than 0.4. We recommend trying loo instead.
M_gen_1 <- add_criterion(M_gen_1, 'loo', file="M_gen")

lgen <- loo_compare(M3_full_author_slope_int, M_gen, M_gen_1, criterion = 'loo')

print(lgen, simplify = FALSE)

##          elpd_diff se_diff elpd_loo se_elpd_loo p_loo
## M3_full_author_slope_int    0.0      0.0 -5905.4    78.4    91.9
## M_gen                  -0.5      0.4 -5905.9    78.5    92.2
## M_gen_1                 -0.5      0.4 -5905.9    78.5    92.2
##          se_p_loo looic   se_looic
## M3_full_author_slope_int    2.5  11810.8    156.9
## M_gen                  2.5  11811.8    156.9
## M_gen_1                 2.5  11811.8    156.9
round(model_weights(M3_full_author_slope_int, M_gen, M_gen_1, weights = 'loo'), 6)
```

## M3_full_author_slope_int	M_gen	M_gen_1
##	0.449407	0.275297