An overview of the models used in 'Limitations of difference-in-difference for measuring convergence'

This file presents all of the R commands used to generate and analyze the models in the paper 'Limitations of difference-in-difference for measuring convergence.' It also includes the commands used to create the simulated dataset analyzed in Study 4.

The Rmd file used to generate this document is attached as a pdf attachement, as is the data used to generate the models, limitations-of-DID-data.tsv.bz2. The Switchboard demographic data is available as part of the documentation of the Switchboard corpus (Godfrey and Holliman, 1997) at https://catalog.ldc.upenn.edu/docs/LDC97S62/caller_tab.csv, used here as `swbd_caller_tab.csv.bz2`, a bz2 compressed file, and is not attached here. It is used only for plotting F0 median values by gender. The code has been minimally modified for readability, but the process and results are the same.

Load libraries and basic data

Load libraries

```
require(tidyverse)
```

```
## Loading required package: tidyverse
```

```
## -- Attaching packages --------------------------------- tidyverse 1.2.1 --
```

```
## v ggplot2 3.2.0     v purrr   0.3.2
## v tibble  2.1.3     v dplyr   0.8.1
## v tidyr   0.8.3     v stringr 1.4.0
## v readr   1.3.1     v forcats 0.4.0
```

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

```
require(knitr)
```

```
## Loading required package: knitr
```

```
require(lmerTest)
```

```
## Loading required package: lmerTest
```

```
## Loading required package: lme4
```

```
## Loading required package: Matrix
```

```
##
## Attaching package: 'Matrix'
```

```
## The following object is masked from 'package:tidyr':
##
##     expand
```

```
##
## Attaching package: 'lmerTest'
```

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

```
##     lmer
## The following object is masked from 'package:stats':
##
##     step
```

```
require(coefplot)
```

```
## Loading required package: coefplot
```

```
set.seed(123)
sessionInfo()
```

```
## R version 3.6.1 (2019-07-05)
## Platform: x86_64-pc-linux-gnu (64-bit)
## Running under: Ubuntu 18.04.2 LTS
##
## Matrix products: default
## BLAS:   /usr/lib/x86_64-linux-gnu/openblas/libblas.so.3
## LAPACK: /usr/lib/x86_64-linux-gnu/libopenblasp-r0.2.20.so
##
## locale:
##  [1] LC_CTYPE=en_US.UTF-8       LC_NUMERIC=C
##  [3] LC_TIME=en_US.UTF-8        LC_COLLATE=en_US.UTF-8
##  [5] LC_MONETARY=en_US.UTF-8    LC_MESSAGES=en_US.UTF-8
##  [7] LC_PAPER=en_US.UTF-8       LC_NAME=C
##  [9] LC_ADDRESS=C               LC_TELEPHONE=C
## [11] LC_MEASUREMENT=en_US.UTF-8 LC_IDENTIFICATION=C
##
## attached base packages:
## [1] stats     graphics  grDevices utils     datasets  methods   base
##
## other attached packages:
##  [1] coefplot_1.2.6  lmerTest_3.1-0  lme4_1.1-21     Matrix_1.2-17
##  [5] knitr_1.23      forcats_0.4.0   stringr_1.4.0   dplyr_0.8.1
##  [9] purrr_0.3.2     readr_1.3.1     tidyr_0.8.3     tibble_2.1.3
## [13] ggplot2_3.2.0   tidyverse_1.2.1
##
## loaded via a namespace (and not attached):
##  [1] tidyselect_0.2.5    xfun_0.7            reshape2_1.4.3
##  [4] splines_3.6.1       haven_2.1.0         lattice_0.20-38
##  [7] colorspace_1.4-1    generics_0.0.2      htmltools_0.3.6
## [10] yaml_2.2.0          rlang_0.3.4         pillar_1.4.1
## [13] nloptr_1.2.1        glue_1.3.1          withr_2.1.2
## [16] modelr_0.1.4        readxl_1.3.1        plyr_1.8.4
## [19] munsell_0.5.0       gtable_0.3.0        cellranger_1.1.0
## [22] rvest_0.3.4         evaluate_0.14       broom_0.5.2
## [25] Rcpp_1.0.1          scales_1.0.0        backports_1.1.4
## [28] jsonlite_1.6        useful_1.2.6        hms_0.4.2
## [31] digest_0.6.19       stringi_1.4.3       numDeriv_2016.8-1.1
## [34] grid_3.6.1          cli_1.1.0           tools_3.6.1
## [37] magrittr_1.5        lazyeval_0.2.2      crayon_1.3.4
## [40] pkgconfig_2.0.2     MASS_7.3-51.4       xml2_1.2.0
## [43] lubridate_1.7.4     assertthat_0.2.1    minqa_1.2.4
## [46] rmarkdown_1.13      httr_1.4.0          rstudioapi_0.10
## [49] R6_2.4.0            boot_1.3-23         nlme_3.1-140
```

```
## [52] compiler_3.6.1
```

```
z. <- function(x){scale(x)[,1]}
fonttheme <- theme(text=element_text(family = "FreeSerif"))
options(stringsAsFactors=FALSE)
cbPalette <- c("#000000", "#E69F00", "#56B4E9", "#009E73", "#F0E442", "#0072B2", "#D55E00", "#CC79
```

Load necessary data

```
dim(alld <- read.table("limitations-of-DID-data.tsv.bz2", T))
```

```
## [1] 17052    10
```

```
model.names <- c(f0.median="F0 median",
                 f0.var="F0 variance",
                 speechrate="Speech rate",
                 uhum="uh:um ratio")
alld$study <- model.names[alld$study]

studies <- unique(alld$study)
names(studies) <- studies
```

This command downloads `swbd_caller_tab.csv.bz2` from the LDC website if it is not already present on the device; it assumes that `wget` and `bzip2` are both available.

```
test -e swbd_caller_tab.csv.bz2 ||
    wget -q -O - https://catalog.ldc.upenn.edu/docs/LDC97S62/caller_tab.csv |
    bzip2 -9 >  swbd_caller_tab.csv.bz2
```

These commands prepare a basic demographics data frame based on the information given in association with the Switchboard callers.

```
dim(all.demo <- read.csv("swbd_caller_tab.csv.bz2", F))
```

```
## [1] 543  14
```

```
basic.demo <- with(all.demo, data.frame(
    speaker=as.character(V1),
    sex=V4,
    region=V6,
    age=1991-V5
    ))
head(basic.demo)
```

```
##   speaker     sex          region age
## 1    1000  FEMALE  SOUTH MIDLAND  37
## 2    1001    MALE         WESTERN  51
## 3    1002  FEMALE       SOUTHERN  28
## 4    1003    MALE  NORTH MIDLAND  44
## 5    1004  FEMALE       NORTHERN  33
## 6    1005  FEMALE         WESTERN  35
```

These commands generate `full.dfs`, which will contain one data frame per study.

```
## based on stack exchange code I can't track anymore (also here:
## https://rdrr.io/cran/modes/src/R/Nonparametric_functions.R)

modedist <- function(x){
```

```
    d.density <- density(x)
    (y.modes <- which(diff(sign(diff(d.density$y)))==-2)+1)
    which(d.density$y == max(d.density$y))
    ret <- apply(sapply(c(-Inf, d.density$x[y.modes]), function(mode){
        abs(x-mode)
    }), 1, min)
    ret
}

full.dfs <- lapply(studies, function(s){
    dim(ret <- subset(alld, study == s & !is.na(speaker.x.value) & !is.na(interlocutor.x.value)))
    ret <- merge(ret, basic.demo)
    within(ret, {
        speaker <- as.character(speaker)
        interlocutor <- as.character(interlocutor)
        DID <- scale(abs(speaker.x.value - interlocutor.x.value) -
                     abs(speaker.value - interlocutor.x.value))[,1]
        modedist <- modedist(speaker.x.value)
    })
})
```

Study 1 models

DID models

In this section, we model convergence as measured by DID, including distance from the interlocutor as a predictor.

```
diddist.models <- lapply(full.dfs, function(df){
    ret <- lmer(DID ~ abs(speaker.x.value - interlocutor.x.value) +
                    (1 | speaker) + (1 | interlocutor) + (1 | convno)
                , data=df)
})
```

```
## boundary (singular) fit: see ?isSingular
## boundary (singular) fit: see ?isSingular
## boundary (singular) fit: see ?isSingular
## boundary (singular) fit: see ?isSingular
```

```
(diddist.results <-
     diddist.models %>% map(summary) %>% map("coefficients") %>%
     map(~.x["abs(speaker.x.value - interlocutor.x.value)",]) %>%
     do.call(rbind, .))
```

```
##              Estimate Std. Error       df   t value      Pr(>|t|)
## F0 median   0.1641642 0.02013609 3599.886  8.152736  4.861324e-16
## F0 variance 0.5375654 0.01795630 3367.665 29.937431 8.277741e-175
## Speech rate 0.4497807 0.01543147 3604.196 29.146982 6.915929e-168
## uh:um ratio 0.4309464 0.01669572 4071.341 25.811784 3.425240e-136
```

These commands prepare the generated results to be plotted.

```
buildResults <- function(results, mname="", inner=1, outer=2){
    ret <- data.frame(Value=results[,"Estimate"],
                      Coefficient=rownames(results),
```

```
                      SE=results[,"Std. Error"])
    ret <- within(ret, {
        Model <- mname
        LowOuter <- Value - outer * SE
        HighOuter <- Value + outer * SE
        LowInner <- Value - inner * SE
        HighInner <- Value + inner * SE
    })
    ret <- ret[,colnames(ret) != "SE"]
    ret
}

##buildResults(diddist.results)
##coefplot(buildResults(diddist.results))
```

In all four measures that were modelled, the absolute distance between the subject's baseline performance and the interlocutor's baseline performance was positively correlated with higher DID values. That is, the DID models were more likely to find convergence for subjects whose baselines were further from their interlocutors' baselines. This is consistent with our predictions, and is not expected to hold in other methods.

The full DID models are provided. These models are generally redundant (they contain random effects without variance).

```
diddist.models %>% map(summary)
```

```
## $`F0 median`
## Linear mixed model fit by REML. t-tests use Satterthwaite's method [
## lmerModLmerTest]
## Formula:
## DID ~ abs(speaker.x.value - interlocutor.x.value) + (1 | speaker) +
##     (1 | interlocutor) + (1 | convno)
##    Data: df
##
## REML criterion at convergence: 10407.5
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -8.7697 -0.4707 -0.0085  0.4657 12.3636
##
## Random effects:
##  Groups       Name        Variance Std.Dev.
##  convno       (Intercept) 0.00000  0.0000
##  interlocutor (Intercept) 0.01268  0.1126
##  speaker      (Intercept) 0.00000  0.0000
##  Residual                 0.96958  0.9847
## Number of obs: 3688, groups:
## convno, 1844; interlocutor, 464; speaker, 464
##
## Fixed effects:
##                                             Estimate Std. Error
## (Intercept)                                -0.17385    0.02754
## abs(speaker.x.value - interlocutor.x.value)  0.16416    0.02014
##                                                   df t value Pr(>|t|)
## (Intercept)                                1429.58058  -6.313 3.64e-10
## abs(speaker.x.value - interlocutor.x.value) 3599.88590   8.153 4.86e-16
##
```

```
## (Intercept)                                     ***
## abs(speaker.x.value - interlocutor.x.value) ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr)
## abs(..-i..) -0.778
## convergence code: 0
## boundary (singular) fit: see ?isSingular
##
##
## $`F0 variance`
## Linear mixed model fit by REML. t-tests use Satterthwaite's method [
## lmerModLmerTest]
## Formula:
## DID ~ abs(speaker.x.value - interlocutor.x.value) + (1 | speaker) +
##     (1 | interlocutor) + (1 | convno)
##    Data: df
##
## REML criterion at convergence: 9674.1
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -5.9275 -0.5548  0.1110  0.6539  3.3181
##
## Random effects:
##  Groups       Name        Variance  Std.Dev.
##  convno       (Intercept) 5.335e-10 0.0000231
##  interlocutor (Intercept) 3.031e-02 0.1741007
##  speaker      (Intercept) 0.000e+00 0.0000000
##  Residual                 7.786e-01 0.8823902
## Number of obs: 3688, groups:
## convno, 1844; interlocutor, 464; speaker, 464
##
## Fixed effects:
##                                                Estimate Std. Error
## (Intercept)                                    -0.59880    0.02634
## abs(speaker.x.value - interlocutor.x.value)     0.53757    0.01796
##                                                      df t value Pr(>|t|)
## (Intercept)                                    1117.16269  -22.73   <2e-16
## abs(speaker.x.value - interlocutor.x.value) 3367.66516   29.94   <2e-16
##
## (Intercept)                                     ***
## abs(speaker.x.value - interlocutor.x.value) ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr)
## abs(..-i..) -0.758
## convergence code: 0
## boundary (singular) fit: see ?isSingular
##
```

```
##
## $`Speech rate`
## Linear mixed model fit by REML. t-tests use Satterthwaite's method [
## lmerModLmerTest]
## Formula:
## DID ~ abs(speaker.x.value - interlocutor.x.value) + (1 | speaker) +
##     (1 | interlocutor) + (1 | convno)
##    Data: df
##
## REML criterion at convergence: 12652.7
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -4.8976 -0.5956  0.0596  0.6651  3.7539
##
## Random effects:
##  Groups       Name        Variance Std.Dev.
##  convno       (Intercept) 0.00000  0.0000
##  interlocutor (Intercept) 0.02211  0.1487
##  speaker      (Intercept) 0.00000  0.0000
##  Residual                 0.82853  0.9102
## Number of obs: 4730, groups:
## convno, 2365; interlocutor, 478; speaker, 478
##
## Fixed effects:
##                                              Estimate Std. Error
## (Intercept)                                  -0.50558    0.02315
## abs(speaker.x.value - interlocutor.x.value)   0.44978    0.01543
##                                                    df t value Pr(>|t|)
## (Intercept)                                  990.72994  -21.84   <2e-16
## abs(speaker.x.value - interlocutor.x.value) 3604.19609   29.15   <2e-16
##
## (Intercept)                                 ***
## abs(speaker.x.value - interlocutor.x.value) ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr)
## abs(..-i..) -0.749
## convergence code: 0
## boundary (singular) fit: see ?isSingular
##
##
## $`uh:um ratio`
## Linear mixed model fit by REML. t-tests use Satterthwaite's method [
## lmerModLmerTest]
## Formula:
## DID ~ abs(speaker.x.value - interlocutor.x.value) + (1 | speaker) +
##     (1 | interlocutor) + (1 | convno)
##    Data: df
##
## REML criterion at convergence: 12658.2
##
```

```
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -4.6958 -0.6030  0.0575  0.6312  4.6373
##
## Random effects:
##  Groups       Name        Variance Std.Dev.
##  convno       (Intercept) 0.00000  0.0000
##  interlocutor (Intercept) 0.03519  0.1876
##  speaker      (Intercept) 0.00000  0.0000
##  Residual                 0.84968  0.9218
## Number of obs: 4670, groups:
## convno, 2335; interlocutor, 477; speaker, 477
##
## Fixed effects:
##                                             Estimate Std. Error        df
## (Intercept)                                  -0.4829     0.0250 1301.3952
## abs(speaker.x.value - interlocutor.x.value)   0.4309     0.0167 4071.3407
##                                            t value Pr(>|t|)
## (Intercept)                                 -19.31   <2e-16 ***
## abs(speaker.x.value - interlocutor.x.value)  25.81   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr)
## abs(..-i..) -0.748
## convergence code: 0
## boundary (singular) fit: see ?isSingular
```

Linear combination models

In this section, we model convergence as measured by the linear combination method, including distance from the interlocutor as a predictor.

```
dist.models <- lapply(full.dfs, function(df){
    ret <- lmer(speaker.value ~ speaker.x.value + interlocutor.x.value +
                    interlocutor.x.value :
                    abs(speaker.x.value - interlocutor.x.value) +
                    (1 + interlocutor.x.value || speaker) +
                    (1 | interlocutor) +
                    (1 | convno)
                , data=df)
})
```

```
## boundary (singular) fit: see ?isSingular
## boundary (singular) fit: see ?isSingular
## boundary (singular) fit: see ?isSingular
## boundary (singular) fit: see ?isSingular
```

```
(dist.results <-
     dist.models %>% map(summary) %>% map("coefficients") %>%
     map(~.x["interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value)",])  %>%
     do.call(rbind, .)
)
```

```
##                 Estimate  Std. Error        df    t value  Pr(>|t|)
## F0 median   -0.006118498 0.007116065 2882.4353 -0.8598147 0.3899627
## F0 variance -0.010792005 0.013420960 1215.2666 -0.8041157 0.4214874
## Speech rate  0.001828955 0.008215712  780.1179  0.2226167 0.8238921
## uh:um ratio -0.013780935 0.011084723 1988.0765 -1.2432367 0.2139272
```

The linear combination models found no significant effect for the interaction between convergence and absolute distance from interlocutor's baseline in any of the measures. These results suggest that there is no special status for the initial distance between the interlocutor and the subject in influencing how much they actually converge, and that the significant interactions found in the DID models were indeed only artifacts of how convergence was defined.

The full linear combination models are provided below. The models are generally redundant (they contain random effects without variance).

```
dist.models %>% map(summary)
```

```
## $`F0 median`
## Linear mixed model fit by REML. t-tests use Satterthwaite's method [
## lmerModLmerTest]
## Formula:
## speaker.value ~ speaker.x.value + interlocutor.x.value + interlocutor.x.value:abs(speaker.x.val
##     interlocutor.x.value) + (1 + interlocutor.x.value || speaker) +
##     (1 | interlocutor) + (1 | convno)
##    Data: df
##
## REML criterion at convergence: -187.1
##
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -11.6285  -0.4370  -0.0052   0.4389   7.8628
##
## Random effects:
##  Groups       Name                 Variance  Std.Dev.
##  convno       (Intercept)          0.0059856 0.07737
##  interlocutor (Intercept)          0.0021426 0.04629
##  speaker      interlocutor.x.value 0.0005825 0.02414
##  speaker.1    (Intercept)          0.0000000 0.00000
##  Residual                          0.0471548 0.21715
## Number of obs: 3688, groups:
## convno, 1844; interlocutor, 464; speaker, 464
##
## Fixed effects:
##                                                                    Estimate
## (Intercept)                                                       3.276e-03
## speaker.x.value                                                   9.664e-01
## interlocutor.x.value                                              2.639e-02
## interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value) -6.118e-03
##                                                                  Std. Error
## (Intercept)                                                       4.742e-03
## speaker.x.value                                                   6.468e-03
## interlocutor.x.value                                              1.027e-02
## interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value)  7.116e-03
##                                                                         df
## (Intercept)                                                       4.056e+02
## speaker.x.value                                                   3.549e+03
## interlocutor.x.value                                              1.507e+03
```

```
## interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value)  2.882e+03
##                                                                  t value
## (Intercept)                                                        0.691
## speaker.x.value                                                  149.406
## interlocutor.x.value                                               2.569
## interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value)  -0.860
##                                                                  Pr(>|t|)
## (Intercept)                                                        0.4901
## speaker.x.value                                                   <2e-16
## interlocutor.x.value                                               0.0103
## interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value)   0.3900
##
## (Intercept)
## speaker.x.value                                                  ***
## interlocutor.x.value                                             *
## interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value)
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) spkr.. intr..
## speakr.x.vl -0.103
## intrlctr.x.  0.114 -0.710
## i..:(..-i.. -0.128  0.800 -0.889
## convergence code: 0
## boundary (singular) fit: see ?isSingular
##
##
## $`F0 variance`
## Linear mixed model fit by REML. t-tests use Satterthwaite's method [
## lmerModLmerTest]
## Formula:
## speaker.value ~ speaker.x.value + interlocutor.x.value + interlocutor.x.value:abs(speaker.x.val
##     interlocutor.x.value) + (1 + interlocutor.x.value || speaker) +
##     (1 | interlocutor) + (1 | convno)
##    Data: df
##
## REML criterion at convergence: 8099.5
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -6.1861 -0.5704 -0.0604  0.5387  3.9722
##
## Random effects:
##  Groups       Name                 Variance Std.Dev.
##  convno       (Intercept)          0.081879 0.2861
##  interlocutor (Intercept)          0.012769 0.1130
##  speaker      interlocutor.x.value 0.003341 0.0578
##  speaker.1    (Intercept)          0.000000 0.0000
##  Residual                          0.432919 0.6580
## Number of obs: 3688, groups:
## convno, 1844; interlocutor, 464; speaker, 464
##
## Fixed effects:
```

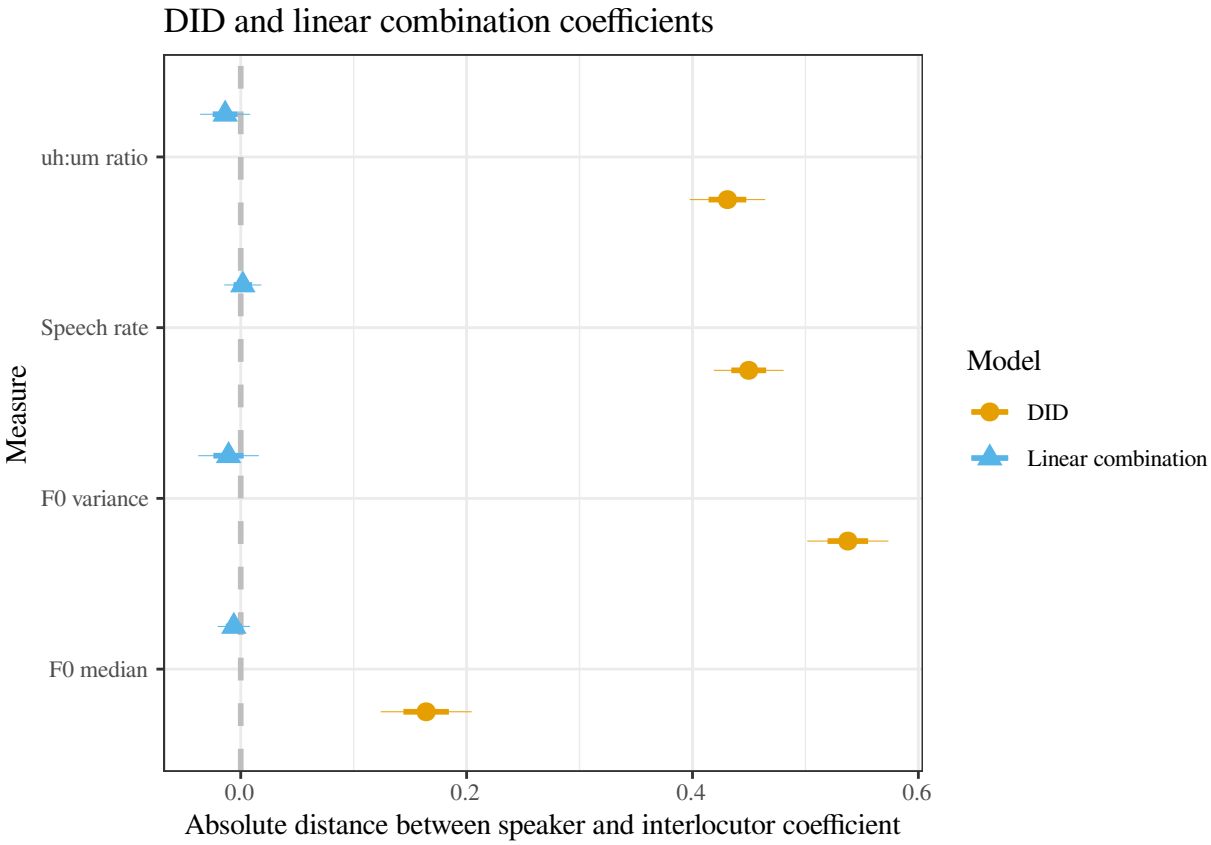
```
##                                                                    Estimate
## (Intercept)                                                         0.00407
## speaker.x.value                                                     0.67147
## interlocutor.x.value                                                0.11117
## interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value)   -0.01079
##                                                                   Std. Error
## (Intercept)                                                         0.01415
## speaker.x.value                                                     0.01420
## interlocutor.x.value                                                0.02610
## interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value)    0.01342
##                                                                          df
## (Intercept)                                                       463.61755
## speaker.x.value                                                  3496.67127
## interlocutor.x.value                                              810.69373
## interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value) 1215.26662
##                                                                   t value
## (Intercept)                                                         0.288
## speaker.x.value                                                    47.274
## interlocutor.x.value                                                4.260
## interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value)   -0.804
##                                                                  Pr(>|t|)
## (Intercept)                                                         0.774
## speaker.x.value                                                  < 2e-16
## interlocutor.x.value                                             2.29e-05
## interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value)    0.421
##
## (Intercept)
## speaker.x.value                                                  ***
## interlocutor.x.value                                             ***
## interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value)
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) spkr.. intr..
## speakr.x.vl -0.042
## intrlctr.x.  0.073 -0.415
## i..:(..-i.. -0.084  0.541 -0.854
## convergence code: 0
## boundary (singular) fit: see ?isSingular
##
##
## $`Speech rate`
## Linear mixed model fit by REML. t-tests use Satterthwaite's method [
## lmerModLmerTest]
## Formula:
## speaker.value ~ speaker.x.value + interlocutor.x.value + interlocutor.x.value:abs(speaker.x.val
##     interlocutor.x.value) + (1 + interlocutor.x.value || speaker) +
##     (1 | interlocutor) + (1 | convno)
##    Data: df
##
## REML criterion at convergence: 8429.3
##
## Scaled residuals:
```

```
##     Min      1Q  Median      3Q     Max
## -4.1696 -0.5475 -0.0057  0.5401  4.5810
##
## Random effects:
##  Groups       Name                 Variance  Std.Dev.
##  convno       (Intercept)          0.1032903 0.32139
##  interlocutor (Intercept)          0.0093239 0.09656
##  speaker      interlocutor.x.value 0.0007551 0.02748
##  speaker.1    (Intercept)          0.0000000 0.00000
##  Residual                          0.2490575 0.49906
## Number of obs: 4730, groups:
## convno, 2365; interlocutor, 478; speaker, 478
##
## Fixed effects:
##                                                                    Estimate
## (Intercept)                                                      -2.639e-03
## speaker.x.value                                                   7.988e-01
## interlocutor.x.value                                              4.201e-02
## interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value)  1.829e-03
##                                                                  Std. Error
## (Intercept)                                                       1.103e-02
## speaker.x.value                                                   9.947e-03
## interlocutor.x.value                                              1.806e-02
## interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value)  8.216e-03
##                                                                         df
## (Intercept)                                                       5.699e+02
## speaker.x.value                                                   4.540e+03
## interlocutor.x.value                                              5.601e+02
## interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value)  7.801e+02
##                                                                  t value
## (Intercept)                                                       -0.239
## speaker.x.value                                                   80.307
## interlocutor.x.value                                               2.326
## interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value)   0.223
##                                                                  Pr(>|t|)
## (Intercept)                                                        0.8110
## speaker.x.value                                                    <2e-16
## interlocutor.x.value                                               0.0204
## interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value)   0.8239
##
## (Intercept)
## speaker.x.value                                                  ***
## interlocutor.x.value                                             *
## interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value)
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) spkr.. intr..
## speakr.x.vl -0.003
## intrlctr.x.  0.006 -0.267
## i..:(..-i.. -0.007  0.477 -0.832
## convergence code: 0
## boundary (singular) fit: see ?isSingular
```

```
##
##
## $`uh:um ratio`
## Linear mixed model fit by REML. t-tests use Satterthwaite's method [
## lmerModLmerTest]
## Formula:
## speaker.value ~ speaker.x.value + interlocutor.x.value + interlocutor.x.value:abs(speaker.x.val
##     interlocutor.x.value) + (1 + interlocutor.x.value || speaker) +
##     (1 | interlocutor) + (1 | convno)
##    Data: df
##
## REML criterion at convergence: 8661
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -3.7500 -0.5930  0.0214  0.5978  5.0051
##
## Random effects:
##  Groups       Name                 Variance Std.Dev.
##  convno       (Intercept)          0.062218 0.24944
##  interlocutor (Intercept)          0.006543 0.08089
##  speaker      interlocutor.x.value 0.005593 0.07479
##  speaker.1    (Intercept)          0.000000 0.00000
##  Residual                          0.304017 0.55138
## Number of obs: 4670, groups:
## convno, 2335; interlocutor, 477; speaker, 477
##
## Fixed effects:
##                                                                    Estimate
## (Intercept)                                                       -6.958e-04
## speaker.x.value                                                    7.800e-01
## interlocutor.x.value                                               5.354e-02
## interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value) -1.378e-02
##                                                                   Std. Error
## (Intercept)                                                        1.057e-02
## speaker.x.value                                                    1.101e-02
## interlocutor.x.value                                               2.082e-02
## interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value)   1.108e-02
##                                                                          df
## (Intercept)                                                        4.640e+02
## speaker.x.value                                                    4.374e+03
## interlocutor.x.value                                               1.097e+03
## interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value)   1.988e+03
##                                                                   t value
## (Intercept)                                                        -0.066
## speaker.x.value                                                    70.829
## interlocutor.x.value                                                2.571
## interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value)   -1.243
##                                                                   Pr(>|t|)
## (Intercept)                                                         0.9475
## speaker.x.value                                                     <2e-16
## interlocutor.x.value                                                0.0103
## interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value)    0.2139
##
```

```
## (Intercept)
## speaker.x.value                                                    ***
## interlocutor.x.value                                               *
## interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value)
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) spkr.. intr..
## speakr.x.vl  0.053
## intrlctr.x. -0.077 -0.443
## i..:(..-i..  0.090  0.580 -0.858
## convergence code: 0
## boundary (singular) fit: see ?isSingular
```

The following plot illustrates the distance between the coefficient and zero. Each point is the estimate for the measure in that model, the thick lines are one standard error in each direction, and the thin lines are two standard errors in each direction. The two types of models are distinguished by color and shape. A dashed line marks zero. The coefficients from DID models are consistently much larger than the coefficients from linear combination models, which are close to zero.



Study 2: Extreme values appearing as convergence in DID models

DID models

In this section, we model convergence using DID, with distance from the mean included as a factor (and post-hoc, distance from the nearest mode).

```
didext.models <- lapply(full.dfs, function(df){
    ret <- lmer(DID ~ 1 +
                    abs(speaker.x.value) +
                    abs(speaker.x.value - interlocutor.x.value) +
                    (1 | speaker) + (1 | interlocutor) + (1 | convno)
                , data=df)
})
```

```
## boundary (singular) fit: see ?isSingular
## boundary (singular) fit: see ?isSingular
## boundary (singular) fit: see ?isSingular
## boundary (singular) fit: see ?isSingular
```

```
(didext.results <-
     didext.models %>% map(summary) %>% map("coefficients") %>%
     map(~.x["abs(speaker.x.value)",]) %>%
     do.call(rbind, .))
```

```
##                Estimate Std. Error       df  t value     Pr(>|t|)
## F0 median    0.03407148 0.04064398 3683.201 0.838291 4.019217e-01
## F0 variance 0.18743858 0.02762242  495.569 6.785741 3.305801e-11
## Speech rate 0.14674529 0.02495862 4644.608 5.879544 4.401999e-09
## uh:um ratio 0.11866550 0.02613554 4662.896 4.540388 5.756570e-06
```

```
(didextdist.results <-
     didext.models %>% map(summary) %>% map("coefficients") %>%
     map(~.x["abs(speaker.x.value - interlocutor.x.value)",]) %>%
     do.call(rbind, .))
```

```
##               Estimate Std. Error       df   t value      Pr(>|t|)
## F0 median    0.1605290 0.02060017 3561.865  7.792606  8.549876e-15
## F0 variance 0.4753702 0.01990483 3068.024 23.882149 9.276544e-116
## Speech rate 0.3951598 0.01771865 2843.776 22.301915 1.133536e-101
## uh:um ratio 0.3902705 0.01857551 3584.090 21.009947  1.621076e-92
```

In three of the four measures (excluding F0 median), the absolute distance between the subject's baseline performance and the mean of the distribution was positively associated with higher DID values. This means that these models were more likely to find convergence for subjects whose initial values were more extreme, consistent with our predictions. The distance between the subjects' and interlocutors' baselines (the focus of Study 1) was still positively correlated with higher DID values, as shown above, which suggests that these are two distinct effects.

The full models are provided below.

```
didext.models %>% map(summary)
```

```
## $`F0 median`
## Linear mixed model fit by REML. t-tests use Satterthwaite's method [
## lmerModLmerTest]
## Formula:
## DID ~ 1 + abs(speaker.x.value) + abs(speaker.x.value - interlocutor.x.value) +
##     (1 | speaker) + (1 | interlocutor) + (1 | convno)
##    Data: df
##
## REML criterion at convergence: 10411.4
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
```

```
## -8.7847 -0.4705 -0.0097  0.4696 12.3392
##
## Random effects:
##  Groups       Name        Variance  Std.Dev.
##  convno       (Intercept) 1.849e-09 0.000043
##  interlocutor (Intercept) 1.256e-02 0.112051
##  speaker      (Intercept) 0.000e+00 0.000000
##  Residual                 9.698e-01 0.984773
## Number of obs: 3688, groups:
## convno, 1844; interlocutor, 464; speaker, 464
##
## Fixed effects:
##                                              Estimate Std. Error
## (Intercept)                                  -0.20107    0.04255
## abs(speaker.x.value)                          0.03407    0.04064
## abs(speaker.x.value - interlocutor.x.value)   0.16053    0.02060
##                                                    df t value Pr(>|t|)
## (Intercept)                                2992.00135  -4.725 2.40e-06
## abs(speaker.x.value)                       3683.20115   0.838    0.402
## abs(speaker.x.value - interlocutor.x.value) 3561.86465   7.793 8.55e-15
##
## (Intercept)                                ***
## abs(speaker.x.value)
## abs(speaker.x.value - interlocutor.x.value) ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) ab(..)
## abs(spkr..) -0.762
## abs(..-i..) -0.331 -0.211
## convergence code: 0
## boundary (singular) fit: see ?isSingular
##
##
## $`F0 variance`
## Linear mixed model fit by REML. t-tests use Satterthwaite's method [
## lmerModLmerTest]
## Formula:
## DID ~ 1 + abs(speaker.x.value) + abs(speaker.x.value - interlocutor.x.value) +
##     (1 | speaker) + (1 | interlocutor) + (1 | convno)
##    Data: df
##
## REML criterion at convergence: 9634.2
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -5.9840 -0.5529  0.1033  0.6597  3.1206
##
## Random effects:
##  Groups       Name        Variance  Std.Dev.
##  convno       (Intercept) 0.0000000 0.00000
##  interlocutor (Intercept) 0.0249295 0.15789
##  speaker      (Intercept) 0.0004256 0.02063
```

```
##  Residual                 0.7726587 0.87901
## Number of obs: 3688, groups:
## convno, 1844; interlocutor, 464; speaker, 464
##
## Fixed effects:
##                                             Estimate Std. Error
## (Intercept)                                 -0.68013    0.02874
## abs(speaker.x.value)                         0.18744    0.02762
## abs(speaker.x.value - interlocutor.x.value)  0.47537    0.01990
##                                                   df t value Pr(>|t|)
## (Intercept)                                 451.96034 -23.663  < 2e-16
## abs(speaker.x.value)                        495.56898   6.786 3.31e-11
## abs(speaker.x.value - interlocutor.x.value) 3068.02363  23.882  < 2e-16
##
## (Intercept)                                ***
## abs(speaker.x.value)                       ***
## abs(speaker.x.value - interlocutor.x.value) ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) ab(..)
## abs(spkr..) -0.430
## abs(..-i..) -0.425 -0.446
## convergence code: 0
## boundary (singular) fit: see ?isSingular
##
##
## $`Speech rate`
## Linear mixed model fit by REML. t-tests use Satterthwaite's method [
## lmerModLmerTest]
## Formula:
## DID ~ 1 + abs(speaker.x.value) + abs(speaker.x.value - interlocutor.x.value) +
##     (1 | speaker) + (1 | interlocutor) + (1 | convno)
##    Data: df
##
## REML criterion at convergence: 12624.2
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -5.0691 -0.5933  0.0575  0.6642  3.9176
##
## Random effects:
##  Groups       Name        Variance Std.Dev.
##  convno       (Intercept) 0.00000  0.0000
##  interlocutor (Intercept) 0.01774  0.1332
##  speaker      (Intercept) 0.00000  0.0000
##  Residual                 0.82603  0.9089
## Number of obs: 4730, groups:
## convno, 2365; interlocutor, 478; speaker, 478
##
## Fixed effects:
##                                             Estimate Std. Error
## (Intercept)                                 -0.55920    0.02474
```

```
## abs(speaker.x.value)                              0.14675    0.02496
## abs(speaker.x.value - interlocutor.x.value)    0.39516    0.01772
##                                                        df t value Pr(>|t|)
## (Intercept)                                   1557.18804  -22.60  < 2e-16
## abs(speaker.x.value)                          4644.60808    5.88  4.4e-09
## abs(speaker.x.value - interlocutor.x.value) 2843.77627   22.30  < 2e-16
##
## (Intercept)                                   ***
## abs(speaker.x.value)                          ***
## abs(speaker.x.value - interlocutor.x.value) ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) ab(..)
## abs(spkr..) -0.390
## abs(..-i..) -0.405 -0.502
## convergence code: 0
## boundary (singular) fit: see ?isSingular
##
##
## $`uh:um ratio`
## Linear mixed model fit by REML. t-tests use Satterthwaite's method [
## lmerModLmerTest]
## Formula:
## DID ~ 1 + abs(speaker.x.value) + abs(speaker.x.value - interlocutor.x.value) +
##     (1 | speaker) + (1 | interlocutor) + (1 | convno)
##    Data: df
##
## REML criterion at convergence: 12643.5
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -4.8261 -0.6162  0.0583  0.6252  4.5743
##
## Random effects:
##  Groups       Name        Variance Std.Dev.
##  convno       (Intercept) 0.00000  0.0000
##  interlocutor (Intercept) 0.03012  0.1736
##  speaker      (Intercept) 0.00000  0.0000
##  Residual                 0.84961  0.9217
## Number of obs: 4670, groups:
## convno, 2335; interlocutor, 477; speaker, 477
##
## Fixed effects:
##                                                 Estimate Std. Error
## (Intercept)                                    -0.53378    0.02741
## abs(speaker.x.value)                            0.11867    0.02614
## abs(speaker.x.value - interlocutor.x.value)    0.39027    0.01858
##                                                        df t value Pr(>|t|)
## (Intercept)                                   1996.42230  -19.48  < 2e-16
## abs(speaker.x.value)                          4662.89592    4.54 5.76e-06
## abs(speaker.x.value - interlocutor.x.value) 3584.08987   21.01  < 2e-16
##
```

```
## (Intercept)                                    ***
## abs(speaker.x.value)                           ***
## abs(speaker.x.value - interlocutor.x.value) ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) ab(..)
## abs(spkr..) -0.434
## abs(..-i..) -0.414 -0.447
## convergence code: 0
## boundary (singular) fit: see ?isSingular
```

There was no robust effect of distance from the median as a predictor of convergence for F0 median, in contrast to the DID models for the other three measures. This lack of effect is likely a result of F0 median having two distinct modes, as shown in Figure 1. Male and female speakers have little overlap in their F0 median values, so the mean of the distribution is not a meaningful reference point. Instead, we may expect regression to the mean to be reflected by shifts towards the respective modes of each group. To test this hypothesis, we retrained the models, replacing absolute distance from the mean with absolute distance from the nearest mode.

```
didmodedist.models <- lapply(full.dfs, function(df){
    ret <- lmer(DID ~ 1 +
                    modedist +
                    abs(speaker.x.value - interlocutor.x.value) +
                    (1 | speaker) + (1 | interlocutor) + (1 | convno)
                , data=df)
})
```

```
## boundary (singular) fit: see ?isSingular
## boundary (singular) fit: see ?isSingular
## boundary (singular) fit: see ?isSingular
## boundary (singular) fit: see ?isSingular
```

```
(didmodedist.results <-
     didmodedist.models %>% map(summary) %>% map("coefficients") %>%
     map(~.x["modedist",]) %>%
     do.call(rbind, .))
```

```
##               Estimate Std. Error       df  t value     Pr(>|t|)
## F0 median   0.16609633 0.06390387 3673.982 2.599159 9.382616e-03
## F0 variance 0.15125666 0.03927509 3659.513 3.851211 1.195465e-04
## Speech rate 0.20479804 0.03983912 4720.331 5.140626 2.848850e-07
## uh:um ratio 0.09374456 0.02892592 4666.631 3.240850 1.200105e-03
```

Indeed, in this post-hoc model, all four measures exhibited a significant correlation between high DID values and distance from the nearest mode.

The full models are provided below.

```
didmodedist.models %>% map(summary)
```

```
## $`F0 median`
## Linear mixed model fit by REML. t-tests use Satterthwaite's method [
## lmerModLmerTest]
## Formula:
## DID ~ 1 + modedist + abs(speaker.x.value - interlocutor.x.value) +
##     (1 | speaker) + (1 | interlocutor) + (1 | convno)
##    Data: df
```

```
##
## REML criterion at convergence: 10404.4
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -8.7967 -0.4624 -0.0070  0.4751 12.2725
##
## Random effects:
##  Groups       Name        Variance Std.Dev.
##  convno       (Intercept) 0.00000  0.0000
##  interlocutor (Intercept) 0.01225  0.1107
##  speaker      (Intercept) 0.00000  0.0000
##  Residual                 0.96844  0.9841
## Number of obs: 3688, groups:
## convno, 1844; interlocutor, 464; speaker, 464
##
## Fixed effects:
##                                             Estimate Std. Error
## (Intercept)                                -0.22360    0.03349
## modedist                                    0.16610    0.06390
## abs(speaker.x.value - interlocutor.x.value)    0.15856    0.02023
##                                                    df t value Pr(>|t|)
## (Intercept)                                2123.43677  -6.677 3.10e-11
## modedist                                   3673.98167   2.599  0.00938
## abs(speaker.x.value - interlocutor.x.value) 3601.01463   7.836 6.06e-15
##
## (Intercept)                                ***
## modedist                                   **
## abs(speaker.x.value - interlocutor.x.value) ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) moddst
## modedist    -0.571
## abs(..-i..) -0.574 -0.107
## convergence code: 0
## boundary (singular) fit: see ?isSingular
##
##
## $`F0 variance`
## Linear mixed model fit by REML. t-tests use Satterthwaite's method [
## lmerModLmerTest]
## Formula:
## DID ~ 1 + modedist + abs(speaker.x.value - interlocutor.x.value) +
##     (1 | speaker) + (1 | interlocutor) + (1 | convno)
##    Data: df
##
## REML criterion at convergence: 9663.9
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -5.9485 -0.5540  0.1140  0.6564  3.4708
##
```

```
## Random effects:
##  Groups       Name        Variance  Std.Dev.
##  convno       (Intercept) 4.623e-10 0.0000215
##  interlocutor (Intercept) 2.875e-02 0.1695726
##  speaker      (Intercept) 0.000e+00 0.0000000
##  Residual                 7.768e-01 0.8813474
## Number of obs: 3688, groups:
## convno, 1844; interlocutor, 464; speaker, 464
##
## Fixed effects:
##                                              Estimate Std. Error
## (Intercept)                                  -0.64628    0.02905
## modedist                                      0.15126    0.03928
## abs(speaker.x.value - interlocutor.x.value)   0.51526    0.01878
##                                                    df t value Pr(>|t|)
## (Intercept)                                1629.42201 -22.247  < 2e-16
## modedist                                   3659.51267   3.851  0.00012
## abs(speaker.x.value - interlocutor.x.value) 3271.97001  27.435  < 2e-16
##
## (Intercept)                                ***
## modedist                                   ***
## abs(speaker.x.value - interlocutor.x.value) ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) moddst
## modedist    -0.431
## abs(..-i..) -0.525 -0.301
## convergence code: 0
## boundary (singular) fit: see ?isSingular
##
##
## $`Speech rate`
## Linear mixed model fit by REML. t-tests use Satterthwaite's method [
## lmerModLmerTest]
## Formula:
## DID ~ 1 + modedist + abs(speaker.x.value - interlocutor.x.value) +
##     (1 | speaker) + (1 | interlocutor) + (1 | convno)
##    Data: df
##
## REML criterion at convergence: 12631.1
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -5.1342 -0.5938  0.0588  0.6643  3.8081
##
## Random effects:
##  Groups       Name        Variance Std.Dev.
##  convno       (Intercept) 0.0000   0.0000
##  interlocutor (Intercept) 0.0197   0.1404
##  speaker      (Intercept) 0.0000   0.0000
##  Residual                 0.8259   0.9088
## Number of obs: 4730, groups:
```

```
## convno, 2365; interlocutor, 478; speaker, 478
##
## Fixed effects:
##                                             Estimate Std. Error
## (Intercept)                                 -0.53761    0.02385
## modedist                                     0.20480    0.03984
## abs(speaker.x.value - interlocutor.x.value)    0.41869    0.01642
##                                                    df t value Pr(>|t|)
## (Intercept)                                1239.37083 -22.539  < 2e-16
## modedist                                   4720.33104   5.141 2.85e-07
## abs(speaker.x.value - interlocutor.x.value) 3285.36196  25.495  < 2e-16
##
## (Intercept)                                ***
## modedist                                   ***
## abs(speaker.x.value - interlocutor.x.value) ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) moddst
## modedist    -0.275
## abs(..-i..) -0.579 -0.354
## convergence code: 0
## boundary (singular) fit: see ?isSingular
##
##
## $`uh:um ratio`
## Linear mixed model fit by REML. t-tests use Satterthwaite's method [
## lmerModLmerTest]
## Formula:
## DID ~ 1 + modedist + abs(speaker.x.value - interlocutor.x.value) +
##     (1 | speaker) + (1 | interlocutor) + (1 | convno)
##    Data: df
##
## REML criterion at convergence: 12653.1
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -4.7996 -0.6185  0.0597  0.6329  4.5519
##
## Random effects:
##  Groups       Name        Variance Std.Dev.
##  convno       (Intercept) 0.00000  0.0000
##  interlocutor (Intercept) 0.03162  0.1778
##  speaker      (Intercept) 0.00000  0.0000
##  Residual                 0.85040  0.9222
## Number of obs: 4670, groups:
## convno, 2335; interlocutor, 477; speaker, 477
##
## Fixed effects:
##                                             Estimate Std. Error
## (Intercept)                                 -0.50180    0.02563
## modedist                                     0.09374    0.02893
## abs(speaker.x.value - interlocutor.x.value)    0.40398    0.01833
```

```
##                                                      df t value Pr(>|t|)
## (Intercept)                                    1543.64742 -19.576   <2e-16
## modedist                                       4666.63110   3.241   0.0012
## abs(speaker.x.value - interlocutor.x.value) 3691.80195  22.035   <2e-16
##
## (Intercept)                                    ***
## modedist                                       **
## abs(speaker.x.value - interlocutor.x.value) ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) moddst
## modedist    -0.254
## abs(..-i..) -0.555 -0.419
## convergence code: 0
## boundary (singular) fit: see ?isSingular
```

Linear combination models

In this section, we model convergence using the linear combination method, with distance from the mean included as a factor (and post-hoc, distance from the nearest mode).

```
ext.models <- lapply(full.dfs, function(df){
    ret <- lmer(speaker.value ~ speaker.x.value + interlocutor.x.value +
                    interlocutor.x.value : abs(speaker.x.value) +
                    interlocutor.x.value :
                    abs(speaker.x.value - interlocutor.x.value) +
                    (1 + interlocutor.x.value || speaker) +
                    (1 | interlocutor) +
                    (1 | convno)
                , data=df)
})
```

```
## boundary (singular) fit: see ?isSingular
## boundary (singular) fit: see ?isSingular
## boundary (singular) fit: see ?isSingular
## boundary (singular) fit: see ?isSingular
```

```
(ext.results <-
     ext.models %>% map(summary) %>% map("coefficients") %>%
     map(~.x["interlocutor.x.value:abs(speaker.x.value)",])  %>%
     do.call(rbind, .)
)
```

```
##                 Estimate Std. Error       df    t value  Pr(>|t|)
## F0 median   -0.008541411 0.01026802 265.9352 -0.8318464 0.4062420
## F0 variance  0.007832218 0.02211007 370.8167  0.3542375 0.7233622
## Speech rate  0.012160156 0.01453512 285.5328  0.8366049 0.4035143
## uh:um ratio  0.011335365 0.01774531 375.0909  0.6387809 0.5233554
```

```
(extdist.results <-
     ext.models %>% map(summary) %>% map("coefficients") %>%
     map(~.x["interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value)",])  %>%
     do.call(rbind, .)
```

```
)
```

```
##                  Estimate  Std. Error       df    t value  Pr(>|t|)
## F0 median   -0.004514236 0.007372979 3311.544 -0.6122676 0.5404028
## F0 variance -0.012262975 0.014075704 1333.287 -0.8712157 0.3837932
## Speech rate -0.001395716 0.009111147 1118.050 -0.1531878 0.8782778
## uh:um ratio -0.015745736 0.011499828 2093.255 -1.3692149 0.1710790
```

The linear combination models found no significant effect for the interaction between absolute distance from the mean and the interlocutors' baseline; that is, there was no interaction between convergence and subjects' baseline distance from the mean, as shown above. This suggests that there is no actual effect of the distance between subjects' baseline and the mean on convergence. As in Study 1, the initial distance between the subject and the interlocutor was not significant.

Model summaries are provided below.

```
ext.models %>% map(summary)
```

```
## $`F0 median`
## Linear mixed model fit by REML. t-tests use Satterthwaite's method [
## lmerModLmerTest]
## Formula:
## speaker.value ~ speaker.x.value + interlocutor.x.value + interlocutor.x.value:abs(speaker.x.val
##     interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value) +
##     (1 + interlocutor.x.value || speaker) + (1 | interlocutor) +
##     (1 | convno)
##    Data: df
##
## REML criterion at convergence: -180.5
##
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -11.6588  -0.4374  -0.0065   0.4360   7.8820
##
## Random effects:
##  Groups       Name                 Variance  Std.Dev.
##  convno       (Intercept)          0.0059868 0.07737
##  interlocutor (Intercept)          0.0021447 0.04631
##  speaker      interlocutor.x.value 0.0005846 0.02418
##  speaker.1    (Intercept)          0.0000000 0.00000
##  Residual                          0.0471549 0.21715
## Number of obs: 3688, groups:
## convno, 1844; interlocutor, 464; speaker, 464
##
## Fixed effects:
##                                                                    Estimate
## (Intercept)                                                       3.137e-03
## speaker.x.value                                                   9.677e-01
## interlocutor.x.value                                              3.207e-02
## interlocutor.x.value:abs(speaker.x.value)                        -8.541e-03
## interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value) -4.514e-03
##                                                                  Std. Error
## (Intercept)                                                       4.746e-03
## speaker.x.value                                                   6.659e-03
## interlocutor.x.value                                              1.234e-02
## interlocutor.x.value:abs(speaker.x.value)                         1.027e-02
## interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value)  7.373e-03
```

```
##                                                                         df
## (Intercept)                                                          4.061e+02
## speaker.x.value                                                      3.569e+03
## interlocutor.x.value                                                 4.901e+02
## interlocutor.x.value:abs(speaker.x.value)                            2.659e+02
## interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value)     3.312e+03
##                                                                     t value
## (Intercept)                                                           0.661
## speaker.x.value                                                     145.320
## interlocutor.x.value                                                  2.600
## interlocutor.x.value:abs(speaker.x.value)                            -0.832
## interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value)     -0.612
##                                                                     Pr(>|t|)
## (Intercept)                                                          0.50906
## speaker.x.value                                                      < 2e-16
## interlocutor.x.value                                                 0.00962
## interlocutor.x.value:abs(speaker.x.value)                            0.40624
## interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value)     0.54040
##
## (Intercept)
## speaker.x.value                                                     ***
## interlocutor.x.value                                                **
## interlocutor.x.value:abs(speaker.x.value)
## interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value)
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) spkr.. intr.. i..:(.
## speakr.x.vl -0.108
## intrlctr.x.  0.075 -0.443
## intr..:(..)  0.035 -0.238 -0.553
## i..:(..-i.. -0.133  0.812 -0.570 -0.261
## convergence code: 0
## boundary (singular) fit: see ?isSingular
##
##
## $`F0 variance`
## Linear mixed model fit by REML. t-tests use Satterthwaite's method [
## lmerModLmerTest]
## Formula:
## speaker.value ~ speaker.x.value + interlocutor.x.value + interlocutor.x.value:abs(speaker.x.val
##     interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value) +
##     (1 + interlocutor.x.value || speaker) + (1 | interlocutor) +
##     (1 | convno)
##    Data: df
##
## REML criterion at convergence: 8105.1
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -6.1671 -0.5698 -0.0587  0.5382  3.9534
##
## Random effects:
```

```
##  Groups       Name                 Variance Std.Dev.
##  convno       (Intercept)          0.082018 0.28639
##  interlocutor (Intercept)          0.012778 0.11304
##  speaker      interlocutor.x.value 0.003456 0.05879
##  speaker.1    (Intercept)          0.000000 0.00000
##  Residual                          0.432812 0.65788
## Number of obs: 3688, groups:
## convno, 1844; interlocutor, 464; speaker, 464
##
## Fixed effects:
##                                                                          Estimate
## (Intercept)                                                             4.316e-03
## speaker.x.value                                                         6.705e-01
## interlocutor.x.value                                                    1.073e-01
## interlocutor.x.value:abs(speaker.x.value)                               7.832e-03
## interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value) -1.226e-02
##                                                                         Std. Error
## (Intercept)                                                             1.418e-02
## speaker.x.value                                                         1.447e-02
## interlocutor.x.value                                                    2.831e-02
## interlocutor.x.value:abs(speaker.x.value)                               2.211e-02
## interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value)        1.408e-02
##                                                                               df
## (Intercept)                                                             4.647e+02
## speaker.x.value                                                         3.431e+03
## interlocutor.x.value                                                    6.015e+02
## interlocutor.x.value:abs(speaker.x.value)                               3.708e+02
## interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value)        1.333e+03
##                                                                        t value
## (Intercept)                                                              0.304
## speaker.x.value                                                         46.352
## interlocutor.x.value                                                     3.789
## interlocutor.x.value:abs(speaker.x.value)                                0.354
## interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value)        -0.871
##                                                                        Pr(>|t|)
## (Intercept)                                                            0.760895
## speaker.x.value                                                         < 2e-16
## interlocutor.x.value                                                   0.000166
## interlocutor.x.value:abs(speaker.x.value)                              0.723362
## interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value)       0.383793
##
## (Intercept)
## speaker.x.value                                                        ***
## interlocutor.x.value                                                   ***
## interlocutor.x.value:abs(speaker.x.value)
## interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value)
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) spkr.. intr.. i..:(.
## speakr.x.vl -0.051
## intrlctr.x.  0.048 -0.303
## intr..:(..)  0.051 -0.189 -0.386
```

```
## i..:(..-i.. -0.095  0.563 -0.636 -0.300
## convergence code: 0
## boundary (singular) fit: see ?isSingular
##
##
## $`Speech rate`
## Linear mixed model fit by REML. t-tests use Satterthwaite's method [
## lmerModLmerTest]
## Formula:
## speaker.value ~ speaker.x.value + interlocutor.x.value + interlocutor.x.value:abs(speaker.x.val
##     interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value) +
##     (1 + interlocutor.x.value || speaker) + (1 | interlocutor) +
##     (1 | convno)
##    Data: df
##
## REML criterion at convergence: 8435.3
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -4.1994 -0.5461 -0.0034  0.5395  4.6016
##
## Random effects:
##  Groups       Name                 Variance  Std.Dev.
##  convno       (Intercept)          0.1034205 0.32159
##  interlocutor (Intercept)          0.0093250 0.09657
##  speaker      interlocutor.x.value 0.0008929 0.02988
##  speaker.1    (Intercept)          0.0000000 0.00000
##  Residual                          0.2488530 0.49885
## Number of obs: 4730, groups:
## convno, 2365; interlocutor, 478; speaker, 478
##
## Fixed effects:
##                                                                    Estimate
## (Intercept)                                                      -2.621e-03
## speaker.x.value                                                   7.973e-01
## interlocutor.x.value                                              3.825e-02
## interlocutor.x.value:abs(speaker.x.value)                         1.216e-02
## interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value) -1.396e-03
##                                                                  Std. Error
## (Intercept)                                                       1.103e-02
## speaker.x.value                                                   1.011e-02
## interlocutor.x.value                                              1.861e-02
## interlocutor.x.value:abs(speaker.x.value)                         1.453e-02
## interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value)  9.111e-03
##                                                                         df
## (Intercept)                                                       5.698e+02
## speaker.x.value                                                   4.289e+03
## interlocutor.x.value                                              4.288e+02
## interlocutor.x.value:abs(speaker.x.value)                         2.855e+02
## interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value)  1.118e+03
##                                                                  t value
## (Intercept)                                                       -0.238
## speaker.x.value                                                   78.896
## interlocutor.x.value                                               2.055
```

```
## interlocutor.x.value:abs(speaker.x.value)                           0.837
## interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value)  -0.153
##                                                                   Pr(>|t|)
## (Intercept)                                                         0.8123
## speaker.x.value                                                     <2e-16
## interlocutor.x.value                                                0.0405
## interlocutor.x.value:abs(speaker.x.value)                           0.4035
## interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value)    0.8783
##
## (Intercept)
## speaker.x.value                                                   ***
## interlocutor.x.value                                              *
## interlocutor.x.value:abs(speaker.x.value)
## interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value)
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) spkr.. intr.. i..:(.
## speakr.x.vl -0.004
## intrlctr.x.  0.005 -0.213
## intr..:(..)  0.002 -0.176 -0.236
## i..:(..-i.. -0.007  0.500 -0.629 -0.430
## convergence code: 0
## boundary (singular) fit: see ?isSingular
##
##
## $`uh:um ratio`
## Linear mixed model fit by REML. t-tests use Satterthwaite's method [
## lmerModLmerTest]
## Formula:
## speaker.value ~ speaker.x.value + interlocutor.x.value + interlocutor.x.value:abs(speaker.x.val
##     interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value) +
##     (1 + interlocutor.x.value || speaker) + (1 | interlocutor) +
##     (1 | convno)
##    Data: df
##
## REML criterion at convergence: 8666.8
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -3.7552 -0.5915  0.0208  0.5997  4.9825
##
## Random effects:
##  Groups       Name                Variance  Std.Dev.
##  convno       (Intercept)         6.228e-02 2.496e-01
##  interlocutor (Intercept)         6.506e-03 8.066e-02
##  speaker      interlocutor.x.value 5.763e-03 7.592e-02
##  speaker.1    (Intercept)         7.814e-11 8.840e-06
##  Residual                         3.039e-01 5.513e-01
## Number of obs: 4670, groups:
## convno, 2335; interlocutor, 477; speaker, 477
##
## Fixed effects:
```

```
##                                                                    Estimate
## (Intercept)                                                       -9.415e-04
## speaker.x.value                                                    7.788e-01
## interlocutor.x.value                                               4.760e-02
## interlocutor.x.value:abs(speaker.x.value)                          1.134e-02
## interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value) -1.575e-02
##                                                                   Std. Error
## (Intercept)                                                        1.057e-02
## speaker.x.value                                                    1.117e-02
## interlocutor.x.value                                               2.286e-02
## interlocutor.x.value:abs(speaker.x.value)                          1.775e-02
## interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value)   1.150e-02
##                                                                          df
## (Intercept)                                                        4.643e+02
## speaker.x.value                                                    4.132e+03
## interlocutor.x.value                                               7.497e+02
## interlocutor.x.value:abs(speaker.x.value)                          3.751e+02
## interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value)   2.093e+03
##                                                                   t value
## (Intercept)                                                        -0.089
## speaker.x.value                                                    69.737
## interlocutor.x.value                                                2.082
## interlocutor.x.value:abs(speaker.x.value)                           0.639
## interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value)   -1.369
##                                                                   Pr(>|t|)
## (Intercept)                                                         0.9291
## speaker.x.value                                                     <2e-16
## interlocutor.x.value                                                0.0377
## interlocutor.x.value:abs(speaker.x.value)                           0.5234
## interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value)    0.1711
##
## (Intercept)
## speaker.x.value                                                   ***
## interlocutor.x.value                                              *
## interlocutor.x.value:abs(speaker.x.value)
## interlocutor.x.value:abs(speaker.x.value - interlocutor.x.value)
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) spkr.. intr.. i..:(.
## speakr.x.vl  0.058
## intrlctr.x. -0.055 -0.330
## intr..:(..) -0.036 -0.166 -0.412
## i..:(..-i..  0.097  0.595 -0.645 -0.265
## convergence code: 0
## boundary (singular) fit: see ?isSingular
```

The following coefficient plot is the same as the one used in Study 1, except that it illustrates the coefficients for absolute distance from the mean as well as for absolute distance from the interlocutor. The coefficients from DID models are consistently much larger than the coefficients from linear combination models, which are close to zero.

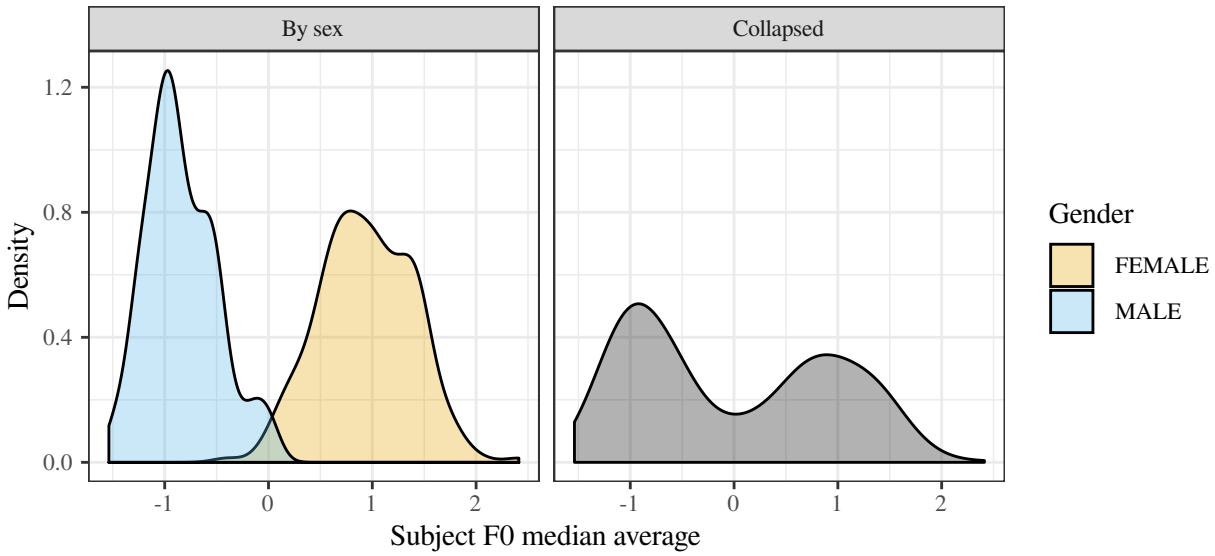
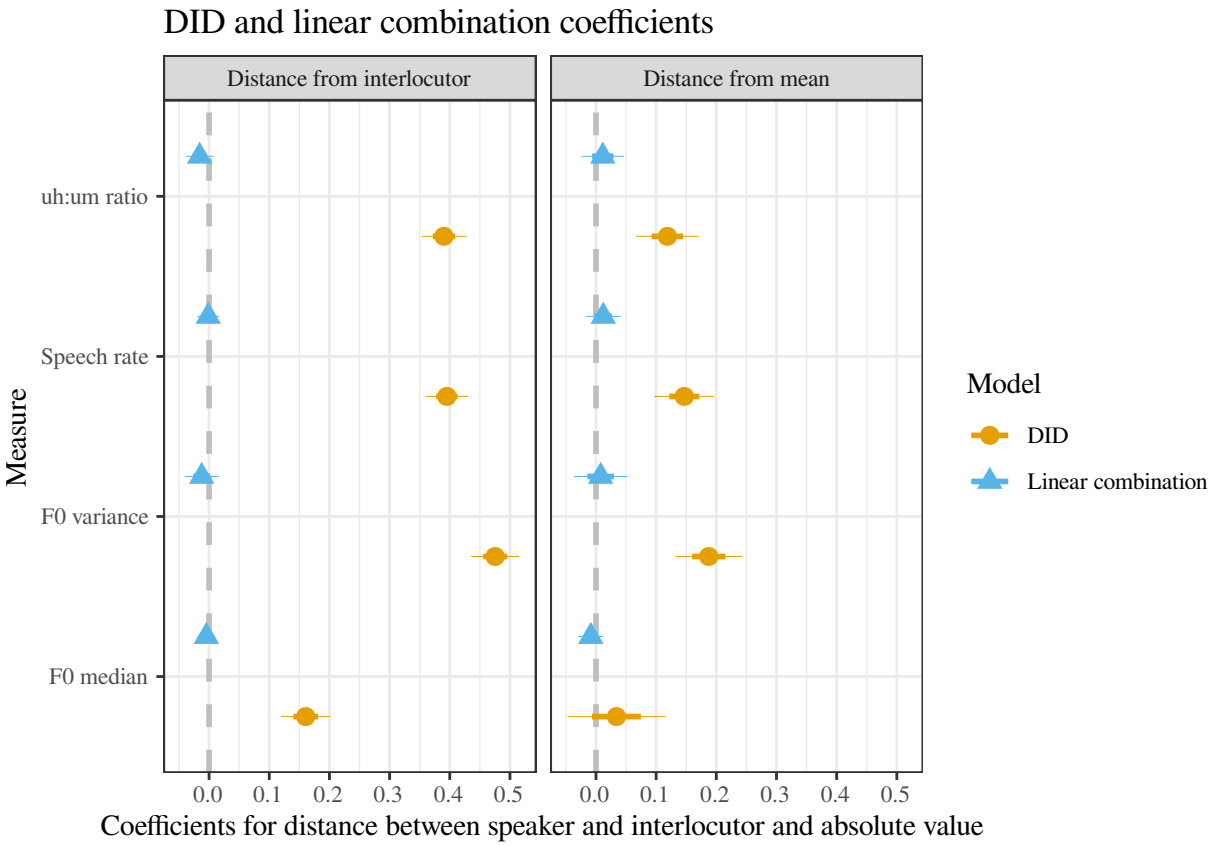


Figure 1: A density plot of F0 values, averaged for each subject. The values are split by sex on the left panel, and collapsed on the right panel.



Study 3: Individual differences

Preparation

In this section, we look for individual differences in convergence, by analyzing per-speaker differences in convergence as calculated by each method.

`basic.models` are the linear combination models to find individual differences in convergence. They include a random slope for interlocutor's basline per speaker, and closely replicate the results found by Cohen Priva and Sanker (2018). The variable of interest in each model is the per-speaker random slope for interlocutor's baseline.

```
basic.models <- lapply(full.dfs, function(df){
    ret <- lmer(speaker.value ~ speaker.x.value + interlocutor.x.value +
                    (1 + interlocutor.x.value || speaker) +
                    (1 | interlocutor) +
                    (1 | convno)
                , data=df)
})
```

```
## boundary (singular) fit: see ?isSingular
## boundary (singular) fit: see ?isSingular
## boundary (singular) fit: see ?isSingular
## boundary (singular) fit: see ?isSingular
```

The models are summarized below.

```
basic.models %>% map(summary)
```

```
## $`F0 median`
## Linear mixed model fit by REML. t-tests use Satterthwaite's method [
## lmerModLmerTest]
## Formula: speaker.value ~ speaker.x.value + interlocutor.x.value + (1 +
##     interlocutor.x.value || speaker) + (1 | interlocutor) + (1 |
##     convno)
##    Data: df
##
## REML criterion at convergence: -194.4
##
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -11.6107  -0.4368  -0.0064   0.4406   7.8540
##
## Random effects:
##  Groups       Name                 Variance  Std.Dev.
##  convno       (Intercept)          0.0059834 0.07735
##  interlocutor (Intercept)          0.0021296 0.04615
##  speaker      interlocutor.x.value 0.0006054 0.02460
##  speaker.1    (Intercept)          0.0000000 0.00000
##  Residual                          0.0471418 0.21712
## Number of obs: 3688, groups:
## convno, 1844; interlocutor, 464; speaker, 464
##
## Fixed effects:
##                       Estimate Std. Error        df t value Pr(>|t|)
## (Intercept)          2.750e-03  4.700e-03 3.970e+02   0.585 0.558842
## speaker.x.value      9.708e-01  3.881e-03 3.674e+03 250.161  < 2e-16 ***
```

```
## interlocutor.x.value 1.855e-02  4.716e-03 2.107e+02   3.935 0.000113 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) spkr..
## speakr.x.vl -0.001
## intrlctr.x.  0.001  0.003
## convergence code: 0
## boundary (singular) fit: see ?isSingular
##
##
## $`F0 variance`
## Linear mixed model fit by REML. t-tests use Satterthwaite's method [
## lmerModLmerTest]
## Formula: speaker.value ~ speaker.x.value + interlocutor.x.value + (1 +
##     interlocutor.x.value || speaker) + (1 | interlocutor) + (1 |
##     convno)
##    Data: df
##
## REML criterion at convergence: 8093.3
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -6.1640 -0.5688 -0.0632  0.5414  3.9898
##
## Random effects:
##  Groups       Name                Variance Std.Dev.
##  convno       (Intercept)         0.082226 0.28675
##  interlocutor (Intercept)         0.012955 0.11382
##  speaker      interlocutor.x.value 0.003503 0.05918
##  speaker.1    (Intercept)         0.000000 0.00000
##  Residual                         0.432278 0.65748
## Number of obs: 3688, groups:
## convno, 1844; interlocutor, 464; speaker, 464
##
## Fixed effects:
##                       Estimate Std. Error        df t value Pr(>|t|)
## (Intercept)          3.127e-03  1.412e-02 4.653e+02   0.221    0.825
## speaker.x.value      6.777e-01  1.195e-02 3.629e+03  56.732  < 2e-16 ***
## interlocutor.x.value 9.329e-02  1.360e-02 2.062e+02   6.858 7.97e-11 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) spkr..
## speakr.x.vl 0.004
## intrlctr.x. 0.004  0.108
## convergence code: 0
## boundary (singular) fit: see ?isSingular
##
##
## $`Speech rate`
## Linear mixed model fit by REML. t-tests use Satterthwaite's method [
```

```
## lmerModLmerTest]
## Formula: speaker.value ~ speaker.x.value + interlocutor.x.value + (1 +
##     interlocutor.x.value || speaker) + (1 | interlocutor) + (1 |
##     convno)
##    Data: df
##
## REML criterion at convergence: 8421.6
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -4.1625 -0.5486 -0.0052  0.5420  4.5917
##
## Random effects:
##  Groups       Name                 Variance  Std.Dev.
##  convno       (Intercept)          0.1034905 0.32170
##  interlocutor (Intercept)          0.0092465 0.09616
##  speaker      interlocutor.x.value 0.0006435 0.02537
##  speaker.1    (Intercept)          0.0000000 0.00000
##  Residual                          0.2490136 0.49901
## Number of obs: 4730, groups:
## convno, 2365; interlocutor, 478; speaker, 478
##
## Fixed effects:
##                         Estimate Std. Error         df t value Pr(>|t|)
## (Intercept)          -2.610e-03  1.102e-02  5.709e+02  -0.237    0.813
## speaker.x.value       7.978e-01  8.741e-03  4.310e+03  91.262  < 2e-16 ***
## interlocutor.x.value  4.537e-02  9.979e-03  2.265e+02   4.547 8.87e-06 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) spkr..
## speakr.x.vl 0.000
## intrlctr.x. 0.001  0.270
## convergence code: 0
## boundary (singular) fit: see ?isSingular
##
##
## $`uh:um ratio`
## Linear mixed model fit by REML. t-tests use Satterthwaite's method [
## lmerModLmerTest]
## Formula: speaker.value ~ speaker.x.value + interlocutor.x.value + (1 +
##     interlocutor.x.value || speaker) + (1 | interlocutor) + (1 |
##     convno)
##    Data: df
##
## REML criterion at convergence: 8655.4
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -3.7501 -0.5921  0.0211  0.6009  4.9912
##
## Random effects:
##  Groups       Name                 Variance Std.Dev.
```

```
##  convno       (Intercept)          0.062465 0.24993
##  interlocutor (Intercept)          0.006836 0.08268
##  speaker      interlocutor.x.value 0.005555 0.07453
##  speaker.1    (Intercept)          0.000000 0.00000
##  Residual                          0.303646 0.55104
## Number of obs: 4670, groups:
## convno, 2335; interlocutor, 477; speaker, 477
##
## Fixed effects:
##                       Estimate Std. Error        df t value Pr(>|t|)
## (Intercept)          4.782e-04  1.056e-02 4.647e+02   0.045  0.96391
## speaker.x.value      7.879e-01  8.972e-03 4.541e+03  87.821  < 2e-16 ***
## interlocutor.x.value 3.133e-02  1.071e-02 2.567e+02   2.924  0.00377 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) spkr..
## speakr.x.vl 0.000
## intrlctr.x. 0.001  0.130
## convergence code: 0
## boundary (singular) fit: see ?isSingular
```

We then calculate additional properties for each individual.

```
speaker.cor <- do.call(rbind, lapply(full.dfs, function(df){
    speakers <- as.character(unique(df$speaker))
    names(speakers) <- speakers
    speakers.n <- xtabs(~speaker, df)
    data.frame(n=c(speakers.n[speakers]),
               speaker=speakers,
               study=unique(df$study))
}))

dim(speaker.baseline <- do.call(rbind, lapply(full.dfs, function(df){
    ret <- aggregate(speaker.value ~ speaker + study, df, mean)
    colnames(ret)[ncol(ret)] <- "speaker.baseline"
    ret$median <- median(ret$speaker.baseline)
    ##ret$mean <- mean(ret$speaker.baseline)
    ret$modedist <- modedist(ret$speaker.baseline)
    ret
})))
```

```
## [1] 1883    5
```

```
dim(speaker.did <- do.call(rbind, lapply(full.dfs, function(df){
    ret <- aggregate(DID ~ speaker + study, df, mean)
    colnames(ret)[ncol(ret)] <- "mean.DID"
    ret
})))
```

```
## [1] 1883    3
```

```
dim(speaker.slopes <- do.call(rbind, lapply(studies, function(mname){
    slope <- z.(ranef(basic.models[[mname]])$speaker[,"interlocutor.x.value"])
    ret <- data.frame(speaker=rownames(ranef(basic.models[[mname]])$speaker), slope, study=mname)
    ret
```

```
}))
```

```
## [1] 1883    3
```

```
dim(speaker.props <-
        list(speaker.baseline, speaker.cor, speaker.did, speaker.slopes) %>% reduce(merge))
```

```
## [1] 1883    8
```

```
speaker.props$measure <- speaker.props$study


head(speaker.props)
```

```
##   speaker       study speaker.baseline      median   modedist  n
## 1    1000   F0 median        2.0215107 -0.23019976 1.12812981  5
## 2    1000 F0 variance        0.1464409 -0.02657973 0.11063491  5
## 3    1000 Speech rate        1.8260718 -0.00926200 1.71107828 10
## 4    1000 uh:um ratio       -0.1990484  0.02439410 0.25739388 10
## 5    1001   F0 median       -0.9435007 -0.23019976 0.02248817  6
## 6    1001 F0 variance        0.4203039 -0.02657973 0.38449785  6
##      mean.DID       slope     measure
## 1  0.10329883 -1.23277086   F0 median
## 2  0.07684253 -0.05476993 F0 variance
## 3  0.44413605 -1.52126136 Speech rate
## 4 -0.35160177 -0.34673556 uh:um ratio
## 5  0.17573517  0.17914808   F0 median
## 6  0.06087636  1.13667998 F0 variance
```

```
corfunc <- function(x, y){
    ret <- lm(y ~ x)
    summary(ret)$coefficients[2,]
}


speaker.lms <- lapply(studies, function(mname){
    dim(d <- subset(speaker.props, study == mname))
    list(did=with(d, corfunc(mean.DID, modedist)),
         slope=with(d, corfunc(slope, modedist)))
})
```

DID correlations

```
speaker.lms %>% map(~.x$did) %>% do.call(rbind, .)
```

For DID models, there was a positive correlation between mean DID and mean performance for all measures; that is, the subject's distance from the nearest mode was related to measured convergence.

Linear combination correlations

```
speaker.lms %>% map(~.x$slope) %>% do.call(rbind, .)
```

For the linear combination model, there was a much smaller relationship between per-individual slopes and mean performance, which did not consistently reach significance.

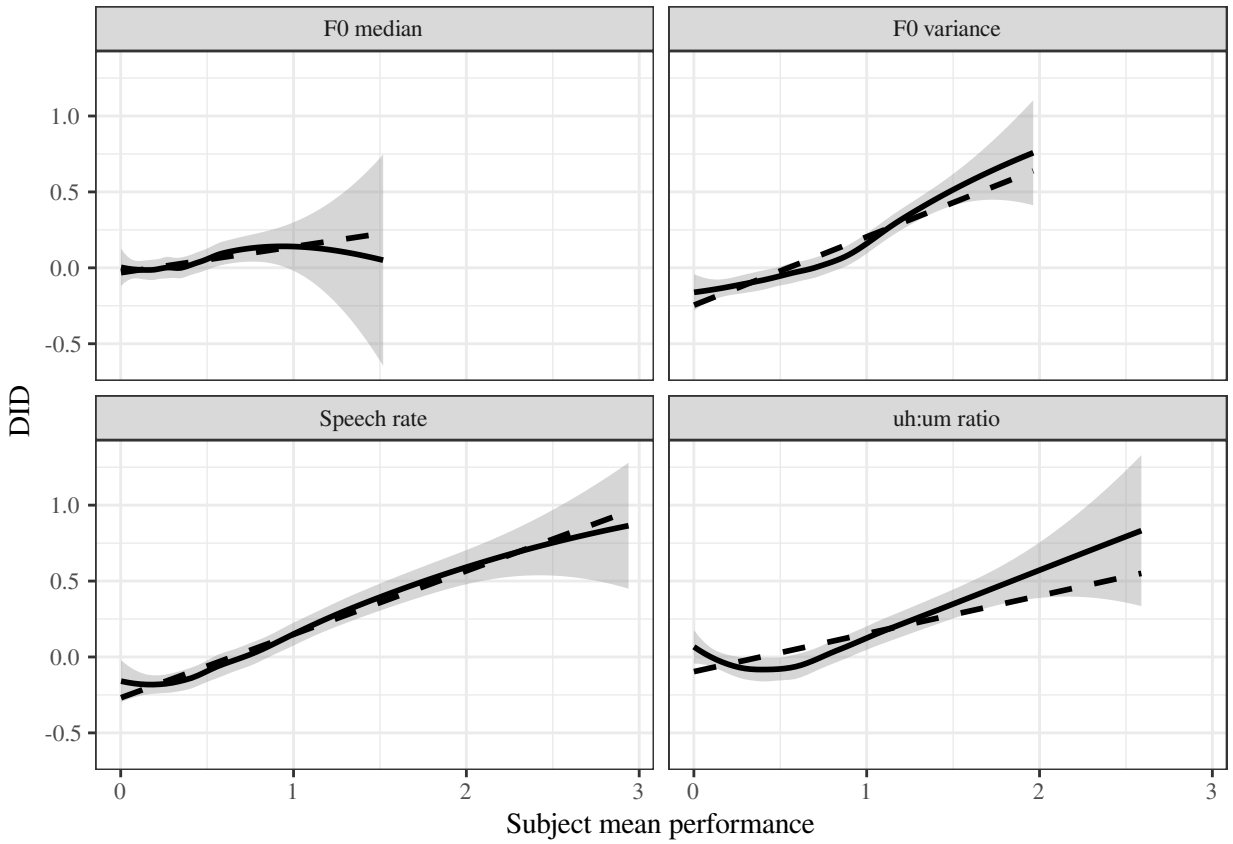


Figure 2: The relationships between proximity to a mode and DID values. The continuous line shows the relationship between the variable using local polynomial regression (loess). The dashed line is the linear relationship. The X-axis is the absolute distance between the subject and the nearest mode. The Y-axis is the DID value. Each panel shows the relationship for a different measure. The results show a clear relationship between proximity to a mode and high DID, though it is much weaker for F0 median than for other properties.

Figure 2 shows the correlation between per-subject mean DID estimates and mean subject performance, for the DID models. Figure 3 shows the relationship between subjects' mean performance and their convergence slopes for the linear combination models; there is no significant trend.

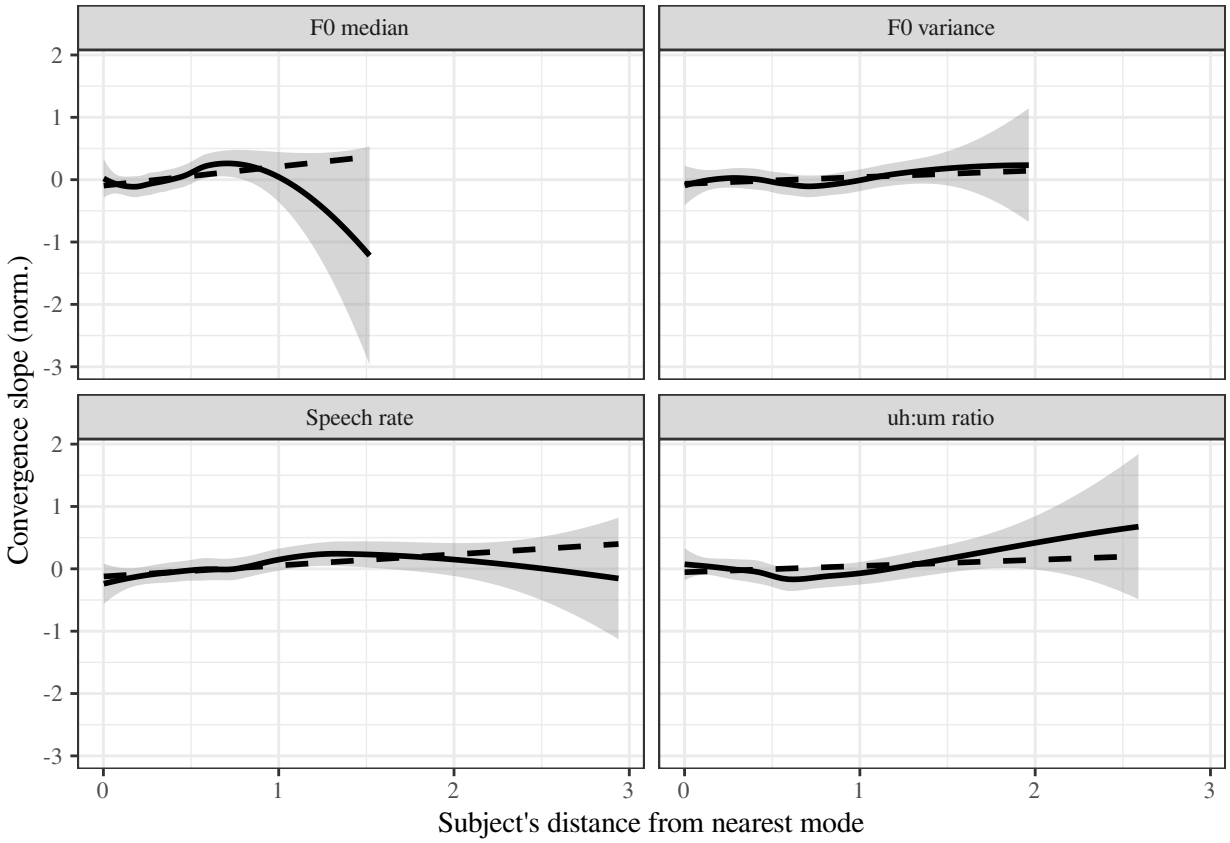


Figure 3: The relationships between proximity to a mode and individual differences in convergence, as measured using a random slope for interlocutors' baseline in a mixed effects model. The continuous line shows the relationship between the variable using local polynomial regression (loess). The dashed line is the linear relationship. The X-axis is the absolute distance between the subject and the nearest mode. The Y-axis is the normalized per-subject convergence slope value. Each panel shows the relationship for a different measure. The results do not show a clear relationship between proximity to the median and convergence.

Study 4: Sampling experiments

In this section, we look for convergence in a dataset simulated to lack convergence, and test whether individual variation in distance from the mean and starting distance from the interlocutor are significant predictors of convergence within each method. Given that there is no convergence, there should also be no individual differences in convergence, or effects of each speaker's baseline productions on convergence.

```
genexperiment <- function(population.sd=1, noise.sd=.5, participants=100){
    participant.baseline <- rnorm(participants, mean=0, sd=population.sd)
    subject.before <- rnorm(participants,
                            mean=participant.baseline,
                            sd=noise.sd)
    subject.after <- rnorm(participants,
                           mean=participant.baseline,
                           sd=noise.sd)
    subjects <- 1:participants
    convno <- c(1:(participants/2),
                1:(participants/2))

    ret.df <- data.frame(subject=as.character(subjects),
                         subject.before, subject.after, convno)
    ret.df <- merge(ret.df, ret.df, by="convno", suffixes=c("", ".y"))
    ret.df <- subset(ret.df, !subject== subject.y)
    colnames(ret.df) <- gsub("(subject)(.*)\\.y",
                             "interlocutor\\2",
                             colnames(ret.df))
    ret.df <- within(ret.df, {
        DID <- scale(abs(subject.before - interlocutor.before) -
                     abs(subject.after - interlocutor.before))[,1]
    })

    did.lm <- lm(
    DID ~ 1 + abs(subject.before) +
            abs(subject.before - interlocutor.before), data=ret.df)
    linear.lm <- lm(
    subject.after ~ 1 + subject.before + interlocutor.before +
            interlocutor.before:abs(subject.before) +
            interlocutor.before:abs(subject.before - interlocutor.before)
      , data=ret.df)

    ret <- list(populationsd=population.sd,
                noisesd=noise.sd,
                participants=participants,
                cor=with(ret.df, cor(subject.before, subject.after)),
                did=summary(did.lm)$coefficients,
                lm=summary(linear.lm)$coefficients)
    ret
}



genexperiment()$cor
```

```
## [1] 0.7745571
```

```
genexperiment()$noisesd
```

```
## [1] 0.5
```

```
genexperiment()$did
```

```
##                                              Estimate Std. Error   t value
## (Intercept)                                -0.8004886 0.16645229 -4.809117
## abs(subject.before)                         0.3154416 0.14374798  2.194407
## abs(subject.before - interlocutor.before)   0.4070275 0.09379715  4.339445
##                                                Pr(>|t|)
## (Intercept)                                5.548125e-06
## abs(subject.before)                        3.059321e-02
## abs(subject.before - interlocutor.before) 3.504452e-05
```

```
genexperiment()$lm
```

```
##                                                                  Estimate
## (Intercept)                                                   -0.05265044
## subject.before                                                 0.72764719
## interlocutor.before                                            0.17989967
## interlocutor.before:abs(subject.before)                       -0.12608644
## interlocutor.before:abs(subject.before - interlocutor.before) -0.03912699
##                                                               Std. Error
## (Intercept)                                                   0.06433097
## subject.before                                                0.05776123
## interlocutor.before                                           0.13433843
## interlocutor.before:abs(subject.before)                       0.07475312
## interlocutor.before:abs(subject.before - interlocutor.before) 0.05942515
##                                                                  t value
## (Intercept)                                                   -0.8184308
## subject.before                                                12.5975017
## interlocutor.before                                            1.3391526
## interlocutor.before:abs(subject.before)                       -1.6867047
## interlocutor.before:abs(subject.before - interlocutor.before) -0.6584248
##                                                                  Pr(>|t|)
## (Intercept)                                                   4.151595e-01
## subject.before                                                5.598308e-22
## interlocutor.before                                           1.837163e-01
## interlocutor.before:abs(subject.before)                       9.494147e-02
## interlocutor.before:abs(subject.before - interlocutor.before) 5.118578e-01
```

```
set.seed(123)
samples <- replicate(10**4, genexperiment())

(samples.cor.median <- samples["cor",]  %>% as.numeric %>% median %>% round(3))
```

```
## [1] 0.802
```

```
(samples.did.modedist <-
     samples["did",] %>%
     map(~.x["abs(subject.before)",]) %>%
     map(~I(.x["Estimate"] > 0 & .x["Pr(>|t|)"] < .05)) %>%
     as.numeric %>% mean
)
```

```
## [1] 0.2467
```

```
(samples.did.interlocutordist <-
     samples["did",] %>%
     map(~.x["abs(subject.before - interlocutor.before)",]) %>%
     map(~I(.x["Estimate"] > 0 & .x["Pr(>|t|)"] < .05)) %>%
     as.numeric %>% mean
)
```

```
## [1] 0.7081
```

```
(samples.lm.modedist <-
     samples["lm",] %>%
     map(~.x["interlocutor.before:abs(subject.before)",]) %>%
     map(~I(.x["Estimate"] > 0 & .x["Pr(>|t|)"] < .05)) %>%
     as.numeric %>% mean
)
```

```
## [1] 0.0242
```

```
(samples.lm.interlocutordist <-
     samples["lm",] %>%
     map(~.x["interlocutor.before:abs(subject.before - interlocutor.before)",]) %>%
     map(~I(.x["Estimate"] > 0 & .x["Pr(>|t|)"] < .05)) %>%
     as.numeric %>% mean
)
```

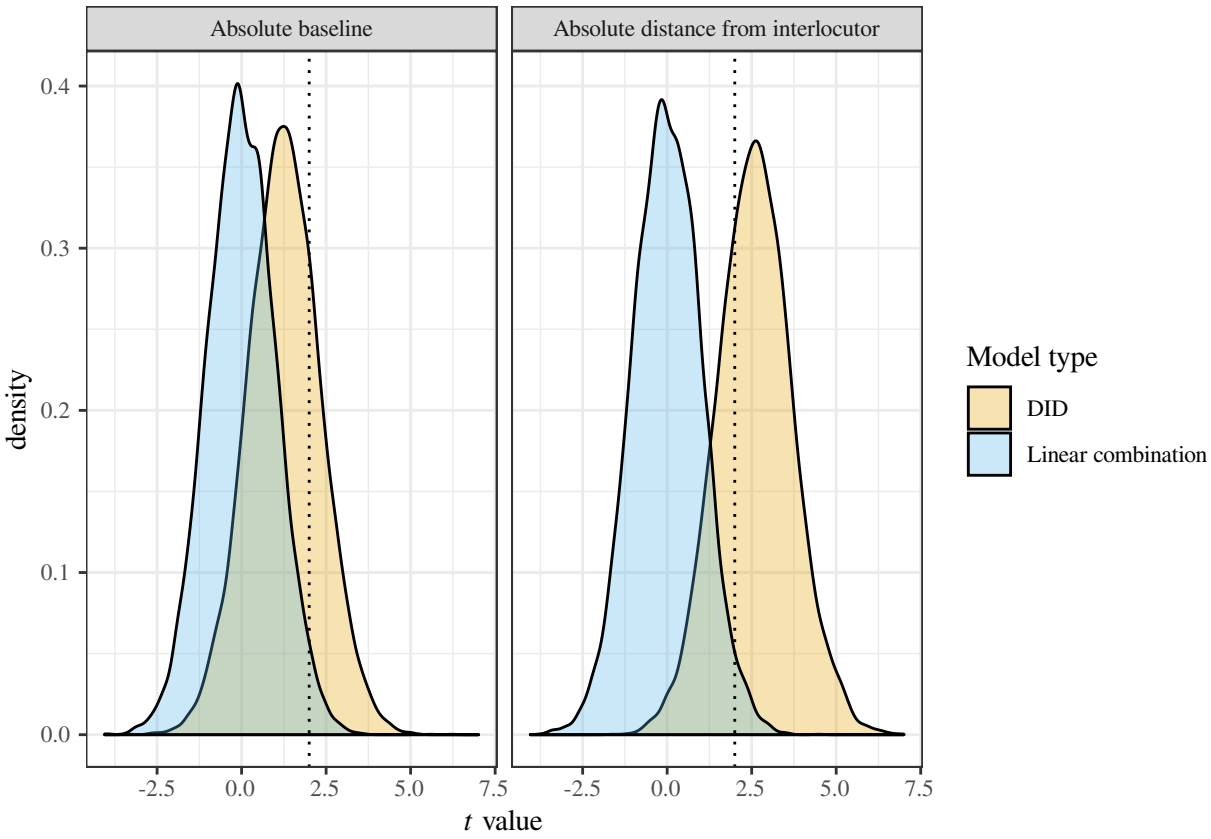
```
## [1] 0.0251
```

Of the ten thousand samples, the median correlation between each subject's *before* and *after* values was 0.802, indicating a level of consistency in productions that is typical of measures of natural speech. In DID models, the absolute distance of the subjects' distance from zero resulted in statistically significant ($p<0.05$) positive coefficients 24.7% of the time, which is greater than what would be expected by chance. The coefficient for the absolute distance between the speakers and their interlocutors was statistically significant and positive 70.8% of the time.

In the linear combination models, in contrast, the absolute distance between the subject and the population mean (defined as zero) resulted in statistically significant positive coefficients 2.4% of the time, and the coefficient for the absolute distance between the speakers and their interlocutors was statistically significant and positive 2.5% of the time. Both linear combination results are within what would be expected by chance.

The results clearly indicate that even in the complete absence of an underlying relationship between distance from the mode or the interlocutor and convergence, such effects superfluously emerge repeatedly, even with a sample of just 50 conversation pairs.

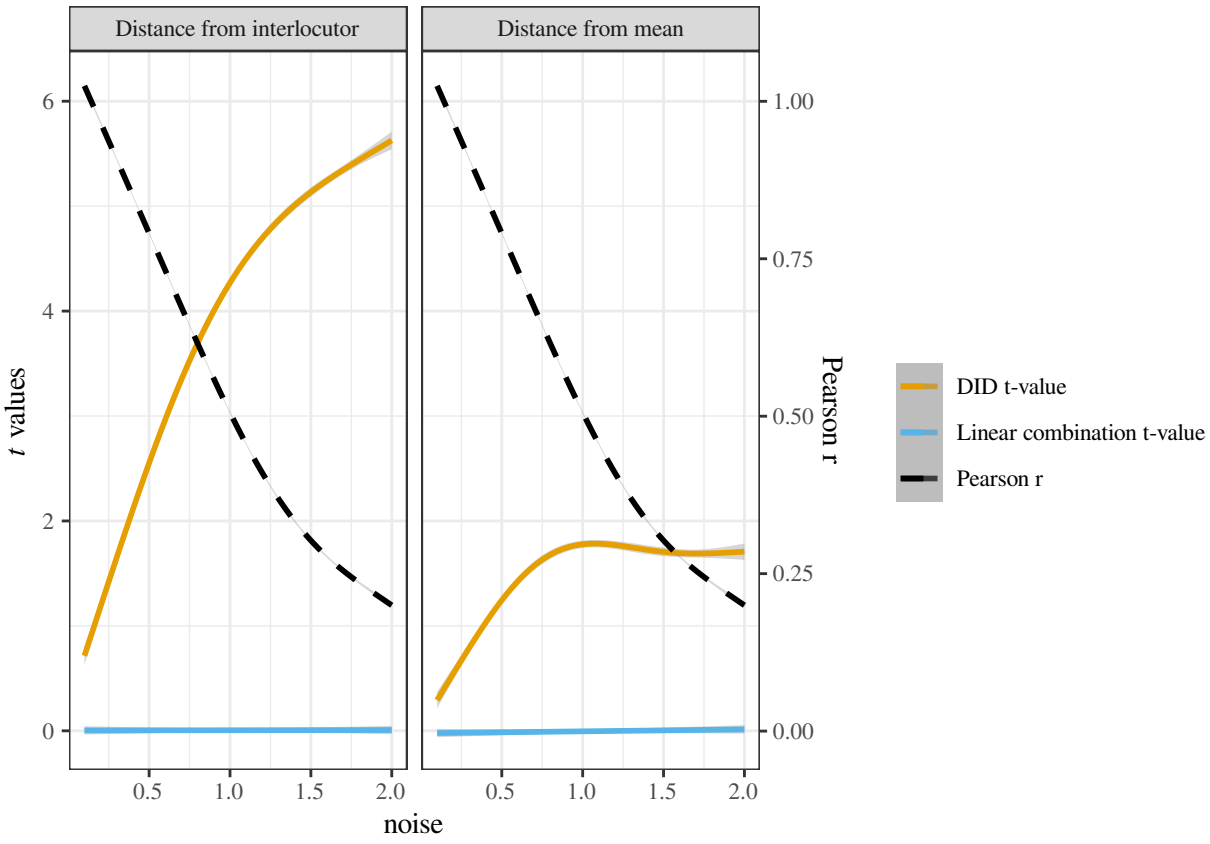
The following plot shows the density plots of *t*-values for the two coefficients in the 10,000 samples taken in Study 3, for both the DID models and in the linear combination models. The dotted line is at *2*, which is roughly the point at which the *t*-value would appear to be significant. It is evident that the distribution of *t*-values in the linear combination models is centered around zero, and though for a small fraction of the models a positive correlation is found, negative correlations are as likely to be found. In contrast, in the DID models the coefficients are systematically biased to be positive, making spurious positive values more likely to be found than chance alone would predict.



We argue that the spurious effects in the DID model are due to mishandling the noise that exists between measurements of an individual. These predict that spurious effects would be more likely in more noisy measurements than in less noisy ones. We therefore replicated the results presented above with varying amounts of noise, between 0.1 and 2 standard deviations (that parameter was fixed at 0.5 in the results discussed above). The following figure presentes the results. Indeed, less noise translates to lower *t*-values for both variables, and more noise translates to higher *t*-values for both variables. The values seem to peak at high degrees of noise, but that happens well after self-consistency drops below Pearson *r*=0.3, which is not typical of phonetic variables (all the variables in our dataset have higher consistency).

```
samples.morevar <- lapply(1:10**4, function(i){
    noise <- runif(1, 0.1, 2)
    genexperiment(noise.sd=noise)
})
```

The relationship between speaker self-consistency, as measured by noise SD, and the *t*-values of the DID and linear combination coefficients in Study 4. The x-axis is the degree of noise, in standard deviations (0.5 in the results reported above). The y-axis (left) is the *t*-value of the coefficient. The solid lines represent the trend of the *t*-values of the two variables, one in each panel. The Pearson *r* values associated with each noise value are provided by a black dashed line. All lines were smoothed by the gam function, with 4 knots to allow for greater smoothing. It is evident that the amount of noise has no influence on the predictors in linear combination models, but does affect DID coefficients.



References

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Godfrey, John J. and Holliman, Edward, 1997. Switchboard-1 release 2. Linguistic Data Consortium, Philadelphia.