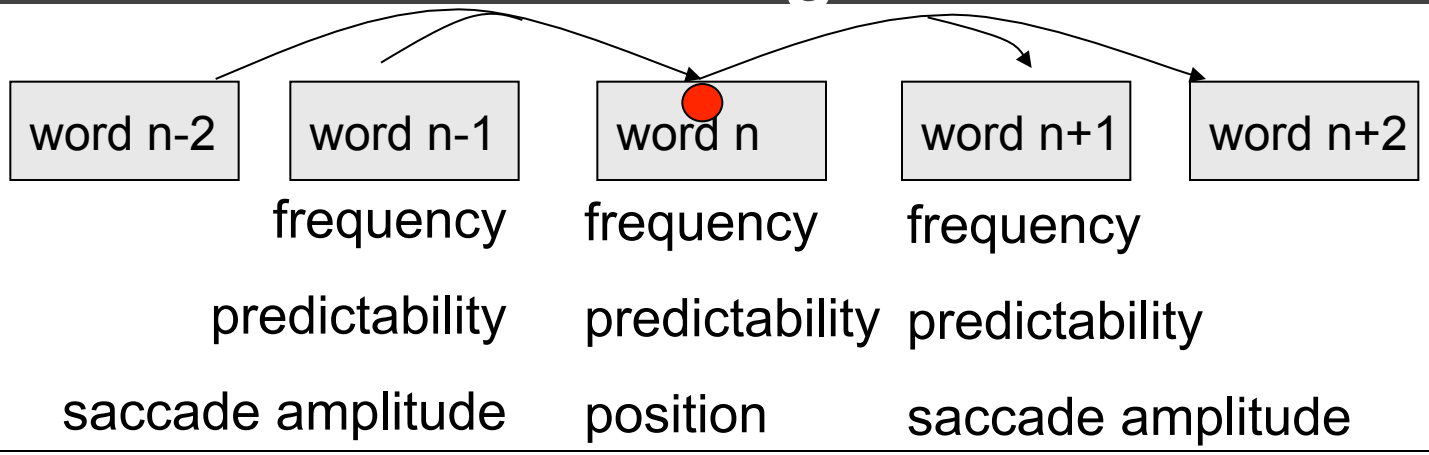
Distributed Processing Across Reading Fixations

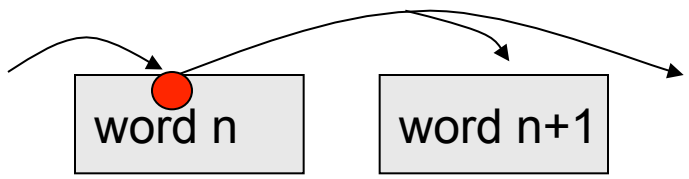


Dep. variable	first-pass single-fixation durations (over 90 000)
Word frequency	DWDS corpus (125 million words)
Word predictability	prob(guessing word n | words 1 to n-1); 83 guesses/wrd
Fixation data	222 subjects, collapsing across 9 experiments
Analysis	linear mixed-effect models, using *lmer* (lme4 package in R)

CONTEXT	**experiments**	**quasi-experiments**
@ reader	instruction, bitebar, ...	age, expertise, ...
@ sentence/word	preview, contrast, ...	grammar, lexical status, ...

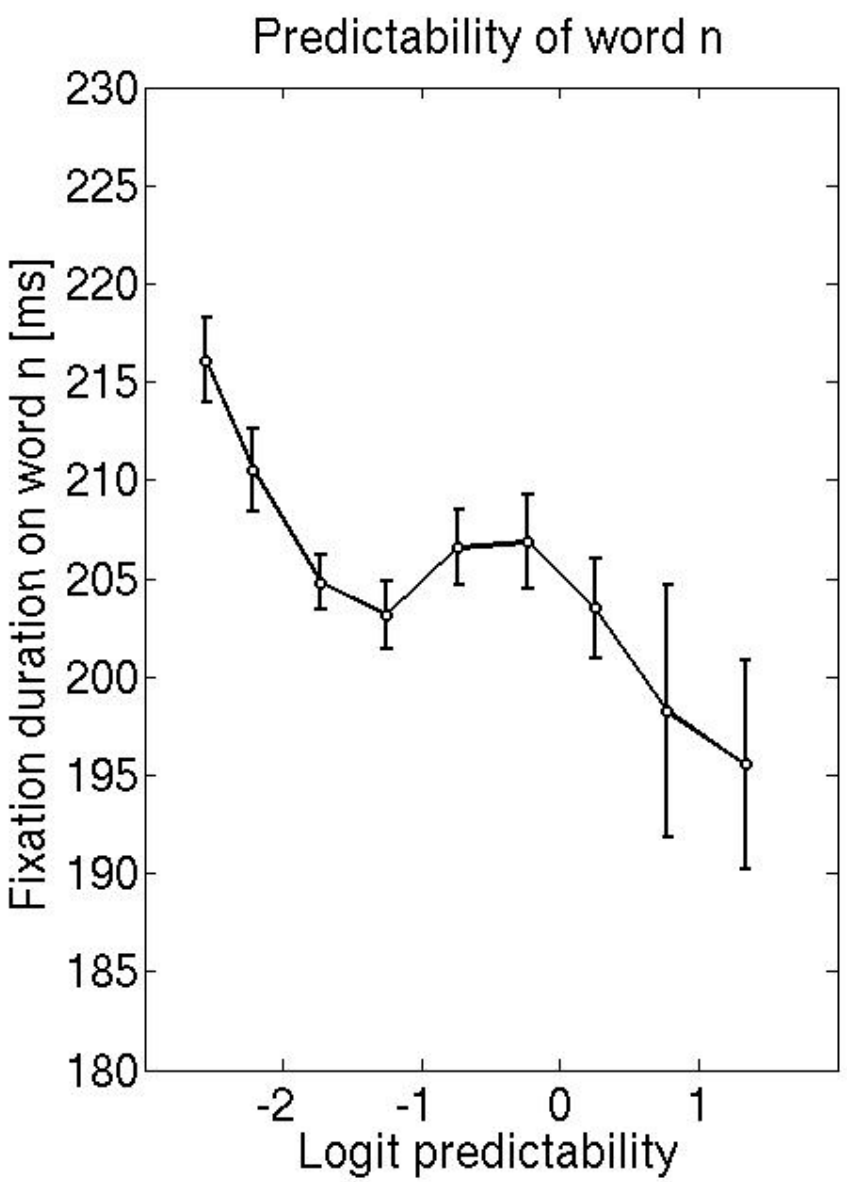
I. Predictability of words in sentences

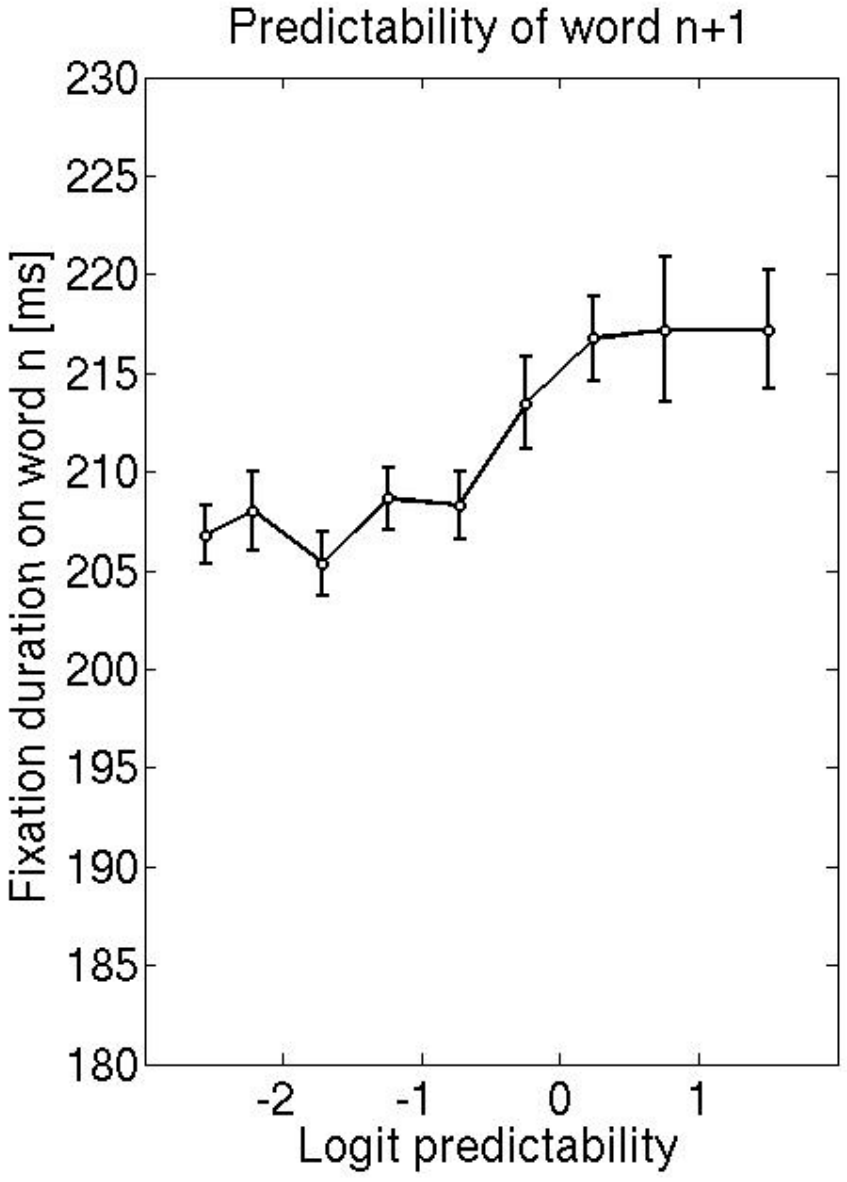
Predictability of the next word in reading increases fixation duration on the earlier word (Method: multivariate statistics; Kliegl et al., 2006)

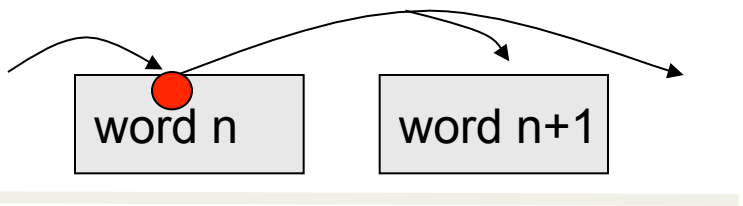


Successor Effect of Memory

Predictability (Inverted) of n+1

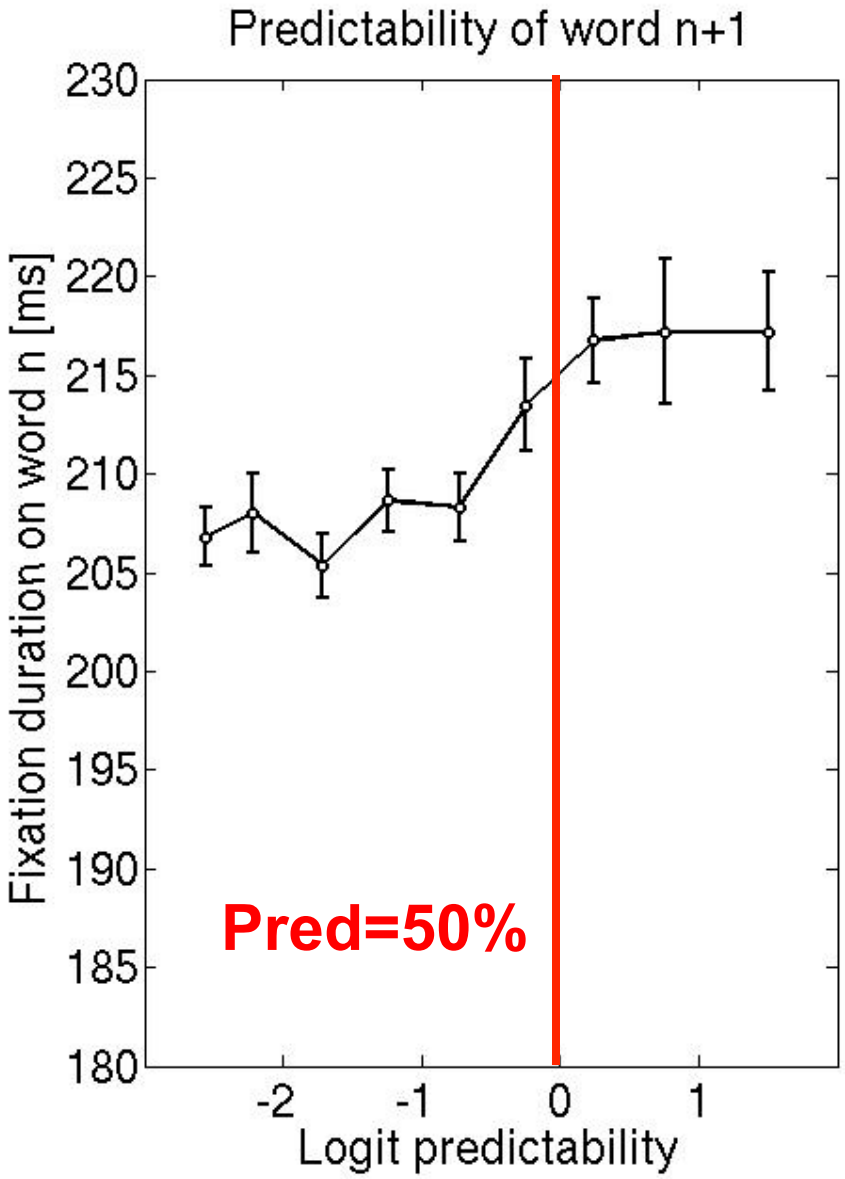






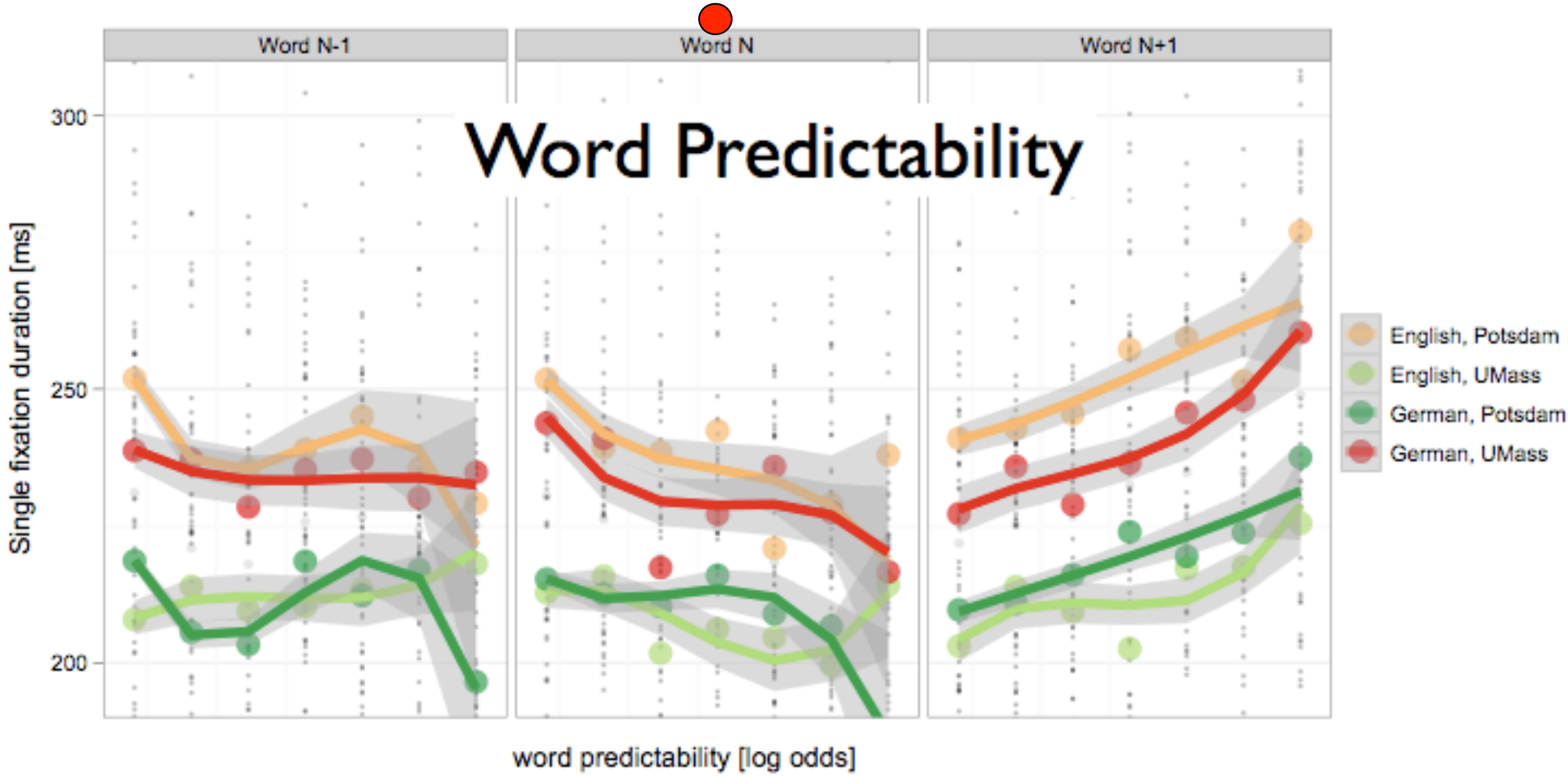
Successor Effect of Memory

Predictability (Inverted) of n+1



- **Anticipatory retrieval of word n+1**
- - some words can be **predicted** from sentence context
- need no (or only minimal) visual information for recognition
- tend to be skipped, approached with longer saccades (O'Regan, '79)
- **word n+1** partially processed during fixation on **word n**
- **predictability effect reduced, not eliminated if word n+1 is fixated**

Bilingual Reading of German and English Sentences



- 30 English-German readers; 30 German-English readers
- UMass Amherst Corpus (48 sentences; Schilling et al., 1998; Reichle et al., 1998)
- Potsdam Sentence Corpus (144 sentences; Kliegl et al., 2004)

Features of Chinese Script

- Example

  医生提醒市民们傍晚乘凉时尽量少去草丛茂密的地方。

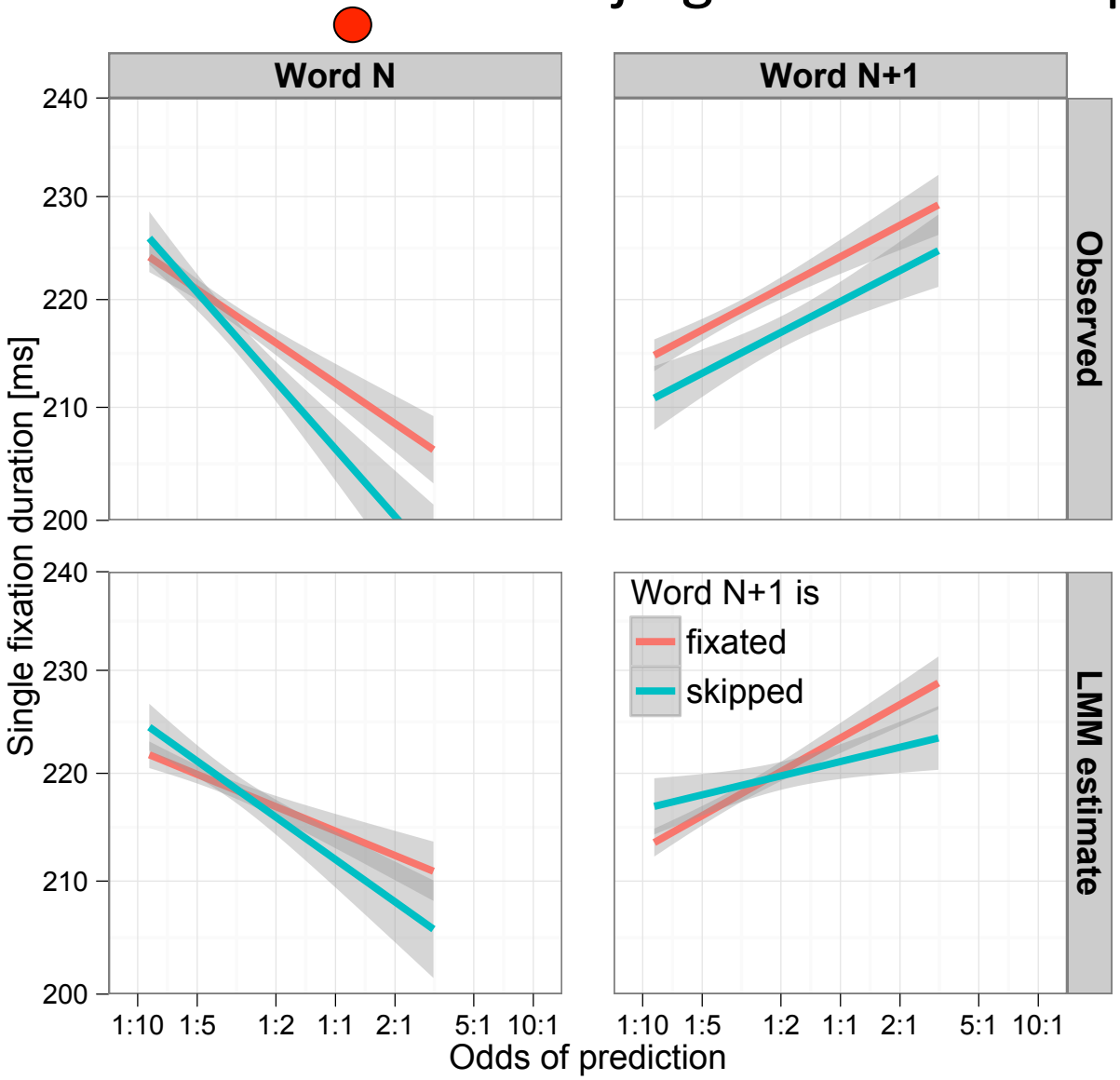
  The doctor reminded the citizens that they should avoid lush grass

- Each character takes same amount of horizontal extent with different levels of visual complexity.

- The majority of linguistically defined Chinese words are one and two characters in length (Yu et al., 1985).

- A Chinese character typically occupies the space of 3 letters in alphabetic languages (i.e., Tsai & McCokie, 1995), but carries comparatively more information about meaning.

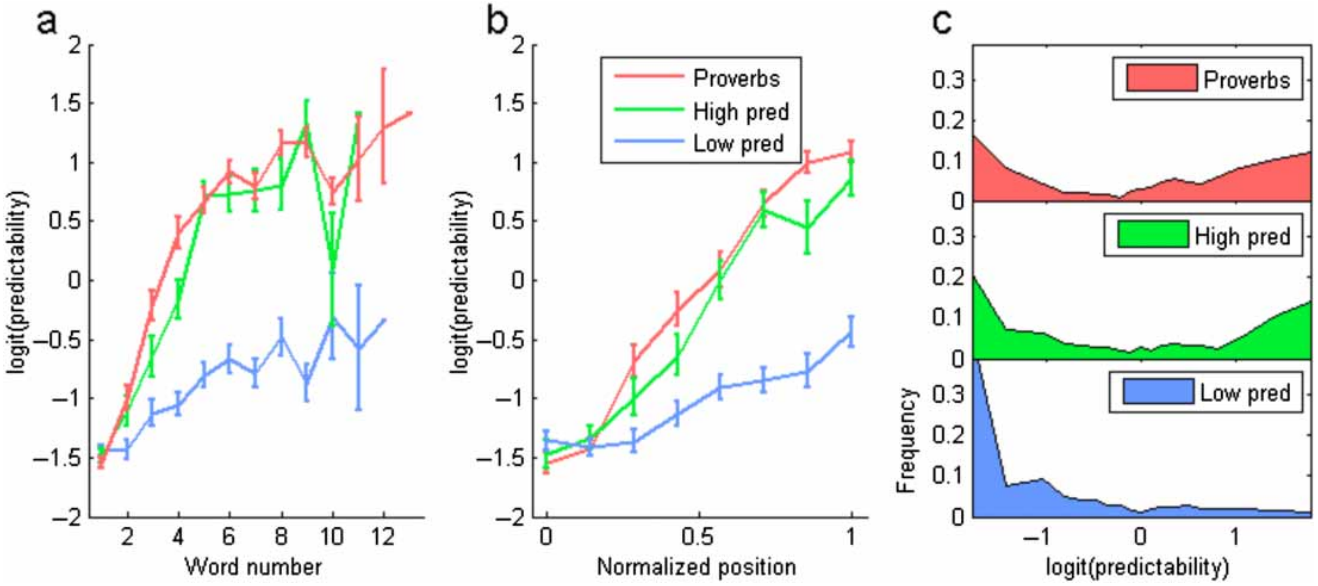
Reading Sentences in Simplified Chinese: Beijing Sentence Corpus

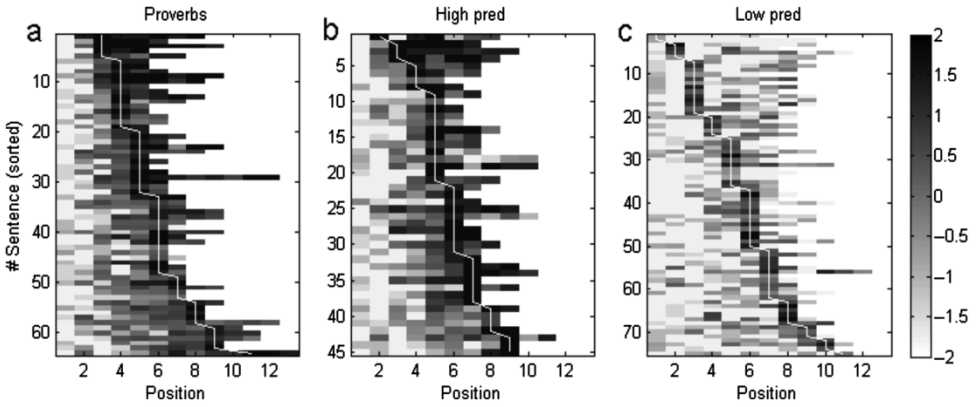


- 60 readers of Simplified Chinese (Beijing)
- 150 sentences
- 32, 414 single-fixation durations (firstpass reading)

Kliegl, Yan, et al. (2012)

Reading Spanish Proverbs and High and Low Predictable Sentences: **Max-Jump of Predictability**



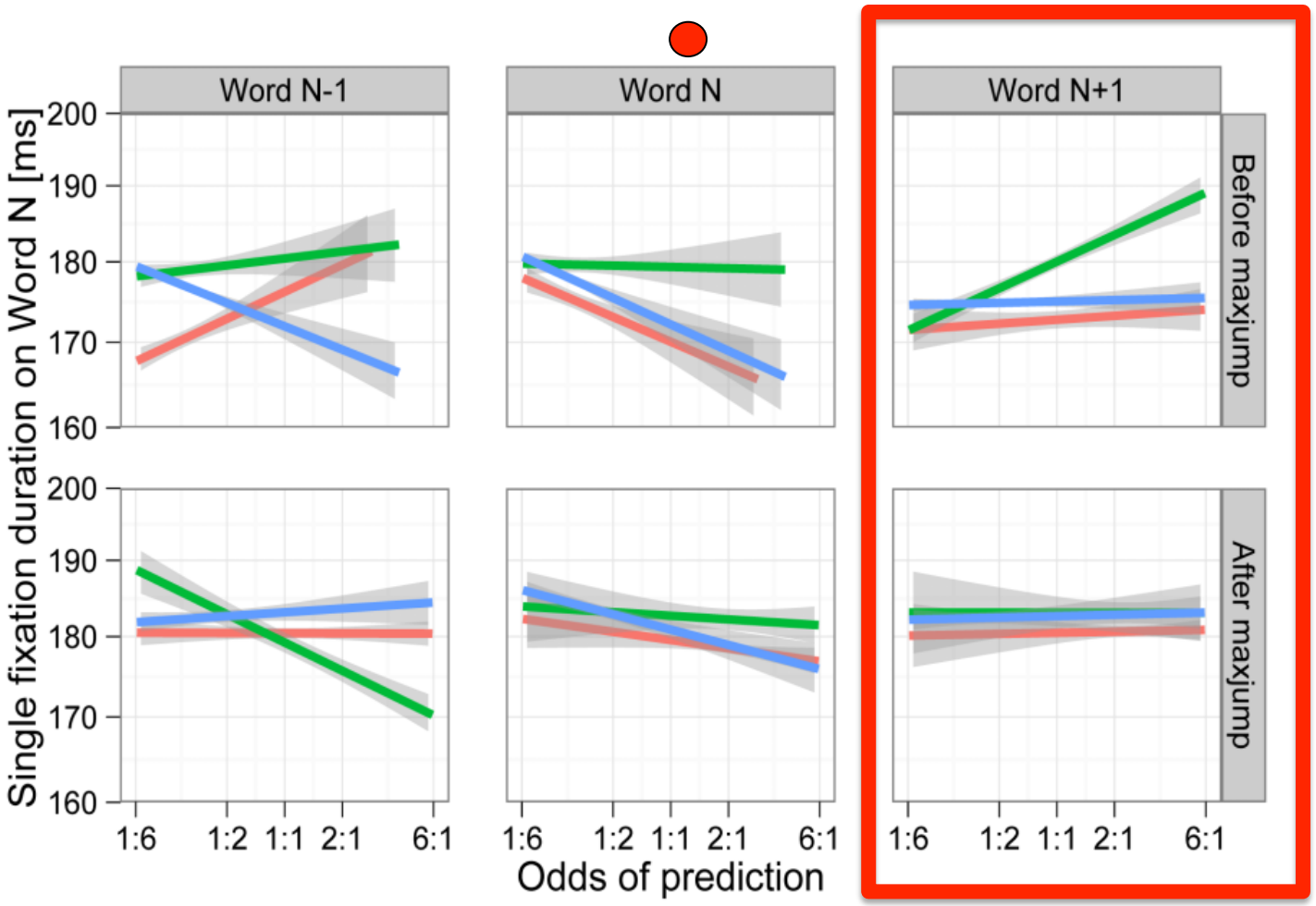


- 41 Argentinian readers of Spanish (Bahia Blanca & Buenos Aires)
- 184 sentences (75 low predictable, 45 high predictable, 64 proverbs)
- 19,550 single-fixation durations (firstpass reading)

Low predictable
High predictable
Proverb

Fernández, Shalom, Kliegl, & Sigman (2014)

Reading Spanish Proverbs and High and Low Predictable Sentences: **Before and After Pred-Jump**



41 Argentinian readers of Spanish (Bahia Blanca & Buenos Aires)

184 sentences (75 low predictable, 45 high predictable, 64 proverbs)

19,550 single-fixation durations (firstpass reading)

Low predictable
High predictable
Proverb

Fernández, Shalom, Kliegl, & Sigman (2014)

II. Age of reader and visibility of text

Reinhold Kliegl, Antje Nuthmann, Jochen Laubrock, Sarah Risse, Eike Richter, & Thomas Weskott (in preparation)

~ 250 readers ranging from 16 to 80 years reading 60 paragraphs (~ short newspaper clips)

Nachbarn machten grausigen Fund (NEUKÖLLN.)

Wie die Polizeidirektion 8 in der Sonnenallee gestern meldete, ist das Verbrechen um den lange Zeit als vermisst geltenden Teppichunternehmer Hardy L. nun endlich aufgeklärt. Der Nachbar fand den Mann am Samstag in seiner Wohnung in der Weserstraße. Der Anblick war alles andere als erfreulich. Die Nachbarn wurden zum psychologischen Betreuungsdienst des Sozialamtes in der Parthestraße gebracht.

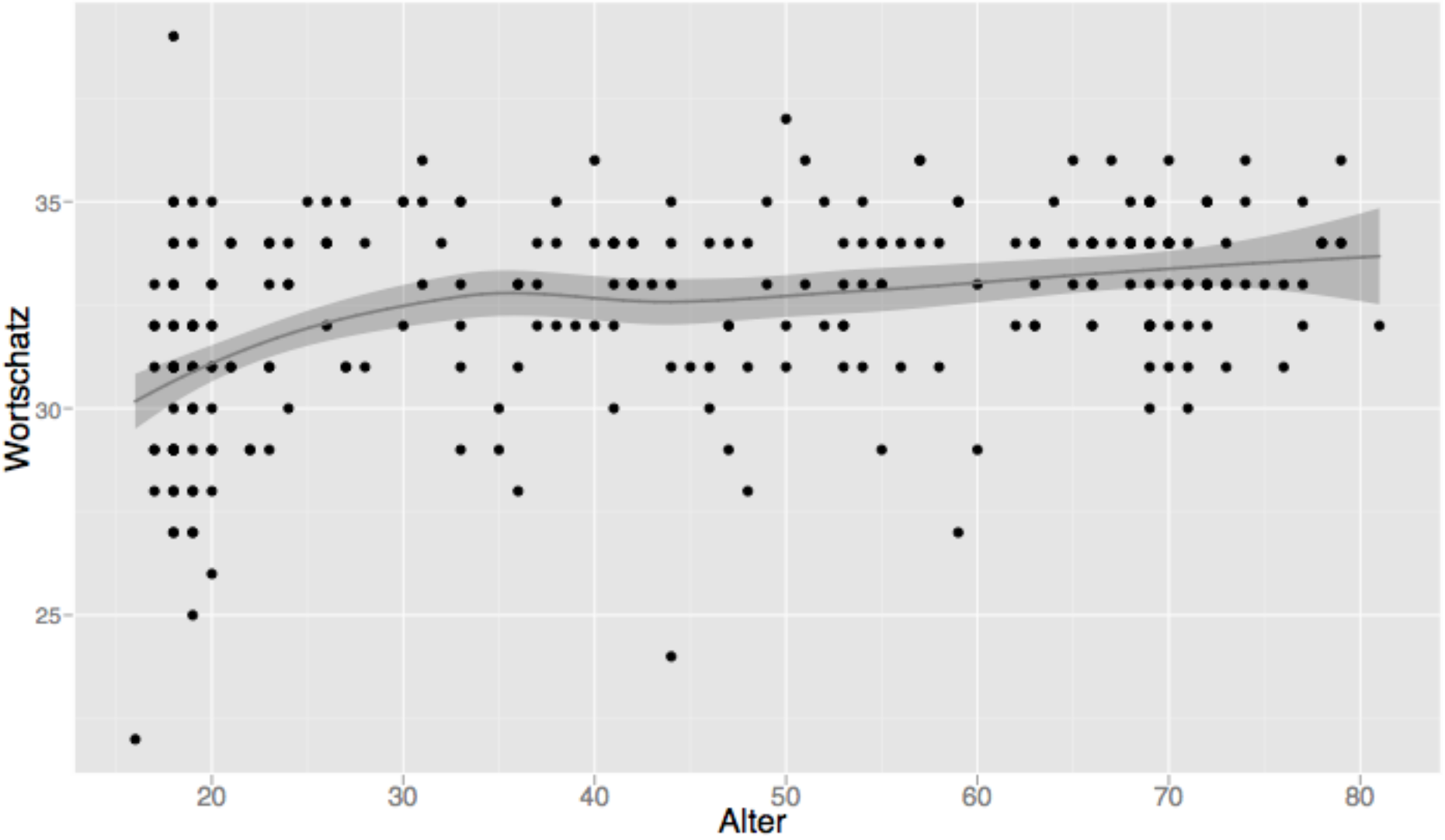
3 Types of question:

... from the beginning : Ist die Polizeidirektion in der Hermannstraße? (**Nein)**

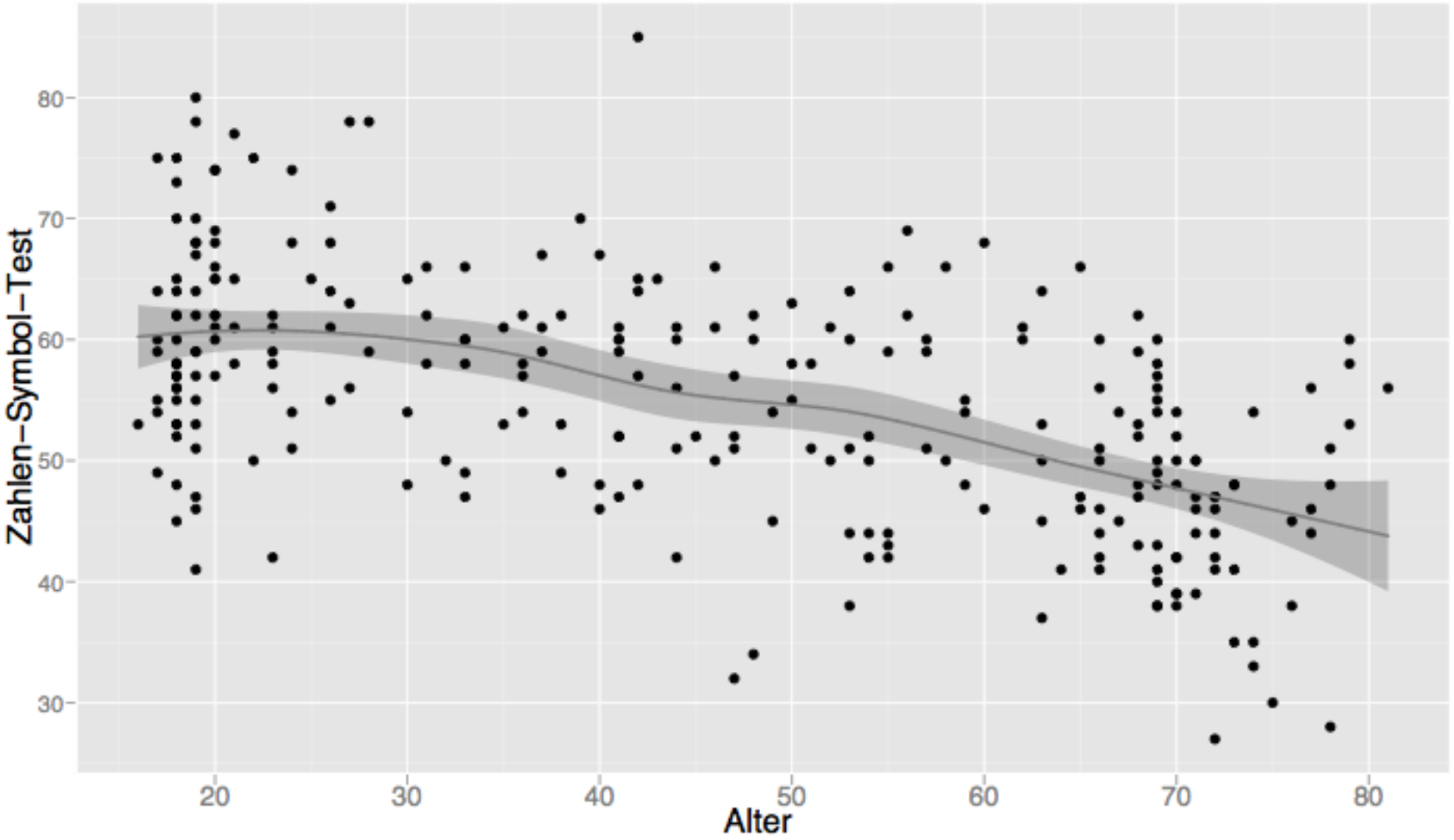
... from critical sentence: Fand der Nachbar den Mann? (**Ja)**

... from end: Wurde der Teppichhändler von seinen Kindern gefunden? **(Nein)**

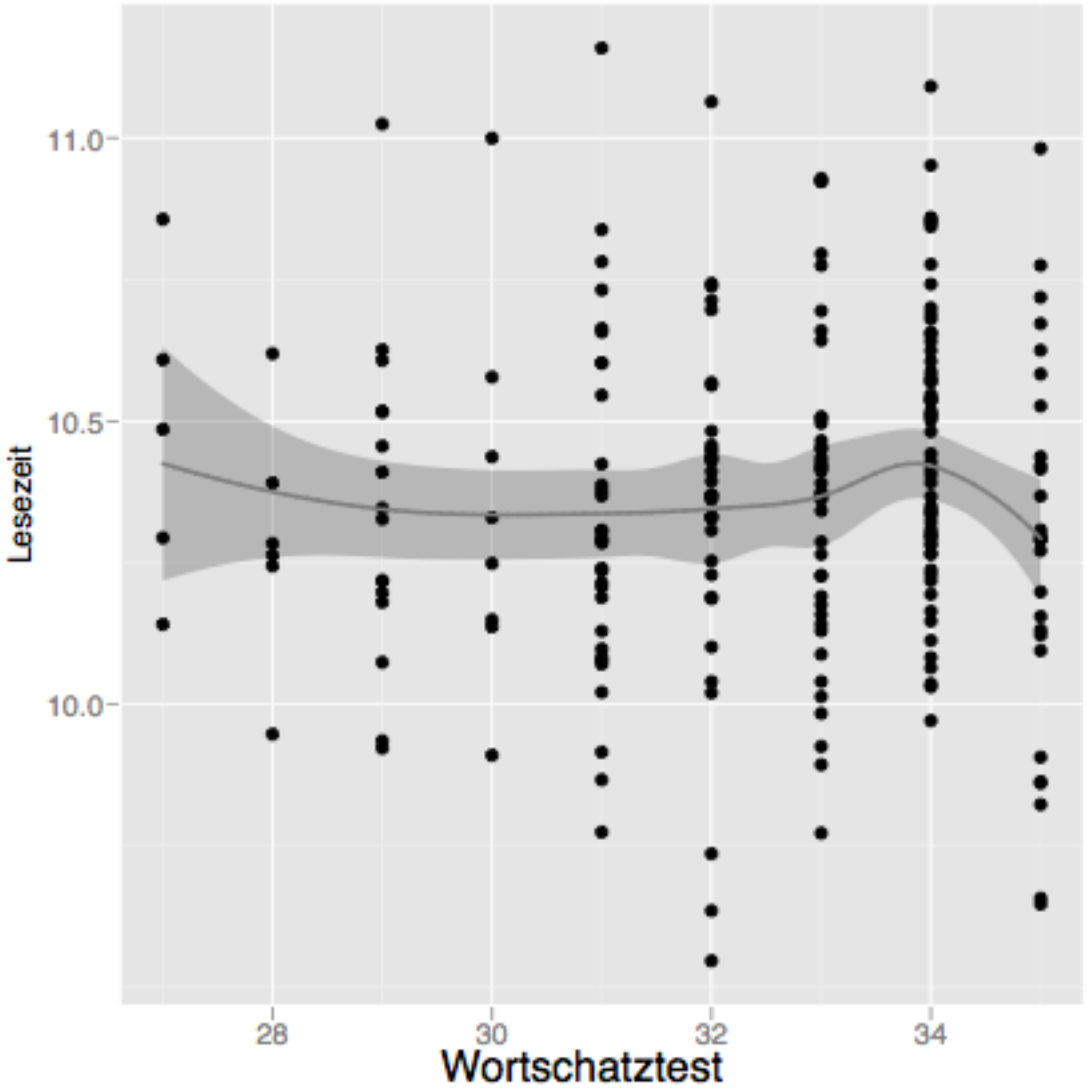
Vocabulary over Age (N ~ 250)



Digit-Symbol Substitution over Age

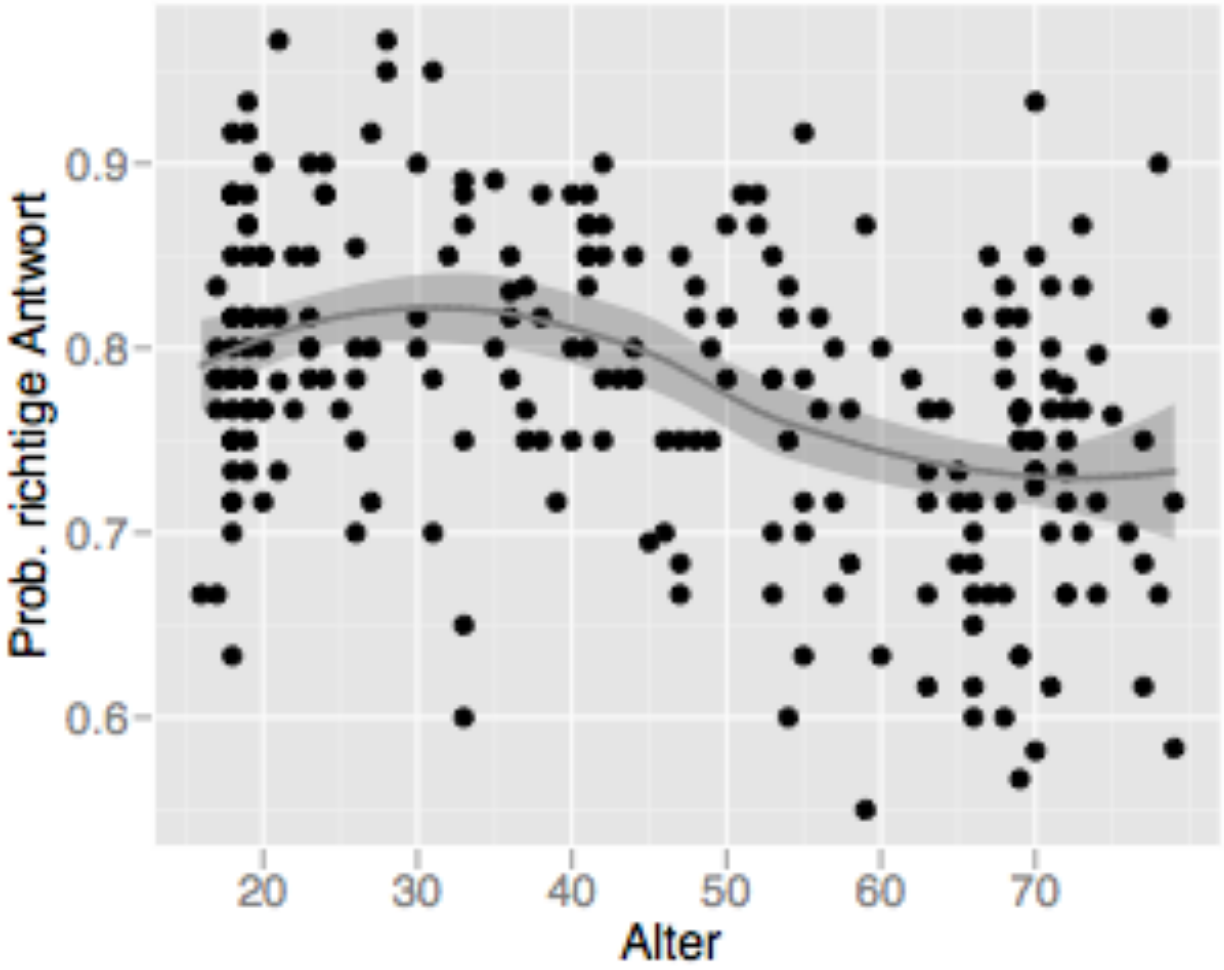


Reading Time over Vocabulary



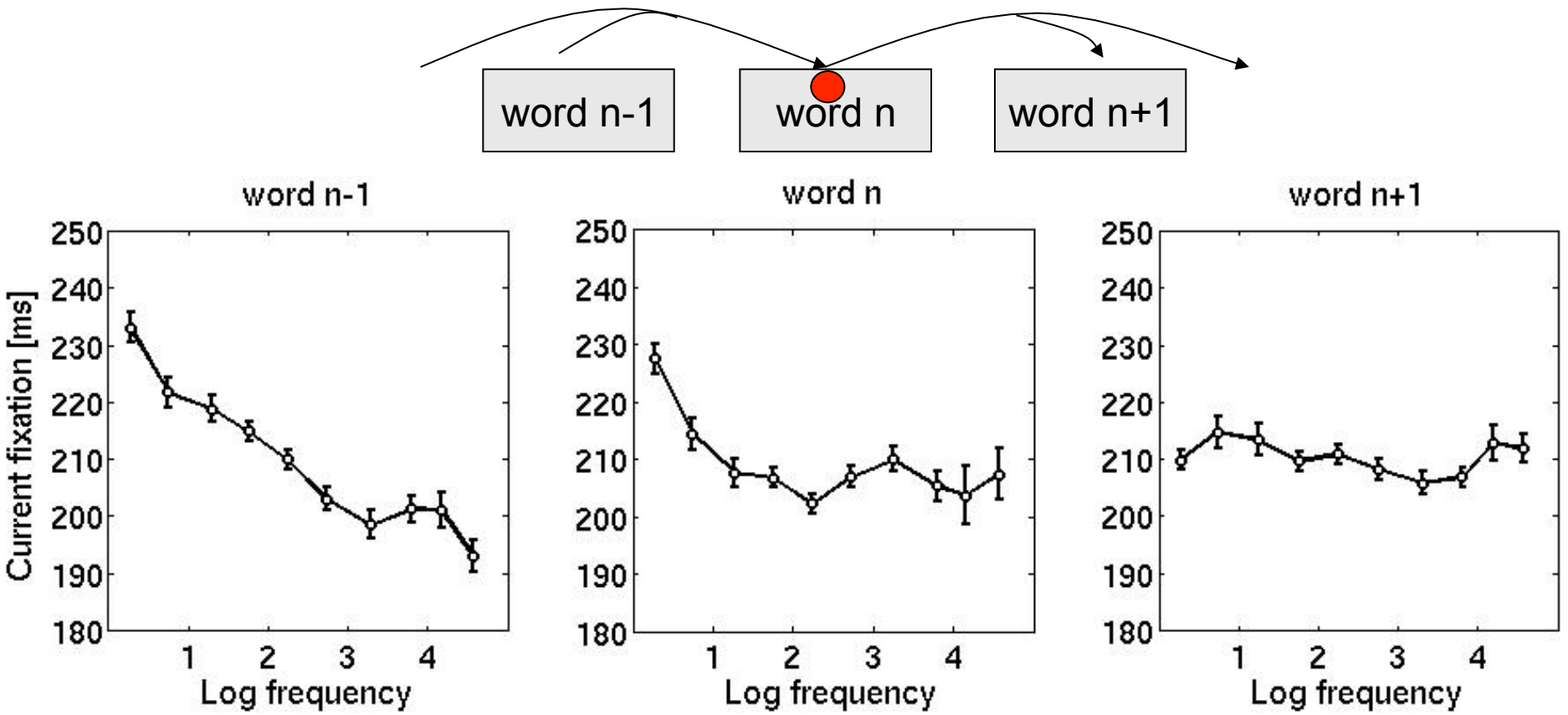
Kern, Weskott, & Kliegl (2008)

Comprehension over Age



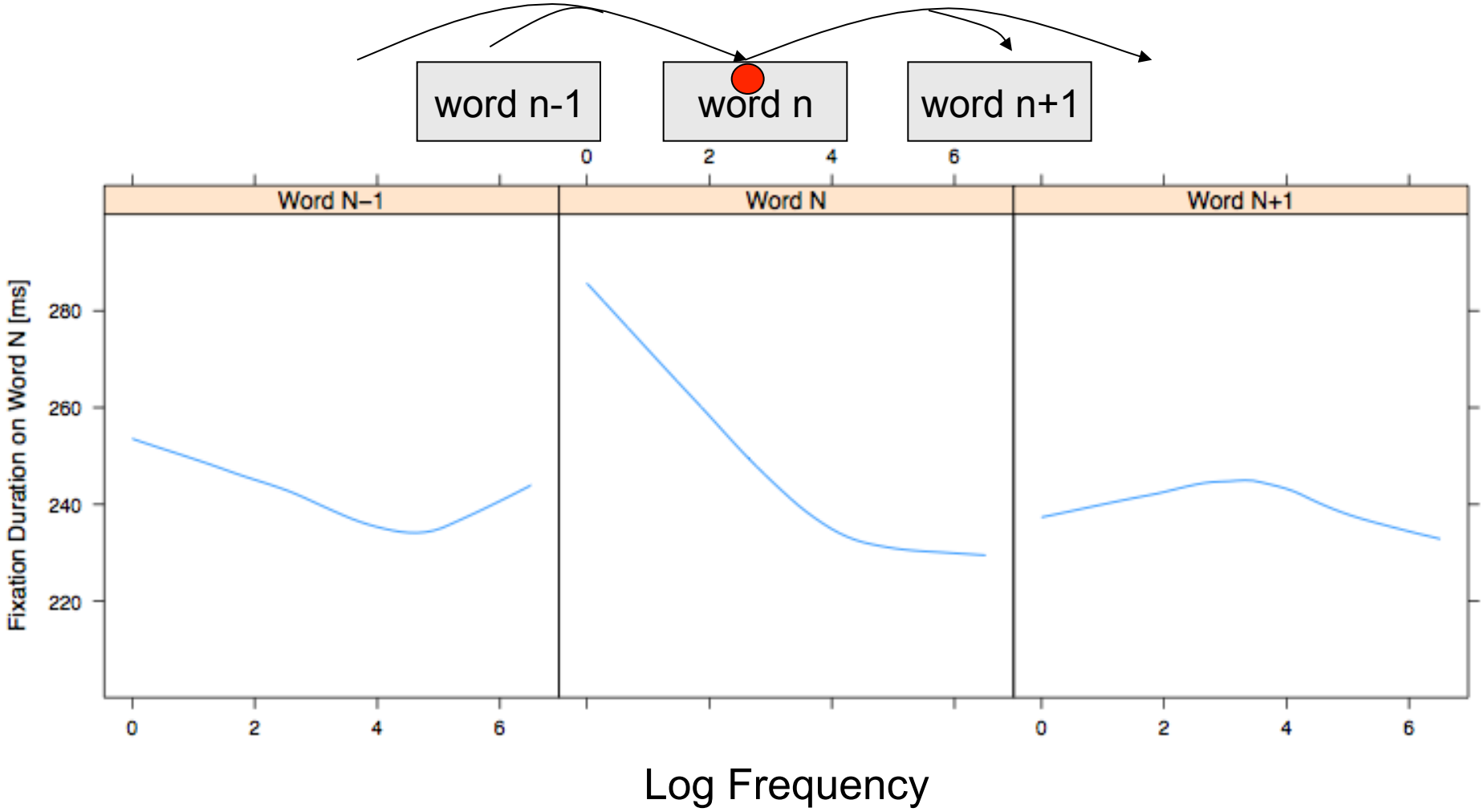
Kern, Weskott, & Kliegl (2008)

Three Word Frequency Effects in Sentence Reading



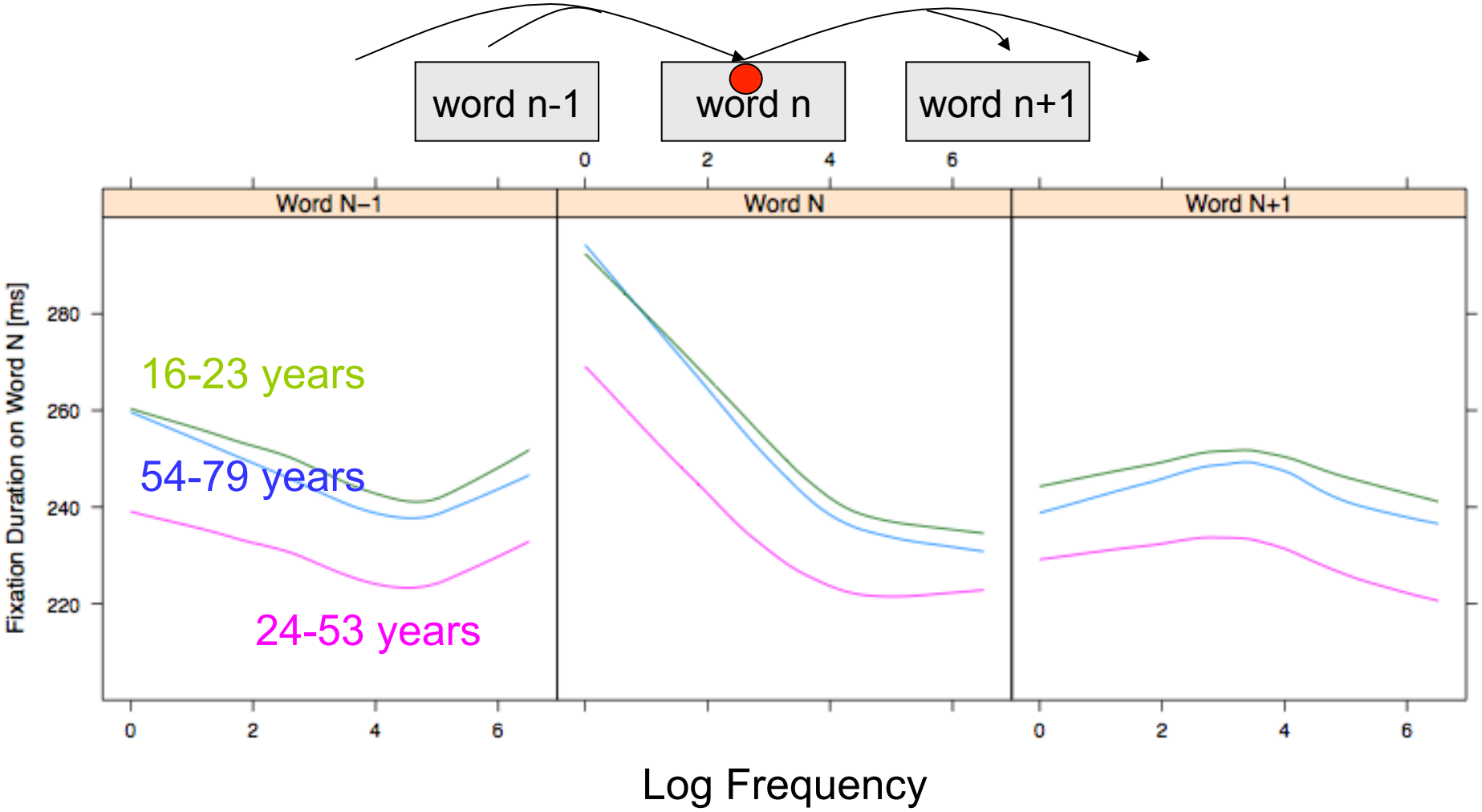
Kliegl et al. (2006, *J Exp Psychol: General*)

Three Word Frequency Effects in Paragraph Reading



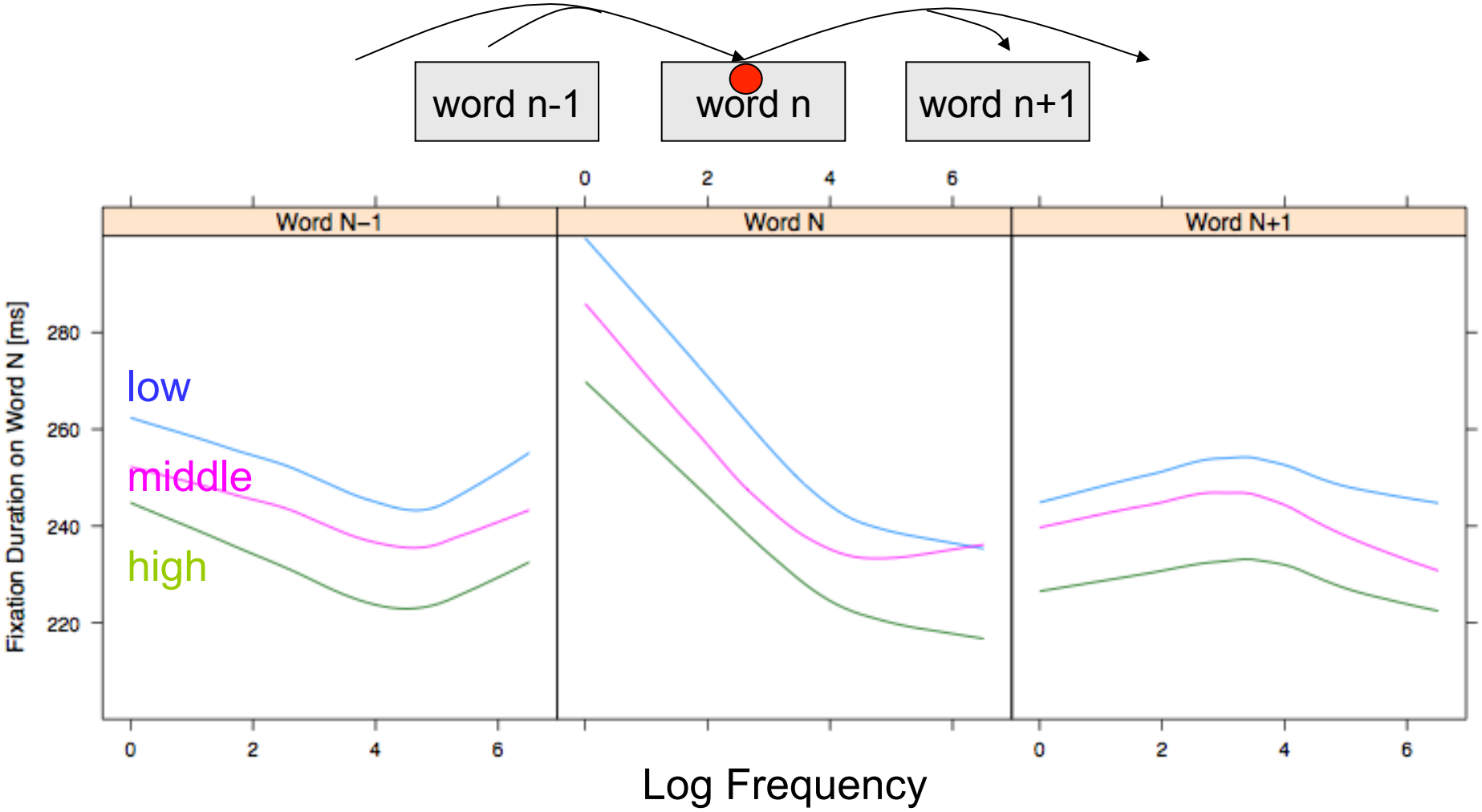
Kern, Weskott, & Kliegl (2008)

Three Word Frequency Effects in Paragraph Reading: Age Differences



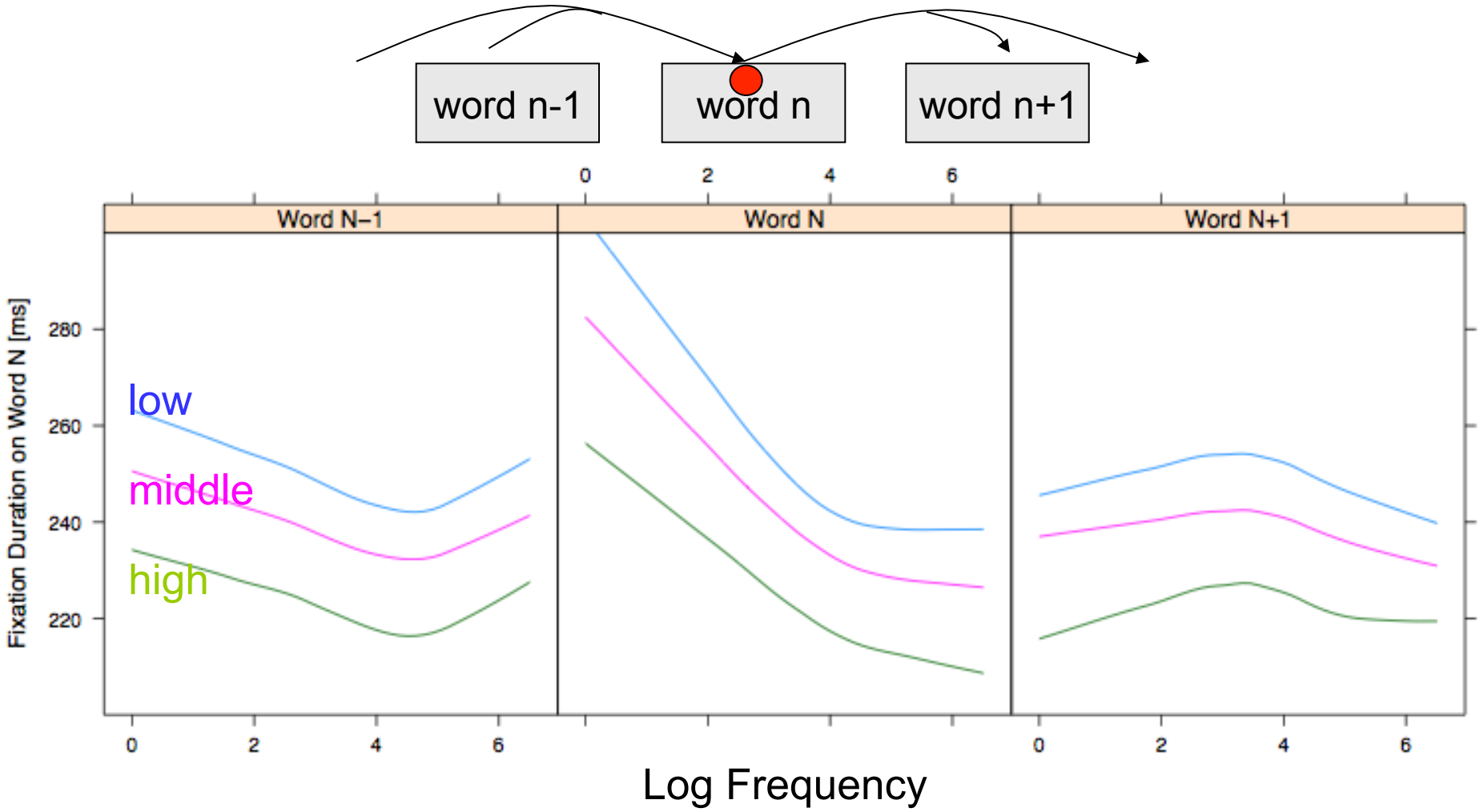
Kern, Weskott, & Kliegl (2008)

Three Word Frequency Effects in Paragraph Reading: Digit-Symbol Substitution Differences

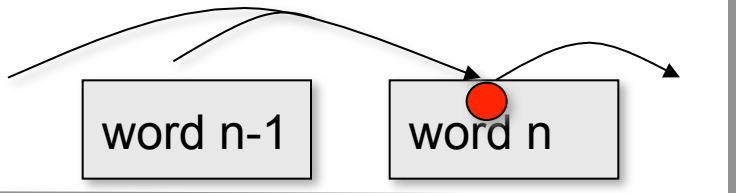


Kern, Weskott, & Kliegl (2008)

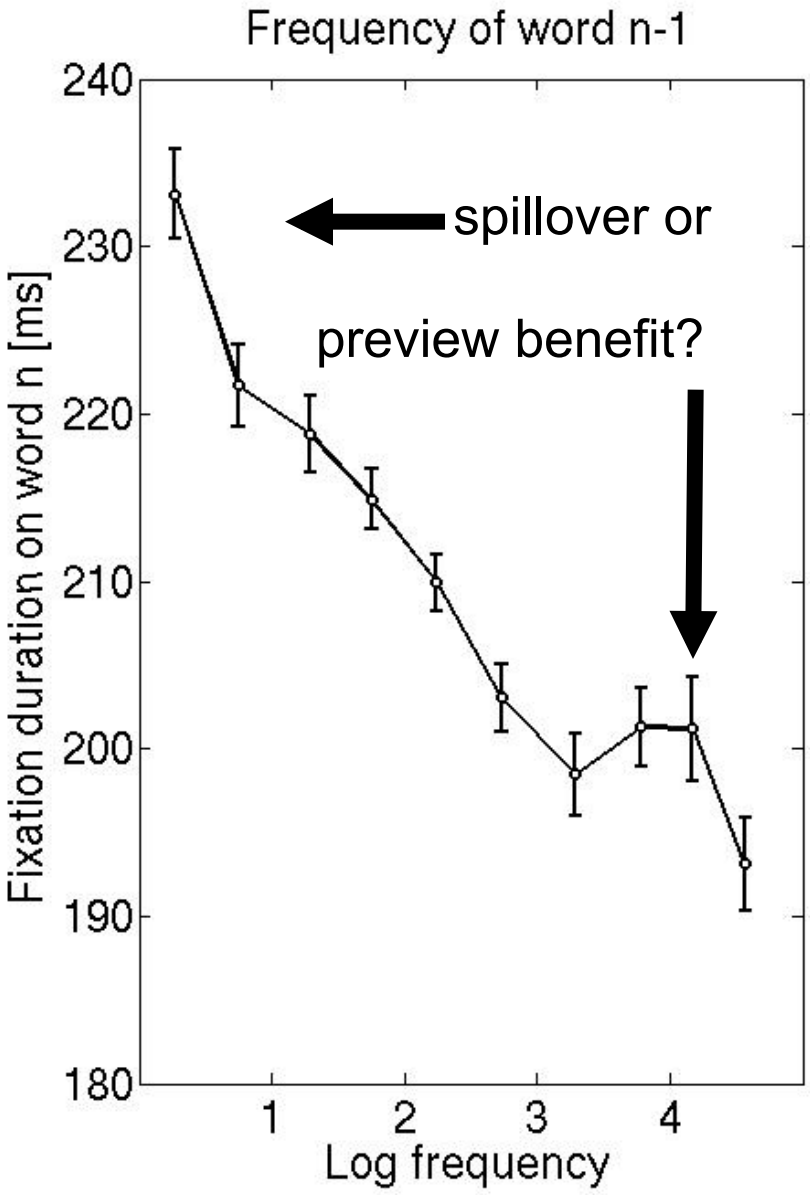
Three Word Frequency Effects in Paragraph Reading
Vocabulary Differences



Kern, Weskott, & Kliegl (2008)



Lag Effects



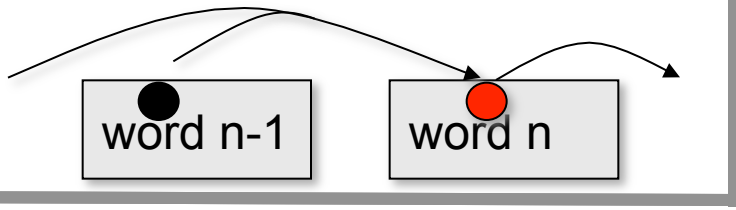
Properties of word **n-1** influence fixation duration
on word **n**

Evidence from experiments manipulating target words:

preview benefit
e.g., Balota et al. (1985)

spillover
e.g., Rayner & Duffy (1986)

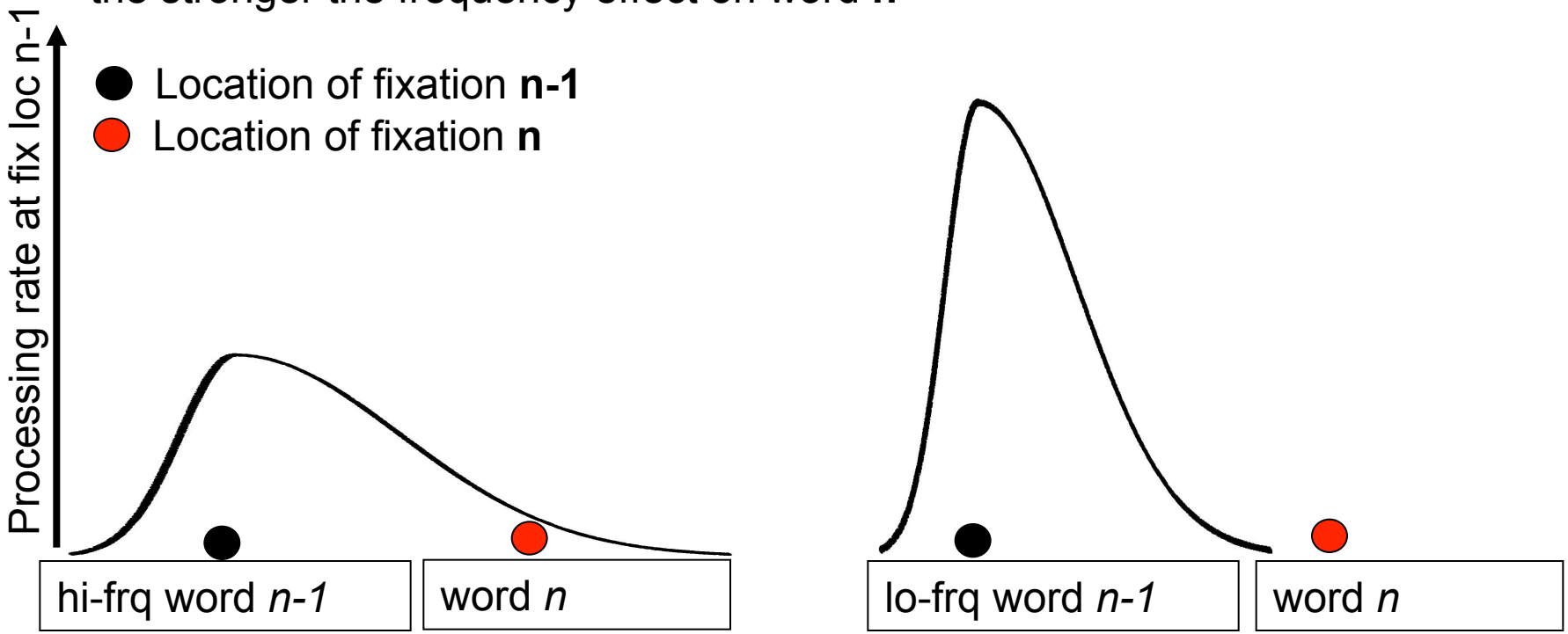
foveal load
e.g., Henderson & Ferreira (1990)

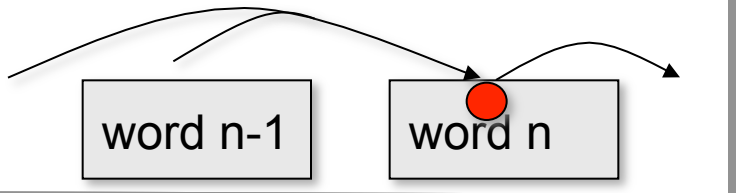


Lag of Foveal-Load Effect
Freq (n-1)/Freq(n)

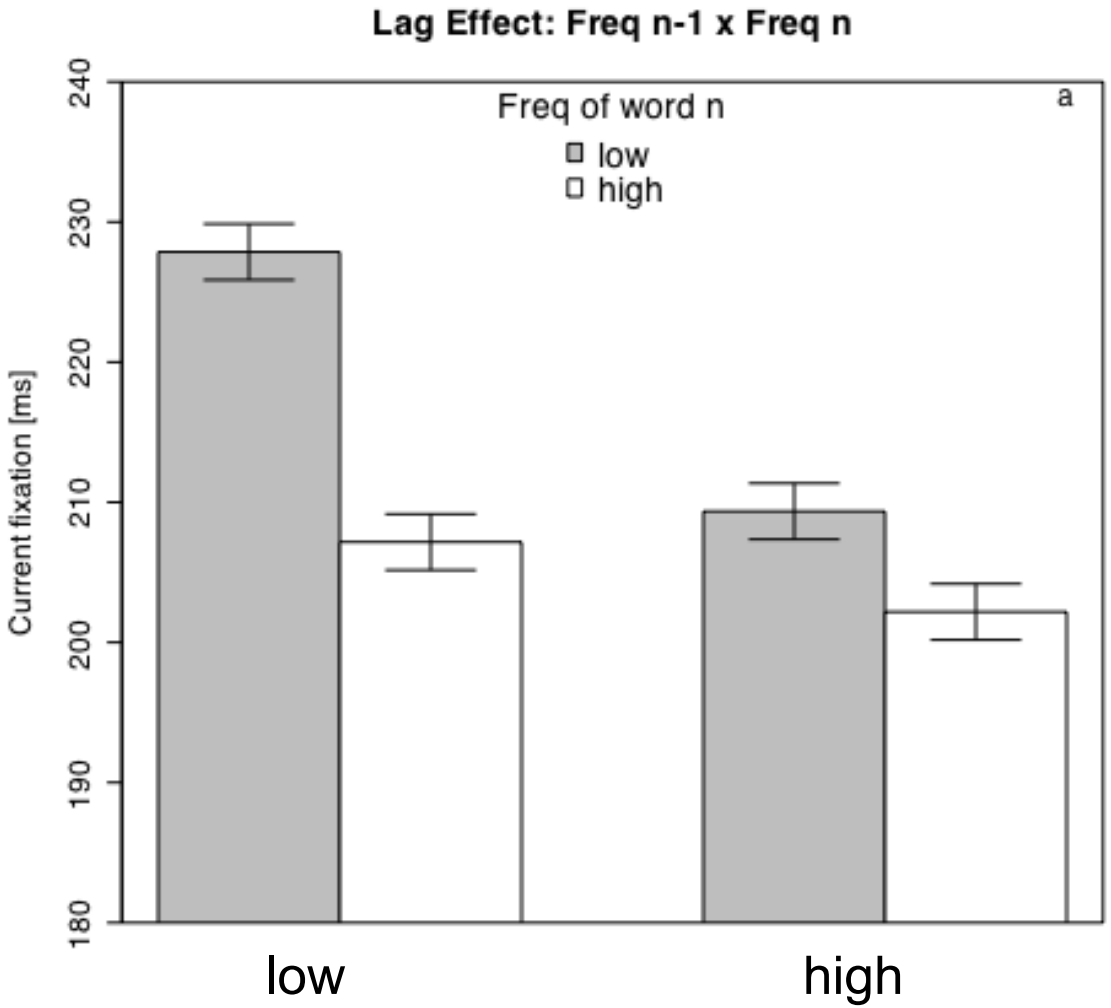
Dynamical modulation of the perceptual span (e.g., Henderson & Ferreira, 1990)

- the less frequent word **n-1**,
- the greater the foveal load during processing of word **n-1**,
- the more focused the perceptual span,
- the smaller the preview benefit for word **n**,
- the stronger the frequency effect on word **n**





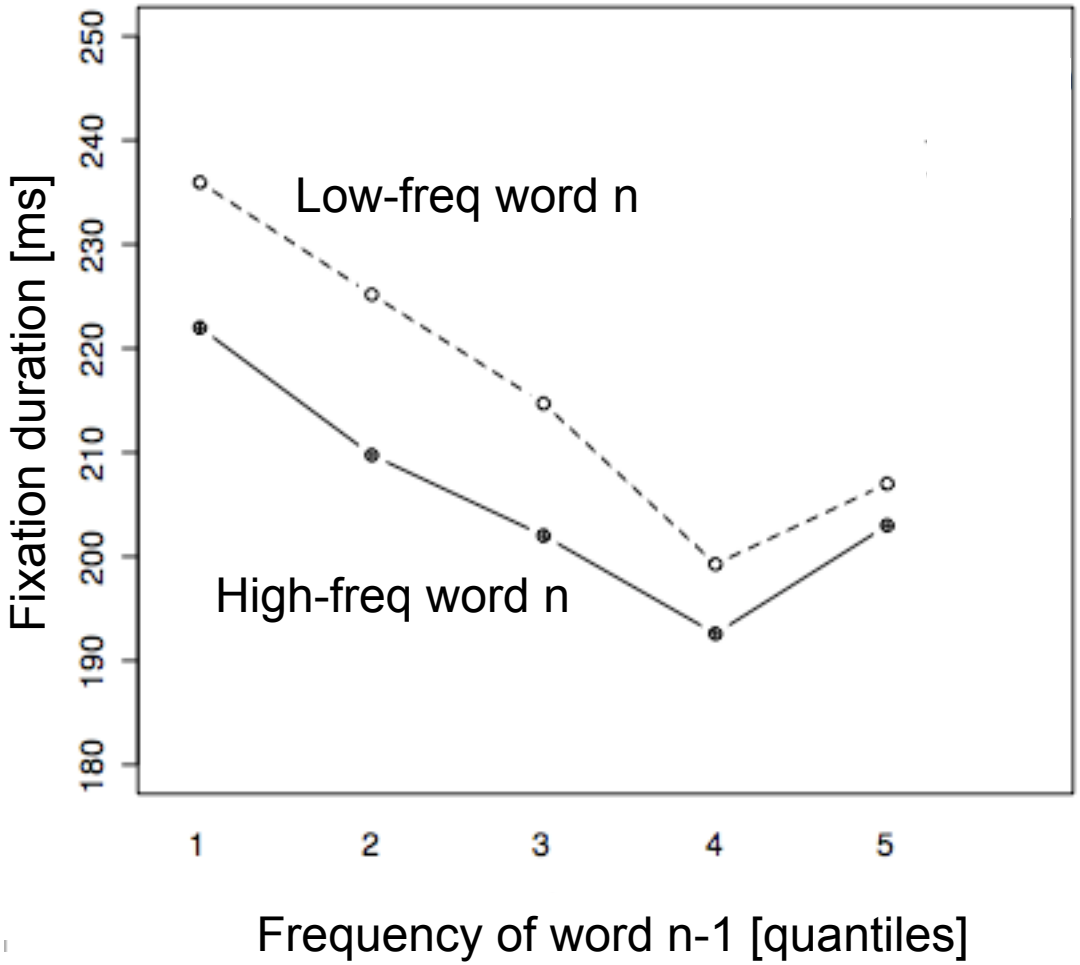
Lag of Foveal-Load Effect
Freq (n-1)/Freq(n)



For low-frequency word n-1, there is a stronger effect of the frequency of word n on the fixation on word n.

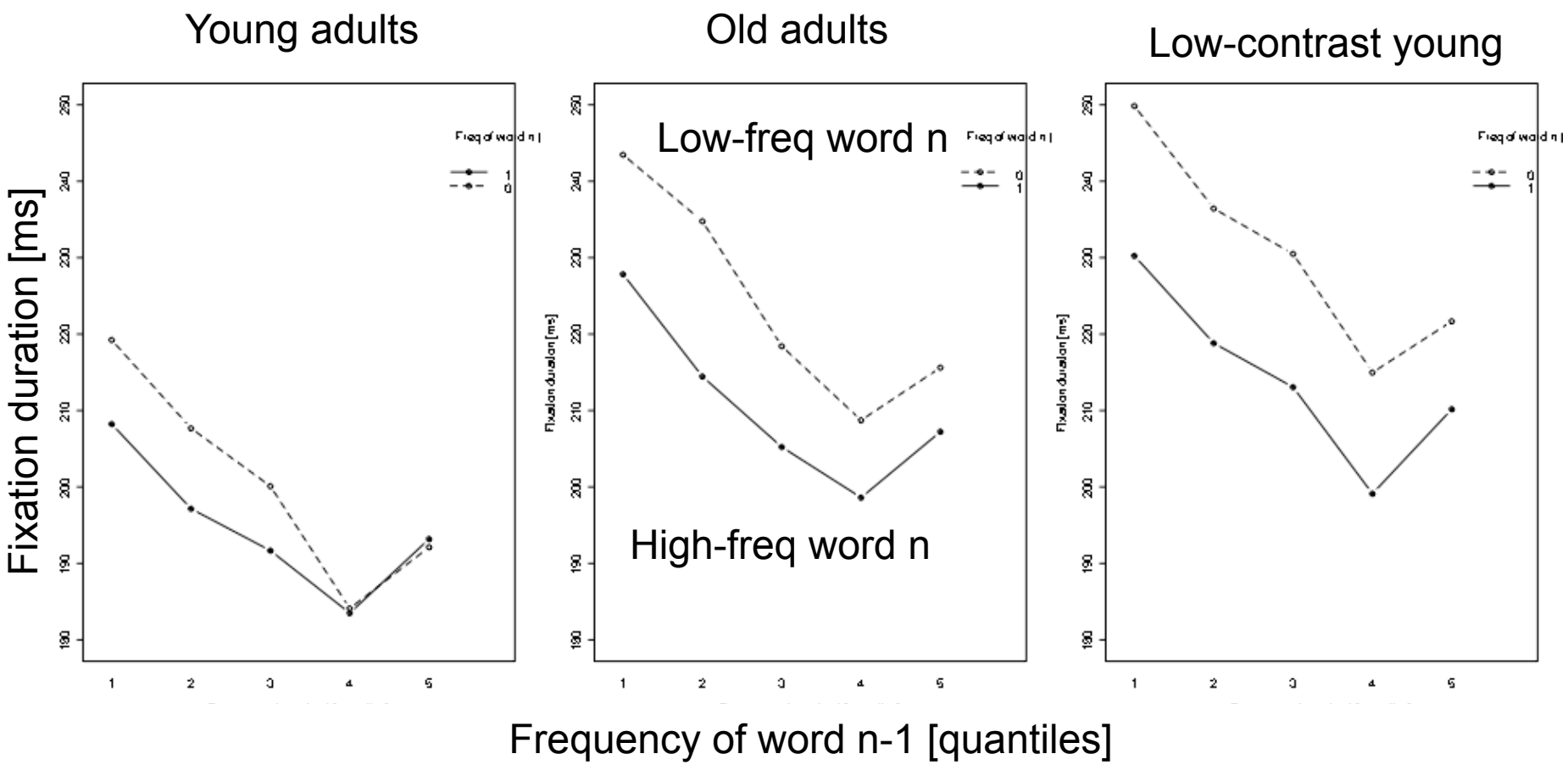
Kliegl et al., 2006

Word-level interactions for Fixation Duration



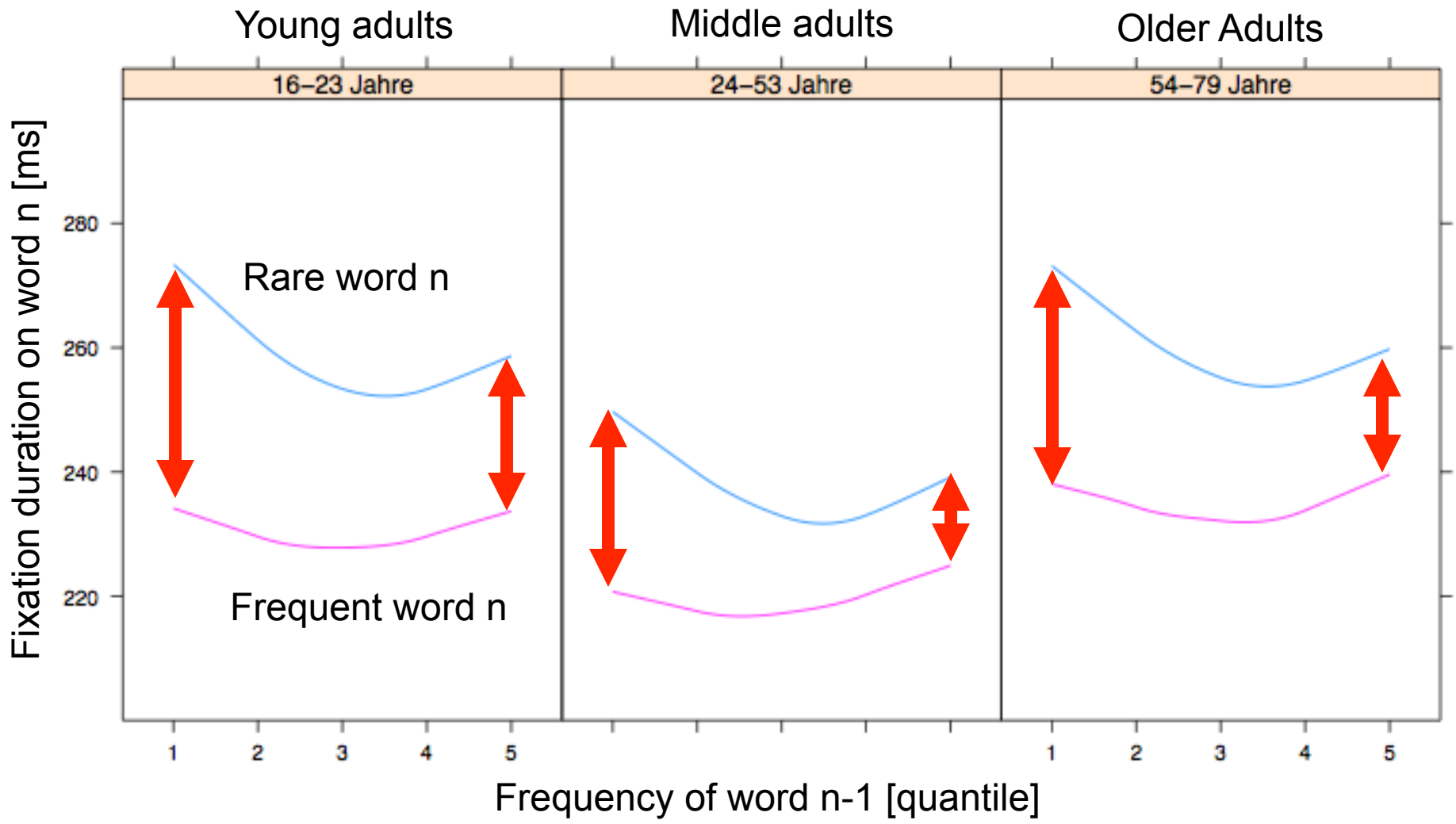
GLMM for model in Kliegl et al., 2006

Two 3-Factor Crosslevel Interactions for Fixation Durations



Effects of N-Frequeny, N-1-Frequency, and Age on Fixation Duration in Reading Paragraphs

Paragraphs



Kern, Weskott, & Kliegl (2008)

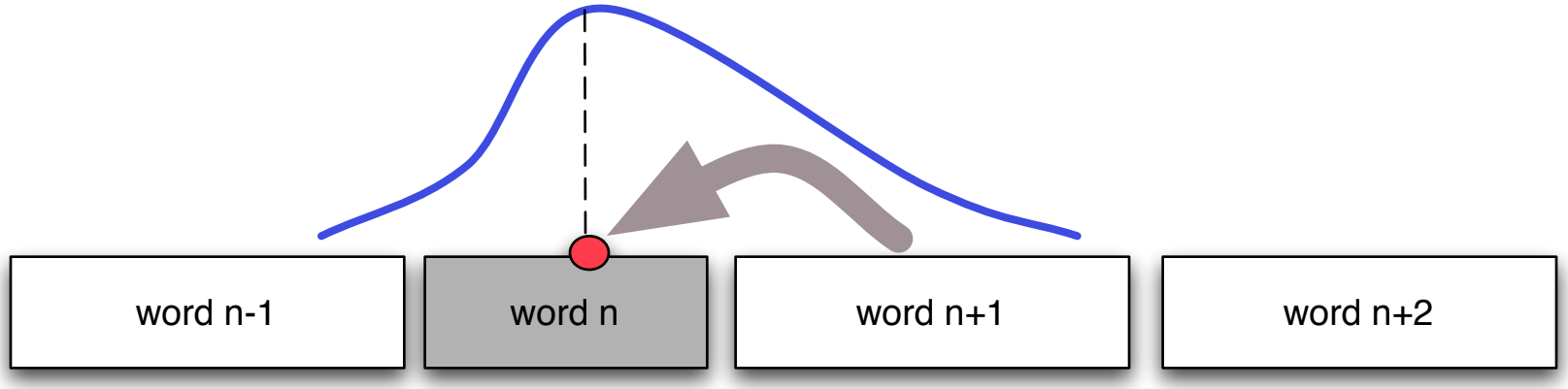
III. Effects of Age on Scanpath regularity

Titus von der Malsburg, Reinhold Kliegl, &
Shravan Vasishth (2015). *Cognitive Science*

IV. Reading strategy impacts on parafoveal-on-foveal effects in sentence reading

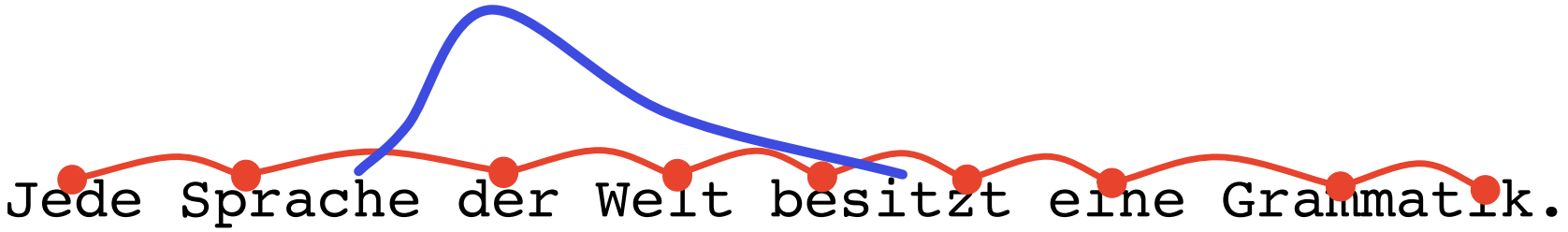
Christiane Wotschack & Reinhold Kliegl (2011).
Quarterly Journal of Experimental Psychology

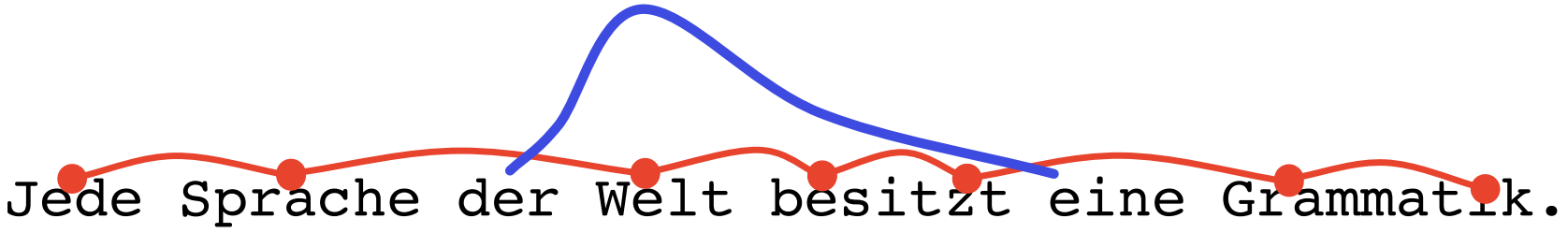
Parafoveal-on-Foveal (PoF) Effects



- Perceptual span: stronger parafoveal effects if word n is short (Kennedy & Pynte 2005)
- Foveal load: more preprocessing of word n+1 if word n is easy to process (Henderson & Ferreira 1990, 1993)

Selectivity in reading





Selectivity effects in reading: 1. Age

- Reading is selective process: 10-30% of words are skipped
- Short, high frequent, predictable words are skipped more often (Rayner 1998, Drieghe et al. 2008):
  Function words are prime candidates for skipping
- In old age: more skipping, more regressive eye movements
  (Kliegl et al. 2004, Rayner et al. 2006, Laubrock et al. 2006)

⇒ In corpus analyses: Different reading behavior in terms of fixational selectivity (especially in old age) may lead to different composition of data base

May also give rise to critical parafoveal-on-foveal effects?

Selectivity effects in reading: 2. Comp difficulty

Martins gebrochener Zeh schwoll rasch an.

Martin's broken toe swelled quickly.

---

easy: Was schwoll an?

What was swelling?

Fuß *foot/* Ferse *heel/* Zeh *toe*

---

hard: Was passierte mit Martins Zeh?

What happened to Martin's toe?

wurde blau /wurde steif /wurde dick

became blue / became stiff/ became thick

Questions and Measures

Reading for comprehension in 2 conditions and 2 age groups

- *Do reading intention and age affect the selectivity of fixated words?*

- *Is the selectivity of fixated words related to effects of distributed processing?*

Variables of interest: single fixation duration (SFD)

- selectivity in first-pass single fixation cases (SFC)

- effects of word frequency (n) on first-pass SFD

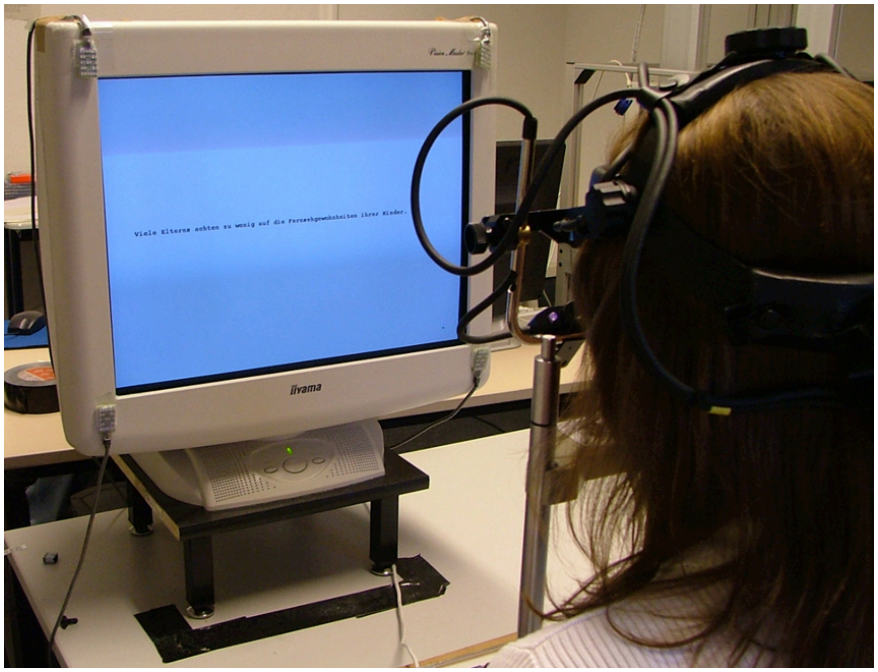
- effects of word frequency (n+1) on first-pass SFD

Experiments

	easy young	easy old	hard young	hard old
n subjects	24	32	30	23
Ø-age (years)	17.6	70.6	18.5	68.0
reading material	144 sent. (Potsdam Sentence Corpus)			
instruction	read for comprehension			
freq. of questions	27%		100%	
type of questions	easy		hard	

Method

- *Eye Movement Recording:* EyeLink-II-System, 500 Hz
- Binocular calibration and recording
- Isolated sentences presented on the center line of a monitor, response via mouse klick



- *Analyses*: Effects of distributed processing on single fixation duration (SFD) with LMM (Pinheiro & Bates 2000)
- Separate models for old and young readers, focus on condition effects

Results: summary statistics

first pass	**skipping**	**regression**	**SFD (ms)**
easy young	.16	.07	231
hard young	.16	.18	242
easy old	.25	.14	224
hard old	.21	.25	245

age effect:
F(1,105)=25.2 ***
cond. effect old:
F(1,53)=4.14*

age effect:
F(1,105)=7.2 **
condition effect:
F(1,105)=27.8 ***

condition effect:
F(1,105)=6.3 *

Results: selectivity effects (SFC)

word n	**frequency**	**length**	**predictab.**	**function word prop.**
Corpus-reference	2.3	5.4	-1.48	.37
easy young	2.24	4.5	-1.58	.32
hard young	2.26	4.5	-1.55	.33
easy old	2.03	4.9	-1.65	.27
hard old	2.23 ***	4.6 ***	-1.52 **	.33 ***

Summary results: selectivity (Single Fixation Cases)

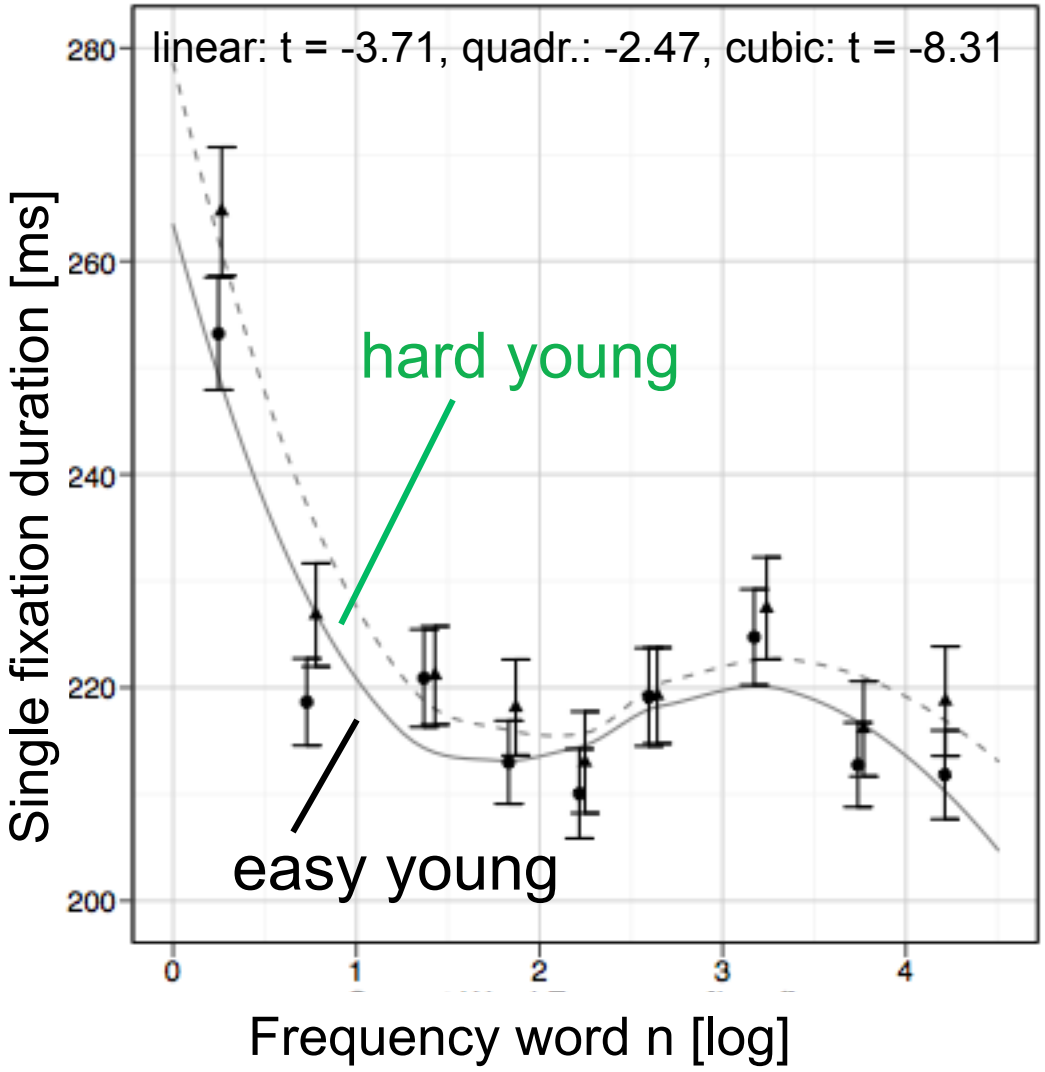
- No selectivity effect between young samples
- Demanding questions changed fixational behavior in old readers:

  Single Fixation Cases in easy old readers were proportionally more often:
  - lower frequent words
  - longer words
  - words of lower predictability

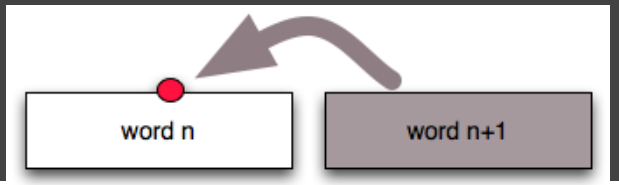
⇨ hard old fixated more function words (FW) than easy old

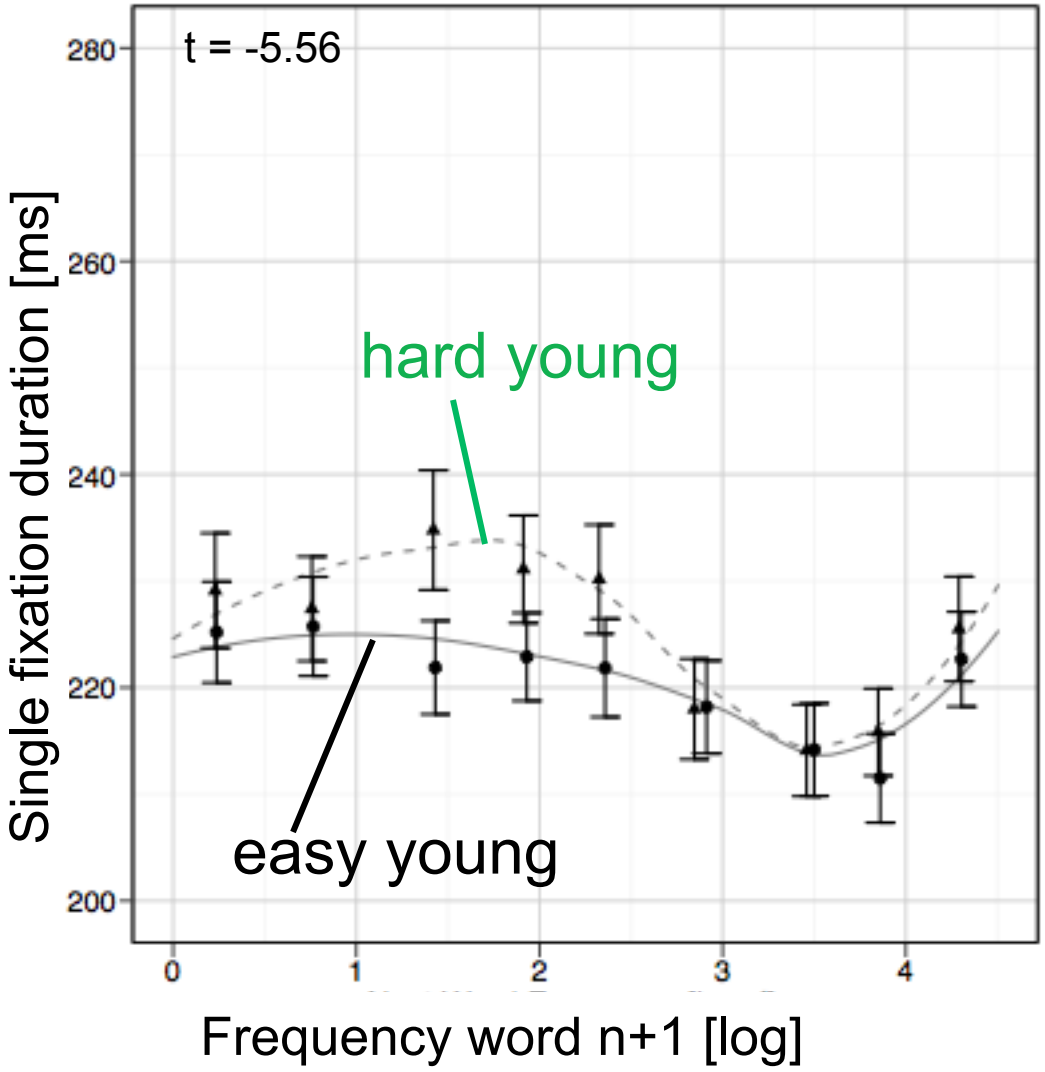
Word frequency effect: young

word n



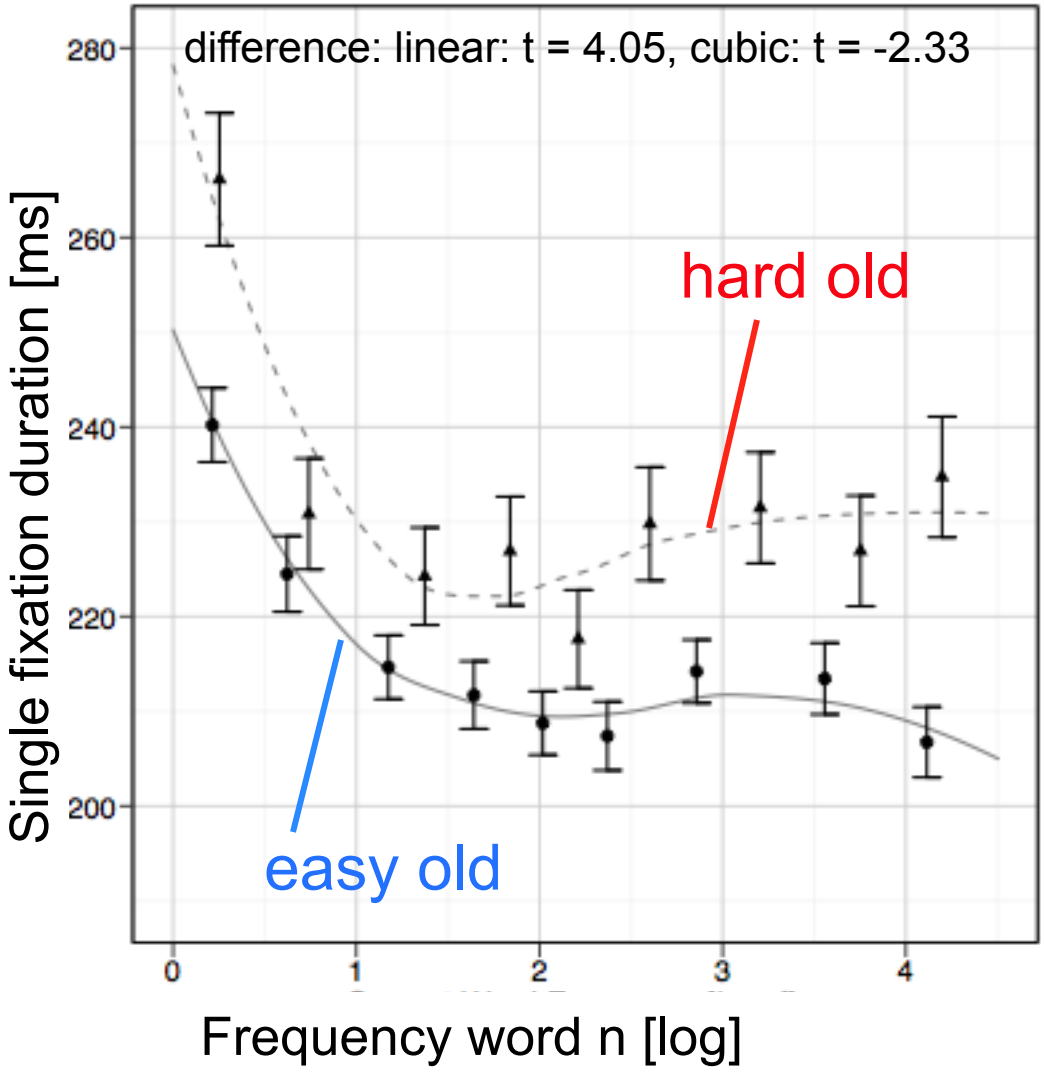
Parafoveal-on-foveal effect



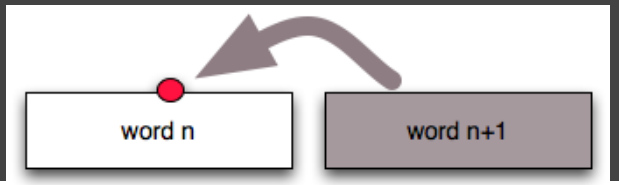


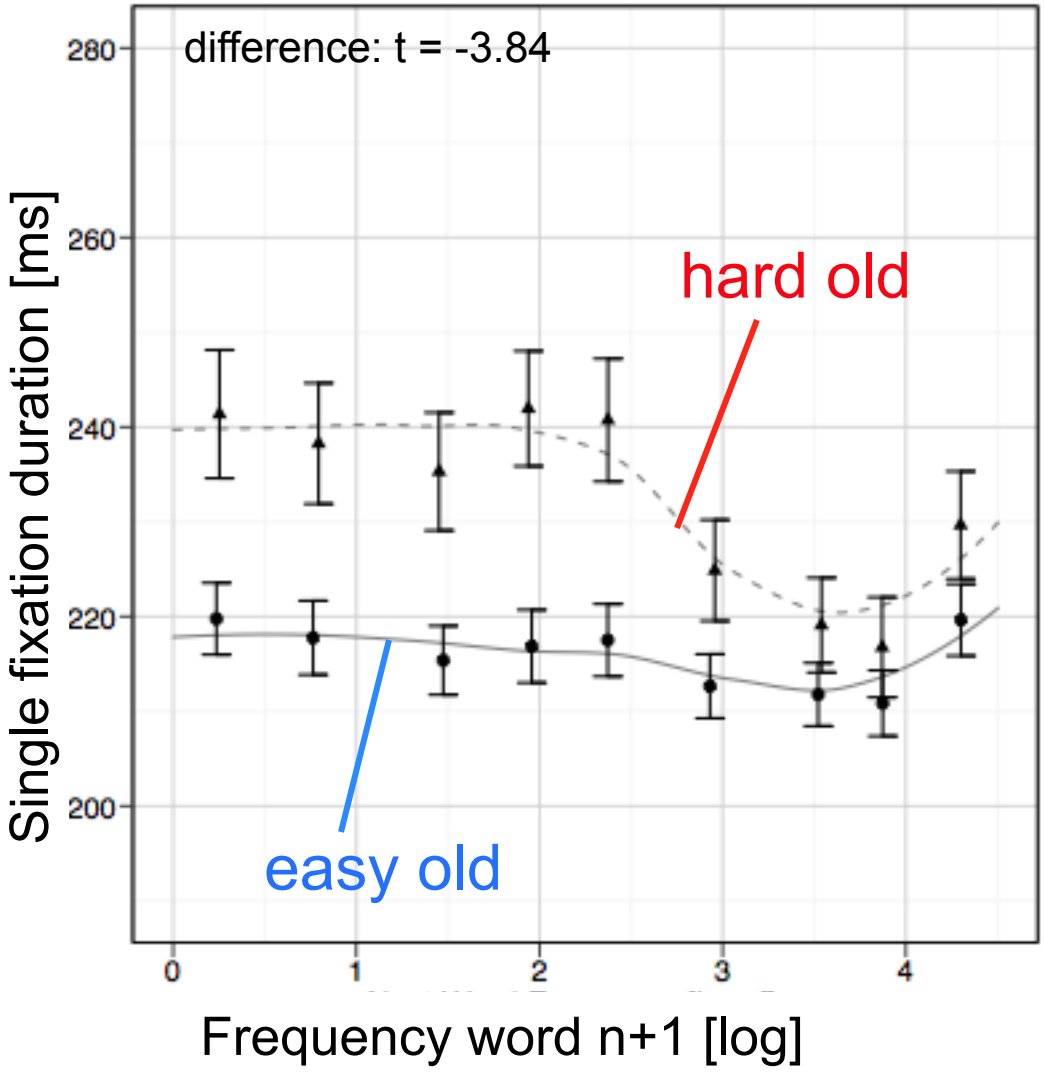
Word frequency effect: old

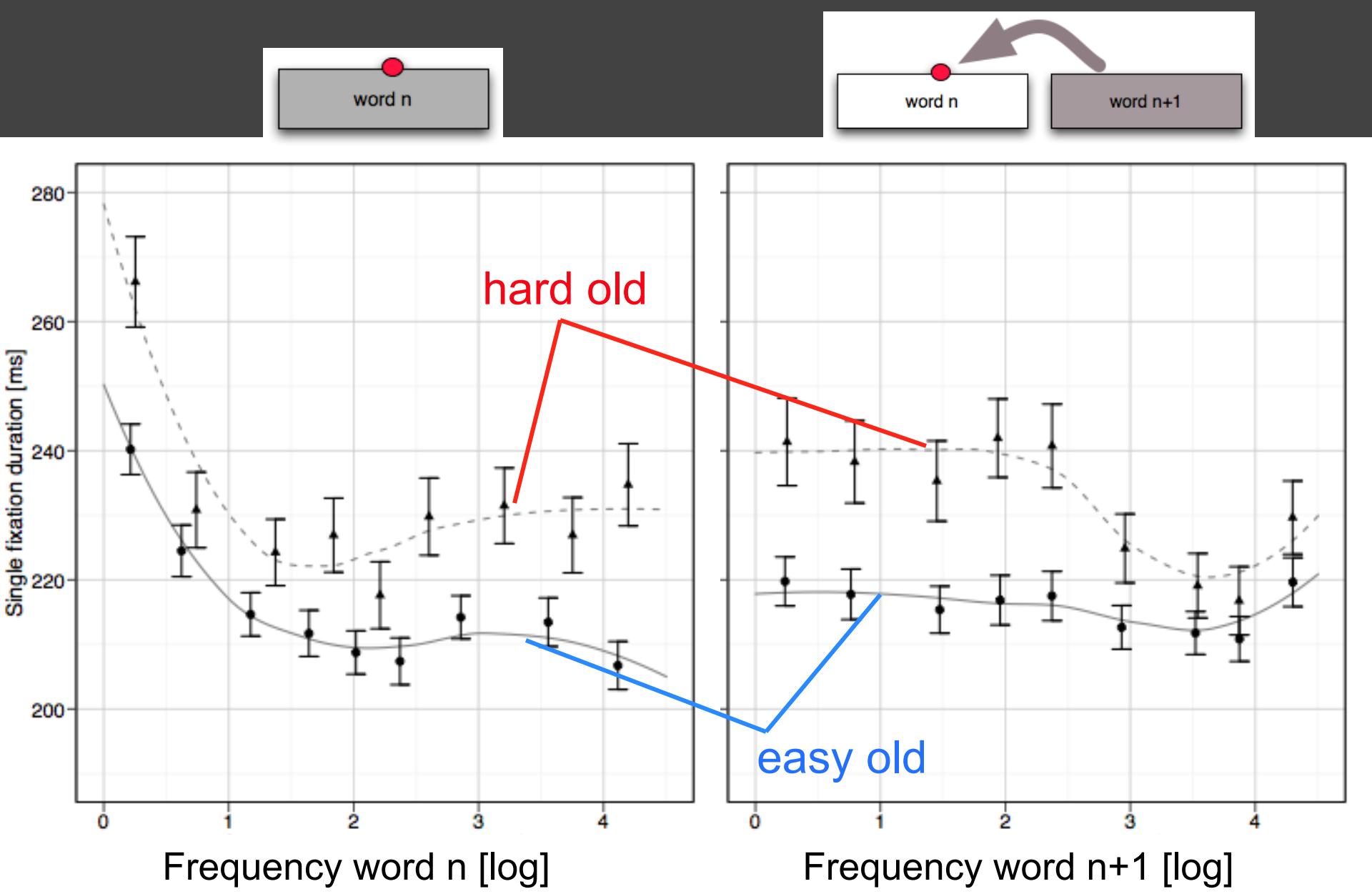
word n



Parafoveal-on-foveal effect





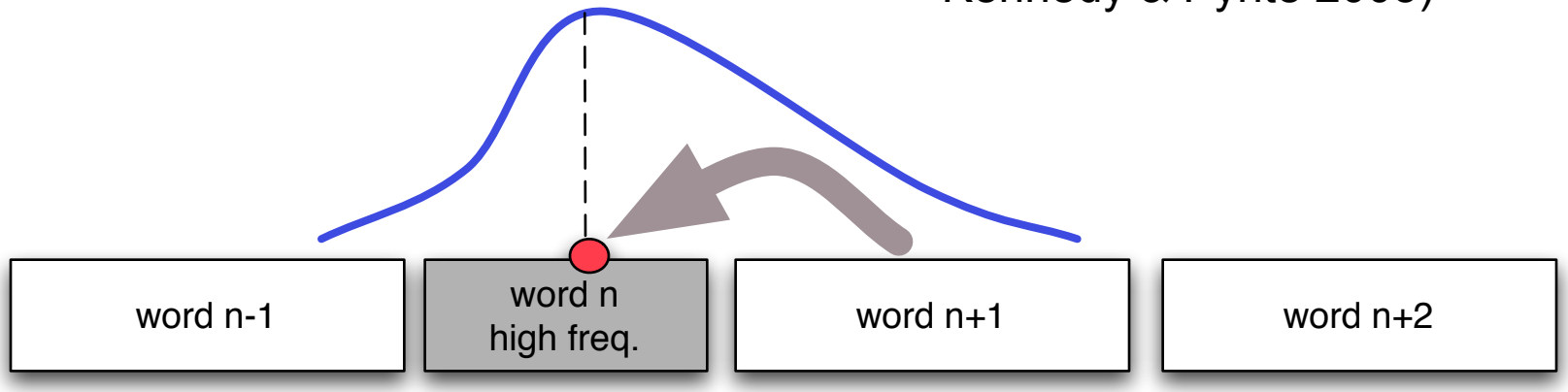

word n
word n
word n+1
hard old
easy old
Single fixation duration [ms]
280
260
240
220
200
0
1
2
3
4
Frequency word n [log]
Frequency word n+1 [log]

Condition effects due to top-down strategy

- Fewer skippings, shorter sacc. amplitudes: due to reduced perceptual span in response to task demands

- Selectivity effect in old age: if fewer words are skipped, more FW are fixated (= short and highly frequent)

(Henderson & Ferreira 1990, Kennedy & Pynte 2005)



stronger next-word frequency effect on SFD

Summary and Conclusion

- Reading strategy/ task demands impact in top-down fashion on eye movement behavior, reading identical material
  (Radach, Huestegge, Reilly 2008, Wotschack 2009)

- Selectivity effects in corpus analyses may give rise to PoF-effects
  - need to be considered in group comparisons

- Results confirm idea of distributed processing within the perceptual span

- Perceptual span modulated by reading intention and locally by processing demands