# Supplementary materials for 'Online perception of glottalized coda stops in American English'

## Contents



## Introduction

This study investigates the timecourse of perception of glottalization of voiceless and voiced stops in American English. We explore two measures: (1) overall fixations to the target, and (2) first target fixation latency.

## Measure 1: Overall fixation proportions

### Data pre-processing

```
library(lmerTest)
library(dplyr)
library(ggplot2)
library(tidyr)
library(reshape2)
```

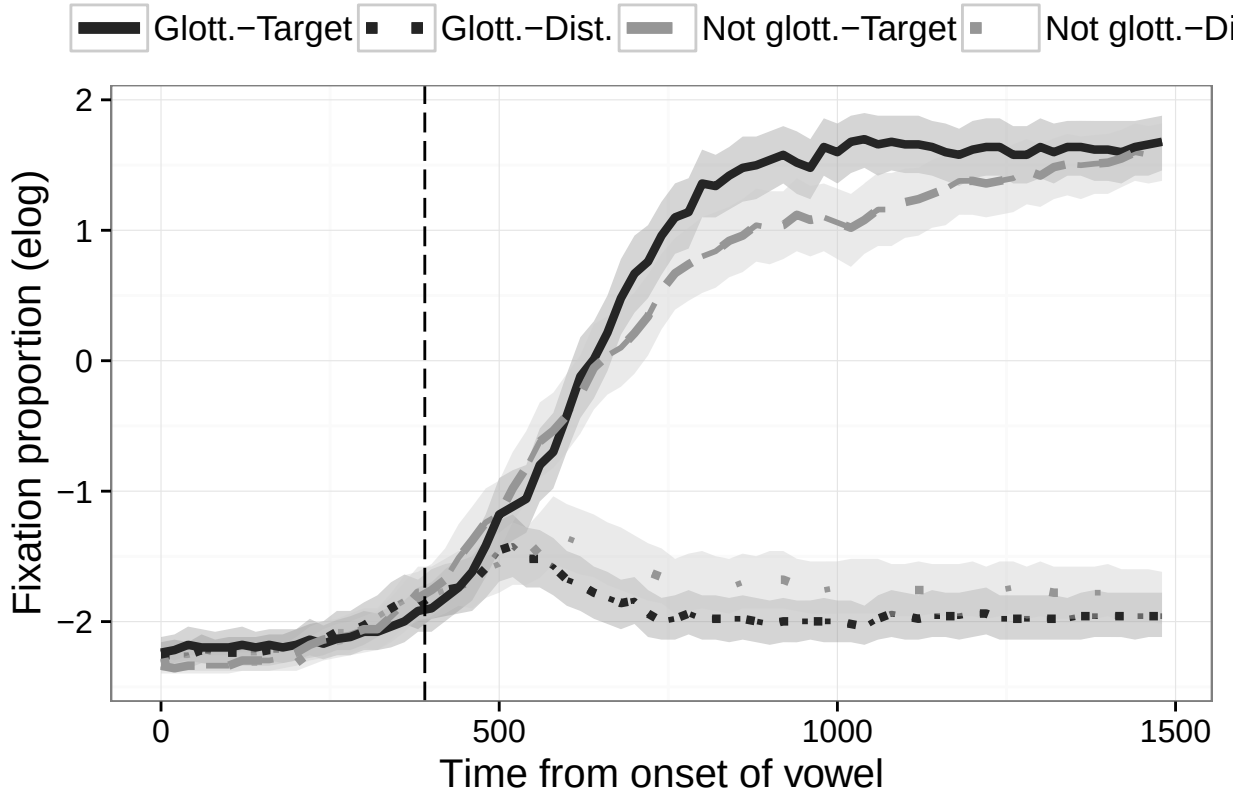
Participants were excluded for having the wrong language background or who were not engaged in the task. We should have a total of 60 participants left.

```
## [1] 60
```

### Baseline sub-experiment (Base)

In the **Baseline** sub-experiment, we are comparing coda [theta] and [s] let's do the empirical transformation (following Barr, 2008):

Plot fixation curves:




#### Baseline analysis - LMER

LME model output for **Baseline** condition:

```
#b$glot=relevel(b$glot, ref="ng")
#contrast coding
contrasts(b$glot)=c(-.5,.5)

summary(lmer(elog ~ glot +
               (1 + glot | subject) + (1 + glot| word),
             data=b))
```

```
## Linear mixed model fit by REML t-tests use Satterthwaite approximations
##   to degrees of freedom [lmerMod]
## Formula: elog ~ glot + (1 + glot | subject) + (1 + glot | word)
##    Data: b
##
## REML criterion at convergence: 2160.8
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
```

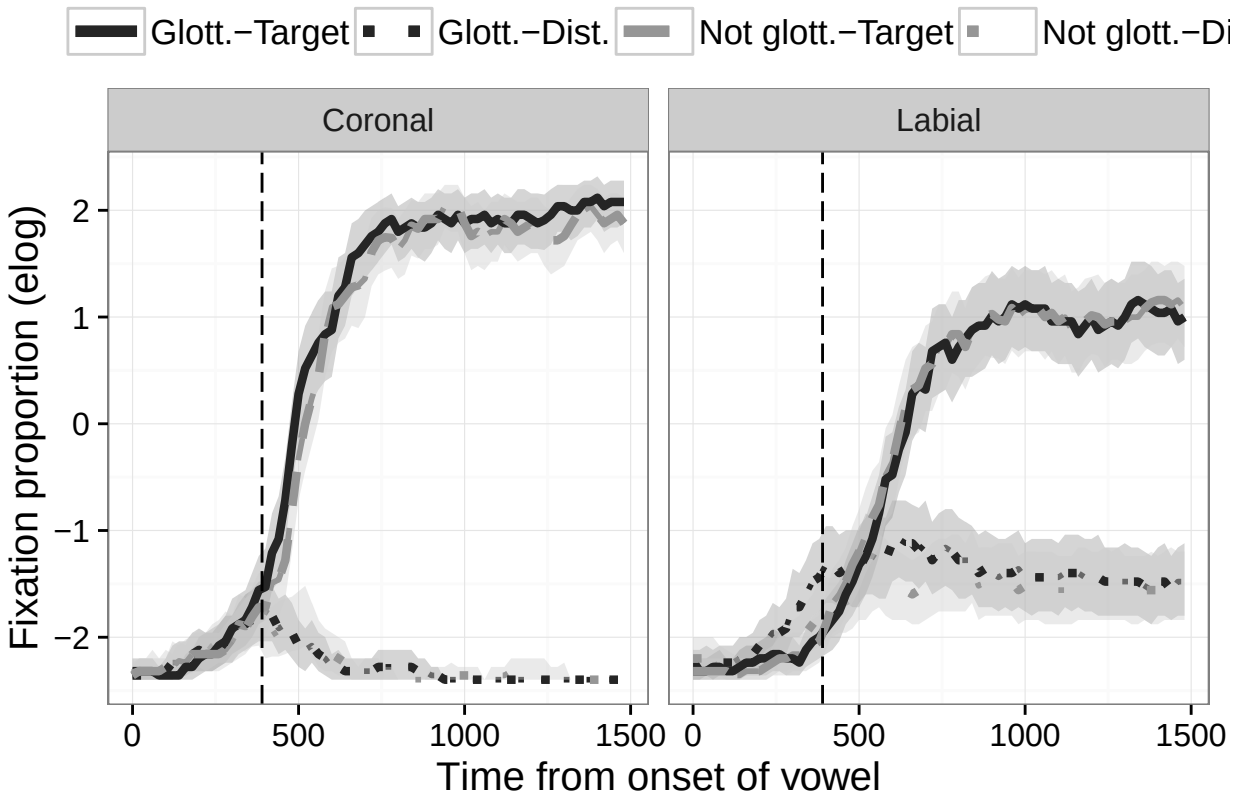
```
## -2.7511 -0.1617  0.1514  0.4980  3.1952
##
## Random effects:
##  Groups   Name        Variance Std.Dev. Corr
##  subject  (Intercept) 0.3759   0.6131
##           glot1       0.2872   0.5359   1.00
##  word     (Intercept) 0.3772   0.6142
##           glot1       0.1651   0.4064   0.82
##  Residual             4.7699   2.1840
## Number of obs: 480, groups:  subject, 60; word, 8
##
## Fixed effects:
##             Estimate Std. Error      df t value Pr(>|t|)
## (Intercept)  -0.8100     0.2517  8.4900  -3.218   0.0113 *
## glot1        -0.4140     0.2553  7.8320  -1.621   0.1444
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##       (Intr)
## glot1 0.484
```

## Place of articulation sub-experiment (POA)

In the **POA** sub-experiment, we are comparing coda [p] and [t]. We perform the same empirical logit transformation on the data.

```
##   word poa glot bin subject target dist sampleCount totalLooks tlog2 dlog2
## 1  cot cor    g   0    glp1      0    0           5          0     0     0
## 2 shot cor    g   0    glp1      0    0           5          0     0     0
## 3  pop lab    g   0    glp1      0    0           5          0     0     0
## 4  rap lab    g   0    glp1      0    0           5          0     0     0
## 5  pot cor   ng   0    glp1      0    0           5          0     0     0
##       IA      elog       var
## 1 target -2.397895  g target
## 2 target -2.397895  g target
## 3 target -2.397895  g target
## 4 target -2.397895  g target
## 5 target -2.397895 ng target
```

Plot fixation curves:




**POA analysis - LMER**

LME model output for **POA** condition:

```
#contrast coding
contrasts(poa_dat$glot)=c(-.5,.5)
contrasts(poa_dat$poa)=c(-.5,.5)

summary(lmer(elog ~
               glot +
               poa +
               glot : poa +
               (1 + glot + poa | subject) + (1 + glot | word),
             data=poa_dat))
```

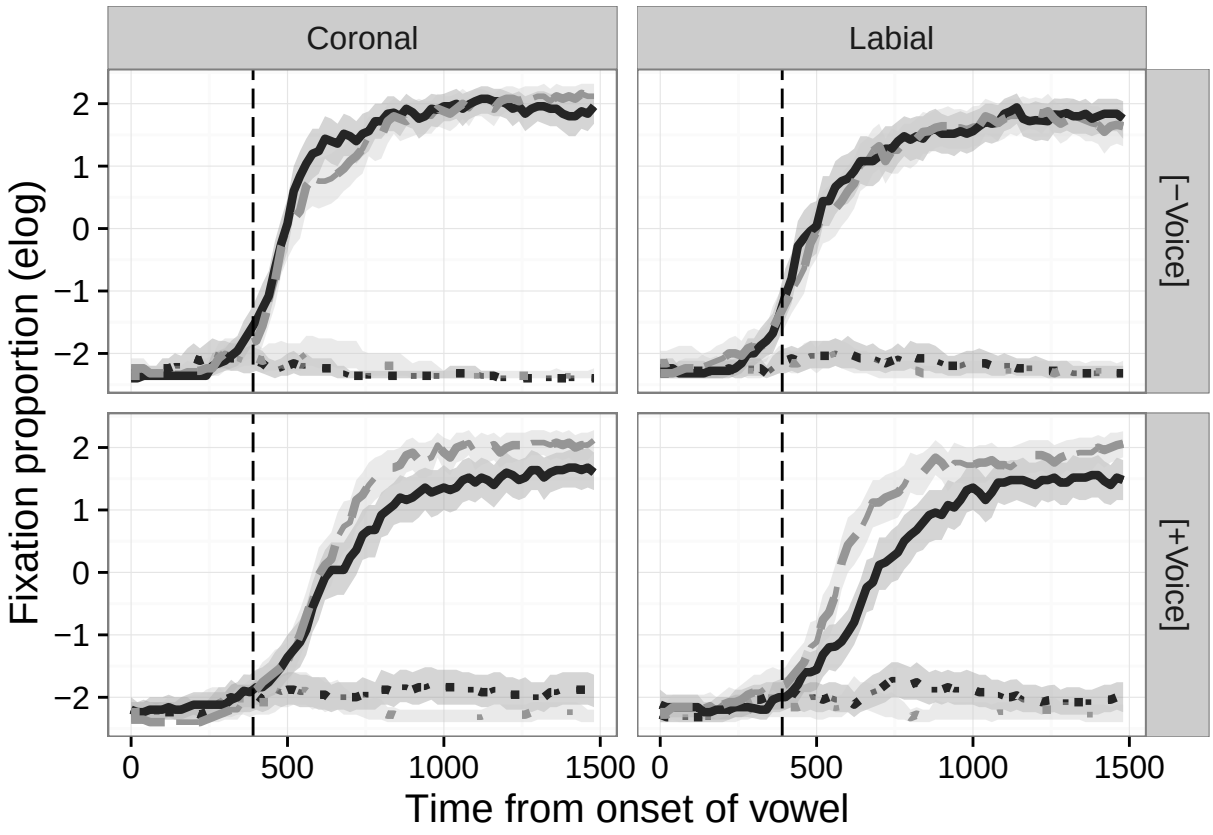
```
## Linear mixed model fit by REML t-tests use Satterthwaite approximations
##   to degrees of freedom [lmerMod]
## Formula: elog ~ glot + poa + glot:poa + (1 + glot + poa | subject) + (1 +
##     glot | word)
##    Data: poa_dat
##
## REML criterion at convergence: 2051.5
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -3.2858 -0.3102  0.1096  0.4612  3.0299
##
```

```
## Random effects:
##  Groups   Name        Variance Std.Dev. Corr
##  subject  (Intercept) 0.29842  0.5463
##           glot1       0.08872  0.2979   1.00
##           poa1        1.44556  1.2023   1.00  1.00
##  word     (Intercept) 0.51584  0.7182
##           glot1       0.10266  0.3204   -1.00
##  Residual             3.62958  1.9051
## Number of obs: 480, groups:  subject, 60; word, 8
##
## Fixed effects:
##             Estimate Std. Error       df t value Pr(>|t|)
## (Intercept) -0.49502    0.27752  6.84300  -1.784   0.1186
## glot1        0.03893    0.21109 11.73600   0.184   0.8568
## poa1        -1.55699    0.55880  7.02700  -2.786   0.0269 *
## glot1:poa1  -0.01668    0.41511 11.11800  -0.040   0.9687
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##            (Intr) glot1  poa1
## glot1      -0.445
## poa1        0.071  0.051
## glot1:poa1  0.000  0.000 -0.496
```

## Voicing sub-experiment (VOI)

```
##   word poa voice glot bin subject target dist sampleCount totalLooks tlog2
## 1  mat cor     0    g   0    glp1      0    0           5          0     0
## 2  not cor     0    g   0    glp1      0    0           5          0     0
## 3  mop lab     0    g   0    glp1      0    0           5          0     0
## 4  nap lab     0    g   0    glp1      0    0           5          0     0
## 5  bad cor     1    g   0    glp1      0    0           5          0     0
##   dlog2   IA      elog    var
## 1     0 tlog -2.397895 g tlog
## 2     0 tlog -2.397895 g tlog
## 3     0 tlog -2.397895 g tlog
## 4     0 tlog -2.397895 g tlog
## 5     0 tlog -2.397895 g tlog
```

Plotting the data:




**Voicing analysis - LMER**

LME model output for **Voicing** condition

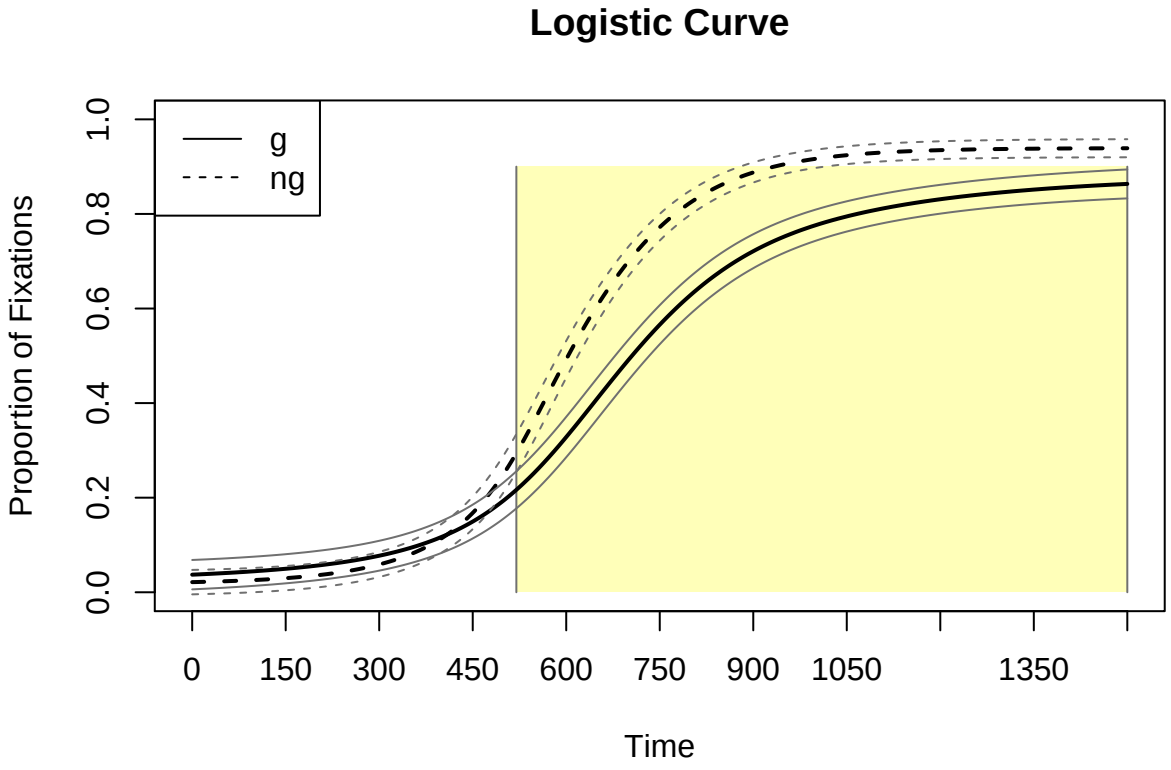
```
#contrast coding
contrasts(voi_dat$glot)=c(-.5,.5)
contrasts(voi_dat$poa)=c(-.5,.5)
contrasts(voi_dat$voice)=c(-.5,.5)

summary(lmer(elog ~
               glot * poa * voice +
               (glot*poa + poa*voice + glot*voice |subject)+(glot|word),
             data = voi_dat))
```

```
## Linear mixed model fit by REML t-tests use Satterthwaite approximations
##   to degrees of freedom [lmerMod]
## Formula: elog ~ glot * poa * voice + (glot * poa + poa * voice + glot *
##     voice | subject) + (glot | word)
##    Data: voi_dat
##
## REML criterion at convergence: 3899.4
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -3.6818 -0.2174  0.1209  0.4113  3.6462
##
```

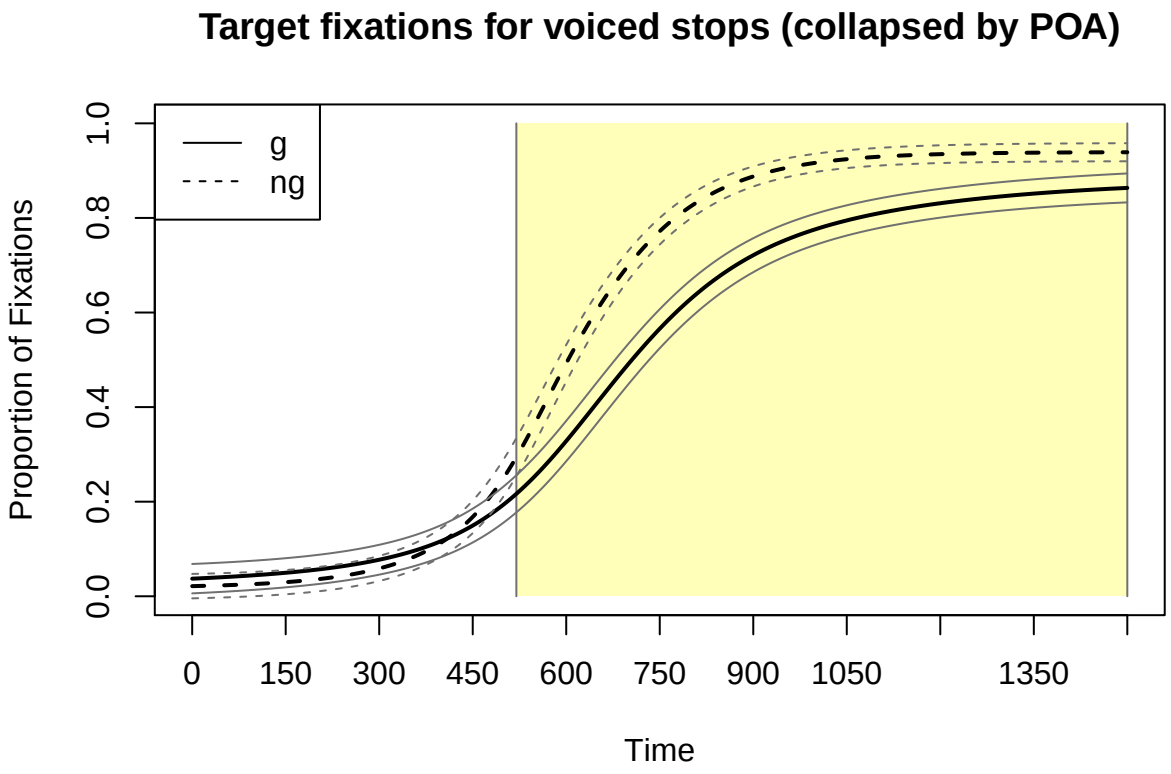
```
## Random effects:
##  Groups   Name         Variance Std.Dev. Corr
##  subject  (Intercept)  0.36053  0.6004
##           glot1        0.14987  0.3871    0.20
##           poa1         0.47568  0.6897    0.59  0.19
##           voice1       0.27998  0.5291   -0.18 -0.63 -0.58
##           glot1:poa1   0.48190  0.6942    0.51  0.27 -0.36  0.29
##           poa1:voice1  0.39947  0.6320   -0.54  0.28  0.14 -0.13 -0.61
##           glot1:voice1 1.25119  1.1186   -0.30  0.58  0.41 -0.81 -0.62
##  word     (Intercept)  0.04832  0.2198
##           glot1        0.01954  0.1398   -1.00
##  Residual              2.88946  1.6998
##
##
##
##
##
##
##
##   0.66
##
##
##
## Number of obs: 960, groups:  subject, 60; word, 16
##
## Fixed effects:
##                   Estimate Std. Error       df t value Pr(>|t|)
## (Intercept)       -0.29520    0.10972 31.97000  -2.690  0.01125 *
## glot1              0.32770    0.12553 34.51000   2.610  0.01329 *
## poa1              -0.07861    0.17902 18.18000  -0.439  0.66575
## voice1            -0.65520    0.16967 15.09000  -3.862  0.00152 **
## glot1:poa1         0.40060    0.24713 35.17000   1.621  0.11396
## glot1:voice1       0.87378    0.27184 39.32000   3.214  0.00261 **
## poa1:voice1       -0.09489    0.32115 12.66000  -0.295  0.77243
## glot1:poa1:voice1  0.22417    0.46062 33.79000   0.487  0.62963
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) glot1  poa1   voice1 glt1:p1 glt1:v1 p1:vc1
## glot1       -0.084
## poa1         0.208  0.039
## voice1      -0.050 -0.102 -0.116
## glot1:poa1   0.130  0.039 -0.238  0.043
## glot1:voic1 -0.113  0.122  0.108 -0.340 -0.119
## poa1:voice1 -0.096  0.028  0.017 -0.013 -0.056   0.090
## glt1:p1:vc1  0.000  0.000  0.000  0.000  0.000   0.000  -0.208
```

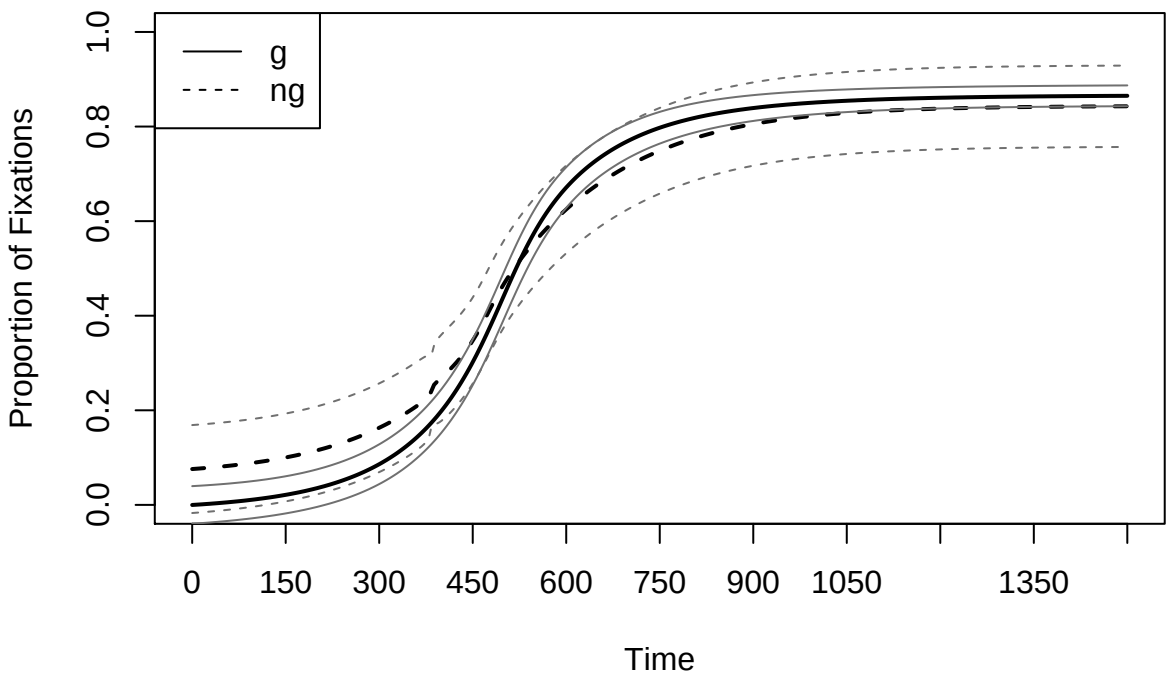
**Timecourse in Voicing analysis**

Using the **bdots** package, we compare the timecourse of fixations to voiced stop targets (collapsed by place of articulation) to ascertain the exact timing of the effect of glottalization on word recognition.



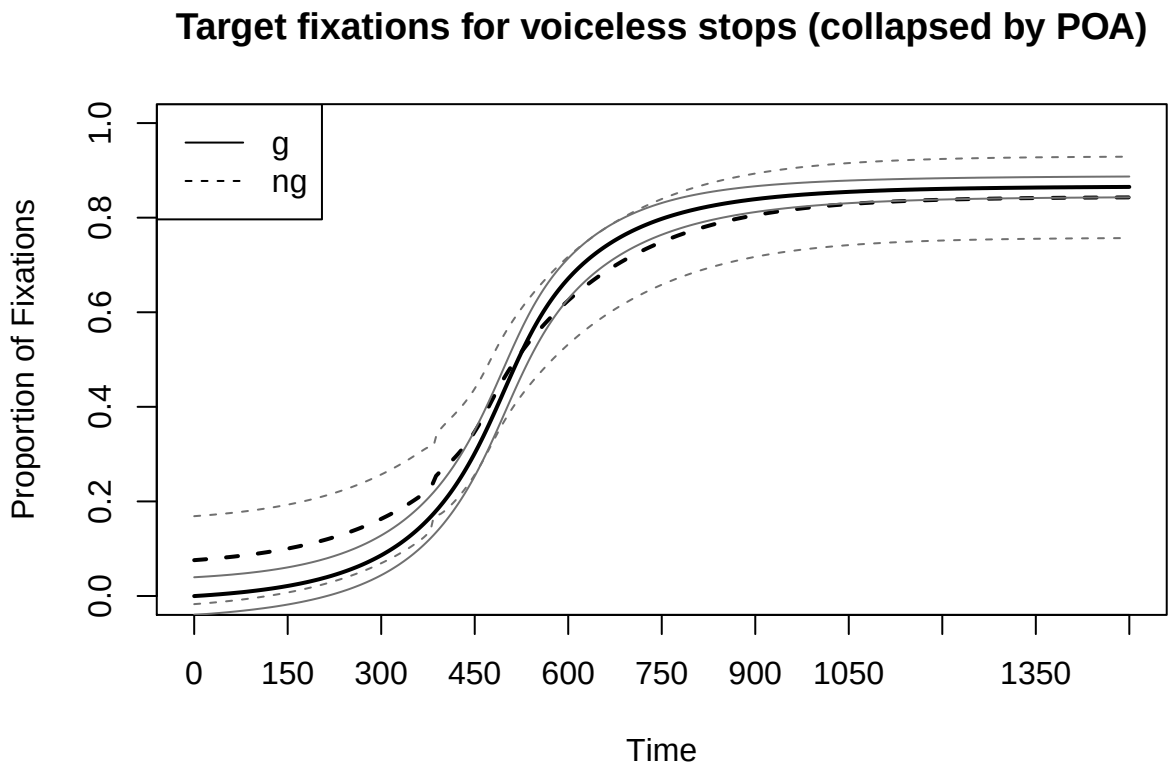

```
FALSE $alpha
FALSE     alpha alpha.adj   rho.est
FALSE    0.0500    0.0063    0.9974
FALSE
FALSE $significant
FALSE      [,1] [,2]
FALSE [1,]  520 1500
```




```
FALSE $alpha
FALSE     alpha alpha.adj   rho.est
FALSE    0.0500    0.0057    0.9964
FALSE
FALSE $significant
```

```
FALSE NULL
```




## Measure 2: First correct fixation latency analysis

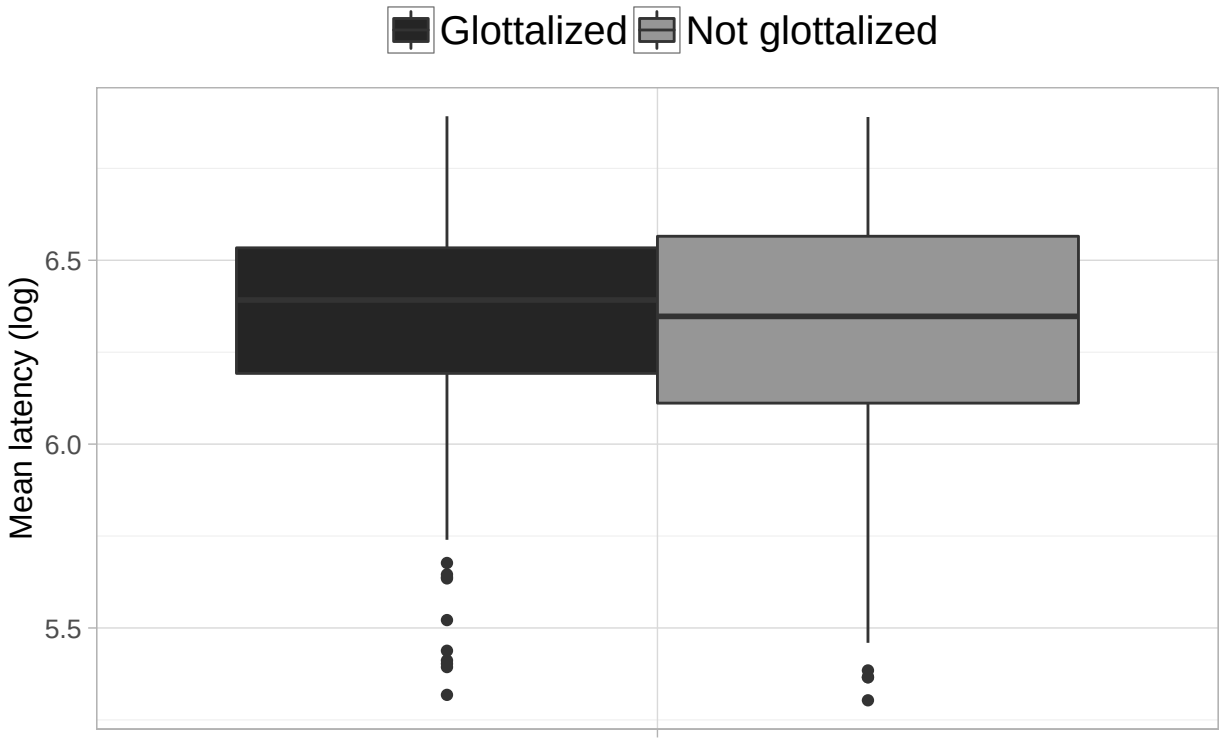
A second measure that Beddor et al. (2013) used was first correct fixation latency. Let's first read in the relevant file.

Trials excluded due to the following reasons: 1. Did not look to the correct image (i.e. they looked at the distractor - errors) 2. Looked at the target less than 200 ms after the onset of the vowel (given the 200ms time it takes to initiate a saccade in response to an auditory stimulus) 3. Fixation times were more than 1 second (1000ms) post vowel onset

### Baseline

```
##        g       ng
## 587.2335 578.6324
```

```
##        g       ng
## 151.6259 168.8768
```




LME model output for baseline condition:

```
lat_base$log.latency= log(lat_base$latency)
contrasts(lat_base$glot)=c(-.5,.5)

summary(lmer(scale(log.latency) ~
             glot +
             (glot|subject)+(1|targetWord),
             data = lat_base))
```

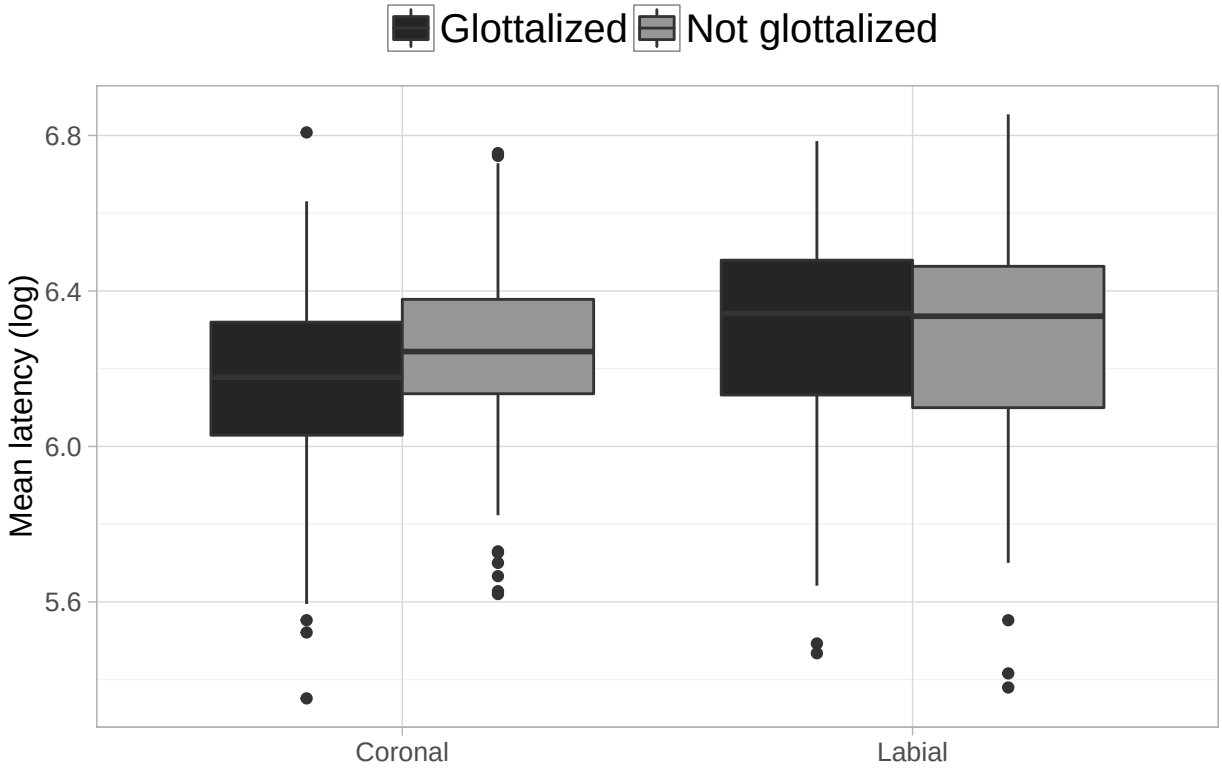
```
## Linear mixed model fit by REML t-tests use Satterthwaite approximations
##   to degrees of freedom [lmerMod]
## Formula: scale(log.latency) ~ glot + (glot | subject) + (1 | targetWord)
##    Data: lat_base
##
## REML criterion at convergence: 1056.2
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -3.5803 -0.4664  0.1750  0.6569  1.9886
##
## Random effects:
##  Groups     Name        Variance Std.Dev. Corr
##  subject    (Intercept) 0.230777 0.48039
##             glot1       0.026471 0.16270  1.00
##  targetWord (Intercept) 0.009537 0.09766
##  Residual               0.770757 0.87793
## Number of obs: 382, groups:  subject, 60; targetWord, 8
##
## Fixed effects:
```

```
##              Estimate Std. Error        df t value Pr(>|t|)
## (Intercept)  -0.01730    0.08442  23.70000  -0.205    0.839
## glot1        -0.06800    0.09357 199.29000  -0.727    0.468
##
## Correlation of Fixed Effects:
##       (Intr)
## glot1 0.186
```

## POA

```
##         cor      lab
## g  491.3727 560.7711
## ng 531.7838 557.4881
```

```
##         cor      lab
## g  120.6792 142.3131
## ng 124.7374 151.6036
```




LME model output for POA condition:

```
contrasts(lat_poa$glot)=c(-.5,.5)
contrasts(lat_poa$place)=c(-.5,.5)

summary(lmer(scale(log(latency)) ~
              glot * place +
             (glot*place|subject)+(glot|targetWord),
           data = lat_poa))
```

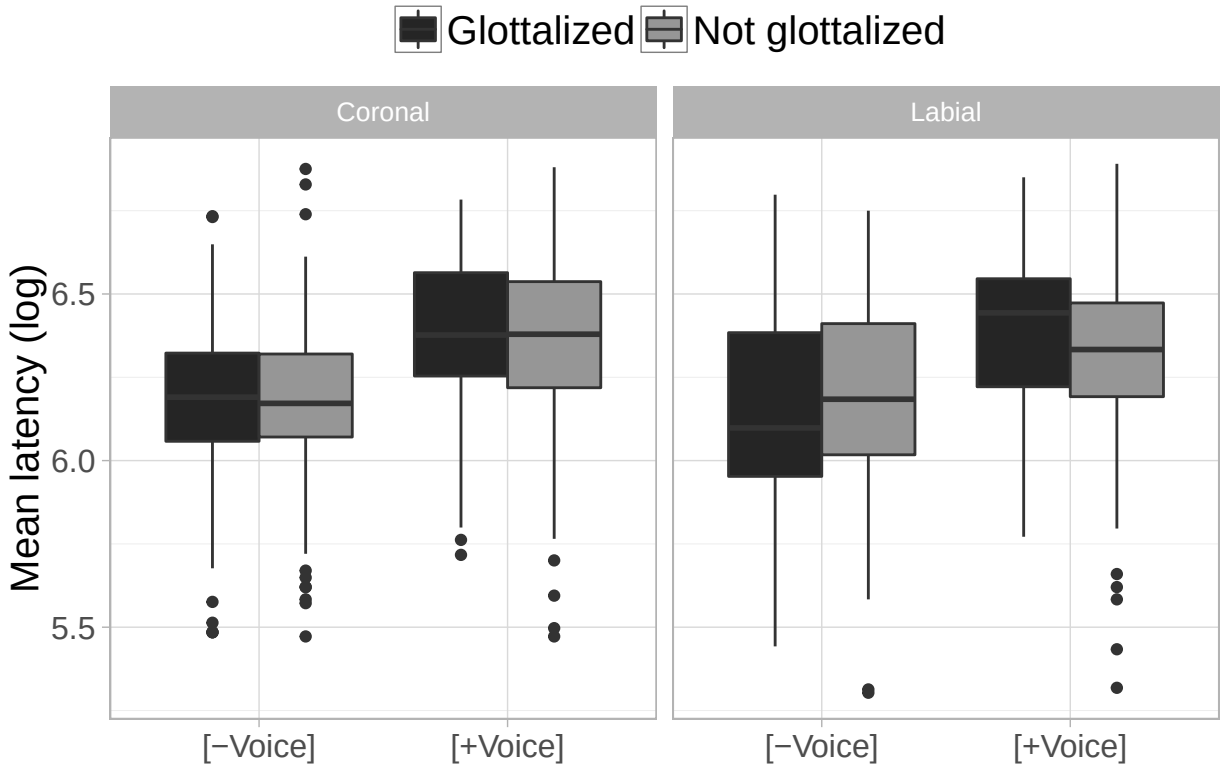
```
## Linear mixed model fit by REML t-tests use Satterthwaite approximations
##   to degrees of freedom [lmerMod]
## Formula: scale(log(latency)) ~ glot * place + (glot * place | subject) +
##     (glot | targetWord)
##    Data: lat_poa
##
## REML criterion at convergence: 1064.4
##
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -2.90340 -0.47301  0.05504  0.57487  2.72418
##
## Random effects:
##  Groups     Name         Variance Std.Dev. Corr
##  subject    (Intercept)  0.144113 0.37962
##             glot1        0.148262 0.38505  0.23
##             place1       0.054214 0.23284  1.00  0.20
##             glot1:place1 0.450382 0.67111  0.22  1.00 0.18
##  targetWord (Intercept)  0.045180 0.21256
##             glot1        0.004097 0.06401  -1.00
##  Residual                0.728592 0.85358
## Number of obs: 388, groups:  subject, 60; targetWord, 8
##
## Fixed effects:
##               Estimate Std. Error        df t value Pr(>|t|)
## (Intercept)   0.009414   0.100654 10.040000   0.094   0.9273
## glot1         0.125947   0.105342 35.770000   1.196   0.2397
## place1        0.287674   0.178135  6.350000   1.615   0.1547
## glot1:place1 -0.362375   0.205020 36.390000  -1.768   0.0855 .
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) glot1  place1
## glot1       -0.108
## place1       0.128  0.016
## glot1:plac1  0.045  0.338 -0.175
```

## Voicing

```
## , , 0
##
##         cor      lab
## g  493.4522 488.6635
## ng 506.1058 507.2828
##
## , , 1
##
##         cor      lab
## g  606.5529 607.4605
## ng 590.1727 562.2500
```

```
## , , 0
```

```
##
##         cor      lab
## g  120.9902 149.0633
## ng 136.7027 138.2013
##
## , , 1
##
##         cor      lab
## g  138.4169 138.7012
## ng 150.6868 135.2826
```




LME model output for *Voicing* condition:

```
contrasts(lat_voi$glot)=c(-.5,.5)
contrasts(lat_voi$place)=c(-.5,.5)
contrasts(lat_voi$voice)=c(-.5,.5)

summary(lmer(scale(log(latency)) ~
             glot * place * voice +
             (glot*place +glot*voice + voice*place|subject)+(glot|targetWord),
           data = lat_voi))
```

```
## Linear mixed model fit by REML t-tests use Satterthwaite approximations
##   to degrees of freedom [lmerMod]
## Formula: scale(log(latency)) ~ glot * place * voice + (glot * place +
##     glot * voice + voice * place | subject) + (glot | targetWord)
##    Data: lat_voi
##
## REML criterion at convergence: 2063.7
```

```
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -3.3372 -0.5202  0.0405  0.6011  2.4987
##
## Random effects:
##  Groups     Name          Variance Std.Dev. Corr
##  subject    (Intercept)   0.215942 0.46470
##             glot1         0.028203 0.16794   0.70
##             place1        0.019341 0.13907   0.13  0.09
##             voice1        0.087167 0.29524  -0.27 -0.67  0.65
##             glot1:place1  0.071400 0.26721   0.06  0.55  0.70 -0.02
##             glot1:voice1  0.065335 0.25561   0.27  0.65  0.74 -0.02  0.98
##             place1:voice1 0.560823 0.74888  -0.21 -0.22 -0.99 -0.55 -0.76
##  targetWord (Intercept)   0.006544 0.08089
##             glot1         0.002149 0.04635  1.00
##  Residual                 0.615263 0.78439
##
##
##
##
##
##
##
##  -0.81
##
##
##
## Number of obs: 797, groups:  subject, 60; targetWord, 16
##
## Fixed effects:
##                      Estimate Std. Error       df t value Pr(>|t|)
## (Intercept)           0.01651    0.06941 51.32000   0.238    0.813
## glot1                -0.02700    0.06193 61.99000  -0.436    0.664
## place1               -0.04105    0.07197 13.81000  -0.570    0.578
## voice1                0.60336    0.07944 18.27000   7.595 4.62e-07 ***
## glot1:place1         -0.01652    0.12067 63.33000  -0.137    0.892
## glot1:voice1         -0.27643    0.12034 61.74000  -2.297    0.025 *
## place1:voice1        -0.03016    0.16977 21.42000  -0.178    0.861
## glot1:place1:voice1 -0.32436    0.23155 77.96000  -1.401    0.165
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) glot1  place1 voice1 glt1:p1 glt1:v1 plc1:1
## glot1        0.241
## place1       0.042 -0.005
## voice1      -0.089 -0.184  0.082
## glot1:plac1  0.006  0.094  0.112 -0.008
## glot1:voic1  0.022  0.126  0.045  0.052  0.085
## place1:voc1 -0.103 -0.047 -0.101 -0.130 -0.190  -0.139
## glt1:plc1:1 -0.003  0.003 -0.082 -0.013  0.065   0.042   0.055
```