# Landmark analyses

*Last updated: 2018-06-12*

## Contents



## Setup

### Load libraries

```
library(tidyverse)
library(broom)
library(knitr)
library(kableExtra)
library(lme4)
library(merTools)
```

### Load data

```
learners <- read_csv("./data/landmarks_stress_la_lb_ss.csv")
heritage <- read_csv("./data/landmarks_stress_la_hs_ss.csv")
wm_df_learners <- read_csv("./data/wm.csv")
wm_df_heritage <- read_csv("./data/wm_all.csv")
pstm_df <- read_csv("./data/dur_stress_background_info.csv")
```

# Late learners and native controls

## Do they predict above chance?

The data analyzed using a linear model with intercept removed. This makes each parameter estimate a two-sided test of independence ($H_a \neq 0$). In order to make this test one-sided ($H_a > 0$) we will take the t-values from the model and calculate the associated probability from the t-distribution for a one-sided test using the model degrees of freedom. In R this can be done with the following function:

```
pt(t_values, mod_df, lower = FALSE)
```

The p-values from the model will now be one-sided tests that the mean difference is greater than 0. Next, we need to put the target fixations (dependent variable) on the same scale. As is, chance = 50%, thus everything will be significant because target fixations are on average at 50% as a minimum. To get around this issue we can subtract 0.5 from each participants mean target fixation at each landmark and test to see if that value is greater than 0. For example, if at the target word onset you are fixating on the target 50% of the time (i.e., at chance), then when we subtract 0.5 from 0.5, we get 0. 0 is not greater than 0 so it wouldn't be significant. We will conduct this test for each group, at each landmark. Then we will add the 0.5 back on to the model estimates and the confidence intervals for plotting purposes.

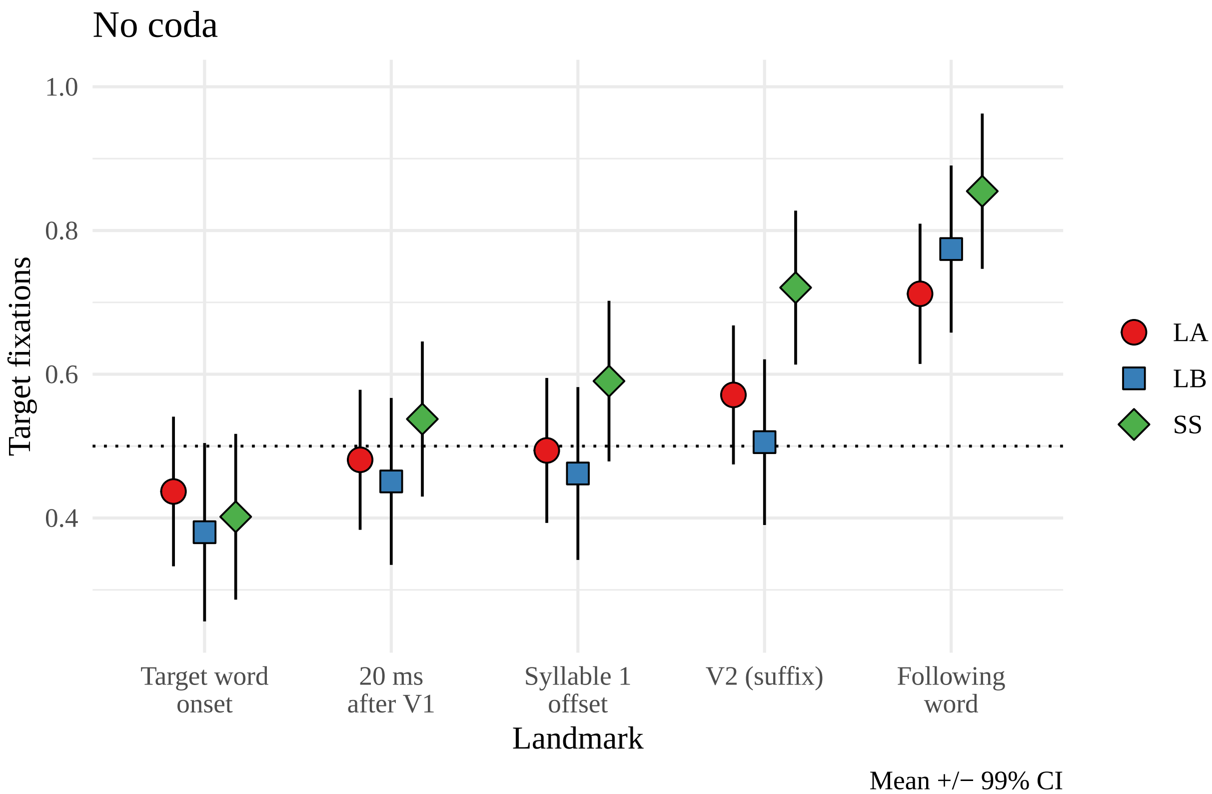
```
# Model degrees of freedom
learner_mod_df <- 65

learner_mods <- learners %>%
  filter(., !(landmark %in% c('start_sentence', 'word2_c1v1',
                              'end_sentence'))) %>%
  group_by(., participant, group, coda, landmark) %>%
  summarize(., target_fix = mean(targetProp)) %>%
  ungroup(.) %>%
  group_by(., landmark, coda) %>%
  do(tidy(lm(I(target_fix - 0.5) ~ -1 + group, data = .), conf.int = T,
        conf.level = 0.99)) %>%
  mutate(., p_adj = pt(statistic, learner_mod_df, lower = F),
            p_adj = formatC(p_adj, digits = 7, format = "f"),
            sig = if_else(p_adj < 0.05, true = "*", false = " ")) %>%
  ungroup(.) %>%
  mutate(., landmark = fct_relevel(landmark,
                                   'word3_c1v1', 'word3_20msafterv1',
                                   'word3_c2', 'word3_c3', 'word3_suffix')) %>%
  arrange(., coda, landmark)
```

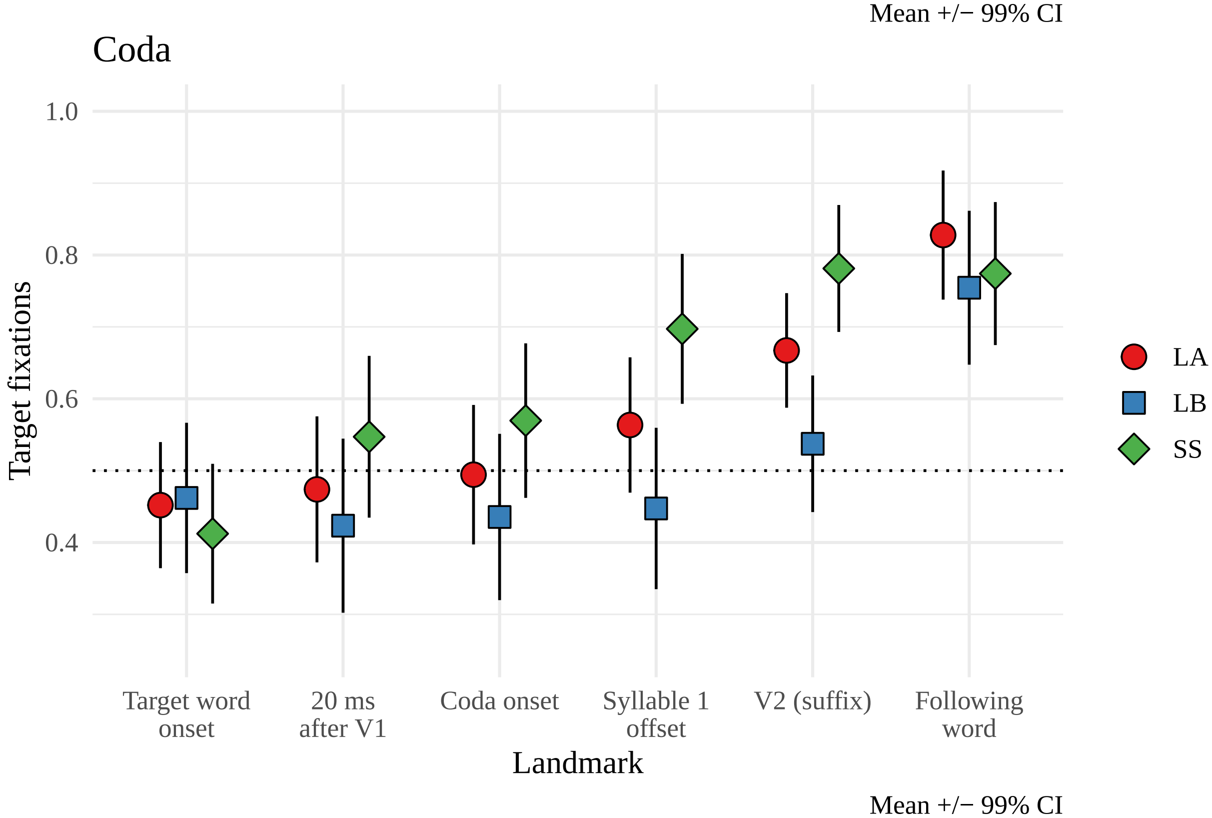
Table 1: Model output

| landmark | term | estimate | std.error | statistic | conf.low | conf.high | p_adj | sig |
|---|---|---|---|---|---|---|---|---|
| **No-coda targets** | | | | | | | | |
| | la | -0.06 | 0.04 | -1.61 | -0.17 | 0.04 | 0.9438315 | |
| word3_c1v1 | lb | -0.12 | 0.05 | -2.56 | -0.24 | 0.00 | 0.9936311 | |
| | ss | -0.10 | 0.04 | -2.26 | -0.21 | 0.02 | 0.9864650 | |
| | la | -0.02 | 0.04 | -0.52 | -0.12 | 0.08 | 0.6971842 | |
| word3_20msafterv1 | lb | -0.05 | 0.04 | -1.12 | -0.17 | 0.07 | 0.8671037 | |
| | ss | 0.04 | 0.04 | 0.93 | -0.07 | 0.15 | 0.1787654 | |
| | la | -0.01 | 0.04 | -0.16 | -0.11 | 0.09 | 0.5624449 | |
| word3_c2 | lb | -0.04 | 0.05 | -0.84 | -0.16 | 0.08 | 0.7982615 | |
| | ss | 0.09 | 0.04 | 2.15 | -0.02 | 0.20 | 0.0176951 | * |
| | la | 0.07 | 0.04 | 1.96 | -0.03 | 0.17 | 0.0274149 | * |
| word3_suffix | lb | 0.01 | 0.04 | 0.13 | -0.11 | 0.12 | 0.4496902 | |
| | ss | 0.22 | 0.04 | 5.46 | 0.11 | 0.33 | 0.0000004 | * |
| | la | 0.21 | 0.04 | 5.76 | 0.11 | 0.31 | 0.0000001 | * |
| word4_c1v1 | lb | 0.27 | 0.04 | 6.26 | 0.16 | 0.39 | 0.0000000 | * |
| | ss | 0.35 | 0.04 | 8.71 | 0.25 | 0.46 | 0.0000000 | * |
| **Coda targets** | | | | | | | | |
| | la | -0.05 | 0.03 | -1.45 | -0.14 | 0.04 | 0.9242526 | |
| word3_c1v1 | lb | -0.04 | 0.04 | -0.96 | -0.14 | 0.07 | 0.8308077 | |
| | ss | -0.09 | 0.04 | -2.40 | -0.18 | 0.01 | 0.9902493 | |
| | la | -0.03 | 0.04 | -0.68 | -0.13 | 0.08 | 0.7508646 | |
| word3_20msafterv1 | lb | -0.08 | 0.05 | -1.68 | -0.20 | 0.04 | 0.9510029 | |
| | ss | 0.05 | 0.04 | 1.11 | -0.07 | 0.16 | 0.1353062 | |
| | la | -0.01 | 0.04 | -0.15 | -0.10 | 0.09 | 0.5610294 | |
| word3_c2 | lb | -0.06 | 0.04 | -1.48 | -0.18 | 0.05 | 0.9281215 | |
| | ss | 0.07 | 0.04 | 1.72 | -0.04 | 0.18 | 0.0452329 | * |
| | la | 0.06 | 0.04 | 1.79 | -0.03 | 0.16 | 0.0390471 | * |
| word3_c3 | lb | -0.05 | 0.04 | -1.24 | -0.16 | 0.06 | 0.8910685 | |
| | ss | 0.20 | 0.04 | 5.02 | 0.09 | 0.30 | 0.0000022 | * |
| | la | 0.17 | 0.03 | 5.57 | 0.09 | 0.25 | 0.0000003 | * |
| word3_suffix | lb | 0.04 | 0.04 | 1.04 | -0.06 | 0.13 | 0.1502988 | |
| | ss | 0.28 | 0.03 | 8.45 | 0.19 | 0.37 | 0.0000000 | * |
| | la | 0.33 | 0.03 | 9.68 | 0.24 | 0.42 | 0.0000000 | * |
| word4_c1v1 | lb | 0.25 | 0.04 | 6.31 | 0.15 | 0.36 | 0.0000000 | * |
| | ss | 0.27 | 0.04 | 7.31 | 0.17 | 0.37 | 0.0000000 | * |

**Note:**
Parameter estimates show average target fixation minus 0.5.
P-values represent one-sided t-tests.
**word3_c2** represents the 2nd syllable onset for no-coda targets and the coda onset for coda targets.

**Landmark plots**



## Is working memory a factor?

```
## Joining, by = "participant"
```

First check for homogeneity of variance.

```r
wm_df %>%
  separate(., participant, into = c('group', 'trash'), sep = 2, remove = F) %>%
  bartlett.test(wm ~ group, data = .)
```

```
##
##  Bartlett test of homogeneity of variances
##
## data:  wm by group
## Bartlett's K-squared = 2.2443, df = 2, p-value = 0.3256
```

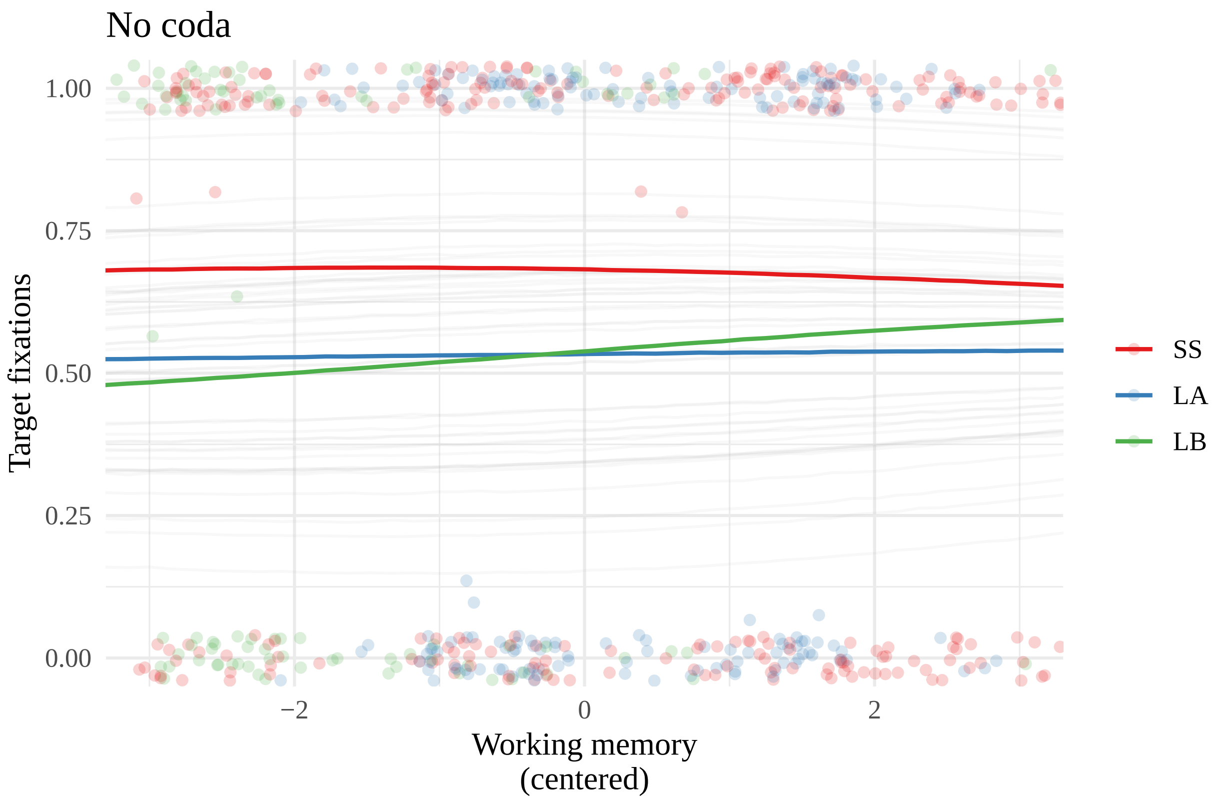
Looks good.

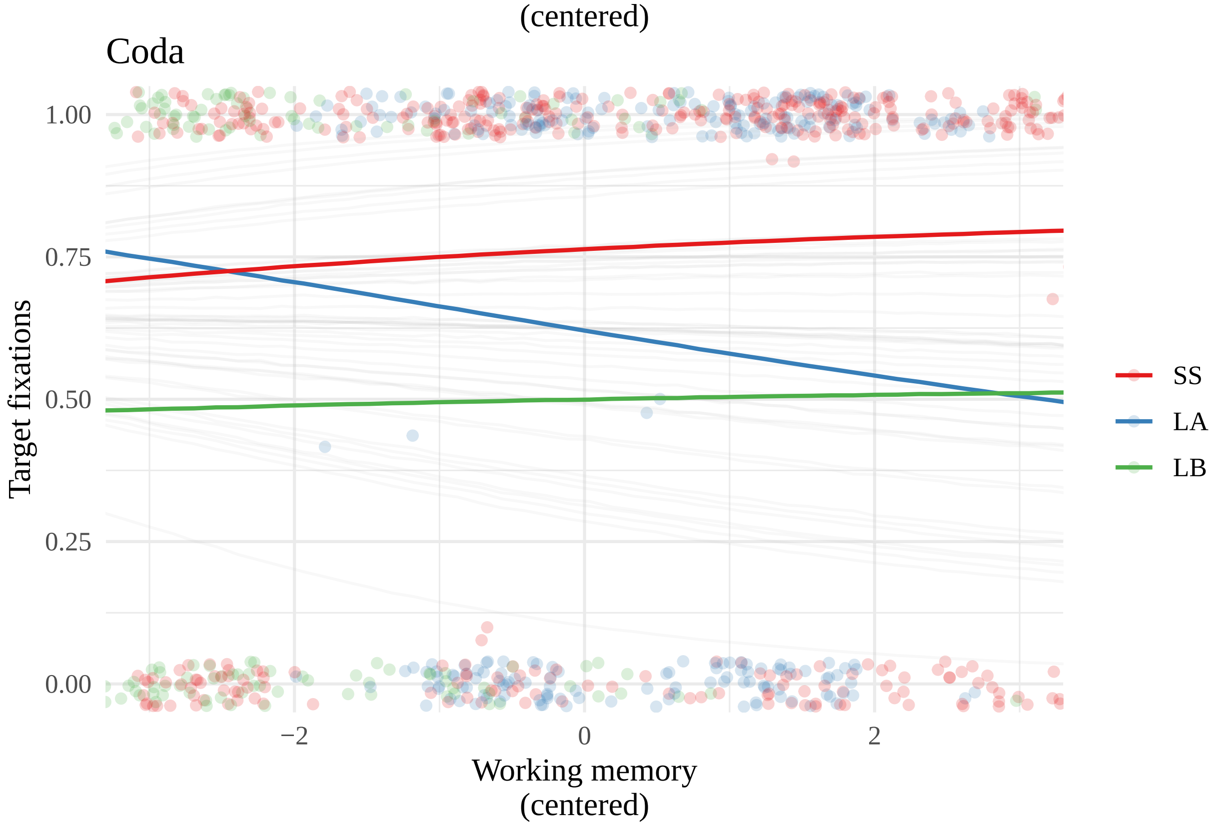
```
## Generalized linear mixed model fit by maximum likelihood (Laplace
##   Approximation) [glmerMod]
##  Family: binomial  ( logit )
## Formula: cbind(targetCount, distractorCount) ~ (1 + wm_c | participant) +
##     (1 + wm_c | target) + group + group:wm_c - 1
##    Data: learners_no_coda
## Control: glmerControl(optimizer = "bobyqa")
##
##      AIC      BIC   logLik deviance df.resid
##   6769.9   6823.8  -3373.0   6745.9      644
##
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -10.8543  -2.2048   0.4665   2.1664   6.5376
##
## Random effects:
##  Groups      Name        Variance  Std.Dev. Corr
##  participant (Intercept) 2.0739192 1.44011
##              wm_c        0.0008718 0.02953  -1.00
##  target      (Intercept) 0.4367887 0.66090
##              wm_c        0.0978779 0.31285  0.19
## Number of obs: 656, groups:  participant, 50; target, 13
##
## Fixed effects:
##              Estimate Std. Error z value Pr(>|z|)
## groupss       1.120239   0.369304   3.033  0.00242 **
## groupla       0.276744   0.411122   0.673  0.50086
## grouplb       0.303418   0.636582   0.477  0.63362
## groupss:wm_c -0.042576   0.113818  -0.374  0.70835
## groupla:wm_c  0.002654   0.202578   0.013  0.98955
## grouplb:wm_c  0.080725   0.210642   0.383  0.70155
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             gropss groupl groplb grps:_ grpl:w_
## groupla      0.225
## grouplb      0.115  0.127
```

```
## gropss:wm_c -0.056  0.060  0.212
## groupl:wm_c  0.044  0.022  0.004  0.303
## groplb:wm_c  0.001  0.037  0.618  0.541  0.144
```

```
## Generalized linear mixed model fit by maximum likelihood (Laplace
##   Approximation) [glmerMod]
##  Family: binomial  ( logit )
## Formula: cbind(targetCount, distractorCount) ~ (1 + wm_c | participant) +
##     (1 + wm_c | target) + group + group:wm_c - 1
##    Data: learners_coda
## Control: glmerControl(optimizer = "bobyqa")
##
##      AIC      BIC   logLik deviance df.resid
##   9438.7   9496.7  -4707.3   9414.7      920
##
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -11.6794  -2.3284   0.8192   1.9981   6.4440
##
## Random effects:
##  Groups      Name        Variance Std.Dev. Corr
##  participant (Intercept) 1.75792  1.3259
##              wm_c        0.03512  0.1874   1.00
##  target      (Intercept) 0.46877  0.6847
##              wm_c        0.02595  0.1611   0.53
## Number of obs: 932, groups:  participant, 50; target, 19
##
## Fixed effects:
##             Estimate Std. Error z value Pr(>|z|)
## groupss       1.47328    0.33361   4.416    1e-05 ***
## groupla       0.67667    0.38199   1.771   0.0765 .
## grouplb       0.06149    0.44972   0.137   0.8912
## groupss:wm_c  0.15546    0.07508   2.070   0.0384 *
## groupla:wm_c -0.17746    0.07178  -2.472   0.0134 *
## grouplb:wm_c  0.04160    0.08171   0.509   0.6107
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             gropss groupl groplb grps:_ grpl:w_
## groupla     0.199
## grouplb     0.174  0.159
## gropss:wm_c 0.584  0.095  0.067
## groupl:wm_c 0.123  0.672  0.030  0.261
## groplb:wm_c 0.116  0.114  0.837  0.232  0.114
```

### Working memory plots



### Phonological short-term memory

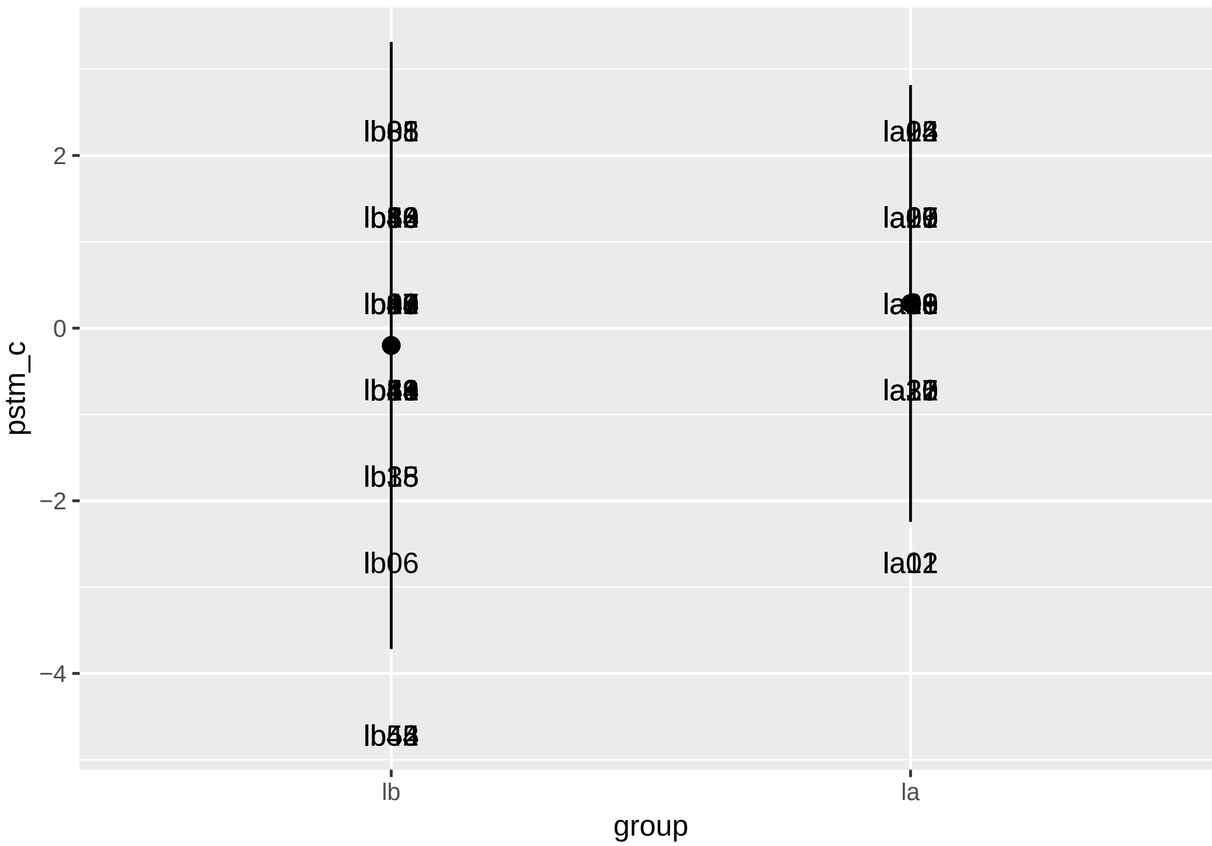
```
## Warning: Column `group` joining factors with different levels, coercing to
## character vector
```

First check for homogeneity of variance.

```
pstm_learners_clean %>%
  bartlett.test(pstm_c ~ group, data = .)
```

```
##
##  Bartlett test of homogeneity of variances
##
## data:  pstm_c by group
## Bartlett's K-squared = 2.9727, df = 1, p-value = 0.08468
```

```
pstm_learners_clean %>%
  na.omit(.) %>%
  ggplot(., aes(x = group, y = pstm_c, label = participant)) +
    geom_text() +
    stat_summary(fun.data = mean_sdl, geom = 'pointrange')
```




Groups look ok. Might have to take some out.

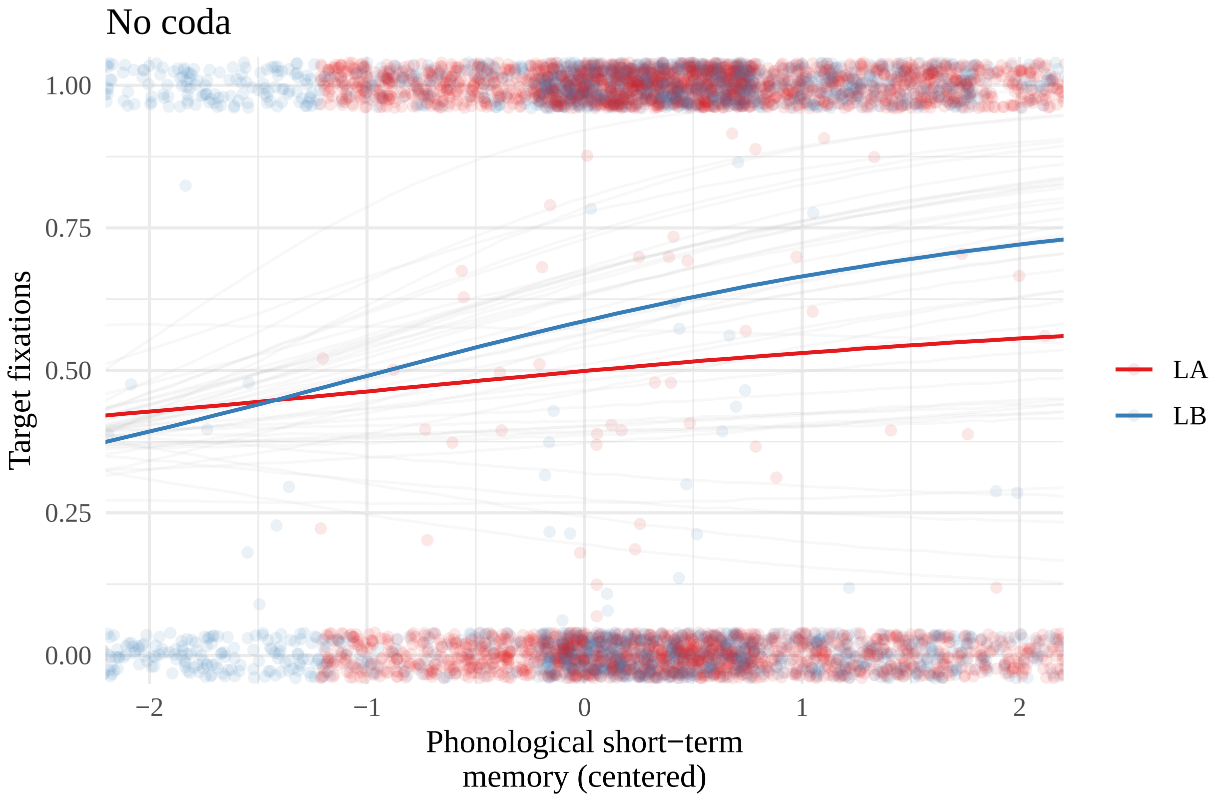
```
## Generalized linear mixed model fit by maximum likelihood (Laplace
##   Approximation) [glmerMod]
##  Family: binomial  ( logit )
## Formula:
## cbind(targetCount, distractorCount) ~ (1 + pstm_c | participant) +
```

```
##     (1 + pstm_c | target) + group + group:pstm_c - 1
##    Data: lb_la_pstm_no_coda
## Control: glmerControl(optimizer = "bobyqa")
##
##      AIC      BIC   logLik deviance df.resid
##   2868.4   2904.1  -1424.2   2848.4      252
##
## Scaled residuals:
##    Min     1Q Median     3Q    Max
## -8.453 -2.276  0.000  2.269  5.607
##
## Random effects:
##  Groups      Name        Variance Std.Dev. Corr
##  participant (Intercept) 0.8337   0.9131
##              pstm_c      0.1759   0.4194   0.72
##  target      (Intercept) 0.2559   0.5059
##              pstm_c      0.2587   0.5087   -0.55
## Number of obs: 262, groups:  participant, 42; target, 13
##
## Fixed effects:
##                Estimate Std. Error z value Pr(>|z|)
## groupla         0.01772    0.25434   0.070    0.944
## grouplb         0.41125    0.30706   1.339    0.180
## groupla:pstm_c  0.15493    0.23447   0.661    0.509
## grouplb:pstm_c  0.42264    0.31776   1.330    0.184
##
## Correlation of Fixed Effects:
##             groupl groplb grpl:p_
## grouplb      0.198
## grpl:pstm_c -0.110 -0.131
## grplb:pstm_ -0.194  0.137  0.205
```

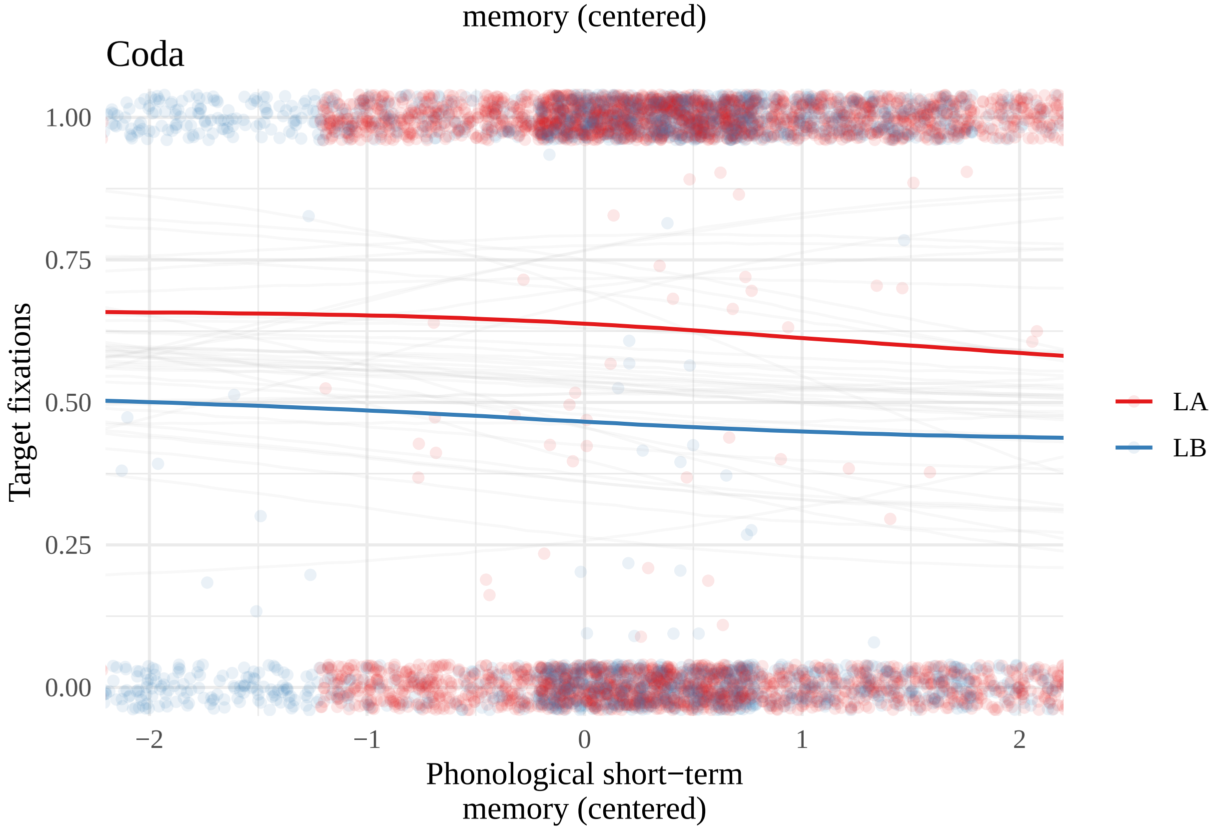
```
## Generalized linear mixed model fit by maximum likelihood (Laplace
##   Approximation) [glmerMod]
##  Family: binomial  ( logit )
## Formula:
## cbind(targetCount, distractorCount) ~ (1 + pstm_c | participant) +
##     (1 + pstm_c | target) + group + group:pstm_c - 1
##    Data: lb_la_pstm_coda
## Control: glmerControl(optimizer = "bobyqa")
##
##      AIC      BIC   logLik deviance df.resid
##   4179.5   4218.9  -2079.7   4159.5      372
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -8.5744 -2.3470  0.6181  2.3402  7.3955
##
## Random effects:
##  Groups      Name        Variance Std.Dev. Corr
##  participant (Intercept) 0.6418   0.8011
##              pstm_c      0.2550   0.5050   -0.04
##  target      (Intercept) 0.4242   0.6513
##              pstm_c      0.4616   0.6794   -0.41
```

```
## Number of obs: 382, groups:  participant, 42; target, 19
##
## Fixed effects:
##                Estimate Std. Error z value Pr(>|z|)
## groupla         0.64642    0.25591   2.526   0.0115 *
## grouplb        -0.15045    0.28920  -0.520   0.6029
## groupla:pstm_c -0.08915    0.26871  -0.332   0.7401
## grouplb:pstm_c -0.06808    0.33013  -0.206   0.8366
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             groupl groplb grpl:p_
## grouplb      0.305
## grpl:pstm_c -0.355 -0.132
## grplb:pstm_ -0.098 -0.306  0.270
```

**PSTM plots**



No coda
Target fixations
1.00
0.75
0.50
0.25
0.00
−2
−1
0
1
2
Phonological short−term memory (centered)
LA
LB

Coda
Target fixations
1.00
0.75
0.50
0.25
0.00
−2
−1
0
1
2
Phonological short−term memory (centered)
LA
LB

## Learners summary

**Without coda**:

- The native speakers fixate on targets above chance at the offset of the first syllable.
- Advanced learners fixate on targets as well by the time they have heard the target suffix.
- All three groups fixate on targets above chance by the following word.
- No effect of working memory for any groups.
- No effect of phonological short-term memory (very high variability).

**With coda**:

- Native speakers fixate on targets above chance at the onset of the coda.
- Advanced learners fixate on targets above chance by the offset of the target syllable.
- All three groups fixate on targets above chance by the following word.
- There is an effect of working memory for natives. Increased WM equals increased target fixations at the offset of the target syllable.
- WM is negatively correlated with target fixations for the advanced learners (I can't think of an explanation for this).
- No effect of phonological short-term memory.

## Late vs. early bilinguals and native (monolingual) controls

### Do they predict above chance?

Same analysis as previously described.

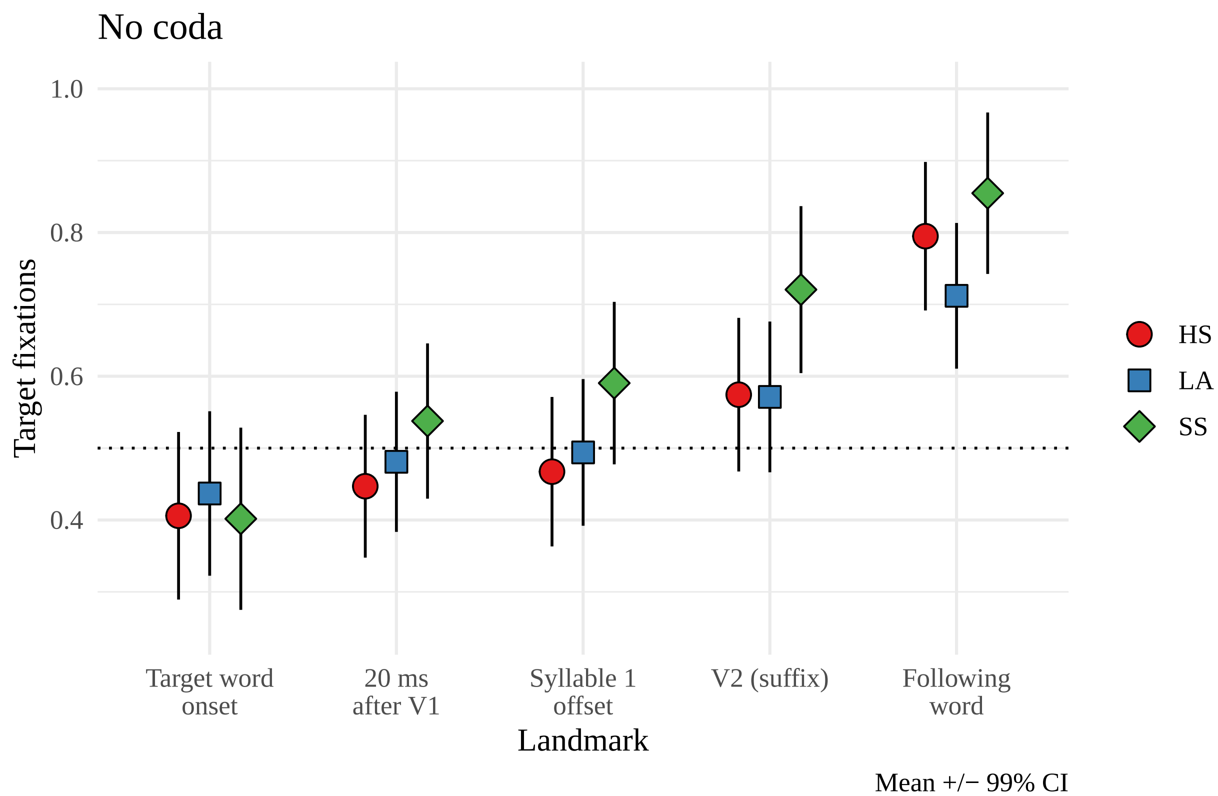
```
# Model degrees of freedom
heritage_mod_df <- 72

heritage_mods <- heritage %>%
  filter(., !(landmark %in% c('start_sentence', 'word2_c1v1',
                              'end_sentence'))) %>%
  group_by(., participant, group, coda, landmark) %>%
  summarize(., target_fix = mean(targetProp)) %>%
  ungroup(.) %>%
  group_by(., landmark, coda) %>%
  do(tidy(lm(I(target_fix - 0.5) ~ -1 + group, data = .), conf.int = T,
        conf.level = 0.99)) %>%
  mutate(., p_adj = pt(statistic, heritage_mod_df, lower = F),
            p_adj = formatC(p_adj, digits = 7, format = "f"),
            sig = if_else(p_adj < 0.05, true = "*", false = " ")) %>%
  ungroup(.) %>%
  mutate(., landmark = fct_relevel(landmark,
                                   'word3_c1v1', 'word3_20msafterv1',
                                   'word3_c2', 'word3_c3', 'word3_suffix')) %>%
  arrange(., coda, landmark)
```

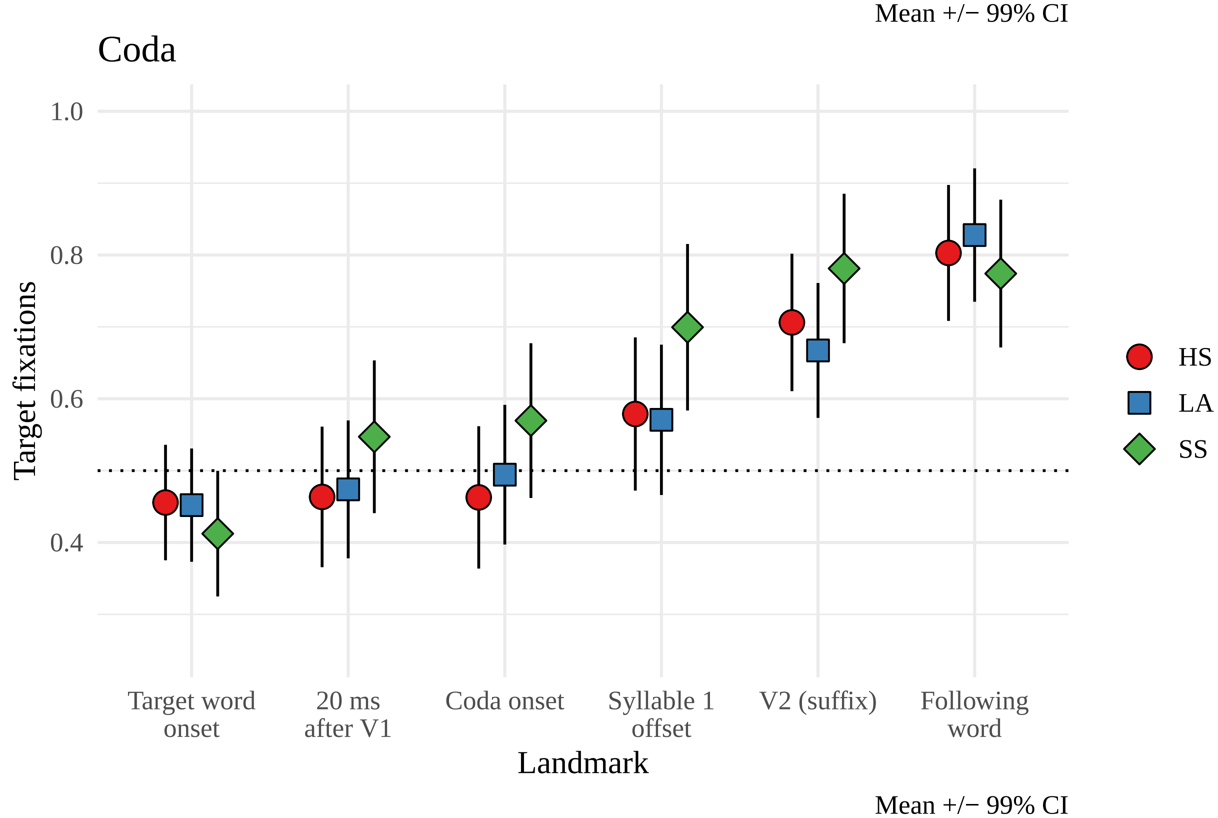
Table 2: Model output

| landmark | term | estimate | std.error | statistic | conf.low | conf.high | p_adj | sig |
|---|---|---|---|---|---|---|---|---|
| **No-coda targets** | | | | | | | | |
| | hs | -0.09 | 0.04 | -2.14 | -0.21 | 0.02 | 0.9819752 | |
| word3_c1v1 | la | -0.06 | 0.04 | -1.46 | -0.18 | 0.05 | 0.9257015 | |
| | ss | -0.10 | 0.05 | -2.05 | -0.23 | 0.03 | 0.9780822 | |
| | hs | -0.05 | 0.04 | -1.41 | -0.15 | 0.05 | 0.9188499 | |
| word3_20msafterv1 | la | -0.02 | 0.04 | -0.52 | -0.12 | 0.08 | 0.6965797 | |
| | ss | 0.04 | 0.04 | 0.92 | -0.07 | 0.15 | 0.1795164 | |
| | hs | -0.03 | 0.04 | -0.83 | -0.14 | 0.07 | 0.7965654 | |
| word3_c2 | la | -0.01 | 0.04 | -0.16 | -0.11 | 0.10 | 0.5615723 | |
| | ss | 0.09 | 0.04 | 2.12 | -0.02 | 0.20 | 0.0188317 | * |
| | hs | 0.07 | 0.04 | 1.84 | -0.03 | 0.18 | 0.0348610 | * |
| word3_suffix | la | 0.07 | 0.04 | 1.80 | -0.03 | 0.18 | 0.0381995 | * |
| | ss | 0.22 | 0.04 | 5.02 | 0.10 | 0.34 | 0.0000018 | * |
| | hs | 0.29 | 0.04 | 7.55 | 0.19 | 0.40 | 0.0000000 | * |
| word4_c1v1 | la | 0.21 | 0.04 | 5.53 | 0.11 | 0.31 | 0.0000002 | * |
| | ss | 0.35 | 0.04 | 8.36 | 0.24 | 0.47 | 0.0000000 | * |
| **Coda targets** | | | | | | | | |
| | hs | -0.04 | 0.03 | -1.46 | -0.12 | 0.04 | 0.9259936 | |
| word3_c1v1 | la | -0.05 | 0.03 | -1.61 | -0.13 | 0.03 | 0.9441519 | |
| | ss | -0.09 | 0.03 | -2.66 | -0.18 | 0.00 | 0.9951562 | |
| | hs | -0.04 | 0.04 | -0.99 | -0.13 | 0.06 | 0.8372537 | |
| word3_20msafterv1 | la | -0.03 | 0.04 | -0.72 | -0.12 | 0.07 | 0.7627565 | |
| | ss | 0.05 | 0.04 | 1.17 | -0.06 | 0.15 | 0.1223290 | |
| | hs | -0.04 | 0.04 | -0.99 | -0.14 | 0.06 | 0.8383116 | |
| word3_c2 | la | -0.01 | 0.04 | -0.15 | -0.10 | 0.09 | 0.5607754 | |
| | ss | 0.07 | 0.04 | 1.71 | -0.04 | 0.18 | 0.0457271 | * |
| | hs | 0.08 | 0.04 | 1.96 | -0.03 | 0.19 | 0.0271484 | * |
| word3_c3 | la | 0.07 | 0.04 | 1.79 | -0.03 | 0.18 | 0.0390024 | * |
| | ss | 0.20 | 0.04 | 4.56 | 0.08 | 0.32 | 0.0000104 | * |
| | hs | 0.21 | 0.04 | 5.71 | 0.11 | 0.30 | 0.0000001 | * |
| word3_suffix | la | 0.17 | 0.04 | 4.72 | 0.07 | 0.26 | 0.0000057 | * |
| | ss | 0.28 | 0.04 | 7.16 | 0.18 | 0.39 | 0.0000000 | * |
| | hs | 0.30 | 0.04 | 8.48 | 0.21 | 0.40 | 0.0000000 | * |
| word4_c1v1 | la | 0.33 | 0.04 | 9.35 | 0.23 | 0.42 | 0.0000000 | * |
| | ss | 0.27 | 0.04 | 7.06 | 0.17 | 0.38 | 0.0000000 | * |

**Note:**
Parameter estimates show average target fixation minus 0.5.
P-values represent one-sided t-tests.
**word3_c2** represents the 2nd syllable onset for no-coda targets and the coda onset for coda targets.

**Landmark plots**



## Is working memory a factor?

```
## Joining, by = c("participant", "group")
```

```
## Warning: Column `group` joining character vector and factor, coercing into
## character vector
```

Check for homogeneity of variance.

```
wm_df_heritage %>%
  filter(., group %in% c("LA", "HS", "S")) %>%
  bartlett.test(WM ~ group, data = .)
```

```
##
##  Bartlett test of homogeneity of variances
##
## data:  WM by group
## Bartlett's K-squared = 1.9167, df = 2, p-value = 0.3835
```

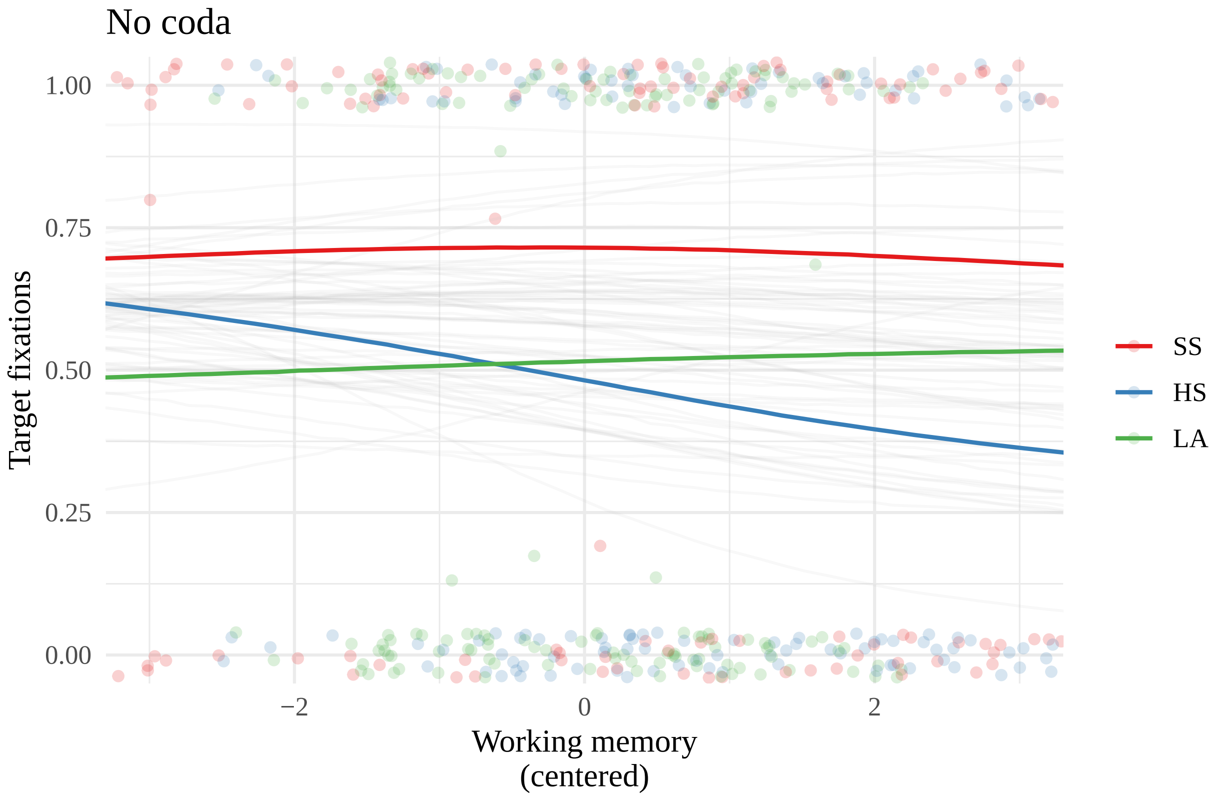
Looks good.

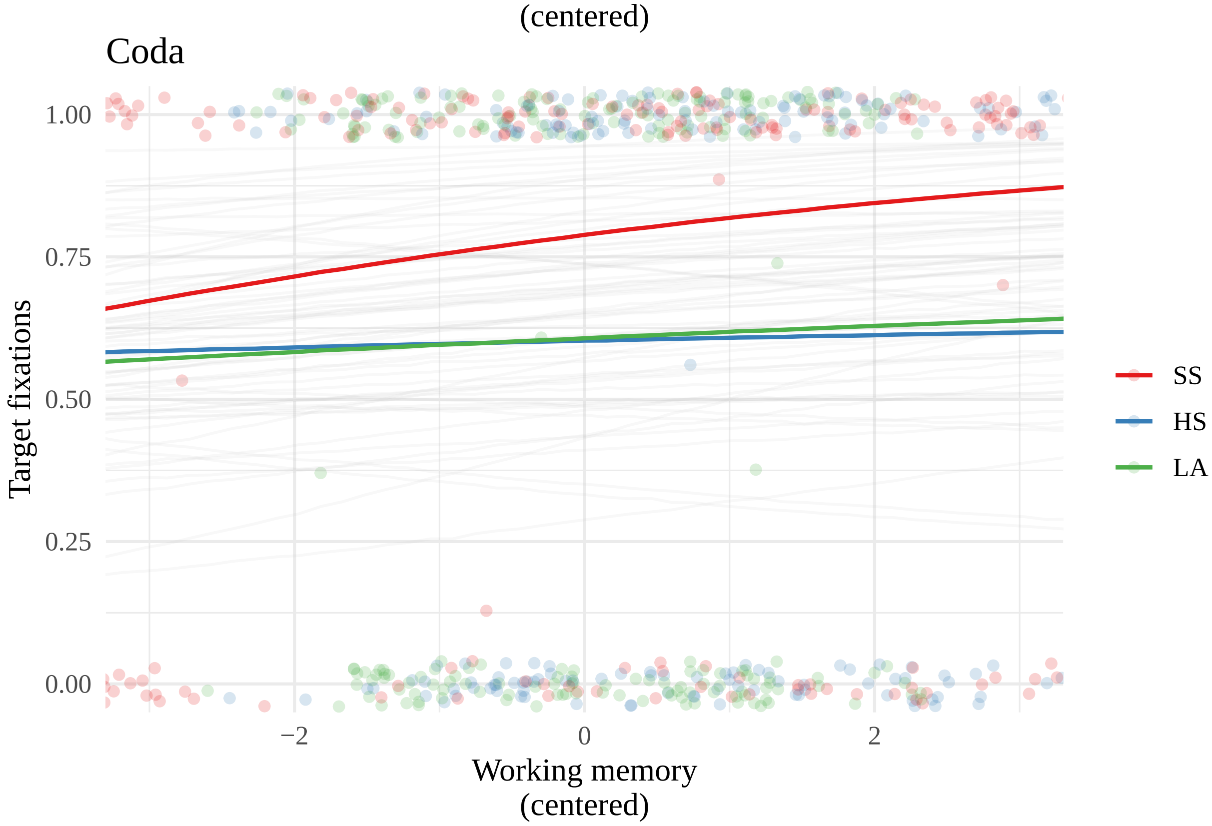
```
## Generalized linear mixed model fit by maximum likelihood (Laplace
##   Approximation) [glmerMod]
##  Family: binomial  ( logit )
## Formula: cbind(targetCount, distractorCount) ~ (1 + wm_c | participant) +
##     (1 + wm_c | target) + group + group:wm_c - 1
##    Data: heritage_no_coda
## Control: glmerControl(optimizer = "bobyqa")
##
##      AIC      BIC   logLik deviance df.resid
##   4464.7   4513.4  -2220.3   4440.7      418
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -11.818  -2.084   0.000   2.157   8.608
##
## Random effects:
##  Groups      Name        Variance Std.Dev. Corr
##  participant (Intercept) 0.78649  0.8868
##              wm_c        0.09341  0.3056   0.28
##  target      (Intercept) 0.56189  0.7496
##              wm_c        0.08844  0.2974   -0.19
## Number of obs: 430, groups:  participant, 67; target, 13
##
## Fixed effects:
##                Estimate Std. Error z value Pr(>|z|)
## groupss       1.1378486  0.3295983   3.452 0.000556 ***
## groupphs     -0.0621776  0.3202746  -0.194 0.846067
## groupla       0.1093136  0.2888496   0.378 0.705100
## groupss:wm_c  0.0005255  0.1716472   0.003 0.997557
## groupphs:wm_c -0.2246620  0.1707950  -1.315 0.188379
## groupla:wm_c  0.0390305  0.1783353   0.219 0.826759
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             gropss grophs groupl grps:_ grph:_
```

```
## groupls      0.412
## groupla      0.454  0.477
## gropss:wm_c  0.068 -0.076 -0.076
## grophs:wm_c -0.055 -0.144 -0.084  0.274
## groupl:wm_c -0.045 -0.019 -0.006  0.213  0.176
```

```
## Generalized linear mixed model fit by maximum likelihood (Laplace
##   Approximation) [glmerMod]
##  Family: binomial  ( logit )
## Formula: cbind(targetCount, distractorCount) ~ (1 + wm_c | participant) +
##     (1 + wm_c | target) + group + group:wm_c - 1
##    Data: heritage_coda
## Control: glmerControl(optimizer = "bobyqa")
##
##      AIC      BIC   logLik deviance df.resid
##   6320.1   6373.3  -3148.1   6296.1      611
##
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -14.4393  -2.3485   0.9542   1.9974   5.9255
##
## Random effects:
##  Groups      Name        Variance Std.Dev. Corr
##  participant (Intercept) 1.02946  1.0146
##              wm_c        0.06093  0.2468   0.20
##  target      (Intercept) 0.24227  0.4922
##              wm_c        0.05640  0.2375   -0.35
## Number of obs: 623, groups:  participant, 67; target, 19
##
## Fixed effects:
##              Estimate Std. Error z value Pr(>|z|)
## groupss       1.53689    0.30076   5.110 3.22e-07 ***
## grouphs       0.50761    0.27925   1.818   0.0691 .
## groupla       0.52173    0.25059   2.082   0.0373 *
## groupss:wm_c  0.23605    0.18356   1.286   0.1984
## grouphs:wm_c  0.04100    0.16652   0.246   0.8055
## groupla:wm_c  0.06045    0.18699   0.323   0.7465
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             gropss grophs groupl grps:_ grph:_
## grouphs      0.105
## groupla      0.129  0.229
## gropss:wm_c  0.039  0.002 -0.013
## grophs:wm_c  0.023 -0.216 -0.126 -0.108
## groupl:wm_c  0.006 -0.117 -0.092 -0.161  0.333
```

**Working memory plots**



### Phonological short-term memory

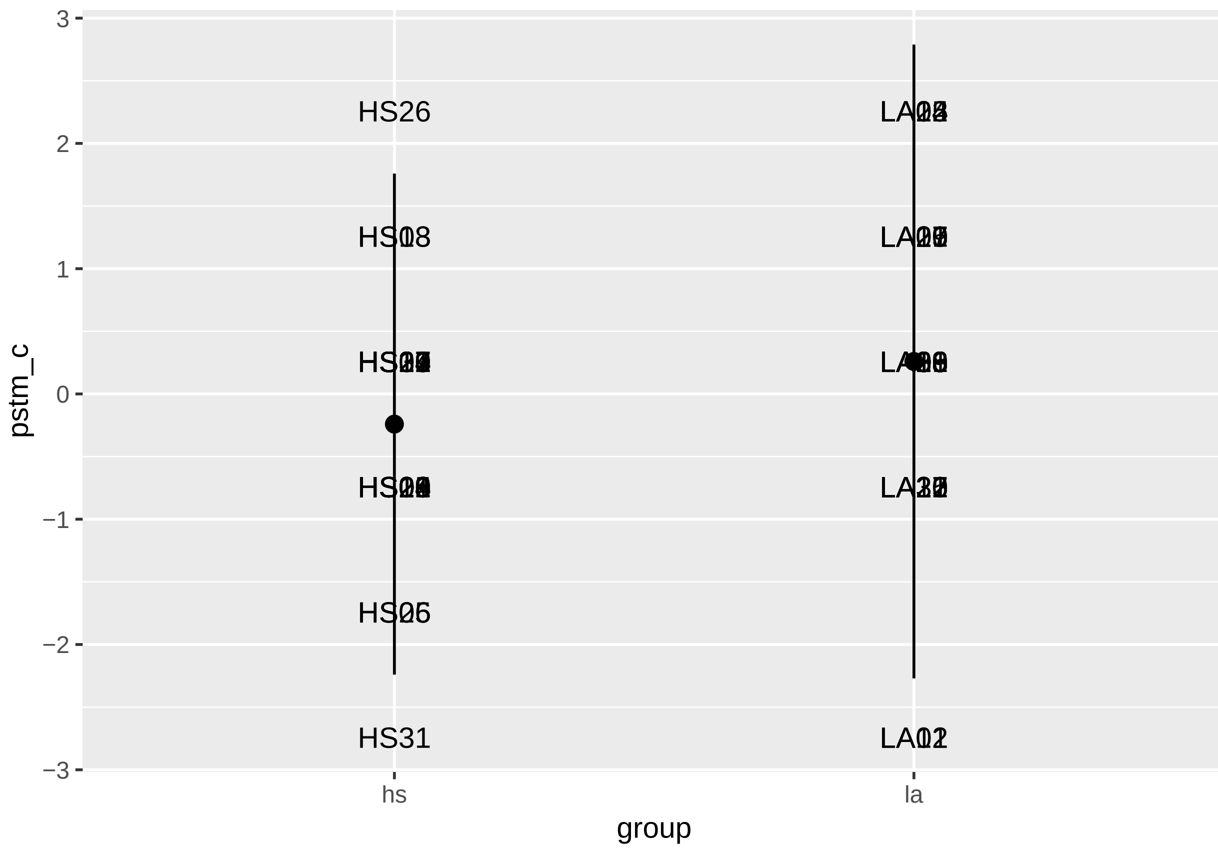
```
## Joining, by = c("participant", "group")
```

First check for homogeneity of variance.

```r
pstm_clean %>%
  bartlett.test(pstm_c ~ group, data = .)
```

```
##
##  Bartlett test of homogeneity of variances
##
## data:  pstm_c by group
## Bartlett's K-squared = 1.4022, df = 1, p-value = 0.2364
```

```r
pstm_clean %>%
  na.omit(.) %>%
  ggplot(., aes(x = group, y = pstm_c, label = participant)) +
    geom_text() +
    stat_summary(fun.data = mean_sdl, geom = 'pointrange')
```



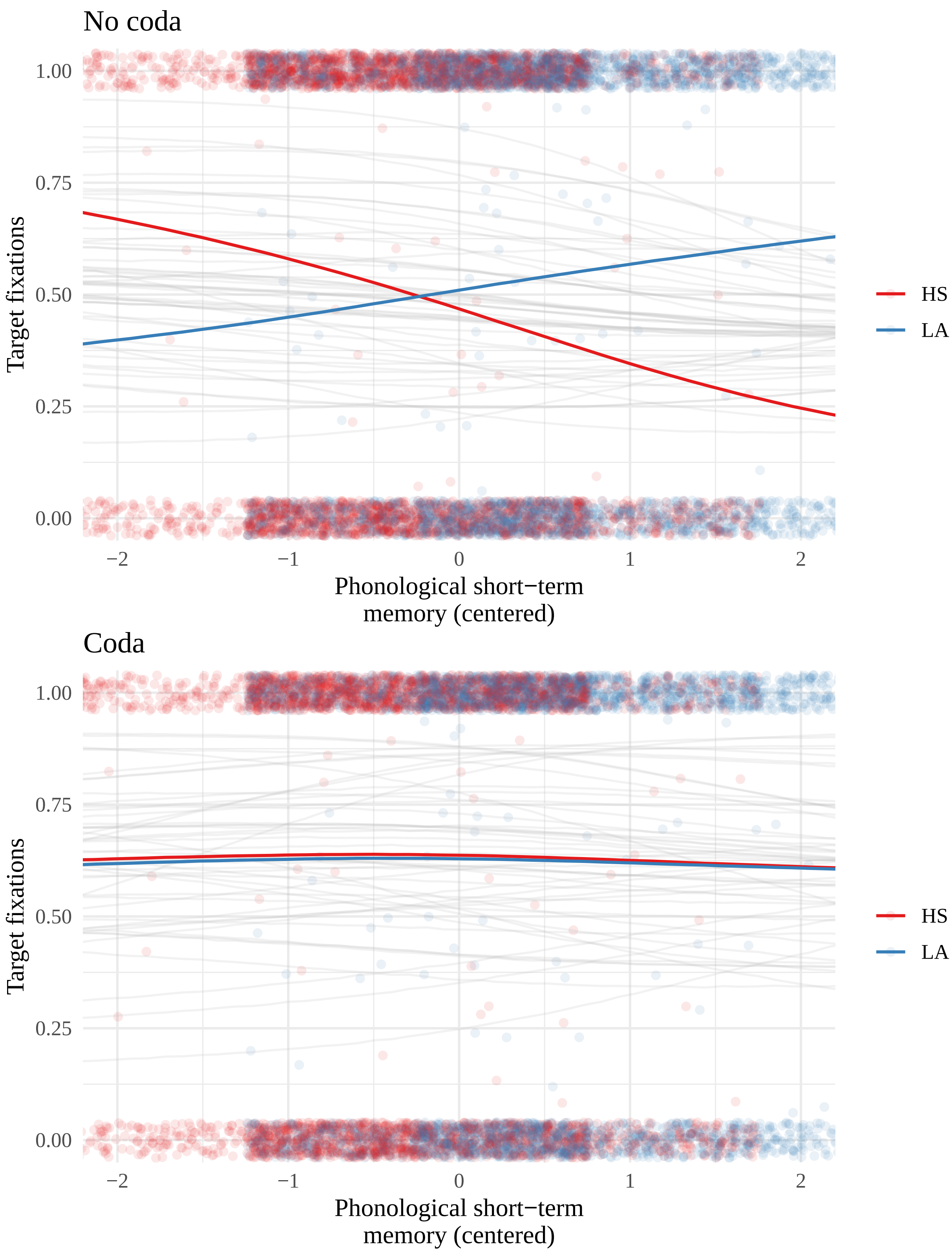

Groups look good.

```
## Generalized linear mixed model fit by maximum likelihood (Laplace
##   Approximation) [glmerMod]
##  Family: binomial  ( logit )
## Formula:
## cbind(targetCount, distractorCount) ~ (1 + pstm_c | participant) +
##     (1 + pstm_c | target) + group + group:pstm_c - 1
```

```
##    Data: hs_la_pstm_no_coda
## Control: glmerControl(optimizer = "bobyqa")
##
##      AIC      BIC   logLik deviance df.resid
##   3201.9   3239.4  -1590.9   3181.9      306
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -16.069  -2.063   0.000   2.119   8.489
##
## Random effects:
##  Groups      Name        Variance Std.Dev. Corr
##  participant (Intercept) 0.8138   0.9021
##              pstm_c      0.1735   0.4165   -0.35
##  target      (Intercept) 0.9015   0.9495
##              pstm_c      0.7006   0.8370   -0.33
## Number of obs: 316, groups:  participant, 50; target, 13
##
## Fixed effects:
##                Estimate Std. Error z value Pr(>|z|)
## groupla         0.05001    0.34025   0.147    0.883
## groupħs        -0.14185    0.35263  -0.402    0.687
## groupla:pstm_c  0.28958    0.30913   0.937    0.349
## groupħs:pstm_c -0.56678    0.40755  -1.391    0.164
##
## Correlation of Fixed Effects:
##             groupl grophs grpl:_
## groupħs      0.580
## grpl:pstm_c -0.362 -0.182
## grphs:pstm_ -0.144 -0.046  0.399

## Generalized linear mixed model fit by maximum likelihood (Laplace
##   Approximation) [glmerMod]
##  Family: binomial  ( logit )
## Formula:
## cbind(targetCount, distractorCount) ~ (1 + pstm_c | participant) +
##     (1 + pstm_c | target) + group + group:pstm_c - 1
##    Data: hs_la_pstm_coda
## Control: glmerControl(optimizer = "bobyqa")
##
##      AIC      BIC   logLik deviance df.resid
##   4703.6   4744.8  -2341.8   4683.6      445
##
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -14.2457  -2.2282   0.9312   2.0076   6.6046
##
## Random effects:
##  Groups      Name        Variance Std.Dev. Corr
##  participant (Intercept) 0.8588   0.9267
##              pstm_c      0.2576   0.5076   -0.01
##  target      (Intercept) 0.2289   0.4785
##              pstm_c      0.5546   0.7447   -0.18
## Number of obs: 455, groups:  participant, 50; target, 19
```

```
##
## Fixed effects:
##                Estimate Std. Error z value Pr(>|z|)
## grouphs         0.66125    0.25831   2.560   0.0105 *
## groupla         0.61823    0.25580   2.417   0.0157 *
## grouphs:pstm_c -0.03598    0.33682  -0.107   0.9149
## groupla:pstm_c -0.02879    0.29049  -0.099   0.9211
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             grophs groupl grph:_
## groupla      0.151
## grphs:pstm_  0.216 -0.003
## grpl:pstm_c -0.029 -0.267  0.258
```

**PSTM plots**



No coda
Target fixations
1.00
0.75
0.50
0.25
0.00
−2
−1
0
1
2
Phonological short−term memory (centered)
HS
LA
Coda
Target fixations
1.00
0.75
0.50
0.25
0.00
−2
−1
0
1
2
Phonological short−term memory (centered)
HS
LA

## Early/late bilinguals summary

## Learners summary

**Without coda**:

- Only monolinguals fixate on target above chance at the offset of the first syllable.
- All three groups fixate on target above chance by the suffix.
- No effect of working memory (a lot of variability for heritage).
- No ffect of PSTM.

**With coda**:

- Only monolinguals fixate on targets above chance at the coda.
- All three groups fixate on targets above chance at the offset of the first syllable.
- No effect of working memory. This is different for monolinguals and advanced learners if compared to the 'learner' analysis above (because the two analyses don't involve the exact same participants because of the homogeneity of variance issue).
- No effect of PSTM.