Smolbny
Санкт-Петербургский государственный университет Bard College
Факультет свободных искусств и наук

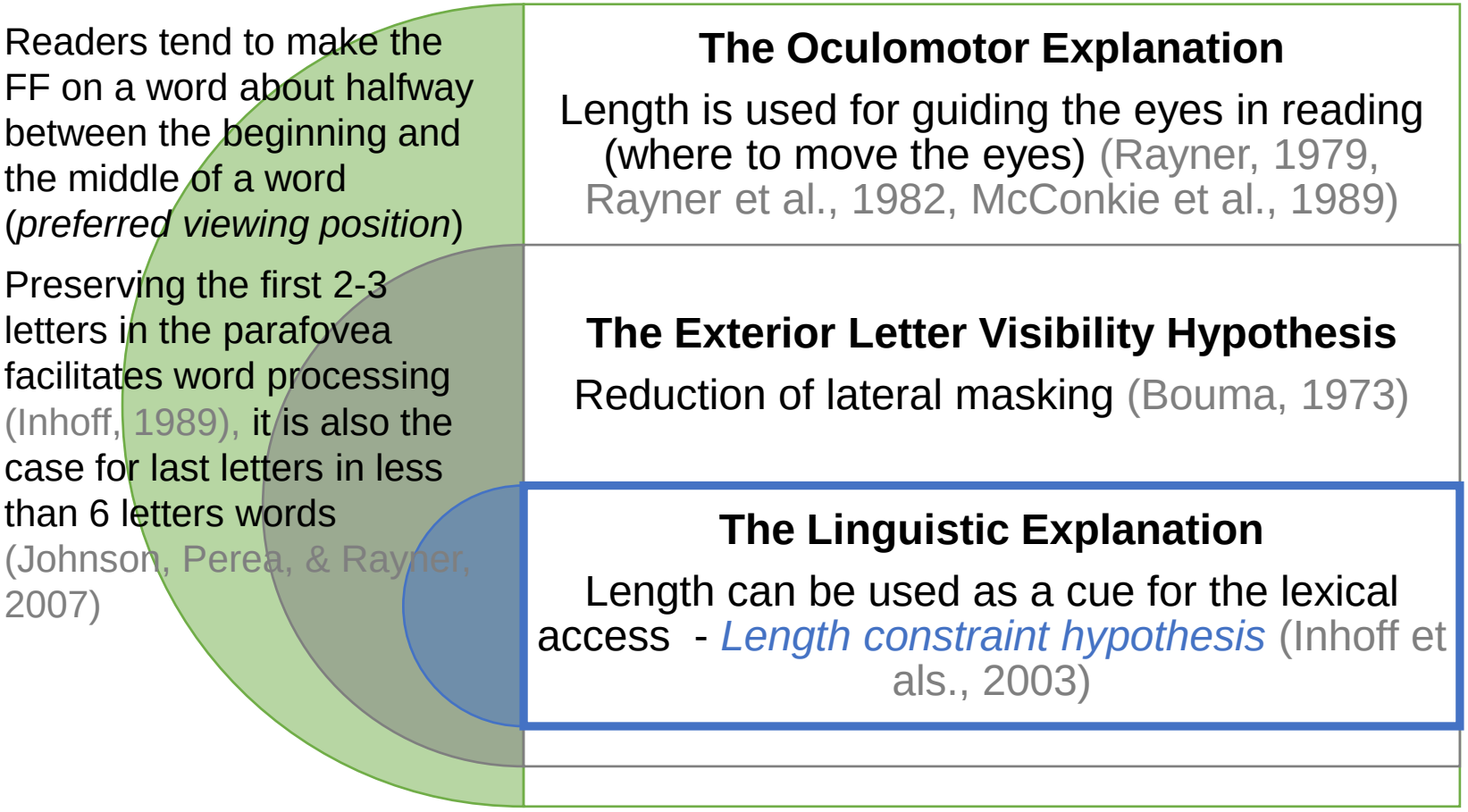
Length constraint hypothesis in parafoveal processing during reading: evidence from Russian

Svetlana Alexeeva, mail@s-alexeeva.ru
St. Petersburg State University

Length in reading

- Word length influences fixation durations and inspection probabilities (Kliegl et al., 2004; Rayner, 1998):
  - The more letters in the word, the more fixations made on the word, and the longer the duration of these fixations
  - 2-3 letter words are only fixated around 25% of the time, whereas 8 letters words or longer are almost always fixated (and often fixated more than once).
- Word length is identified with spaces
  - When spaces are removed or masked, reading rate and saccade length decrease markedly (McConkie & Rayner, 1975; Rayner, 1986; Pollatsek & Rayner, 1982; Rayner & Pollatsek, 1996), initial landing position shifts closer to the beginning of a word (Rayner et al., 1998)

Why is the word boundary information so important?

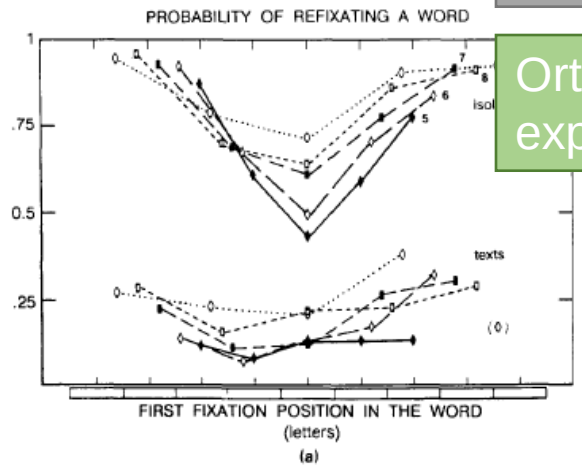


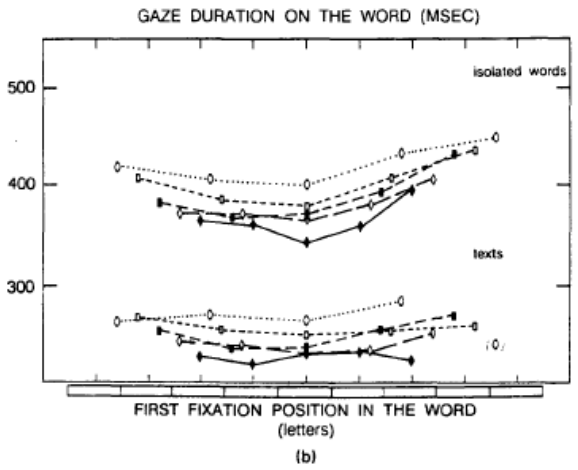
The study by Clark and O'Regan (1990)

Optimal viewing (

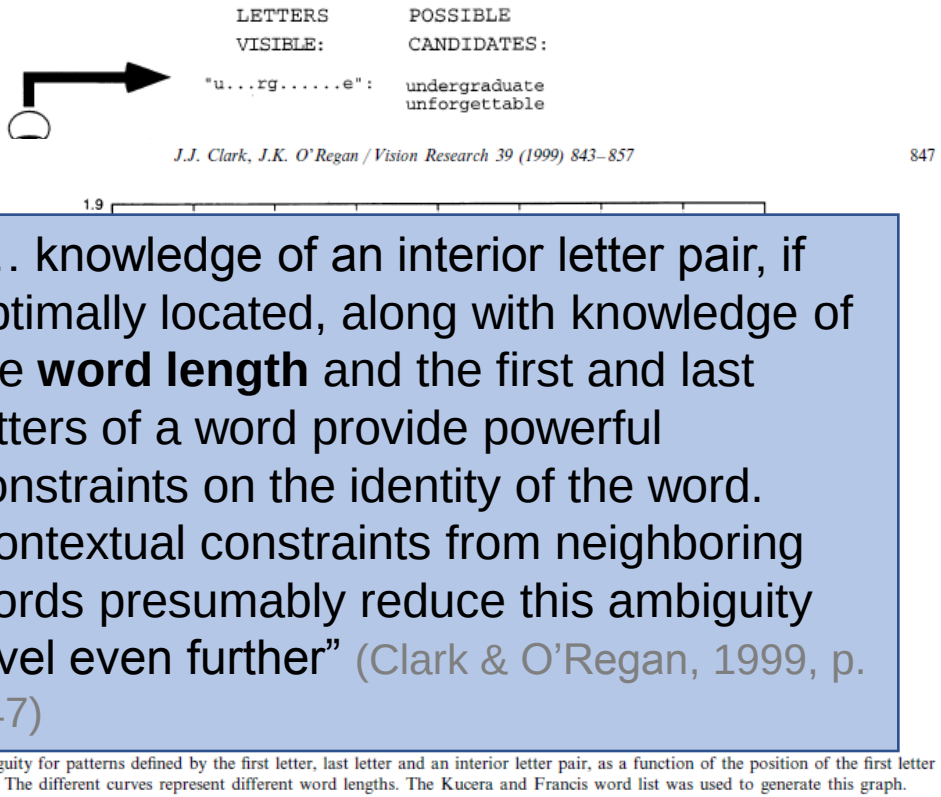
Visual acuity explanation

Orthographic constraint explanation





Vitu, O'Regan, & Mittau (19



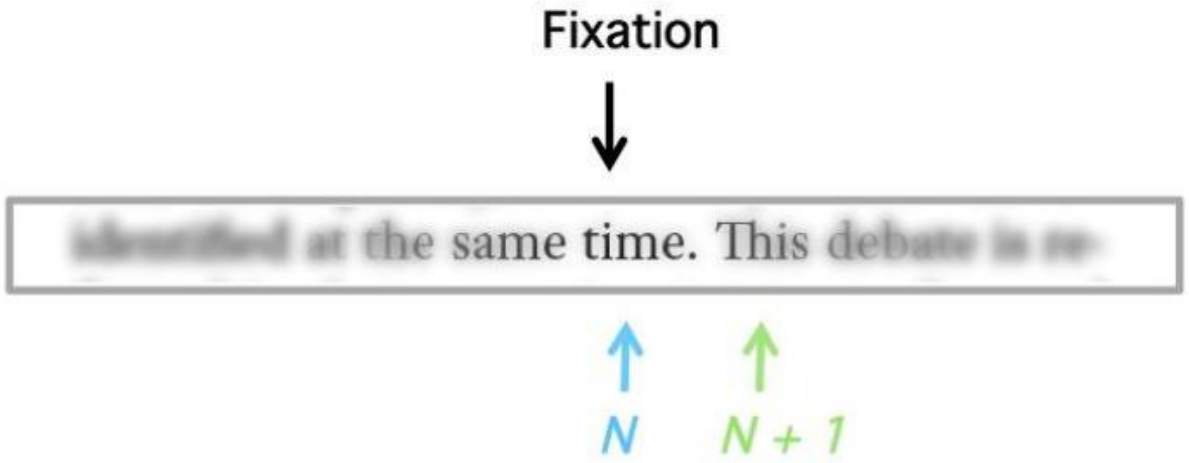
"… knowledge of an interior letter pair, if optimally located, along with knowledge of the **word length** and the first and last letters of a word provide powerful constraints on the identity of the word. Contextual constraints from neighboring words presumably reduce this ambiguity level even further" (Clark & O'Regan, 1999, p. 847)

Length Constraint Hypothesis (LCH)

- the view that readers combine information about the orthography and **length** of upcoming words to narrow down, or constrain, the set of lexical candidates for a to-be-identified word. (postulated by Inhoff et als., 2003)

What is Parafoveal Processing?

- Readers extract information from the words they fixate, but also from words to the right of the fixation (Rayner, 1998; Schotter, Angele & Rayner, 2012)
- The fixated word (*N*) is processed foveally, whilst the word to the right of the fixation (*N+1*) is processed in the parafovea until it is fixated



Parafoveal Preview Benefit

- Parafoveal information can facilitate reading once the word is fixated (see Rayner, 1998, for a review)

Таня была в синей шерстяной | корне и клетчатых брюках.

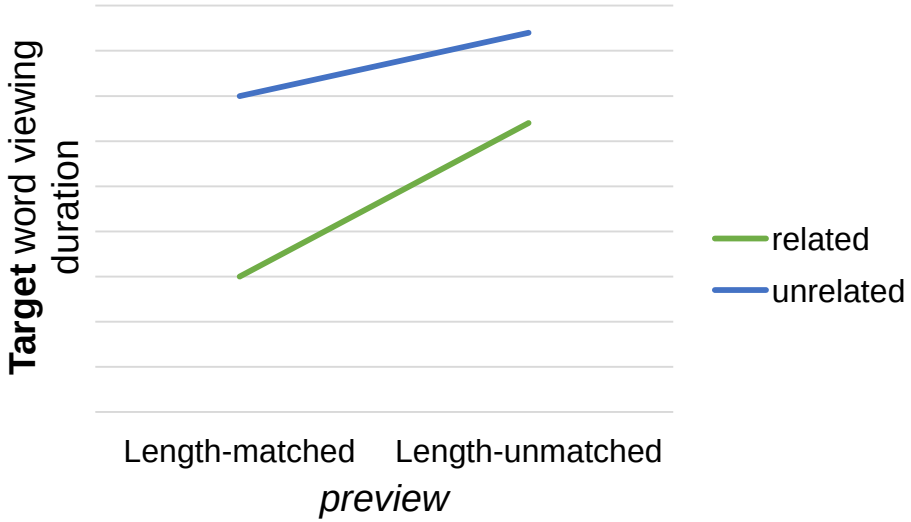
Таня была в синей шерстяной | кофте и клетчатых брюках.

'Tanya wears a blue (*root /korne/*) **sweater /kofte/** and plaid pants" (the preview – *root*, the target - **sweater**)

The boundary paradigm (Rayner, 1975)

LCH predictions

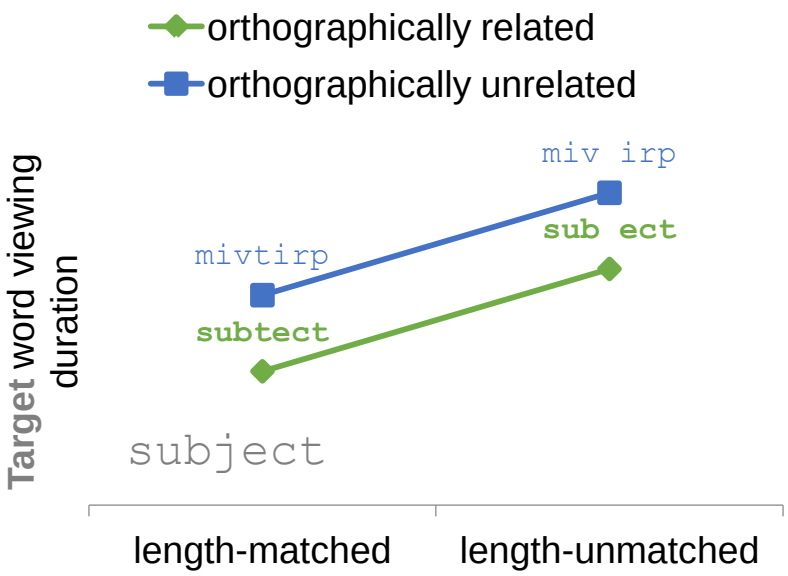
If length assumes linguistic function and plays a role in recognition process we would expect that the preview benefit from orthographically related previews will be greater when the preview also provides accurate length information than when it does not.



Testing LCH

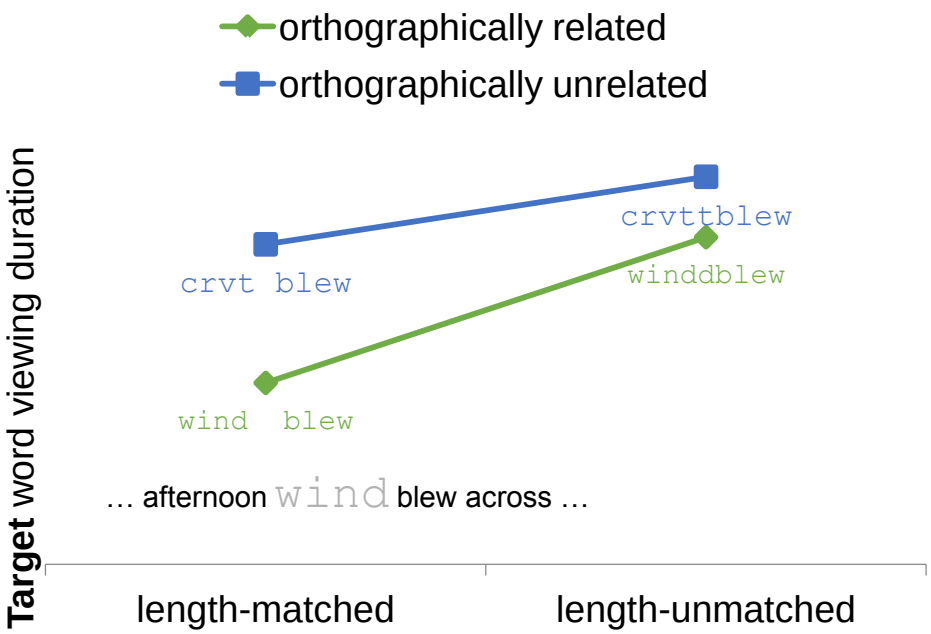
Contra

Inhoff et al. (2003): length (p<0,01), orthographical similarity (p<0,01), interaction (p>0,1). Additional analysis with optimal / non-optimal landing position (p<0,05), 3-way interaction (p>0,1)



Pro

Veldre & Andrews (2015): length (t>8), orthographical similarity (t>14), interaction (t>7,5). ILP is included in LMM (t>2,4), 3-way interaction (no information)

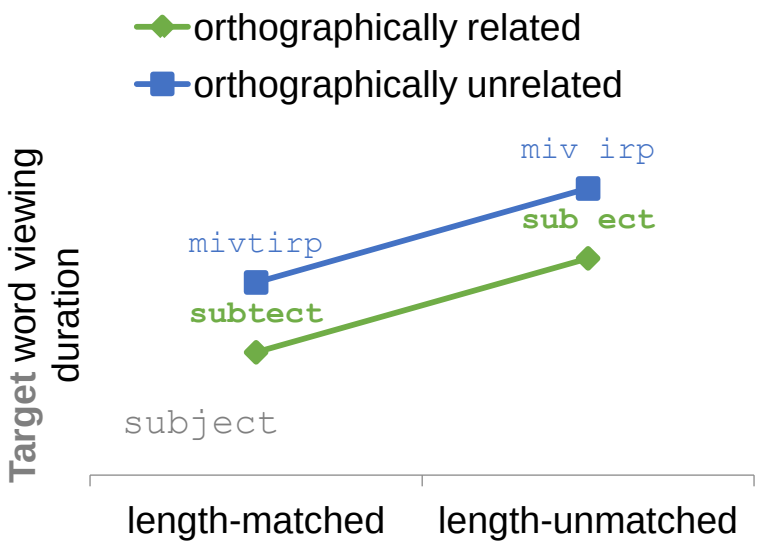


Testing LCH

length * predictability interaction (p<0,001) (White et al., 2005, Juhasz et al., 2008)

Contra

Inhoff et al. (2003): length (p<0,01), orthographical similarity (p<0,01), interaction (p>0,1). Additional analysis with optimal / non-optimal landing position (p<0,05), 3-way interaction (p>0,1)



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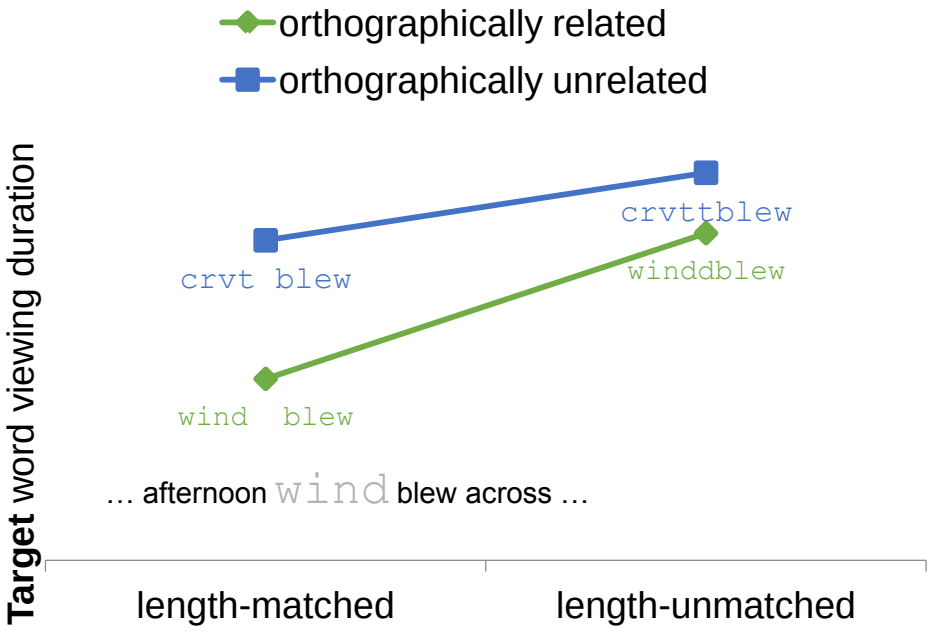


The current study

- Record eye movements during boundary paradigm.
- Explores parafoveal preview benefit for identical previews (IP), length-accurate previews (same L), length-inaccurate previews (diff L)

кокоса ‘coconut, sg, gen’	колена ‘root, sg, gen’	коридора ‘hall, sg, gen’

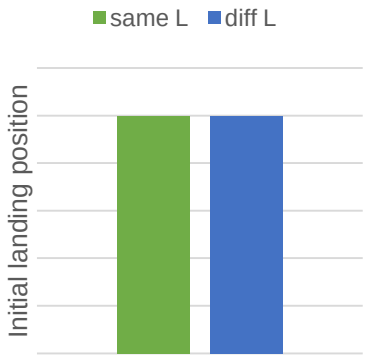
- These effects are explored for high frequency target words (M: 104 ipm) and for low frequency target words (M: ipm) (Alexeeva et als. 2015)
- Non-identical previews are real nouns matched with the target nouns (e. g. кофте ‘sweater, sg, loc’) on:
  - Case and number
  - Visual similarity

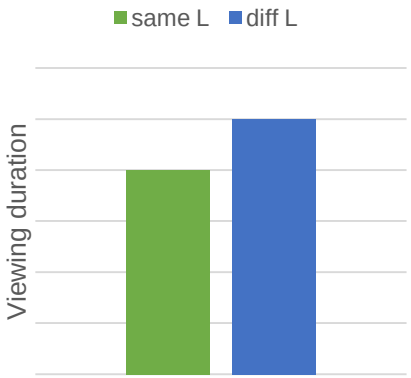
кокоса ‘coconut, **sg, gen**’	колена ‘root, **sg, gen**’	коридора ‘hall, **sg, gen**’
кокоса ‘coconut, sg, gen’	**ко**лена ‘root, sg, gen’	**ко**ридора ‘hall, sg, gen’

Research Question and Predictions

Does length assume linguistic function? If yes:

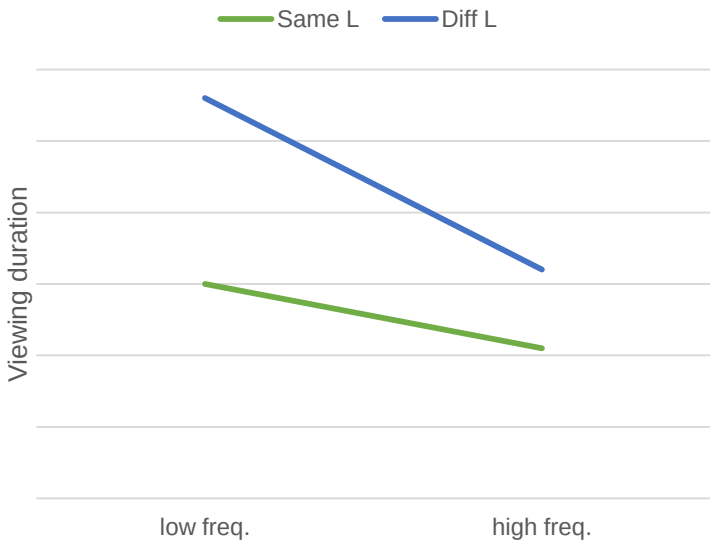
- Direct comparison:
  - Initial landing position: same L = diff L (the length inaccurate preview is just 2 letters longer than target)
  - Viewing durations: same L < diff L





- Interaction with frequency (ilp is included in LMM):

  $(\text{Diff L} - \text{Same L})_{\text{low freq}} > (\text{Diff L} - \text{Same L})_{\text{high freq}}$

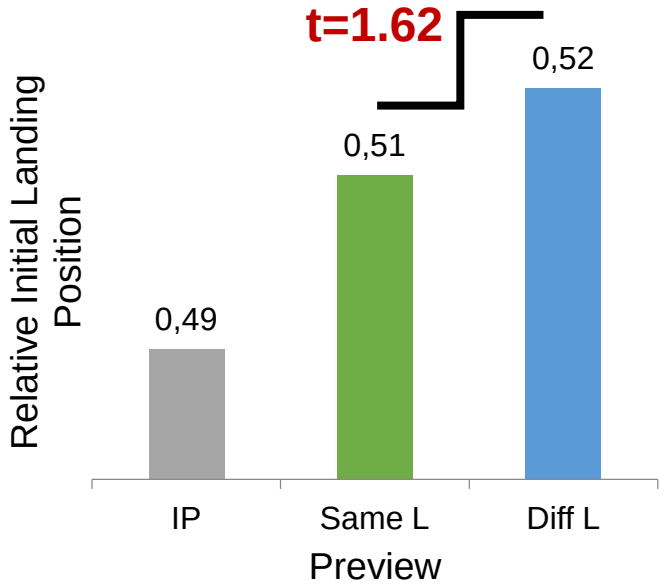


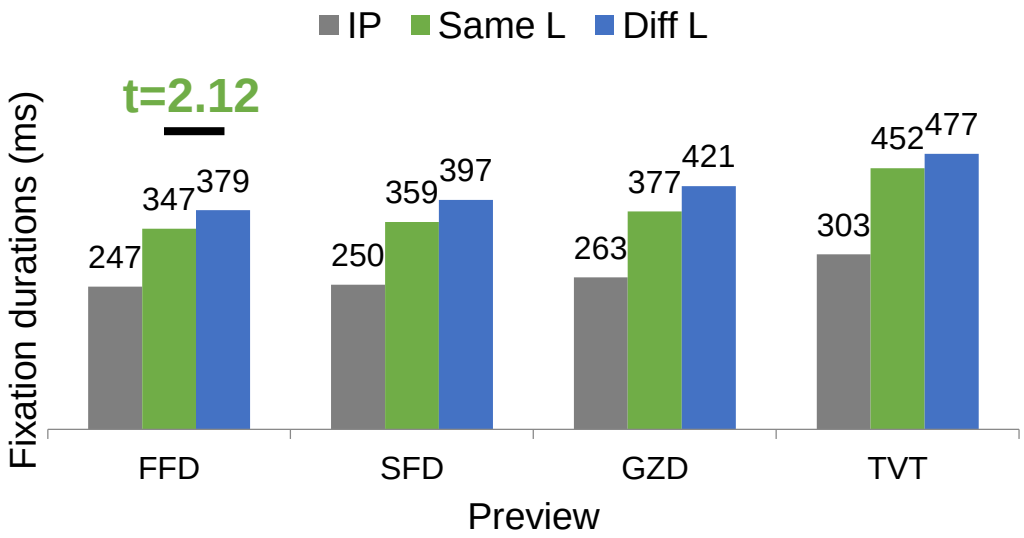
Method

Participants:	24 volunteers (age: 22-28)
Task:	Silent reading, 48 exp. trials (+ 48 fillers)
Design:	Preview (IP, same L, diff L) X Freq (low, high)
Apparatus:	Eyelink 1000+
Ecological validity:	Proportional natural font (Georgia, 18pt), remote mode (without chinrest)
Analysis	LMM with 2 fixed effects. The preview variable is coded as Helmert contrasts

	Example sentence
Identical preview	Созревшие плоды **кокоса** весят в среднем 600 граммов.
Length-accurate preview	Созревшие плоды **колена** весят в среднем 600 граммов.
Length non-accurate preview	Созревшие плоды **коридора** весят в среднем 600 граммов.
Translation	*The ripen fruit of* ***coconut***$_{sg,\ gen}$ ***/ knee***$_{sg,\ gen}$ ***/ hall***$_{sg,\ gen}$ *weigh on average 600 grams.*

Analysis 1





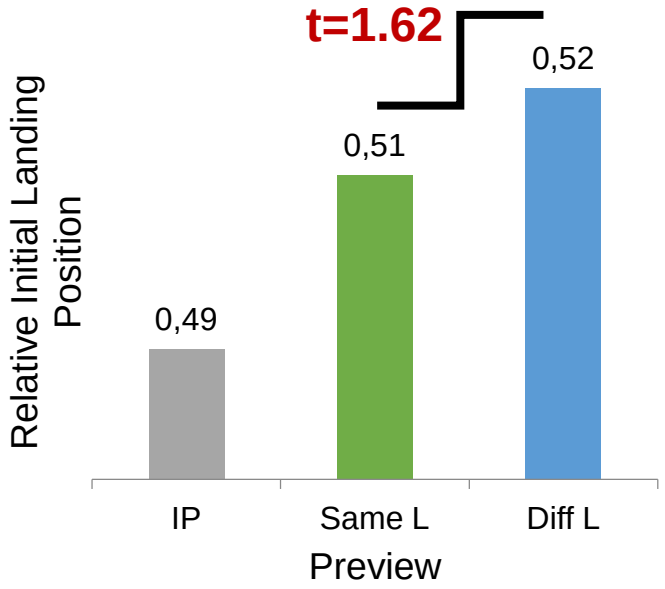
m1.ilp_he_s1 <- lmer(ilp ~ pc_sh*s1 + (1 | id) + (1 | sn), data=em_n0)

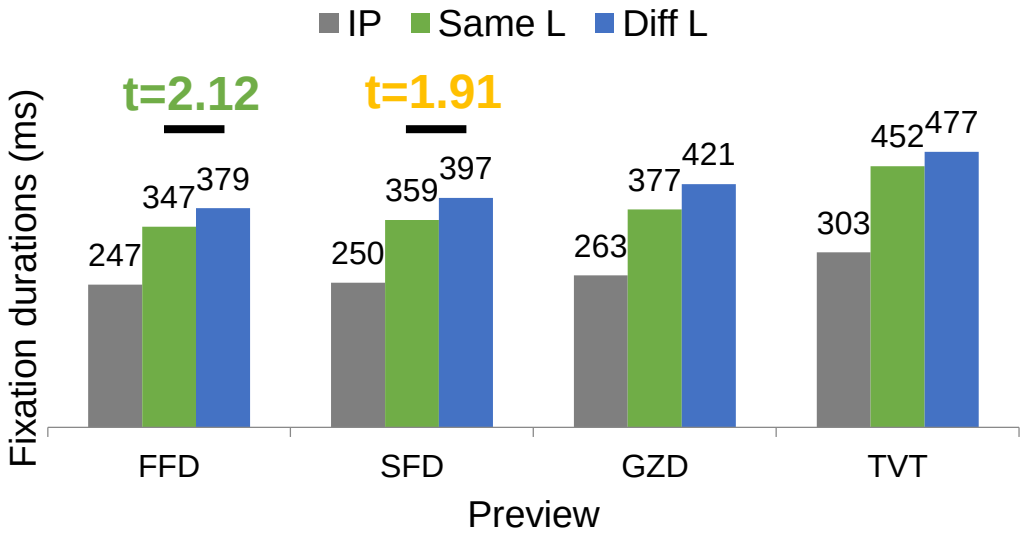
```
Random effects:
 Groups   Name        Variance Std.Dev.
 sn       (Intercept) 0.004092 0.06397
 id       (Intercept) 0.011967 0.10939
 Residual             0.031501 0.17749
Number of obs: 576, groups:  sn, 48; id, 24

Fixed effects:
            Estimate Std. Error t value
(Intercept)  0.490780   0.025557  19.203
pc_sh1       0.015880   0.009749   1.629
pc_sh2      -0.007907   0.005544  -1.426
s1          -0.173950   0.021660  -8.031
pc_sh1:s1    0.021900   0.019831   1.104
pc_sh2:s1   -0.007841   0.011379  -0.689
```

m1.ffd_sh_s1 <- lmer(log(ffd) ~ pc_sh*s1 + (1 | id) + (1 | sn), data=em_n0)

```
Random effects:
 Groups   Name        Variance Std.Dev.
 sn       (Intercept) 0.007235 0.08506
 id       (Intercept) 0.030727 0.17529
 Residual             0.123264 0.35109
Number of obs: 573, groups:  sn, 48; id, 24

Fixed effects:
            Estimate Std. Error t value
(Intercept)  5.70954    0.04113  138.81
pc_sh1       0.04090    0.01930    2.12
pc_sh2      -0.11285    0.01094  -10.32
s1           0.07053    0.03792    1.86
pc_sh1:s1    0.06054    0.03919    1.54
pc_sh2:s1    0.04034    0.02240    1.80
```

Analysis 1





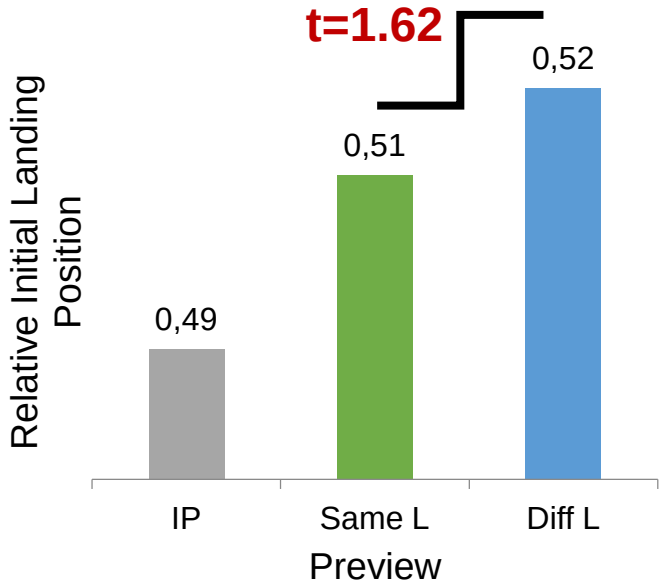
m1.ilp_he_s1 <- lmer(ilp ~ pc_sh*s1 + (1 | id) + (1 | sn), data=em_n0)

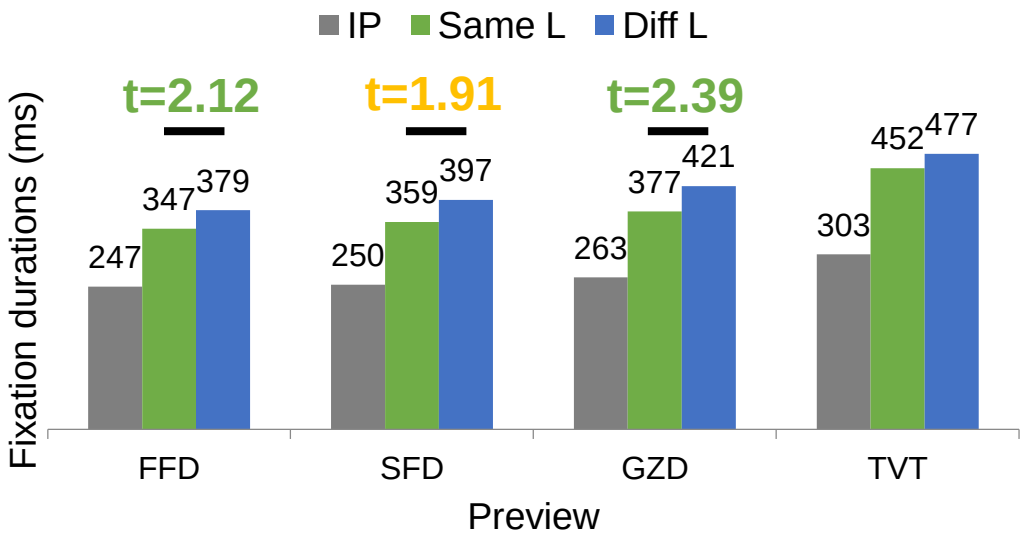
```
Random effects:
 Groups   Name        Variance Std.Dev.
 sn       (Intercept) 0.004092 0.06397
 id       (Intercept) 0.011967 0.10939
 Residual             0.031501 0.17749
Number of obs: 576, groups:  sn, 48; id, 24

Fixed effects:
            Estimate Std. Error t value
(Intercept)  0.490780   0.025557  19.203
pc_sh1       0.015880   0.009749   1.629
pc_sh2      -0.007907   0.005544  -1.426
s1          -0.173950   0.021660  -8.031
pc_sh1:s1    0.021900   0.019831   1.104
pc_sh2:s1   -0.007841   0.011379  -0.689
```

m1.sfd_sh_s1 <- lmer(log(sfd) ~ pc_sh*s1 + (1 | id) + (1 | sn), data=em_n0)

```
Random effects:
 Groups   Name        Variance Std.Dev.
 sn       (Intercept) 0.01235  0.1111
 id       (Intercept) 0.02794  0.1672
 Residual             0.11285  0.3359
Number of obs: 491, groups:  sn, 48; id, 24

Fixed effects:
            Estimate Std. Error t value
(Intercept)  5.74749    0.04155  138.34
pc_sh1       0.03951    0.02072    1.91
pc_sh2      -0.12459    0.01137  -10.96
s1           0.10261    0.04287    2.39
pc_sh1:s1    0.02161    0.04199    0.51
pc_sh2:s1    0.03859    0.02321    1.66
```

Analysis 1





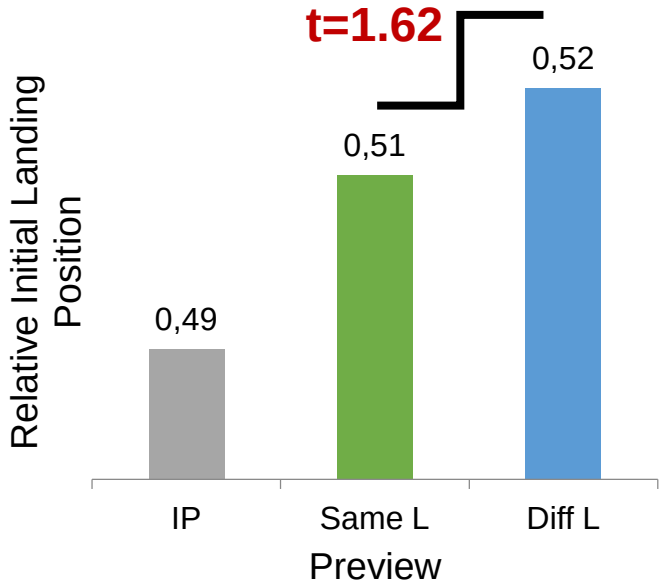
m1.ilp_he_s1 <- lmer(ilp ~ pc_sh*s1 + (1 | id) + (1 | sn), data=em_n0)

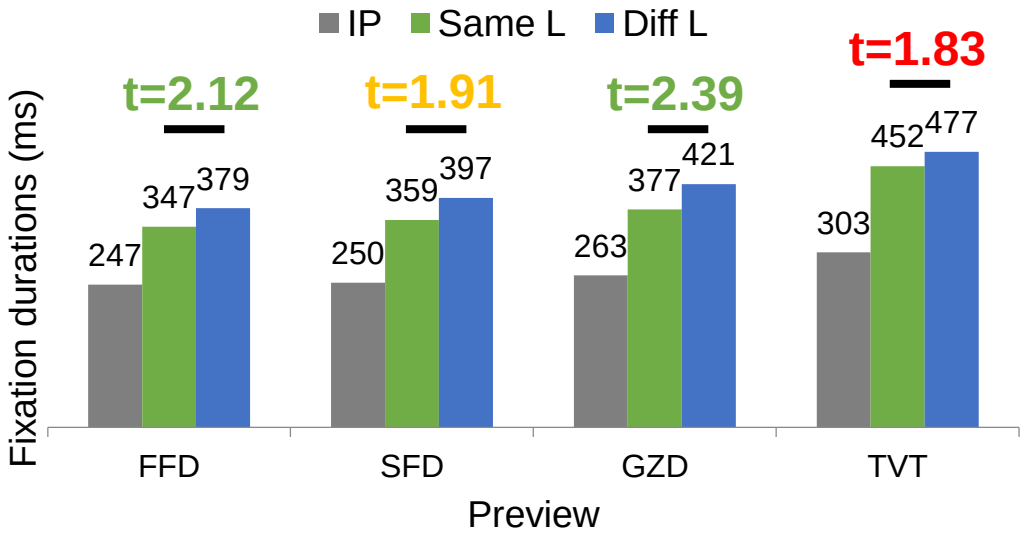
```
Random effects:
 Groups   Name        Variance Std.Dev.
 sn       (Intercept) 0.004092 0.06397
 id       (Intercept) 0.011967 0.10939
 Residual             0.031501 0.17749
Number of obs: 576, groups:  sn, 48; id, 24

Fixed effects:
            Estimate Std. Error t value
(Intercept)  0.490780   0.025557  19.203
pc_sh1       0.015880   0.009749   1.629
pc_sh2      -0.007907   0.005544  -1.426
s1          -0.173950   0.021660  -8.031
pc_sh1:s1    0.021900   0.019831   1.104
pc_sh2:s1   -0.007841   0.011379  -0.689
```

m1.gzd_sh_sk <- lmer(log(gzd) ~ pc_sh*s1 + (1 | id) + (1 | sn), data=em_n0)

```
Random effects:
 Groups   Name        Variance Std.Dev.
 sn       (Intercept) 0.01449  0.1204
 id       (Intercept) 0.02664  0.1632
 Residual             0.11982  0.3461
Number of obs: 571, groups:  sn, 48; id, 24

Fixed effects:
            Estimate Std. Error t value
(Intercept)  5.80350    0.04094  141.76
pc_sh1       0.04579    0.01914    2.39
pc_sh2      -0.13005    0.01083  -12.01
s1           0.13377    0.04185    3.20
pc_sh1:s1    0.03068    0.03894    0.79
pc_sh2:s1    0.03775    0.02220    1.70
```

Analysis 1





m1.ilp_he_s1 <- lmer(ilp ~ pc_sh*s1 + (1 | id) + (1 | sn), data=em_n0)

```
Random effects:
 Groups   Name        Variance Std.Dev.
 sn       (Intercept) 0.004092 0.06397
 id       (Intercept) 0.011967 0.10939
 Residual             0.031501 0.17749
Number of obs: 576, groups:  sn, 48; id, 24

Fixed effects:
            Estimate Std. Error t value
(Intercept)  0.490780   0.025557  19.203
pc_sh1       0.015880   0.009749   1.629
pc_sh2      -0.007907   0.005544  -1.426
s1          -0.173950   0.021660  -8.031
pc_sh1:s1    0.021900   0.019831   1.104
pc_sh2:s1   -0.007841   0.011379  -0.689
```

m1.tvt_sh_sk <- lmer(log(tvt) ~ pc_sh*s1 + (1 | id) + (1 | sn), data=em_n0)

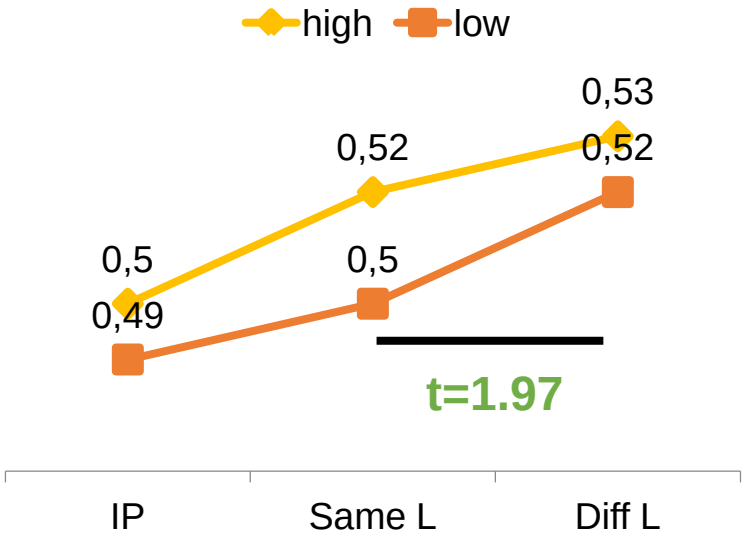
```
Random effects:
 Groups   Name        Variance Std.Dev.
 sn       (Intercept) 0.01869  0.1367
 id       (Intercept) 0.02767  0.1663
 Residual             0.15537  0.3942
Number of obs: 640, groups:  sn, 48; id, 24

Fixed effects:
            Estimate Std. Error t value
(Intercept)  5.93126    0.04291  138.23
pc_sh1       0.03664    0.02003    1.83
pc_sh2      -0.14460    0.01164  -12.42
s1           0.16973    0.04573    3.71
pc_sh1:s1    0.08570    0.04068    2.11
pc_sh2:s1    0.03589    0.02395    1.50
```

Analysis 1. Results

We didn’t find any difference in ILP but fixation durations in the length-matched condition are significantly shorter (in FFD and GZD) than in the length non-matched condition.

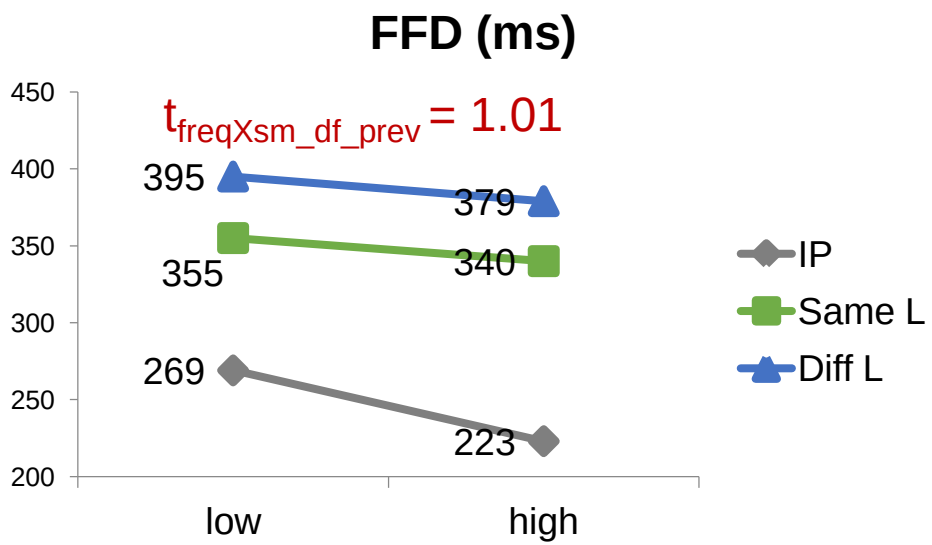
These results confirm the word length as a linguistic function.

Analysis 2. Target Word Frequency X Preview Length



m1.ilp_sh_he <- lmer(ilp ~ freq2*pc_sh + (1 | id) + (1 | sn), data=em_n0)

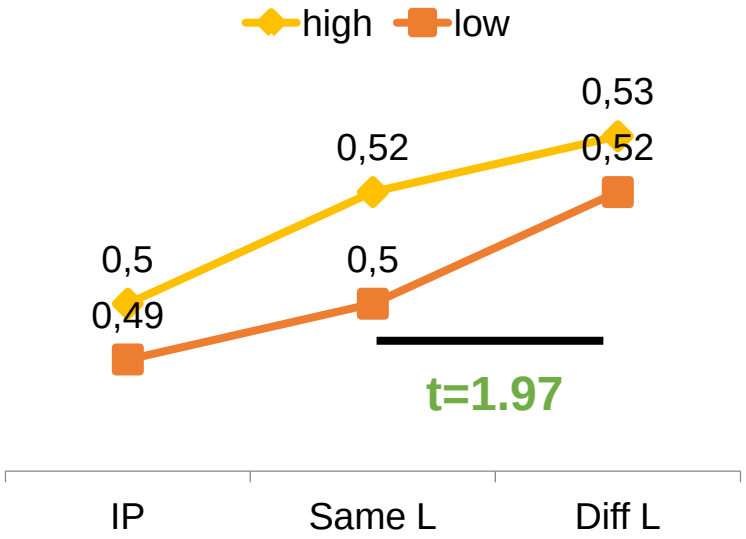
```
Random effects:
 Groups   Name        Variance Std.Dev.
 sn       (Intercept) 0.005769 0.07596
 id       (Intercept) 0.010094 0.10047
 Residual             0.034392 0.18545
Number of obs: 597, groups:  sn, 48; id, 24

Fixed effects:
             Estimate Std. Error t value
(Intercept)  0.515010   0.024582  20.951
freq2       -0.016444   0.026923  -0.611
pc_sh1       0.014003   0.009424   1.486
pc_sh2      -0.009387   0.005477  -1.714
freq2:pc_sh1 -0.004118   0.018940  -0.217
freq2:pc_sh2 -0.001746   0.010930  -0.160
```



m1.ffd_sh_he_s1_ilp <- lmer(log(ffd) ~ freq2*pc_sh*s1*ilp.c + (1 | id) + (1 | sn), data=em_n0)

```
Number of obs: 573, groups:  sn, 48; id, 24

Fixed effects:
             Estimate Std. Error t value
(Intercept)   5.71595    0.04210  135.76
freq2         0.06831    0.04163    1.64
pc_sh1        0.02274    0.02197    1.04
pc_sh2       -0.11452    0.01267   -9.04
s1            0.09631    0.04158    2.32
ilp.c         0.25915    0.09415    2.75
freq2:pc_sh1  0.04443    0.04404    1.01
```

Analysis 2. Target Word Frequency X Preview Length



m1.ilp_sh_he <- lmer(ilp ~ freq2*pc_sh + (1 | id) + (1 | sn), data=em_n0)

```
Random effects:
 Groups   Name        Variance Std.Dev.
 sn       (Intercept) 0.005769 0.07596
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 Residual             0.034392 0.18545
Number of obs: 597, groups:  sn, 48; id, 24

Fixed effects:
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(Intercept)  0.515010   0.024582  20.951
freq2       -0.016444   0.026923  -0.611
pc_sh1       0.014003   0.009424   1.486
pc_sh2      -0.009387   0.005477  -1.714
freq2:pc_sh1 -0.004118   0.018940  -0.217
freq2:pc_sh2 -0.001746   0.010930  -0.160
```
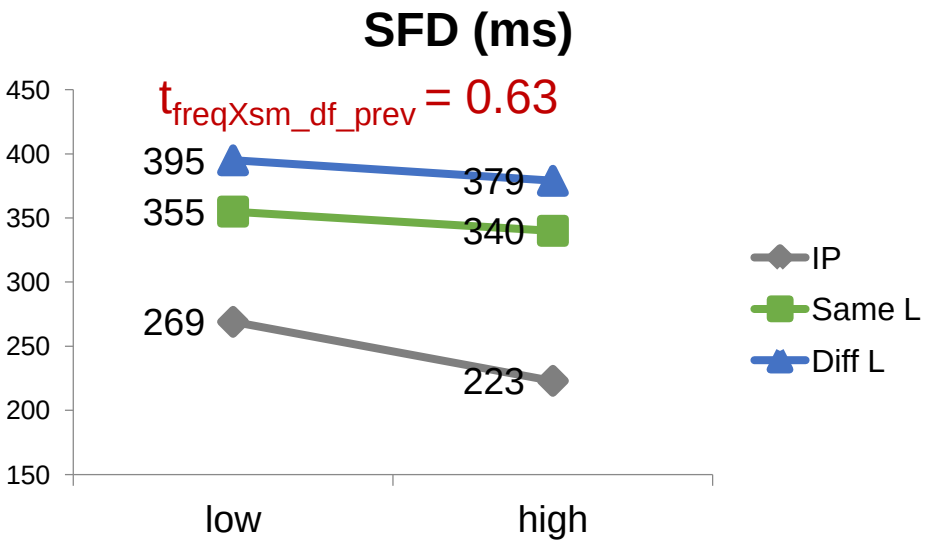
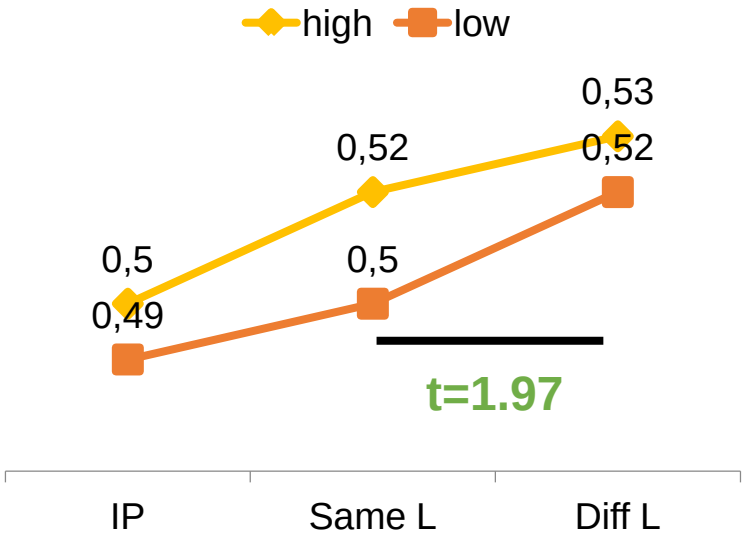



m1.sfd_sh_he_s1_ilp <- lmer(log(sfd) ~ freq2*pc_sh*s1*ilp.c + (1 | id) + (1 | sn), data=em_n0)

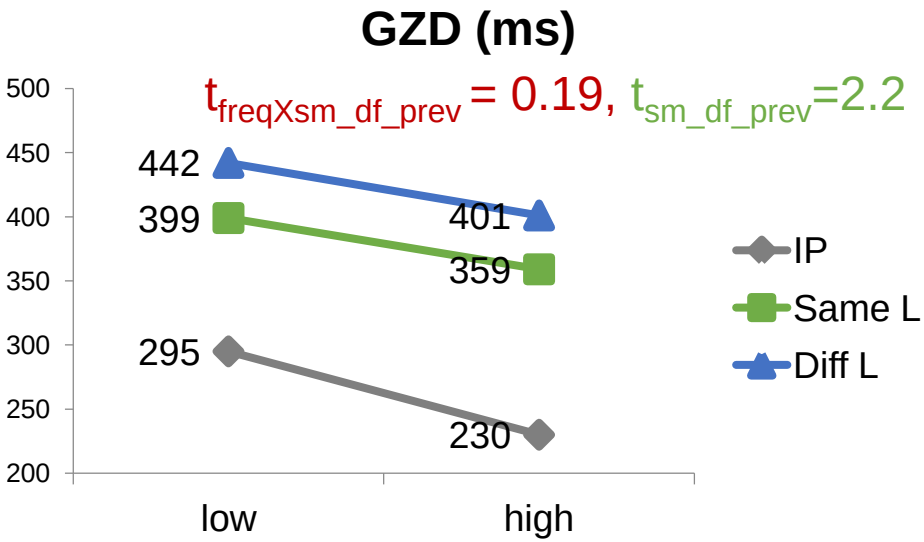
```
Number of obs: 491, groups:  sn, 48; id, 24

Fixed effects:
             Estimate Std. Error t value
(Intercept)  5.748654   0.042097  136.56
freq2        0.086566   0.047736    1.81
pc_sh1       0.034379   0.023763    1.45
pc_sh2      -0.125063   0.013069   -9.57
s1           0.095660   0.046399    2.06
ilp.c        0.091163   0.101000    0.90
freq2:pc_sh1 0.030143   0.047742    0.63
```

Analysis 2. Target Word Frequency X Preview Length



m1.ilp_sh_he <- lmer(ilp ~ freq2*pc_sh + (1 | id) + (1 | sn), data=em_n0)

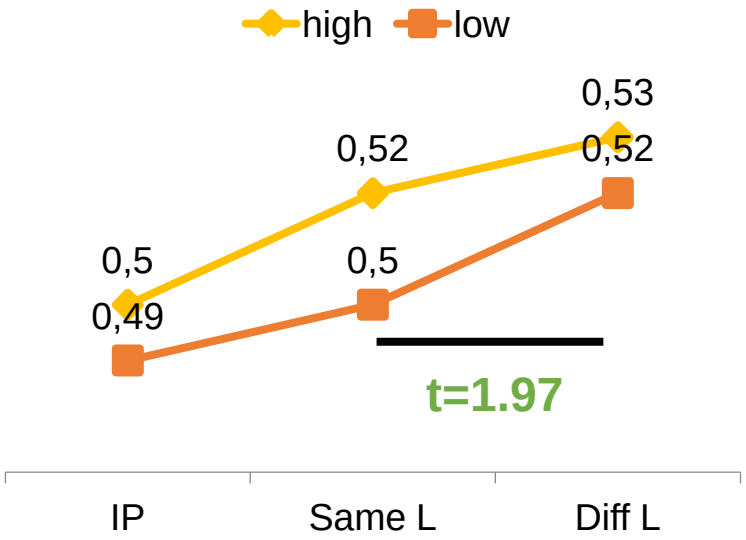
```
Random effects:
 Groups   Name        Variance Std.Dev.
 sn       (Intercept) 0.005769 0.07596
 id       (Intercept) 0.010094 0.10047
 Residual             0.034392 0.18545
Number of obs: 597, groups:  sn, 48; id, 24

Fixed effects:
            Estimate Std. Error t value
(Intercept)  0.515010   0.024582  20.951
freq2       -0.016444   0.026923  -0.611
pc_sh1       0.014003   0.009424   1.486
pc_sh2      -0.009387   0.005477  -1.714
freq2:pc_sh1 -0.004118   0.018940  -0.217
freq2:pc_sh2 -0.001746   0.010930  -0.160
```

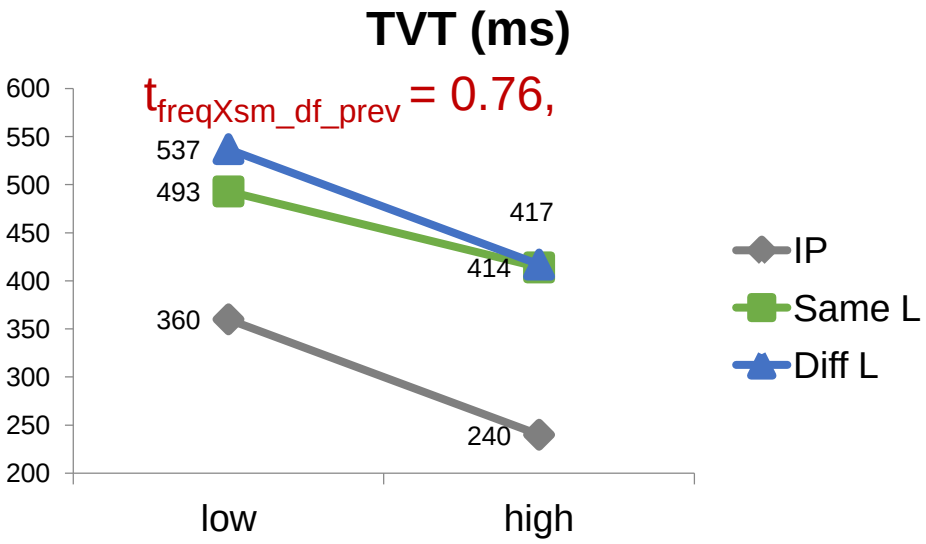


m1.gzd_sh_he_sk_ilp <- lmer(log(gzd) ~ freq2*pc_sh*s1*ilp.c + (1 | id) + (1 | sn), data=em_n0)

```
Number of obs: 571, groups:  sn, 48; id, 24

Fixed effects:
            Estimate Std. Error t value
(Intercept) 5.800231   0.040468  143.33
freq2       0.105005   0.046314    2.27
pc_sh1      0.048601   0.022063    2.20
pc_sh2     -0.133342   0.012679  -10.52
s1          0.088406   0.044745    1.98
ilp.c      -0.103391   0.094680   -1.09
freq2:pc_sh1 0.008298   0.044304    0.19
```

Analysis 2. Target Word Frequency X Preview Length





m1.ilp_sh_he <- lmer(ilp ~ freq2*pc_sh + (1 | id) + (1 | sn), data=em_n0)

```
Random effects:
 Groups   Name        Variance Std.Dev.
 sn       (Intercept) 0.005769 0.07596
 id       (Intercept) 0.010094 0.10047
 Residual             0.034392 0.18545
Number of obs: 597, groups:  sn, 48; id, 24

Fixed effects:
            Estimate Std. Error t value
(Intercept)  0.515010   0.024582  20.951
freq2       -0.016444   0.026923  -0.611
pc_sh1       0.014003   0.009424   1.486
pc_sh2      -0.009387   0.005477  -1.714
freq2:pc_sh1 -0.004118   0.018940  -0.217
freq2:pc_sh2 -0.001746   0.010930  -0.160
```

m1.tvt_sh_he_sk_ilp <- lmer(log(tvt) ~ freq2*pc_sh*s1*ilp.c + (1 | id) + (1 | sn), data=em_n0)

```
Number of obs: 576, groups:  sn, 48; id, 24

Fixed effects:
            Estimate Std. Error t value
(Intercept)  5.928041   0.043108  137.52
freq2        0.221872   0.046383    4.78
pc_sh1       0.021720   0.023663    0.92
pc_sh2      -0.149809   0.013647  -10.98
s1           0.094033   0.045826    2.05
ilp.c       -0.077362   0.101241   -0.76
freq2:pc_sh1 0.036130   0.047442    0.76
```

Analysis 2. Results

- ILP shifted to the right in the non-accurate condition
- There is no evidence of interaction between preview type and word frequency in all fixation measures
- **But** there is the main effect of the preview type in GD even when we have the ILP in the model

These results are rather controversial and may be not reliable

Checklist for a new boundary paradigm experiment testing LCH

- High refreshing rate of the display
- Rather long and frequent pretarget words
  - In my case: 19 of the 48 sentences have a short word before the target so I have to add the extra variable in my model
- Same target region length in all conditions
    - Созревшие плоды **коридора** весят в среднем 600 граммов. ->
    - Созревшие плоды **кокоса** весят в среднем 600 граммов.
  - `Monospaced font` (but Ecological validity)
- Controlling posttarget words (parafoveal-on-foveal effect)
- More sentences and subjects
  - In my case: overall 1152 trials (48 sent * 24 subj), but after filtering only 692 data points left (60%).

Thank you for your attention