Distributed Processing During Fixation Durations in Reading

Contributions of Cross-Language Comparisons

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"And so to completely analyze what we do when we read would almost be the acme of a psychologist's achievements, for it would be to describe very many of the most intricate workings of the human mind, as well as to unravel the tangled story of the most remarkable specific performance that civilization has learned in all its history."
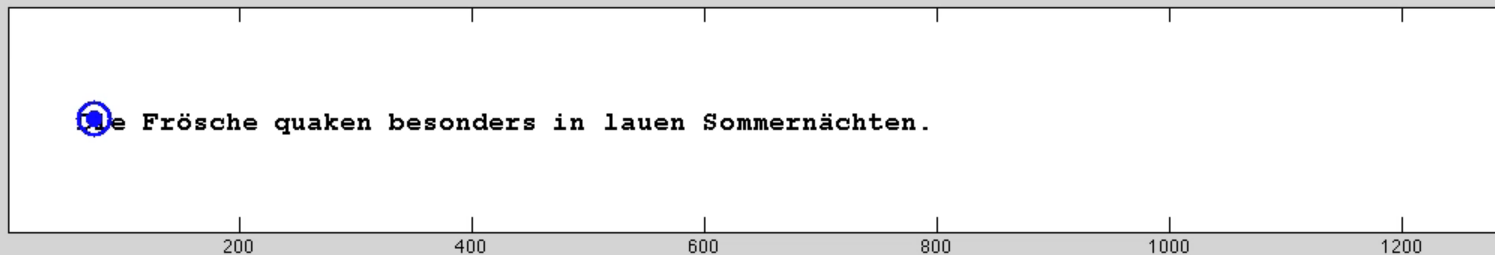
Edmund Burke Huey, 1908

Eye Tracking (EyeLink II, SR Research)

- 2 eye cameras
- 1 head camera
- 500 x/y-positions/sec
- letter accuracy
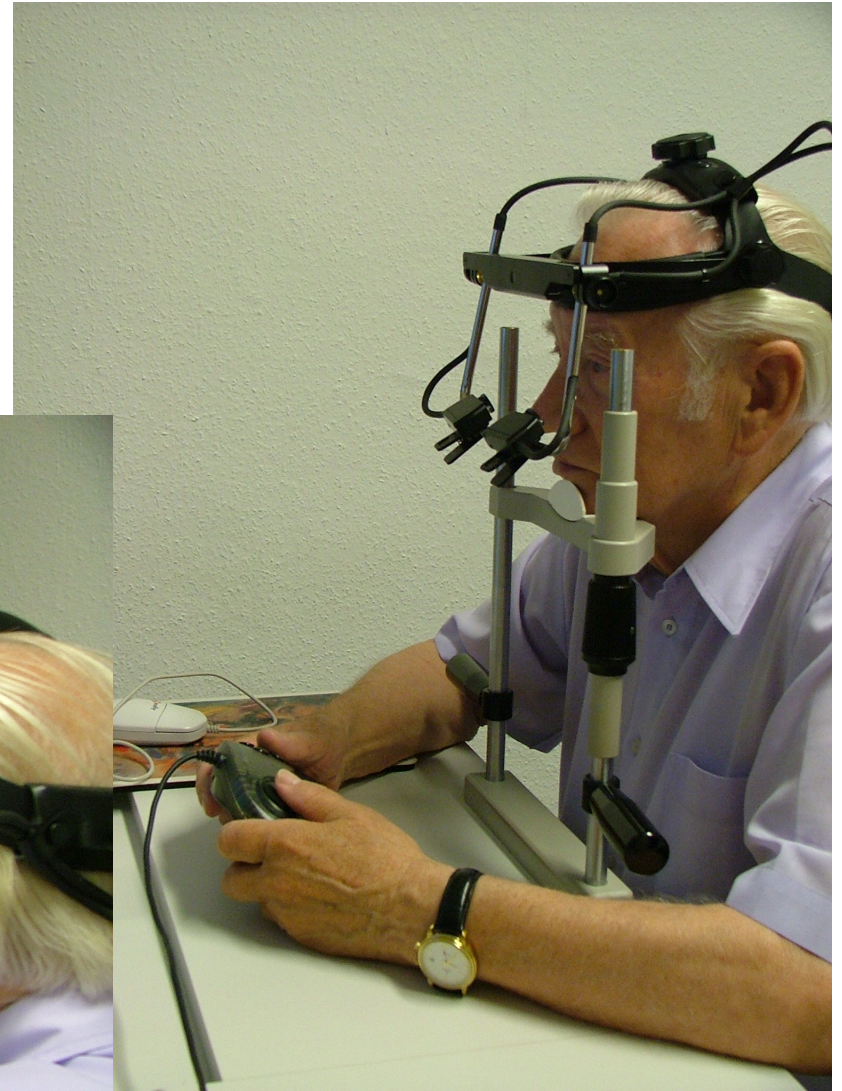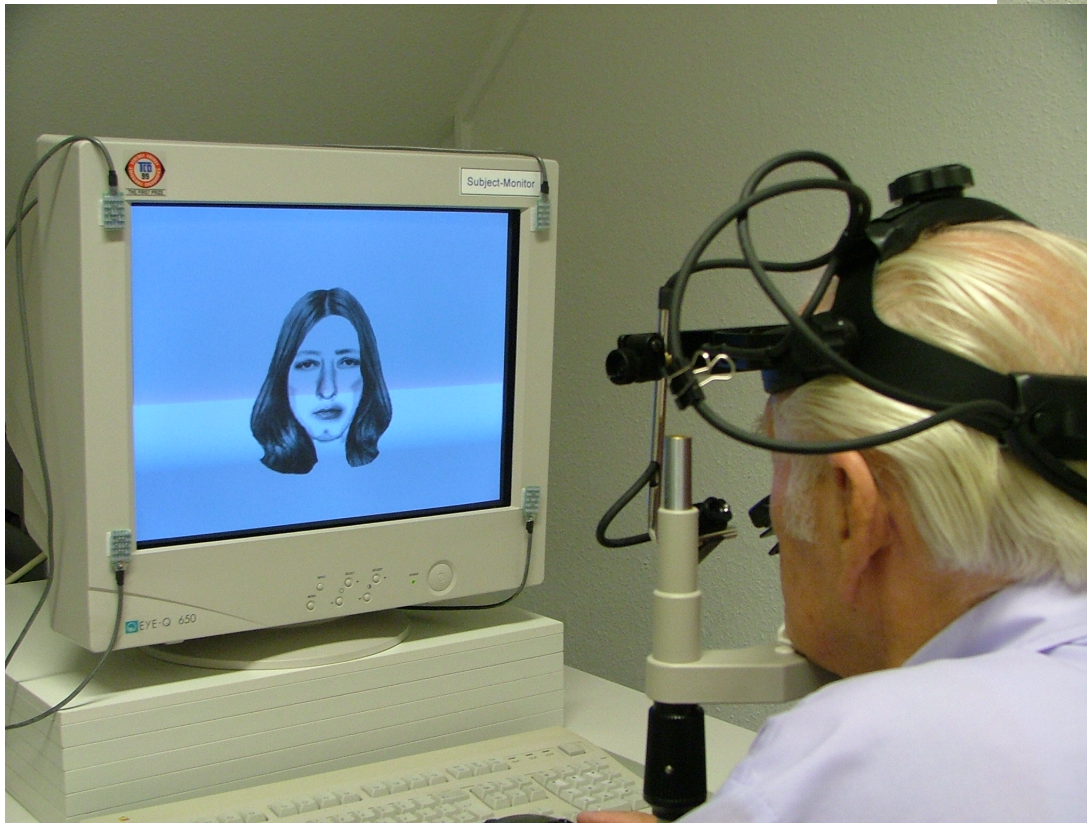
See—Move—Retrieve—Speak—Listen—Comprehend

The frogs croak especially in balmy summer nights.
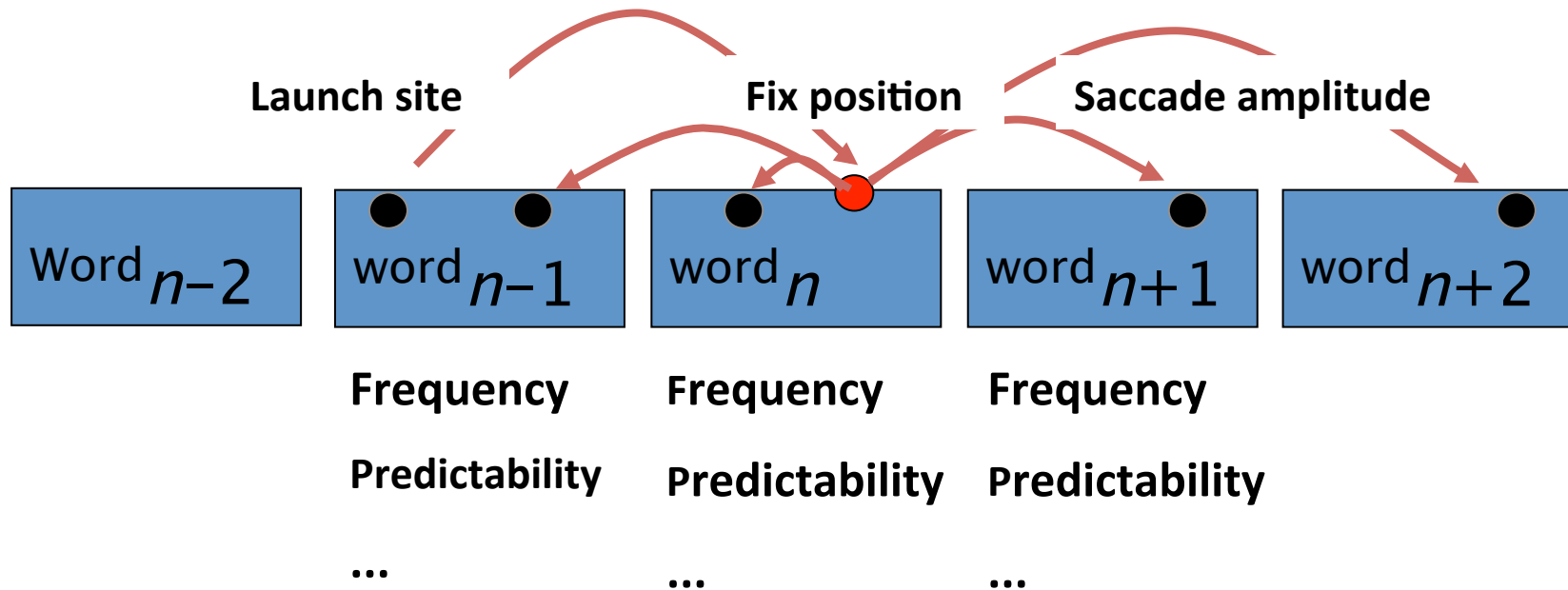Die Frösche quaken besonders in lauen Sommernächten.

See also: http://dasgehirn.info/aktuell/hirnschau/das-sprunghafte-auge-5190/

(Laubrock & Kliegl, 2015)

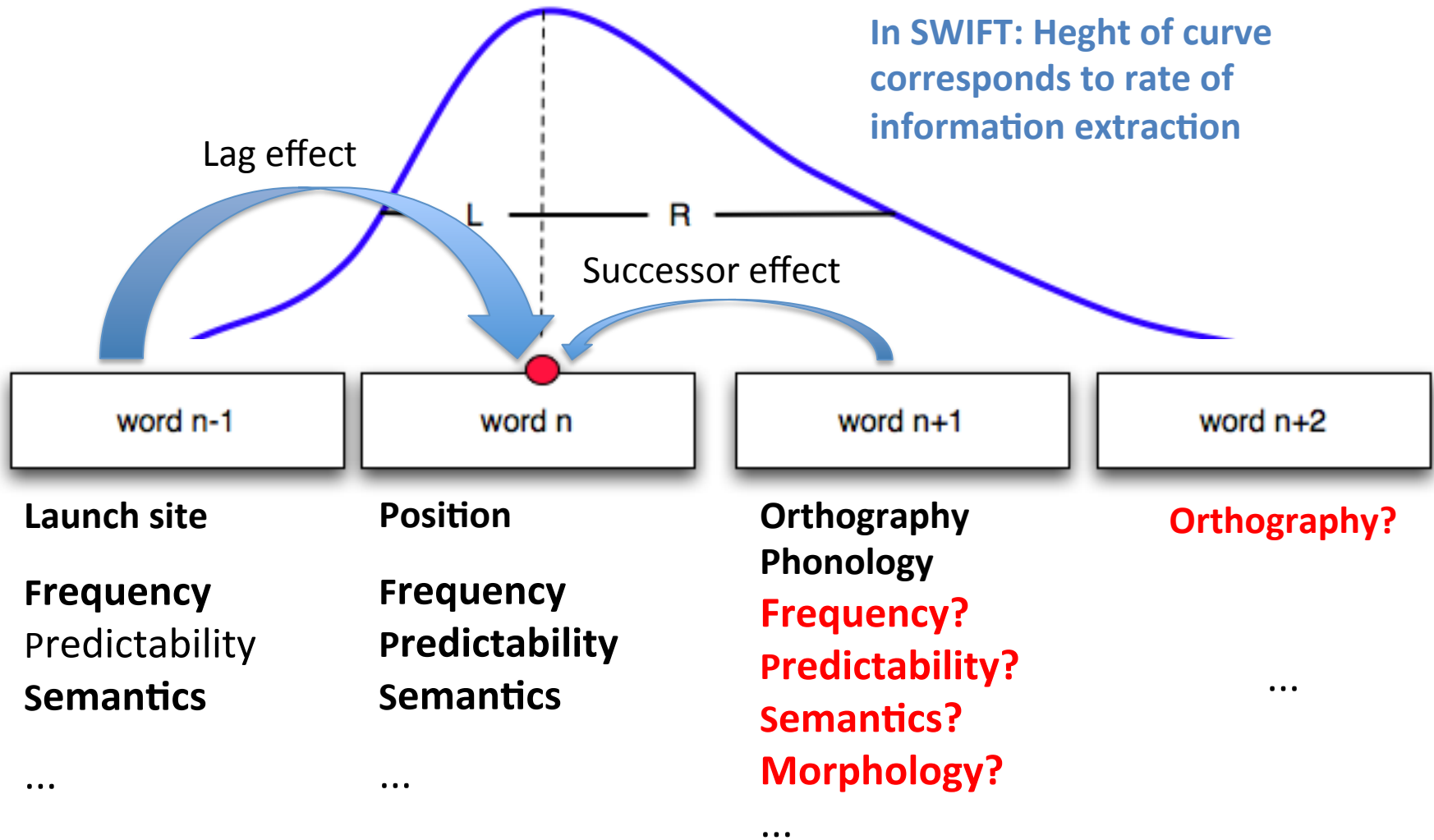Eye Movements and Fixations During Reading

Immediate Effects of Frequency, Predictability, & Fixation Position: Potsdam Sentence Corpus
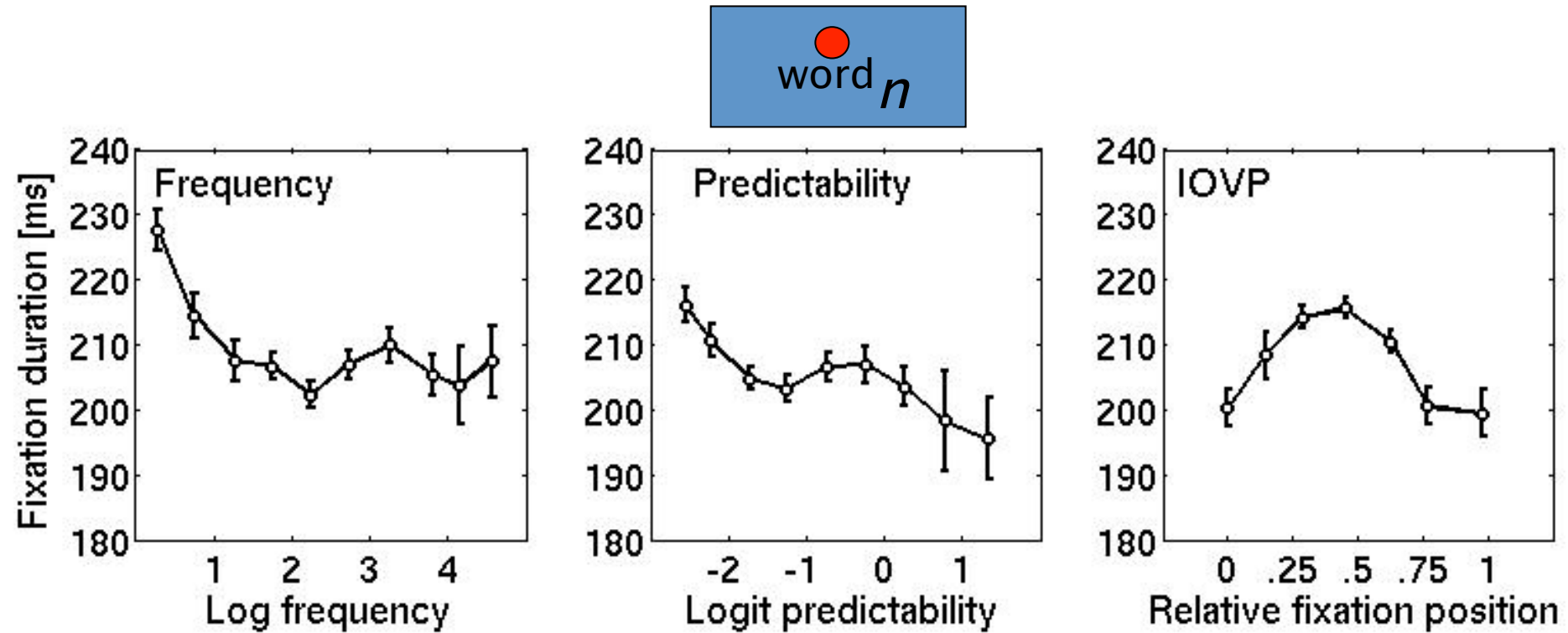
Predictability = prob(guessing word n | words 1 to n-1); 83 guesses/wrd;

metric: logits [log of odds; e.g., log(1:1) = 0].

Kliegl, Nuthmann, & Engbert (2006)

Distributed Processing Effects During Reading

In SWIFT: Heght of curve corresponds to rate of information extraction

Lag effect

L   R

Successor effect

| word n-1 | word n | word n+1 | word n+2 |

Launch site

Frequency
Predictability
Semantics

…

Position

Frequency
Predictability
Semantics

…

Orthography
Phonology
Frequency?
Predictability?
Semantics?
Morphology?
…

Orthography?

…

Three Controversial Issues of Eye-Movement Control during Reading

1. Frequency and predictability of next word

    Dependent variable: single fixation duration

    German, English, Spanish, Chinese (simplified, traditional)

2. Meaning of next word

    Dependent Variable: single fixation duration

    Chinese (simplified, traditional), German, English

3. [Inverted optimal viewing position effect

    Dependent Variable: single fixation duration

    German, Chinese (simplified)]

Part 1
Fixation durations depend on the properties of the fixated and neighboring words
(Method: multivariate statistics; Kennedy & Pynte, 2005; Kliegl et al., 2006; Kliegl, 2007; Heister et al. 2012)

Eye Movements During Reading
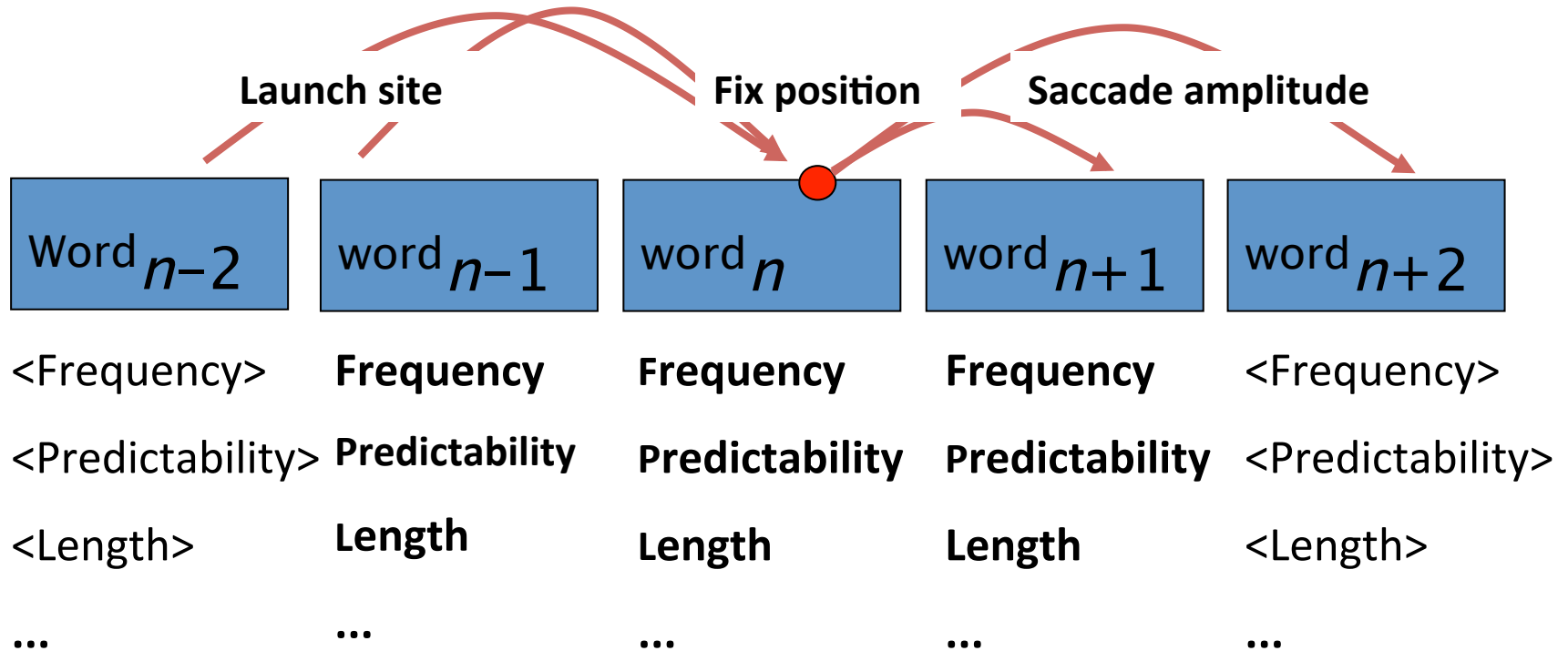
Duration

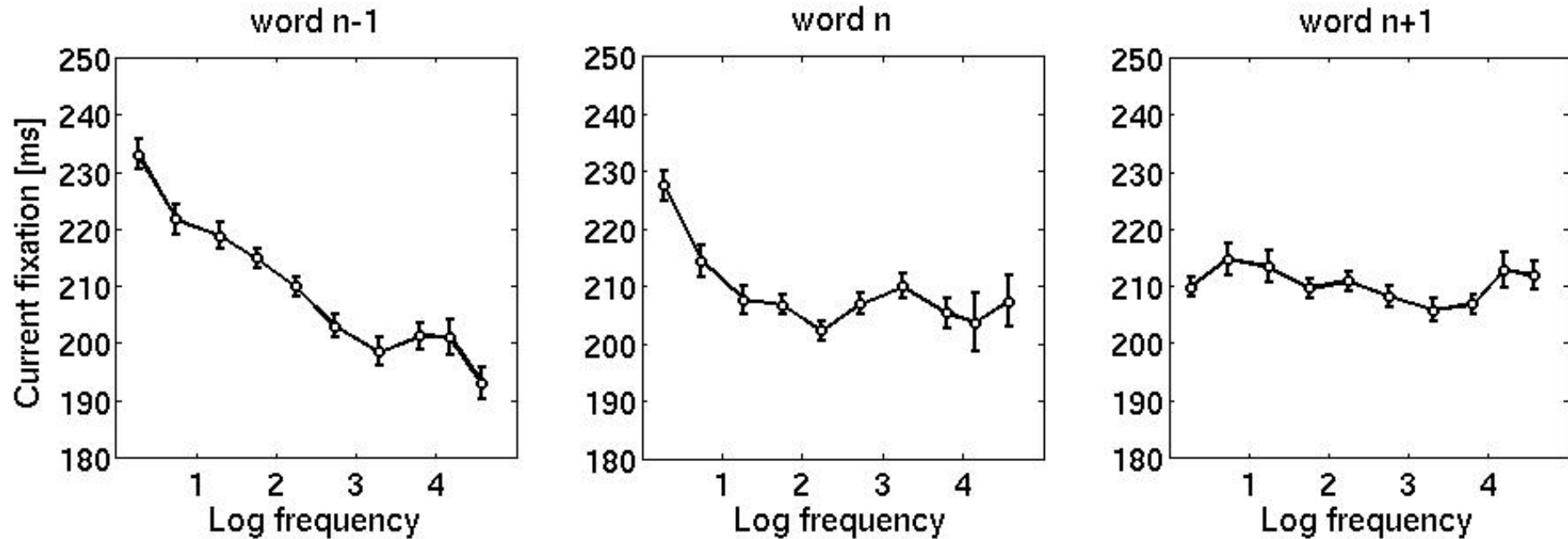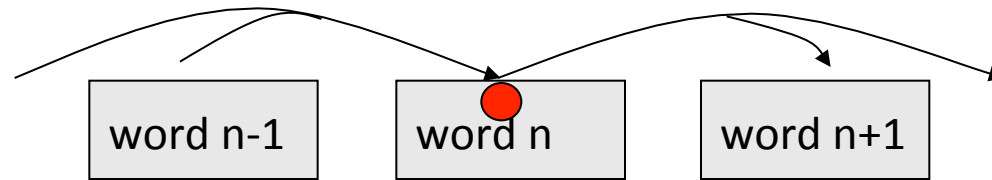🔴   fixation: 30—750 ms

↪   saccade: 20—40 ms

Data

80 530 single fixation durations (1st-pass)

Random factors in linear mixed model:

subject (273); sentence (144); word (369)

Launch site   **Fix position**   **Saccade amplitude**

Word $n-2$	word $n-1$	word n	word $n+1$	word $n+2$
<Frequency>	**Frequency**	**Frequency**	**Frequency**	<Frequency>
<Predictability>	**Predictability**	**Predictability**	**Predictability**	<Predictability>
<Length>	**Length**	**Length**	**Length**	<Length>
…	…	…	…	…

Kliegl, 2007; Heister, Würzner, & Kliegl (2012)

Effects of Frequency of Word n-1, n, and n+1: German Sentences

word n-1   word n   word n+1
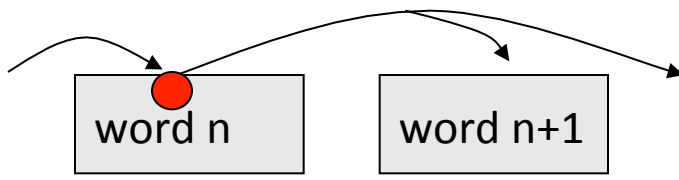
… But Successor Effect of Memory
(Inverted) Predictability of n+1
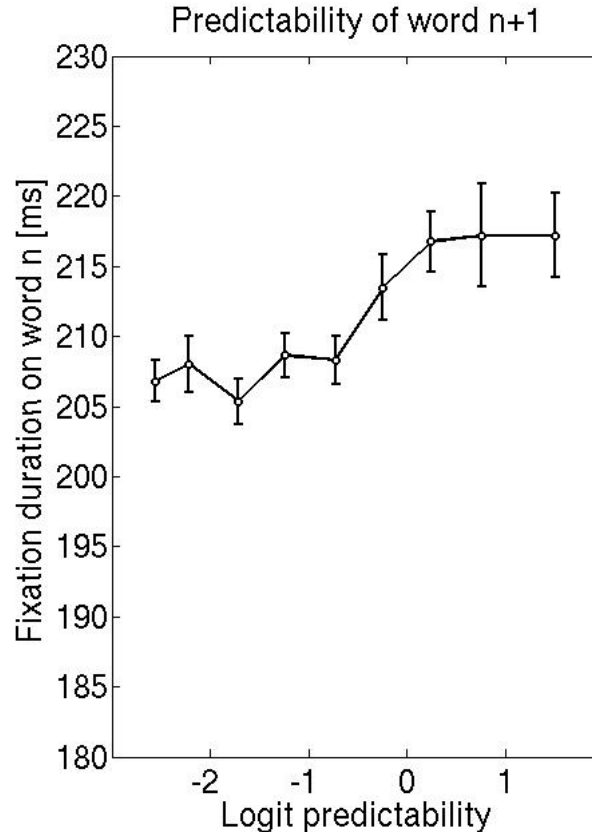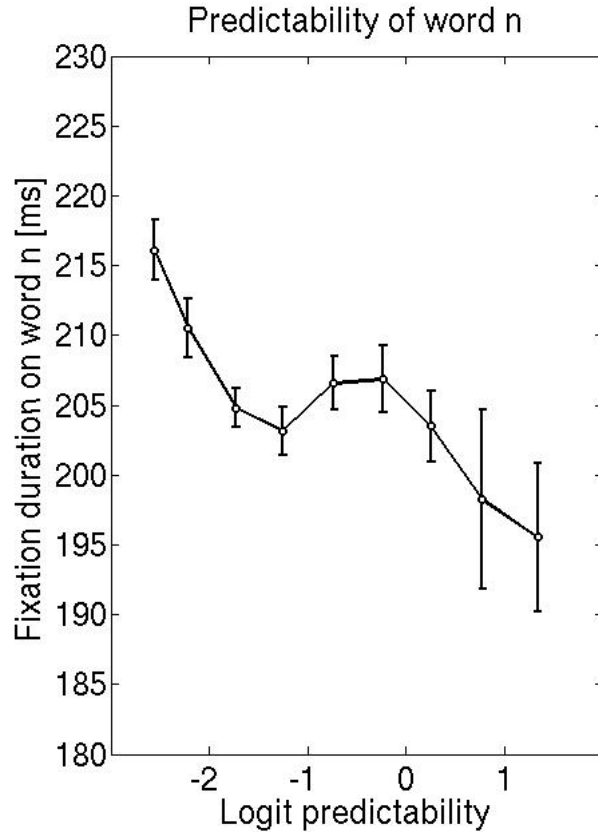
Part 2

The meaning of the next word is accessed during fixations on earlier words
(Method: boundary paradigm; Rayner, 1975)

Fundamental Constraint: The Perceptual Span

- Estimates of span of effective vision are based on the *moving window paradigm* (McConkie and Rayner, 1975)

- 3-4 letters to the left and 14-15 letters to the right of fixation in alphabetic languages

- 1-2 characters to the left and 2-3 characters to the right of fixation in Chinese (Tsai, C.H., & McConkie, 1995; Inhoff & Liu, 1998)

- "Perceptual" span is more about attention than perception (e.g., asymmetry of effects; switch with reading direction)

The Boundary Paradigm

Pretarget word | Preview word

… brilliantly composed a new song for the…..

| Condition | Pretarget | Word Fixated |
		Target
Identical (song-song)	251(228)	246(214)
Semantically Related (tune-song)	250(228)	286(230)
Unrelated (door-song)	251(222)	290(234)
Visually Similar Nonword (sorp-song)	248(219)	251(215)

Rayner, Balota, and Pollatsek (1986)

Direct Access to Meaning

"Bone-shell script"
1200 BC

"Small Seal Script"
221 BC

Traditional Character
"Standard script"
Since 200

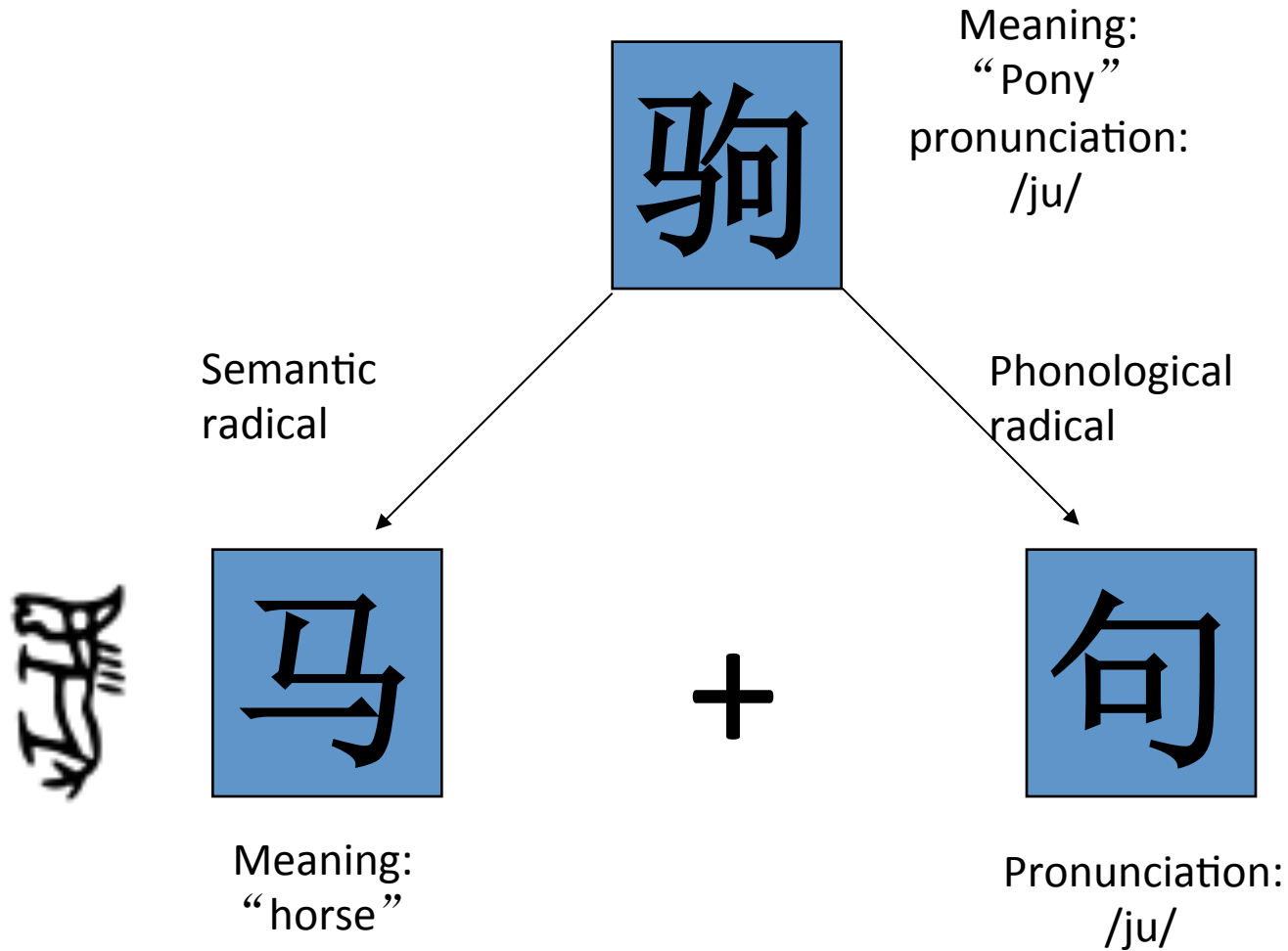Simplified Character
Since 1950s

- Character 马
- Meaning

- Phonological mediation not obligatory

Compound Character

驹

Meaning:
"Pony"
pronunciation:
/ju/

Semantic
radical

Phonological
radical

马 + 句

Meaning:
"horse"

Pronunciation:
/ju/

Semantic Transparency vs. Semantic Opaqueness of Chinese Characters

- Not all compound characters are semantically transparent
- Analogy: Two words starting with car:
  - Transparent meaning: carwash
  - Opaque meaning: carpet
- 马 (horse):
  - 驹 (Pony)
  - 驴 (Donkey)
  - 骗 (deceive)

氵 (water):
  - 江 (river)
  - 洗 (wash)
  - 法 (law)

Yan, Zhou, Shu, & Kliegl (2013)

Semantic Preview Benefit in Chinese

古代的统治者通过户籍编制来...

Preview: door

Target: domicile

N   N+1

Translation:
Ancient Chinese governors **used domicile** system to control their people.

Yan et al. (2009)

Example sentences

- 中国古代的统治者通过户籍编制来统治人民。　　　Identical preview
- 　　　　　*
- 中国古代的统治者通过广籍编制来统治人民。　　　Orthographic preview
- 　　　　　*
- 中国古代的统治者通过门籍编制来统治人民。　　　Semantic preview
- 　　　　　*
- 中国古代的统治者通过互籍编制来统治人民。　　　Phonological preview
- 　　　　　*
- 中国古代的统治者通过丹籍编制来统治人民。　　　Unrelated preview
- 　　　　　*

- 中国古代的统治者通过户籍编制来统治人民。　　　Target
- 　　　　　　　*

- Ancient Chinese governors **used domicile** system to control their people.

Yan et al. (2009)

Materials

S-radical: 才 *hand*
S-radical: 未 *plow*

	Identical	Transparent	Opaque	Unrelated
Example	费	损	耗	笑
Meaning	cost	consume	spend	laugh
Frequency	276 (307)	261 (441)	282 (415)	280 (326)
N of strokes	9.3 (3.0)	9.2 (2.4)	9.2 (2.4)	9.6 (2.3)
Trans. Rating	--	3.8 (0.5)	2.1 (0.4)	--
Sem. Rating	--	4.1 (0.5)	3.9 (0.5)	1.5 (0.3)

N=15 (Trans. Rating)

N=16 (Sem. Rating)

First Fixation Duration on Target

Yan, Zhou, Shu, & Kliegl (2013)
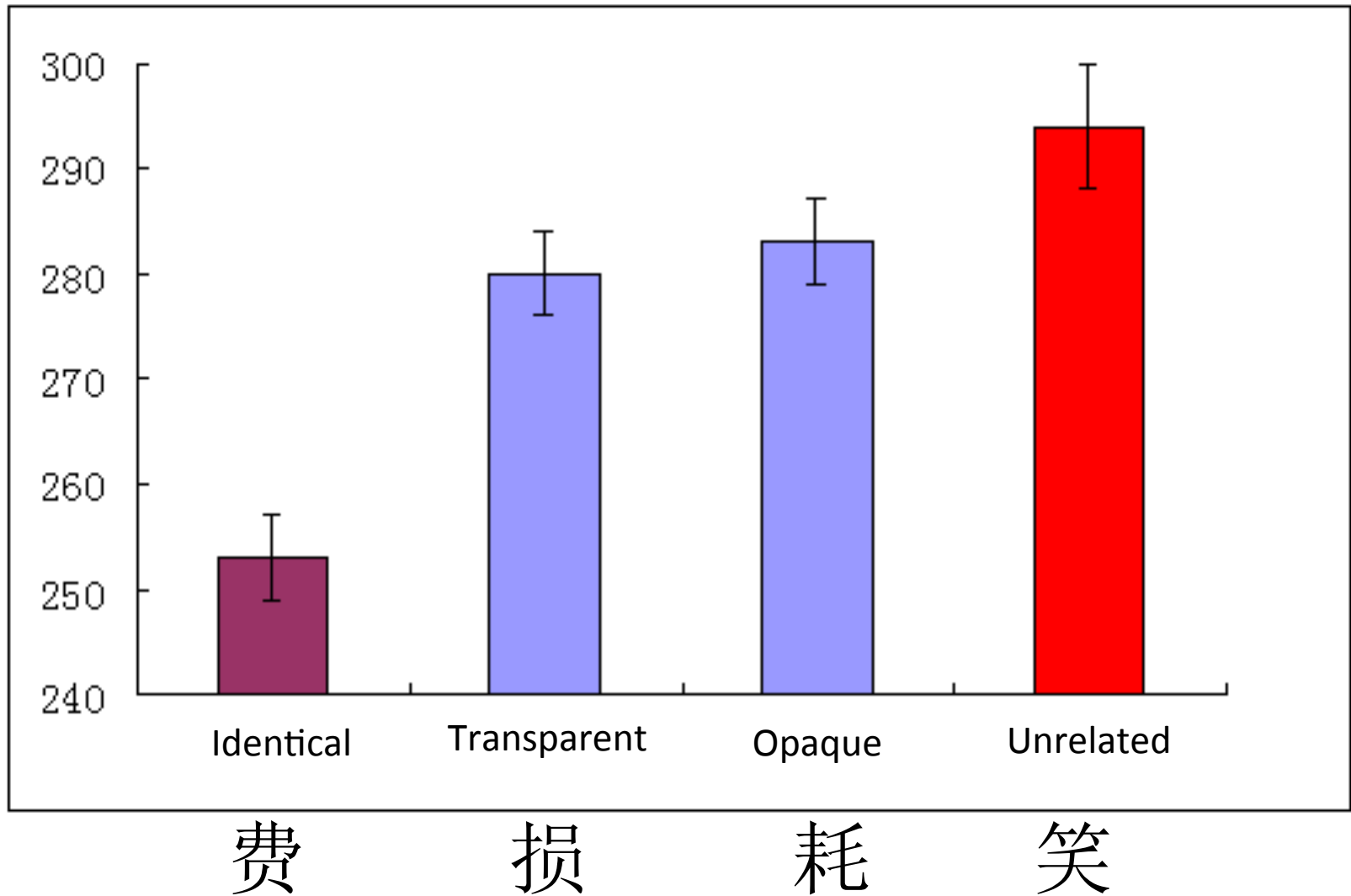
Gaze Duration on Target
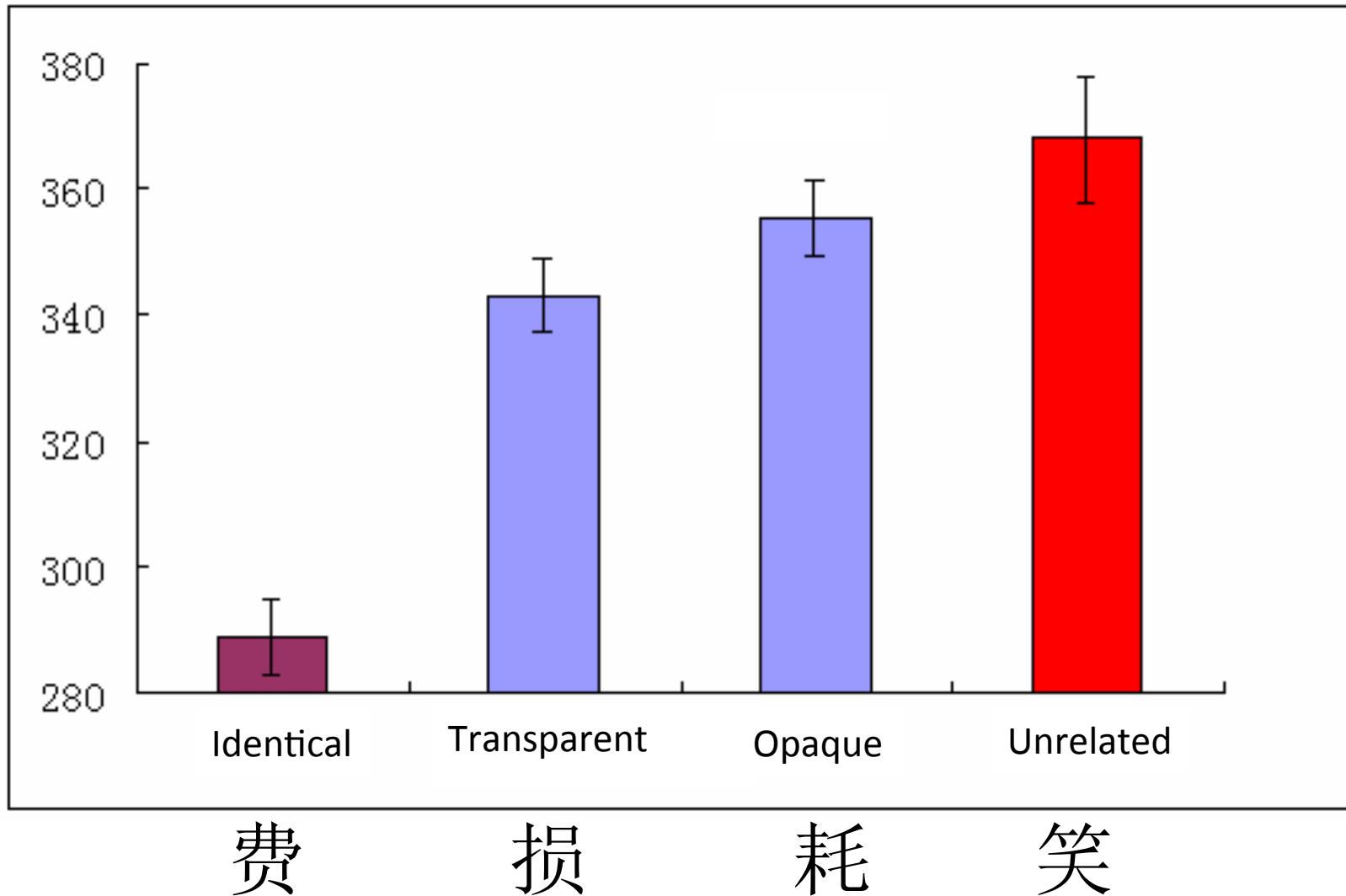
The Boundary Paradigm

Semantically related preview:

★

Beim Ausgraben waren *Schädel* **zum Vorschein gekommen.**
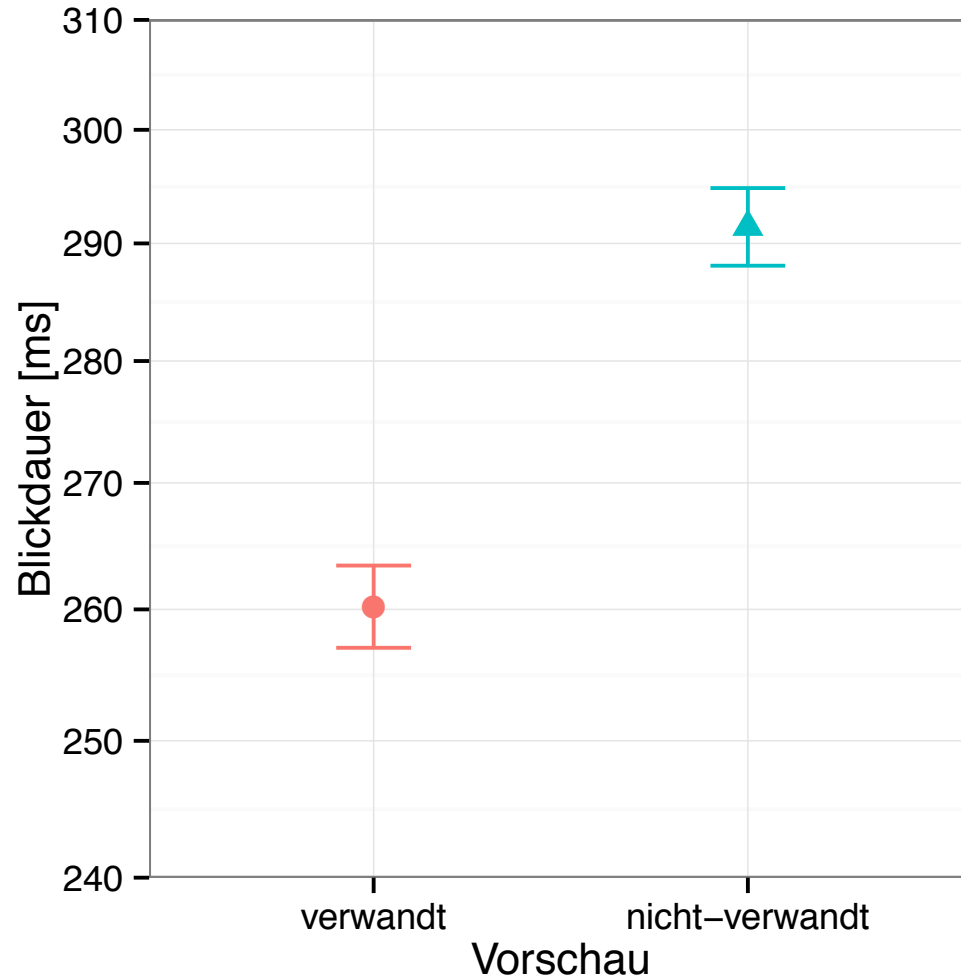
Semantically unrelated preview:

★

Beim Ausgraben waren *Stiefel* **zum Vorschein gekommen.**

Target word:

★

Beim Ausgraben waren *Knochen* **zum Vorschein gekommen.**

Hohenstein & Kliegl (2014)

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Semantic Preview Benefit in German

Special Feature of German

- Capitalization of nouns could be effective parafoveal cues?

- With proper writing ...
  - German texts are read faster
    (Bock et al., 1985; 1989)
  - Letters in texts are found more reliably
    (Müsseler et al., 2005)
  - Isolated words are recognized faster
    (Jacobs et al., 2008)
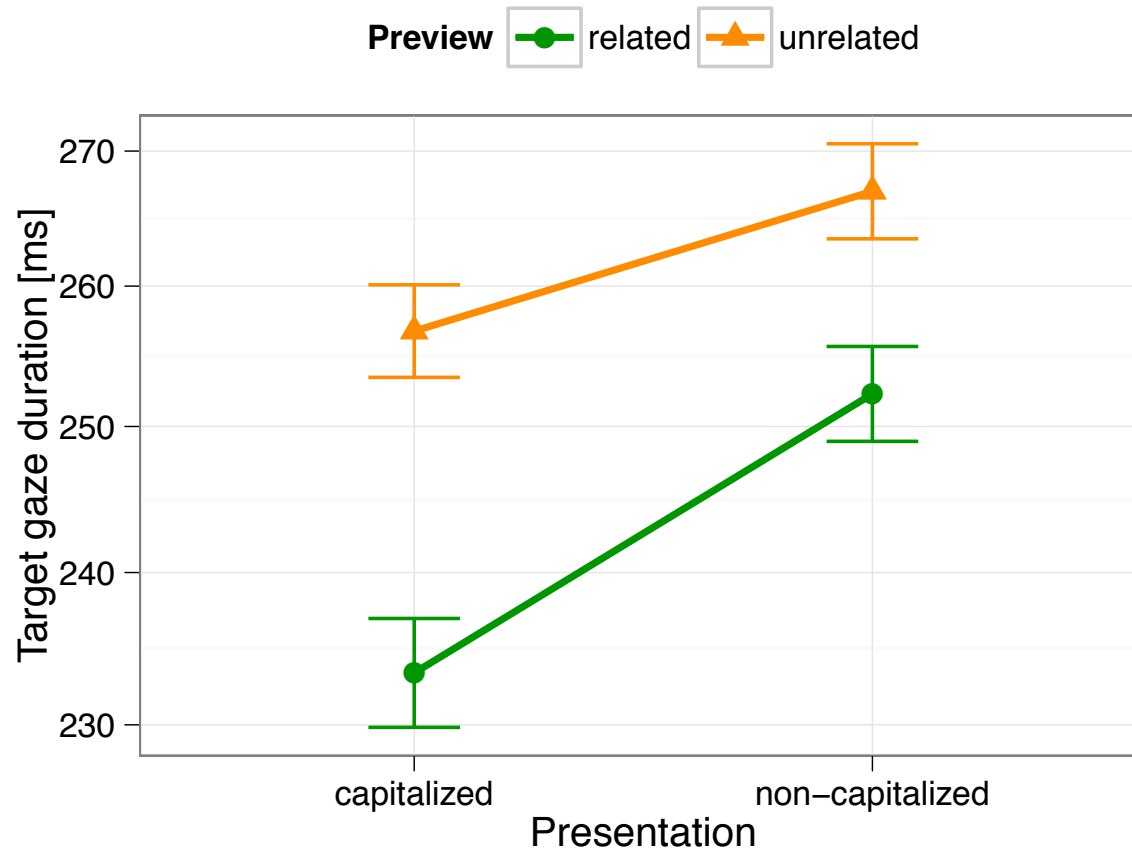
Manipulation of Capitalization

Capitalization (according to German spelling):

Beim Ausgraben waren *Knochen* zum Vorschein gekommen.

All words in lower case:

beim ausgraben waren *knochen* zum vorschein gekommen.

Semantic Preview Benefit in German

➡ Target fixations are reduced if the parafoveal preview was semantically related to the target compared to unrelated previews (*semantic preview benefit*).

➡ Non-capitalized presentation extends fixation durations on the target.

Hohenstein & Kliegl (2014, JEPLMC)

Studies on Semantic Preview Benefit

| Study	Paradigm	Language	Preview	
Rayner, McConkie, & Zola, 1980	Naming	English	Related vs. unrelated	**0**
Rayner, Balota, & Pollatsek, 1986	Boundary	English	Related vs. unrelated	**0**
Replication: Rayner et al., 2014				**0?**
Altarriba, Kambe, Pollatsek, & Rayner, 2001	Boundary/ naming	English/ Spanish	Translation vs. unrelated word in different language	**0**
				0
Hyönä & Häikiö, 2005	Boundary	Finnish	Neutral vs. emotional	**+**
White, Bertram, & Hyönä, 2008 (within word)	Boundary	Finnish	Related vs. unrelated	
Yan, Richter, Shu, & Kliegl, 2009	Boundary	Chinese	Related vs. unrelated	**+**
Hohenstein, Laubrock, & Kliegl, 2010	Fast-priming	German	Related vs. unrelated	**+**
Yang, Wang, Tong, & Rayner, 2012	Boundary	Chinese	Related vs.unrelated	**0/+**
Yan, Zhou, Shu, & Kliegl, 2012	Boundary	Chinese	Related vs. unrelated	**+**
Kim, Radach, & Vorstius, 2012	Boundary	Korean	Related vs. unrelated	**+**
Tsai, Kliegl, & Yan, 2012	Boundary	T. Chinese	Related vs. unrelated	**+**
Schotter, 2013, 2014, 2015	Boundary	English	Related vs. unrelated	**+**
Hohenstein & Kliegl, 2014	Boundary	German	Related vs. unrelated	**+**
Rayner & Schotter, submitted	Boundary	English	Related vs. unrelated	**0/+**

Analyzing Local Dynamics during Reading

- Eye movements in reading are dynamically connected sequences of fixation locations and fixation durations

- Substantive problem: Dynamics not so much in focus of research

- Methodological problems

  - Separate analyses of SFD, FFD, GD, skipping, refixation, regression

  - Separate analyses for neighboring words (pretarget, target, …)

- Related statistical issues

  - Redundancies between measures

  - Correlations between measures of successive words

  See B. Angele & T. v. d. Malsburg: False positives in standard analyses of eye movements in reading. Poster 23, Mo 15:00-17:00
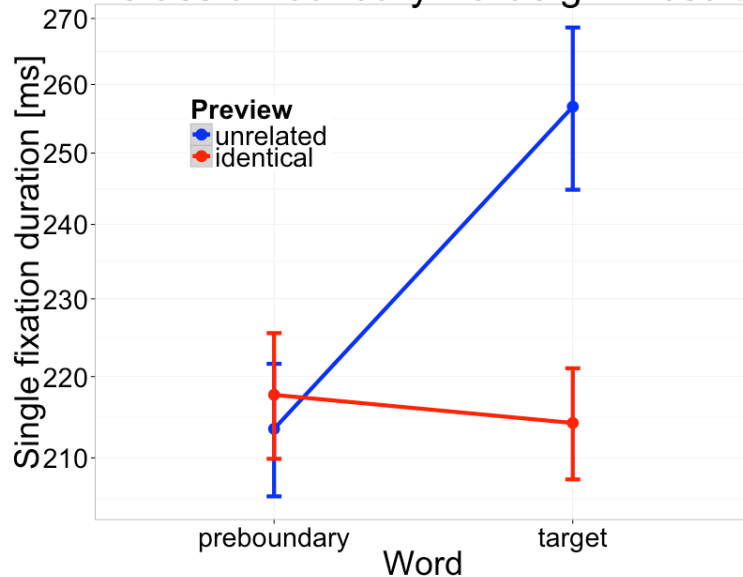
The Simplest Preview-Benefit Study Design
(Boundary Paradigm, Rayner, 1975)

Word$_N$: Word$_{N+1}$
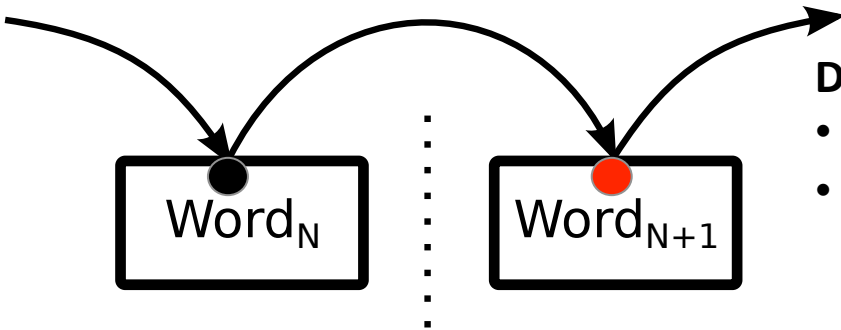
Design (Yan et al., 2009, PBR)
- One dependent variable: fixation duration
- Fixed factors
  - Type of preview (2): related vs. unrelated
  - Word (2): preboundary n vs. target n+1
- 48 subjects, 48 items

**Classic Boundary-Paradigm Result**

Statistical analysis

LMM of FD$_{N+1}$ ~ Type of preview (2) x FD$_N$

**Other options for statistical analysis**

- t-tests of "Type of preview"; one for each word

- 2 x 2 repeated-measures ANOVA (F1, F2)

- 2 x 2 LMM (combines F1, F2)

- 1 x 4 LMM with nested effects within levels of Word

- Linked linear mixed models

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LMM with Preboundary Fixation as Covariate of Semantic Preview Benefit in Chinese
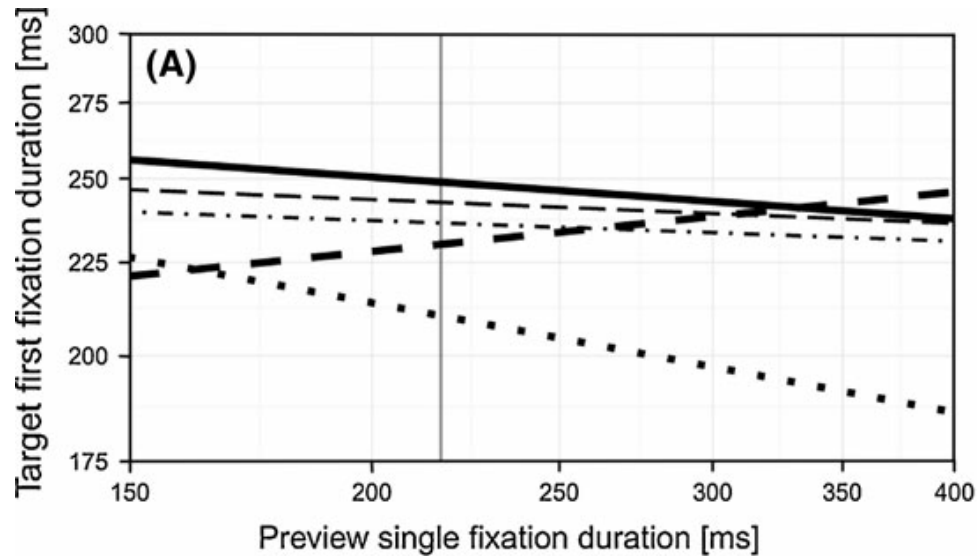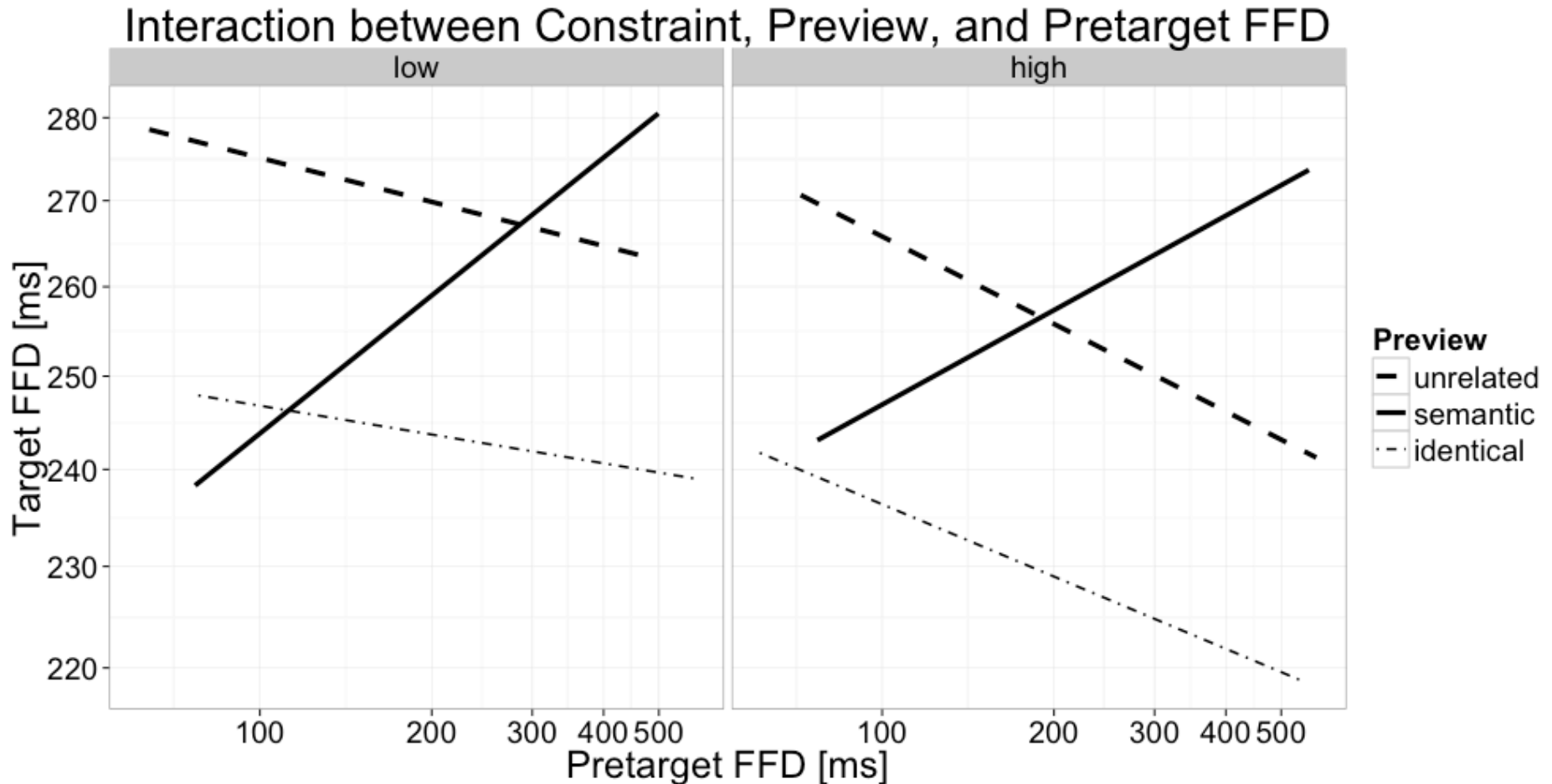

LMM with numeric covariates

- ME: Preview (type)
- ME: Preview time (FD_N)
- Interaction
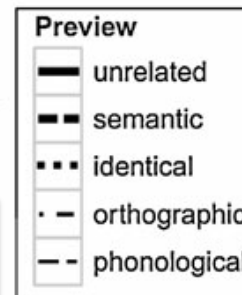
Yan, Risse, Zhou, & Kliegl (2012)
 - based on reanalysis of
Yan et al. (2009)

LMM with Preboundary Fixation Duration as Covariate of Semantic Preview Benefit in Chinese: Replication and Extension

Interaction between Constraint, Preview, and Pretarget FFD

60 subjects, 84 sentences
Constraint: cloze prob for low = .14, for high = .87

Li, Wang, & Kliegl (2015)

Conclusions

- Reader of Chinese extract parafoveal semantic information, independent of character structure or visual complexity (see also Yang, Wang, Tong & Rayner, 2012).

- Characters can be decomposed into radical units parafoveally; sub-lexical semantic information can be accessed during parafoveal processing.

- Semantic information is more easily detected in Chinese than in alphabetic scripts.

- So how about alphabetic languages?

Conclusions

- Information about frequency and predictability of several words around a fixated word significantly influences a fixation duration

- We extract semantic information from the parafoveal word -- Simplified Chinese, German, Traditional Chinese, Korean, (Young_Suk, Radach, & Vorstius, 2012), recently also English (Schotter & Rayner, in prep.)

- Cross-language comparison is very useful research strategy for achieving an understanding of dynamics of eye-movement control and attention allocation during reading and possibly also when we look at paintings

General Conclusion

- We need everything:
  - **Observational designs** (e.g., analyses of corpus data representative of reading situations; individual differences)
  - (**Quasi-)experimental designs** (e.g., boundary, moving window paradigms; manipulation of target words)
  - **Co-registration** of eye-movements and EEG (e.g., fixation-related potentials) – **not shown in this presentation**
  - **Computational models** to validate our theoretical propositions – **shown in presentation tomorrow**
- Reading is a culturally acquired skill, assembled from basic cognitive process, but influences allocation of attention in the visual field (at least when we look at paintings)
- **"Absence of evidence is not evidence of absence"** (Altman & Bland, 1995, *BMJ*) – at least in NHST tradition …

Thanks

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