Integration of Information in Sentence Reading

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Overview of talk

- Similarities and differences between eye-tracking of code reading and sentence reading
- Basic questions in sentence reading research
- Introduction to parafoveal processing
- Evidence for structural integration in parafoveal processing

Sentence reading vs. code reading

	Sentences	Code
lexical processing	✓	✓
syntactic structure	✓	✓
structural ambiguity	✓	✗(?)
linear reading order	✓	✗

Eye-tracking in sentence reading: Questions

How does sentence comprehension work?

Eye-movements as a source of data

How does reading work?

Eye-movements as an object of study

How does language comprehension work?

- How do we recognise words?
- How do we compute syntactic structure?
- How do we form dependencies between new words and previously computed structure?
- How do we use structure to guide interpretation?
- What system do we use to resolve temporary and global ambiguity? (serial heuristics? probability distribution with surprisal?, etc)

All of these questions can be answered by testing for processing difficulty at specific words. Fixation times, regression probability provide good measures.

How does comprehension work? Lexical processing

- Words that are harder to process are fixated for longer

Word frequency

The shiny new gondola moved slowly

The shiny new vehicle moved slowly

How does comprehension work? Lexical processing

- Words that are harder to process are fixated for longer

Word frequency

The shiny new gondola moved slowly
👁262ms

The shiny new vehicle moved slowly
👁225ms

How does comprehension work? Syntactic processing

free [cash withdrawals] = "free withdrawals of cash"

[free cash] withdrawals = "withdrawals of free cash"

How does comprehension work? Syntactic processing


```
for item in [1,2,3,4,5]:
    print item
    print "hello world"
```

```
for item in [1,2,3,4,5]:
    print item
print "hello world"
```

free [cash withdrawals] = "free withdrawals of cash"

[free cash] withdrawals = "withdrawals of free cash"

How does comprehension work? Syntactic processing

Sturt & Kwon, 2015)

Tom didn't trust Amy but was kind to 👁242ms himself...

Amy didn't trust Tom but was kind to 👁257ms himself...

How does comprehension work? Syntactic processing

a. Gemma doesn't think that chess is a sport that I ever actually played.

b. Gemma doesn't think so, but chess is a sport that I ever actually played.

Yoshida & Sturt (2008): longer fixation times for (a) than (b) while reading "ever"

- Sensitivity to scope of negation
- Shows fast integration of "ever" into structure

How does comprehension work? Syntactic processing

a. Gemma doesn't think that chess is a sport that I ever actually played.

b. Gemma doesn't think so, but chess is a sport that I ever actually played.

```
foreach $item (1,2,3,4,5) {
    print "hello world\n";
    print $item, "\n";
}
```

```
foreach $item (1,2,3,4,5) {
    print "hello world\n";
}
print $item, "\n";
```

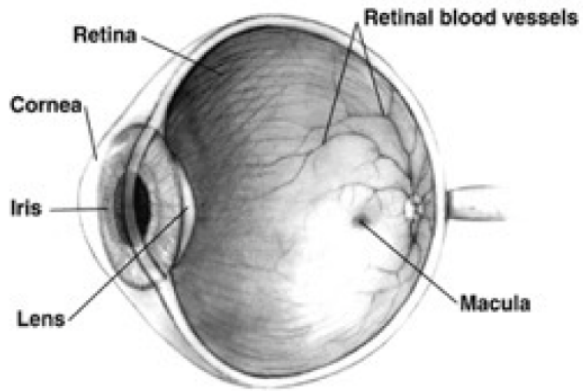
Interim summary

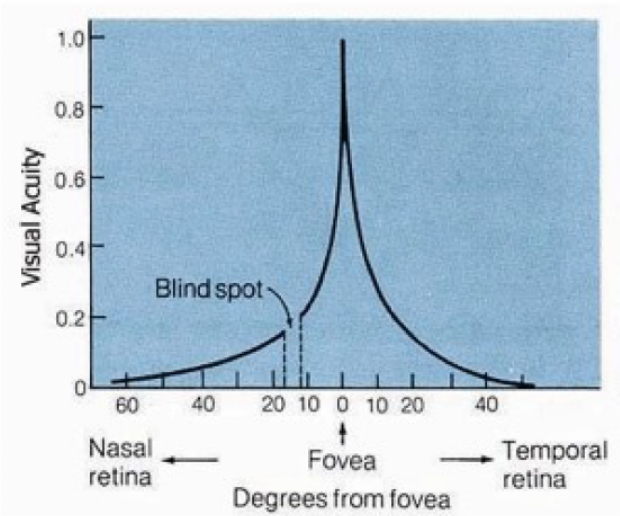
- When a word w is directly fixated, fixation times correlate with the difficulty of processing w
- That difficulty may be related to:
  - Lexical properties of w (e.g. lexical frequency)
  - Integration of w into the interpretation or syntactic structure $\Rightarrow$ tight integration between syntactic information and eye-movement control

How does reading work?

- How is visual attention allocated to words? (e.g. serial? parallel?)
- "Where" question: How do we choose the target of a saccade?
  - landing position within a word? choice to make forward saccade, skip, regression?
- "When" question: what determines the decision to end a fixation and initiate a saccade?

Foveal vs. Parafoveal vision





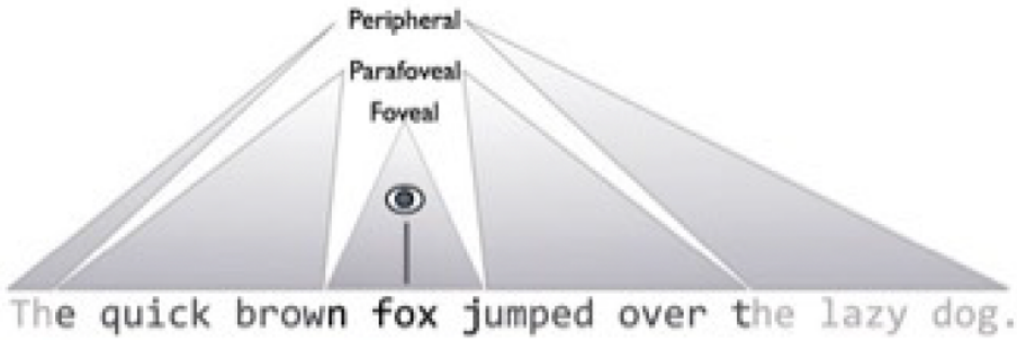


Fig. 1 The foveal, parafoveal, and peripheral regions when three characters make up 1° of visual angle. The eye icon and dotted line represent the location of fixation

Parafoveal processing: sources of evidence

Parafoveal on foveal (PoF) effects

261ms
The opera singer| performed yesterday.

268ms
The opera singer| pvxformed yesterday.

Preview effects

The quick brown| fox jumped over the fence.

The quick brown| fox jumped over the fence.

Skipping

The dog buried his bone in the garden.

The dog buried his food in the garden.

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Preview effects

225ms
The quick brown| fox jumped over the fence.

251ms
The quick brown| fox jumped over the fence.

Skipping

The dog buried his bone in the garden.

The dog buried his food in the garden.

Parafoveal processing: sources of evidence

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👁35%
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Serial Attention Shift models (e.g. EZ Reader)

A

The quick brown fox jumps over the lazy dog.

"A" = Attention

(Reichle et al, 2003, 2009)

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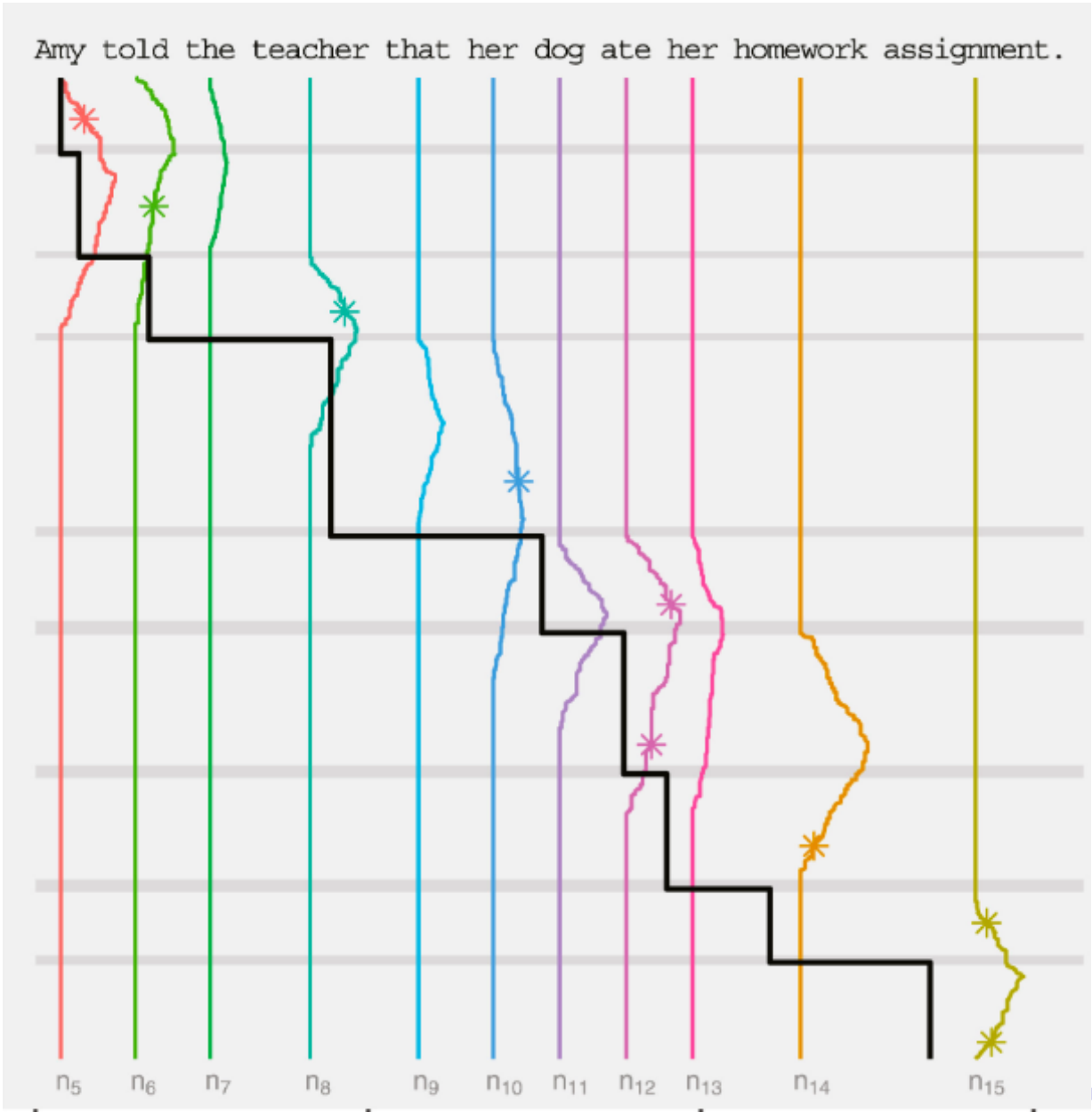
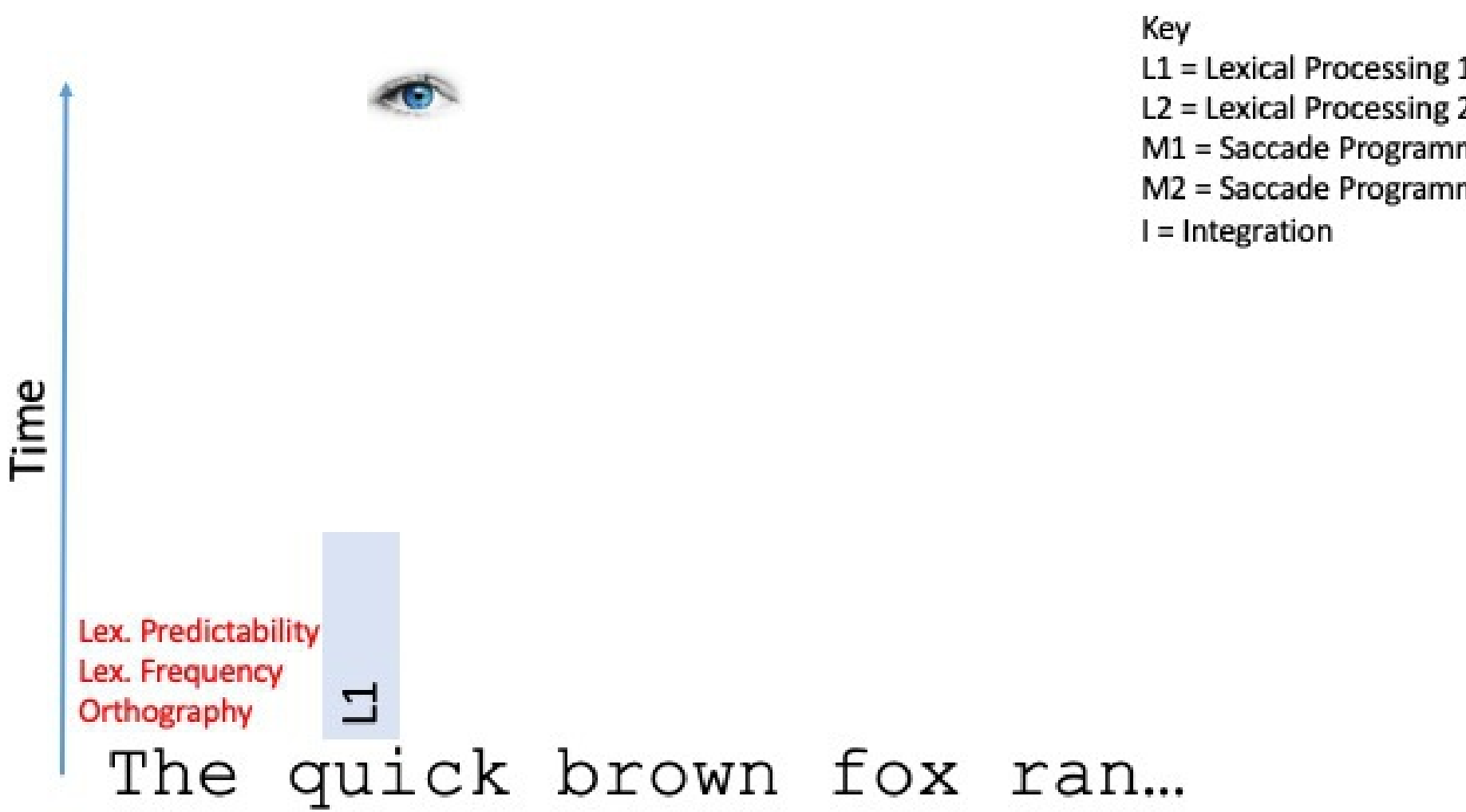
Attentional Gradient models: SWIFT (Engbert et al, 2005)



EZ-Reader model (Reichle et al, 2003; 2009)



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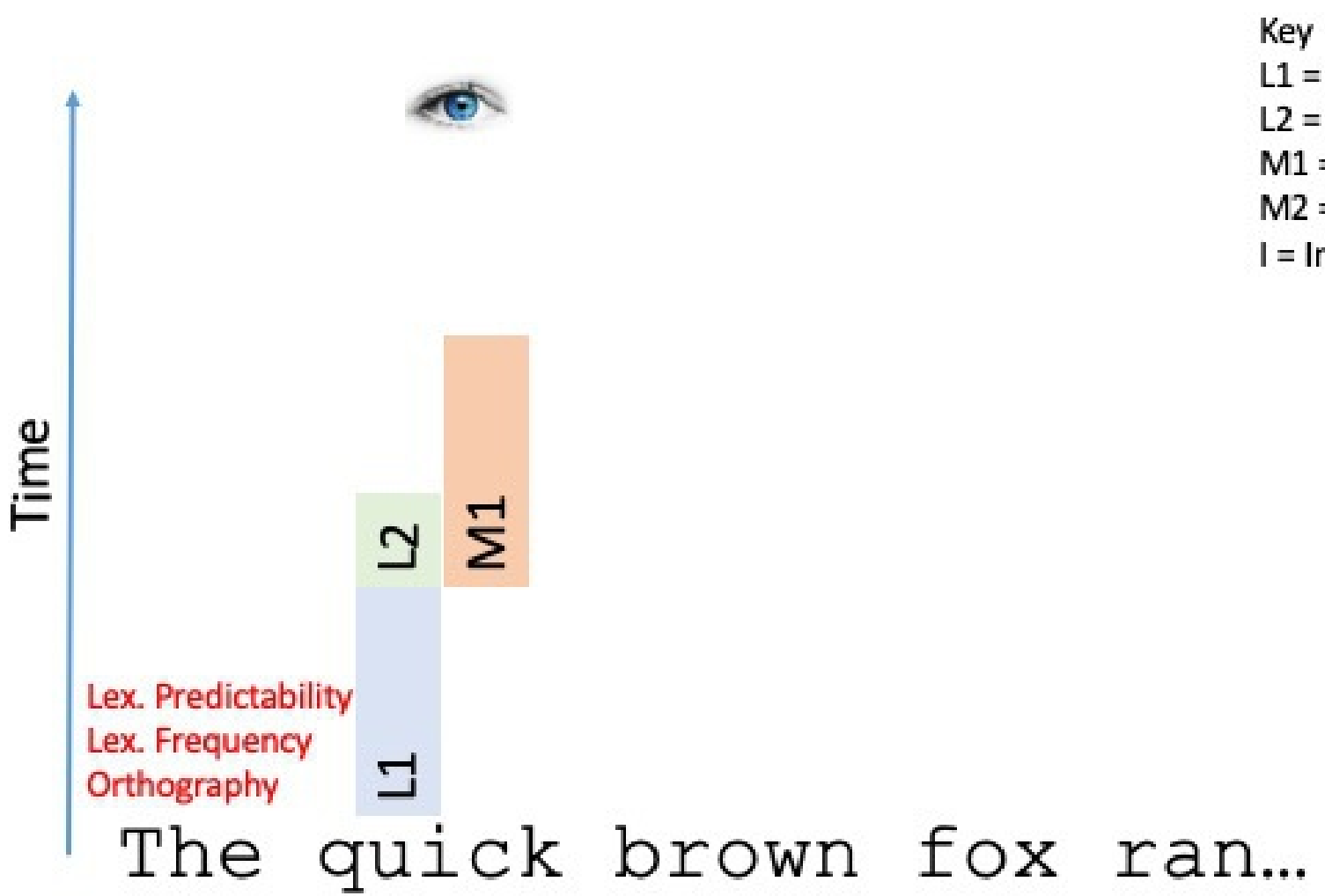

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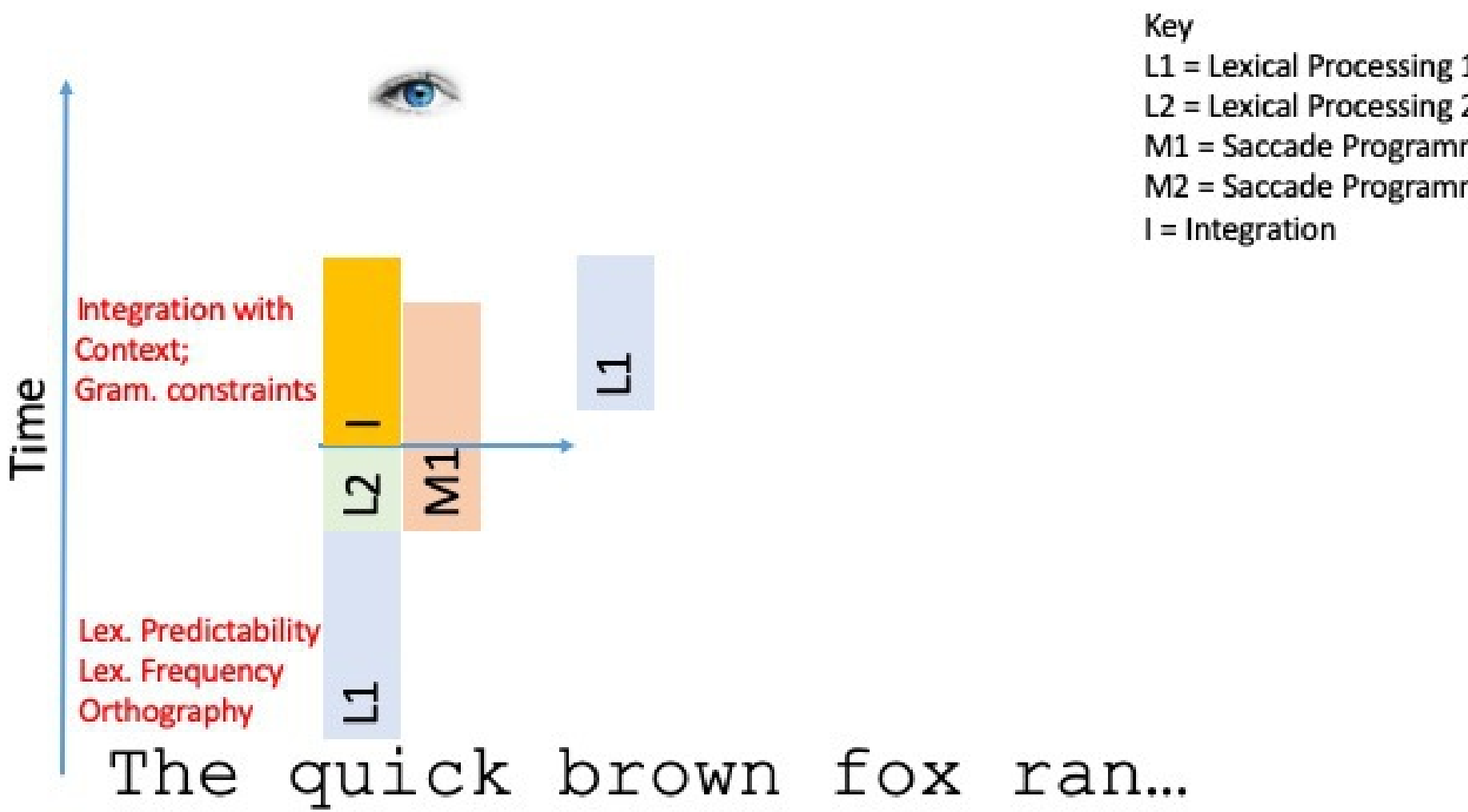

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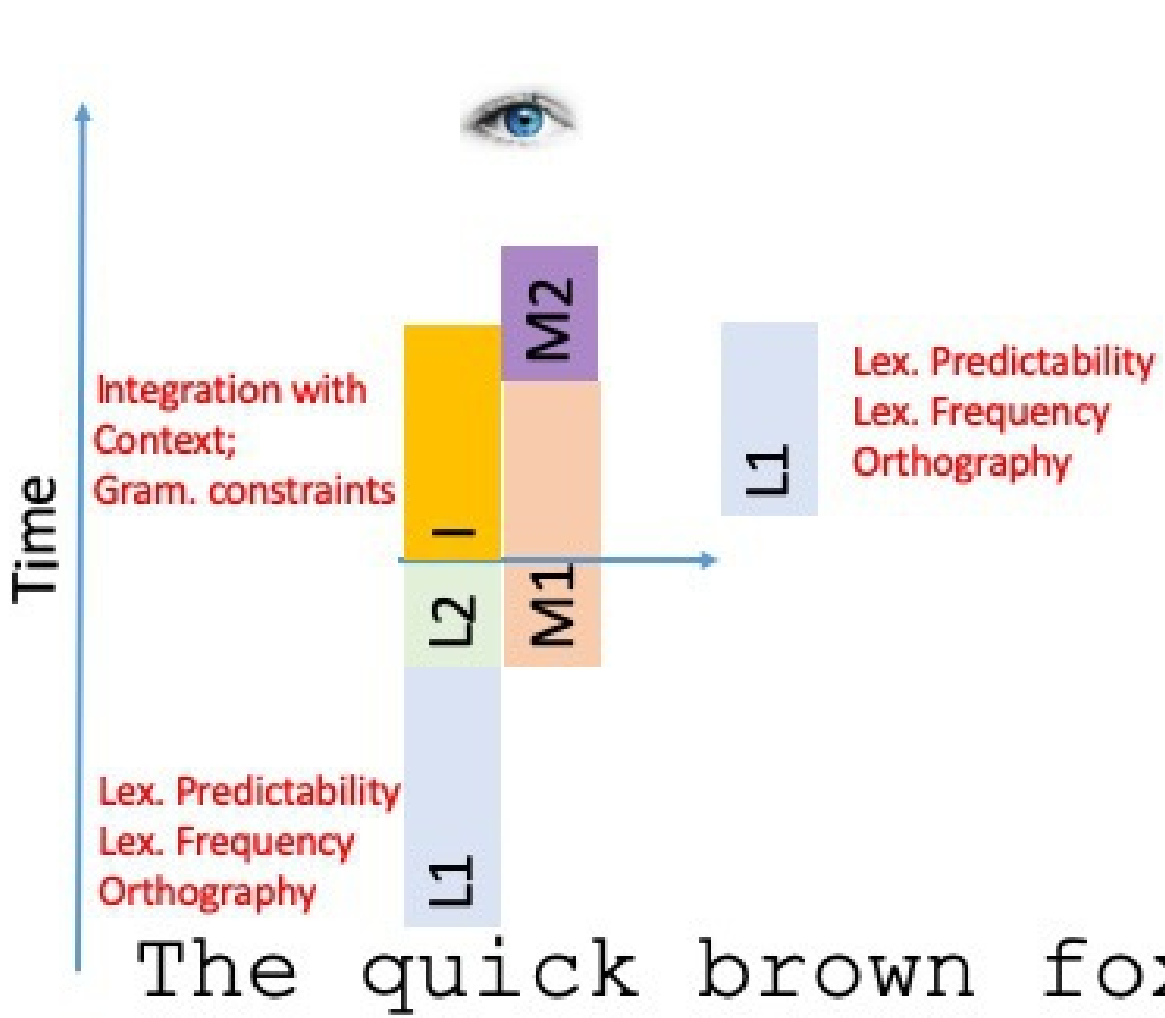

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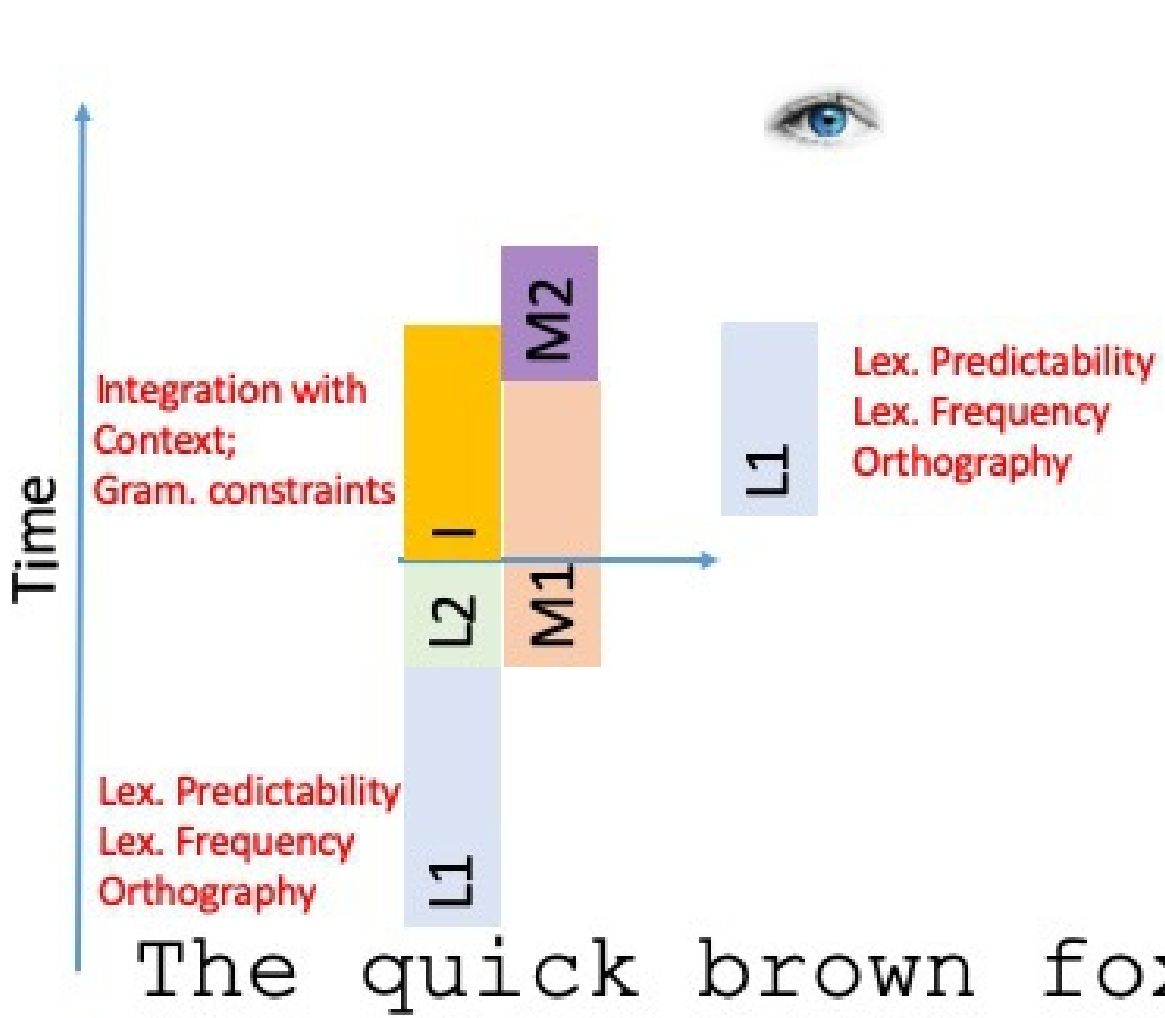

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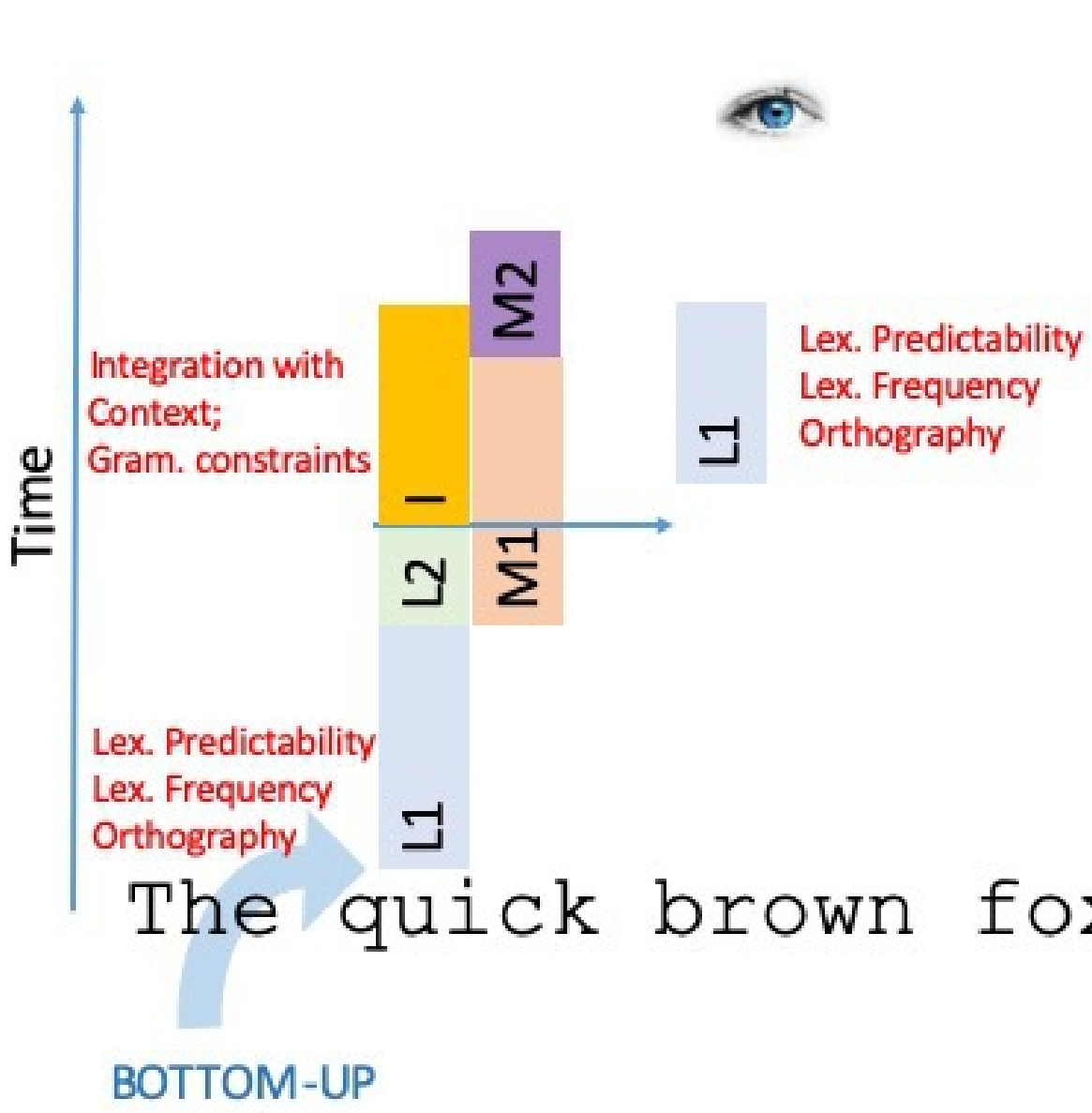

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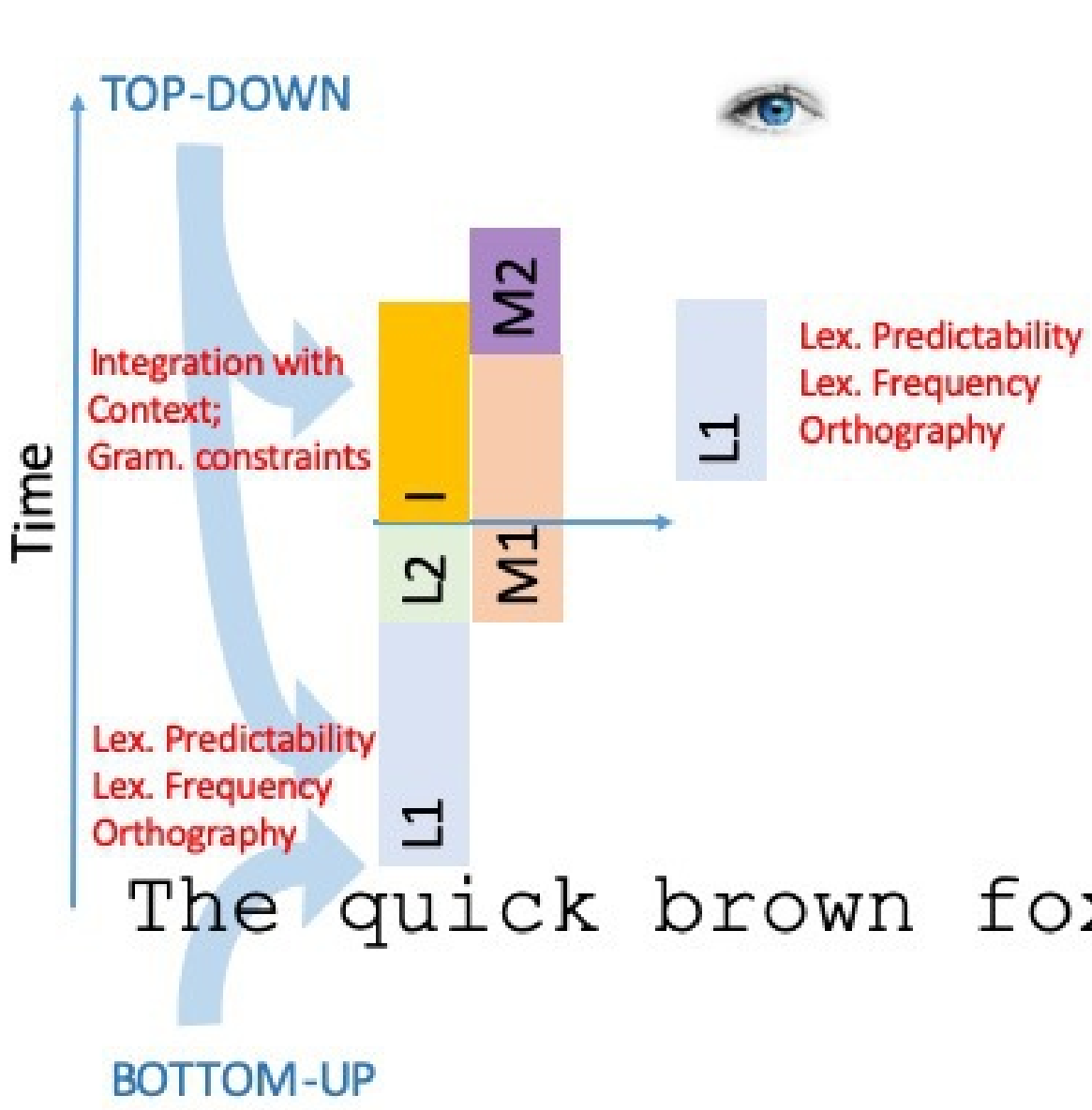
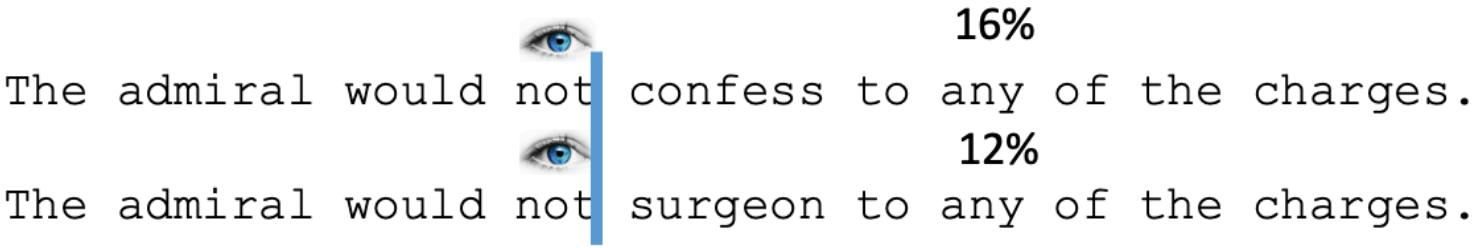


Contextual integration: Brothers & Traxler (2016)



- People skip over syntactically legal words more often than syntactically illegal words
- Target word must be integrated with the context parafoveally.

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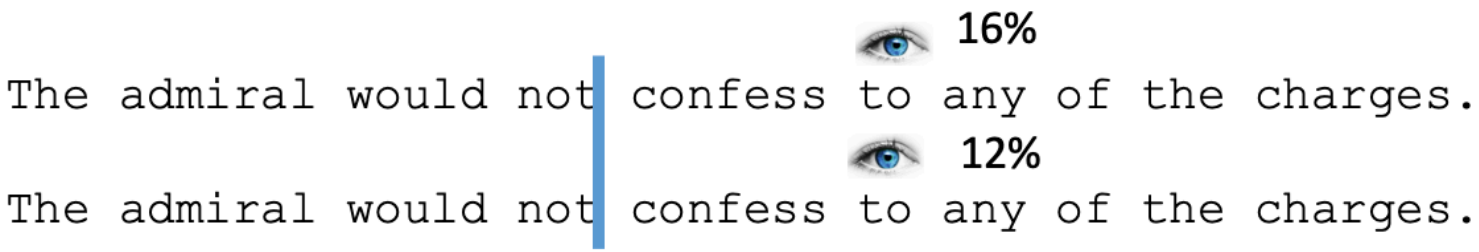

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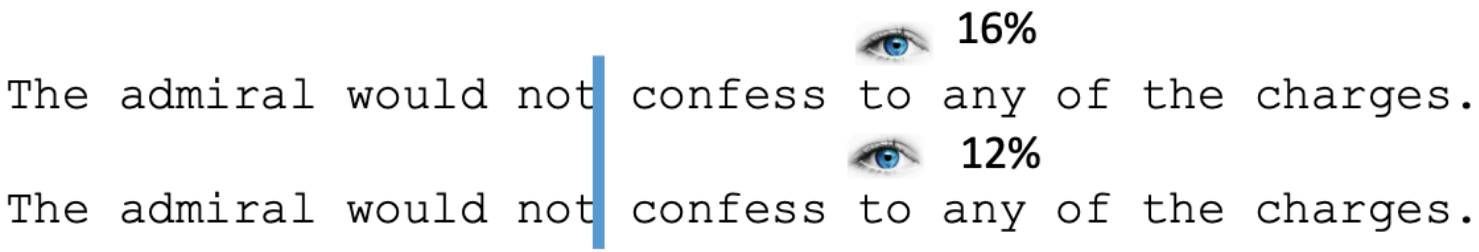

- People skip over syntactically legal words more often than syntactically illegal words
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Contextual integration: Veldre & Andrews (2018)

```
Her plane will probably refuel later than expected.
Her plane will probably depart later than expected.
Her plane will probably landed later than expected.
Her plane will probably stroke later than expected.
```

- Fixation times on target word are affected by:
  - Syntactic fit of preview with context
  - Semantic fit of preview with context

Contextual integration: Veldre & Andrews (2018)

Her plane will probably refuel later than expected. 252msec
Her plane will probably refuel later than expected. 281msec
Her plane will probably refuel later than expected. 295msec
Her plane will probably refuel later than expected. 313msec

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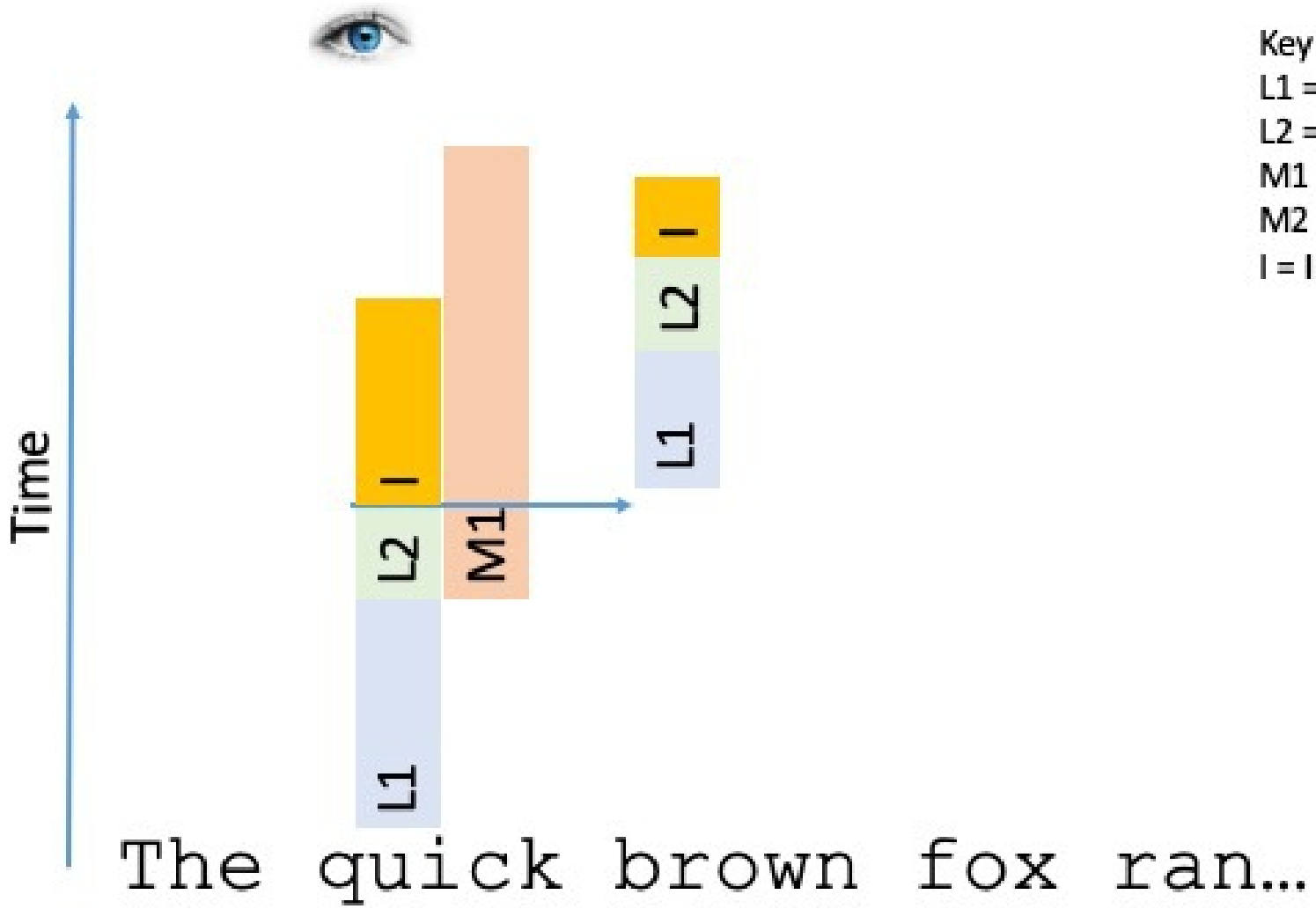

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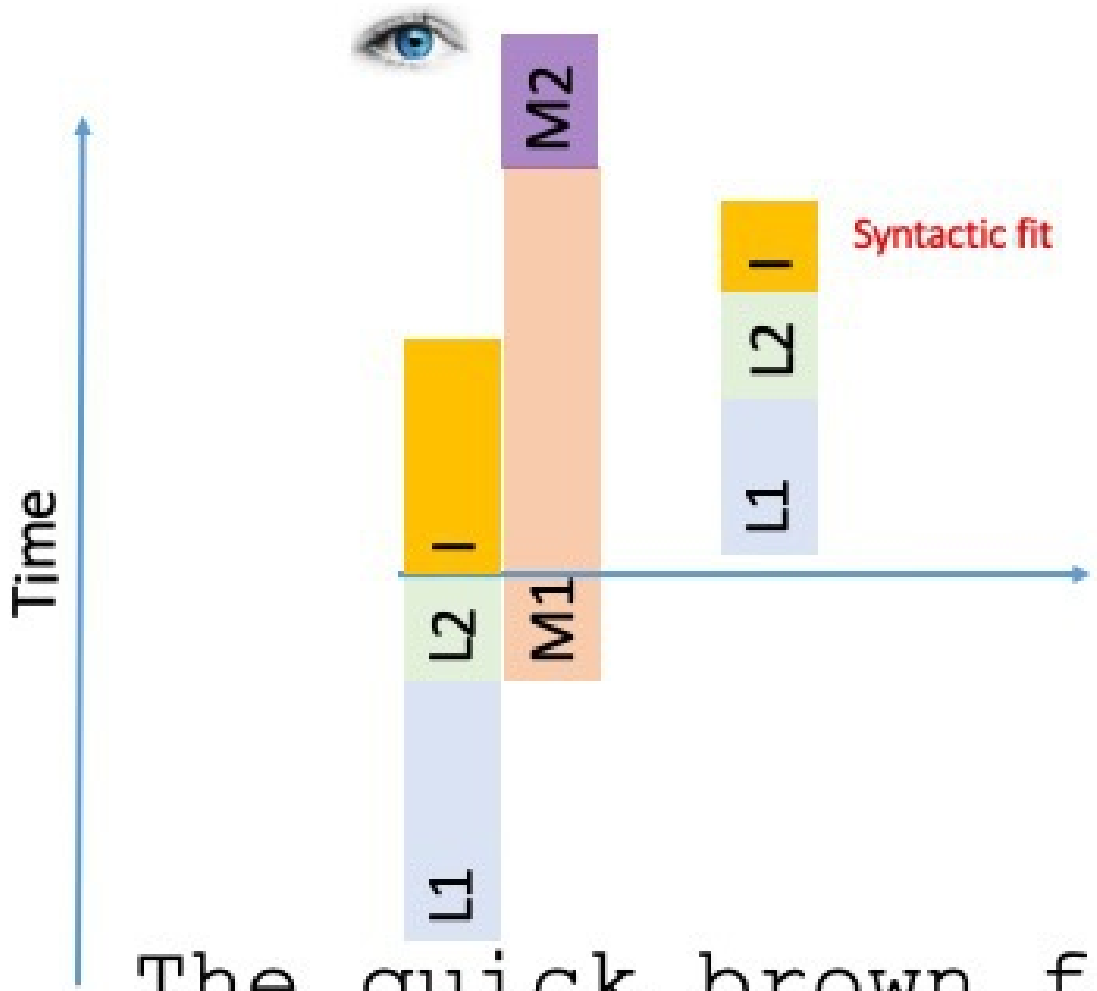
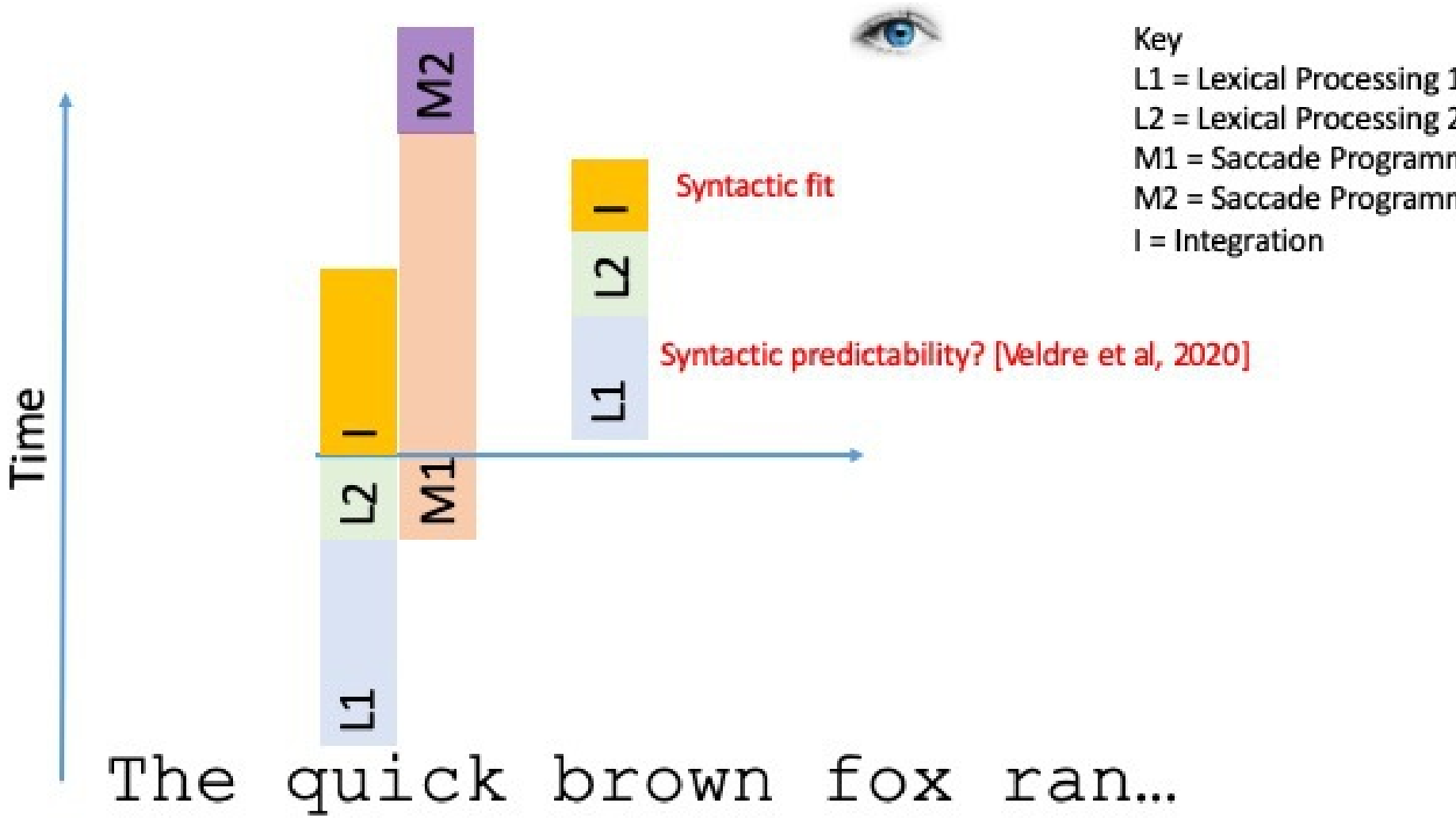


Key
L1 = Lexical Processing 1
L2 = Lexical Processing 2
M1 = Saccade Programm
M2 = Saccade Programm
I = Integration

EZ-Reader model (Reichle et al, 2003; 2009)



Cutter et al (2020): Skipping study

- Predictable words are skipped more often than unpredictable words:

  The dog buried his bone in the garden.

  The dog buried his food in the garden.

- EZ-reader, and other models suggest this is due to lexical pre-activation

See also Pickering & Gambi (2018) Psych. Bull, inter alia

Cutter et al (2020): Skipping study

- Predictable words are skipped more often than unpredictable words:

  The dog buried his bone in the garden. 👁35%

  The dog buried his food in the garden. 👁28%

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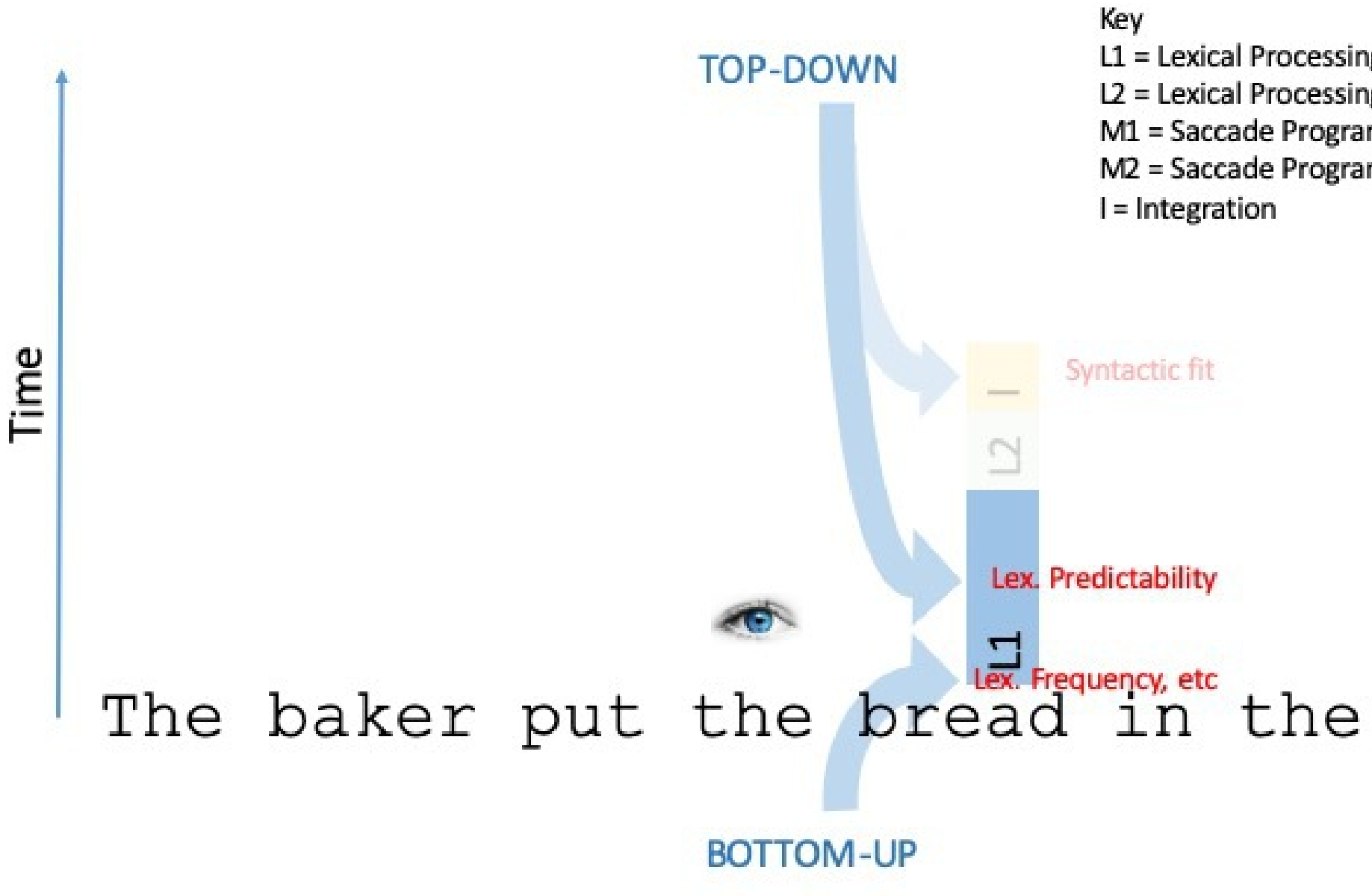
The baker put the bread in the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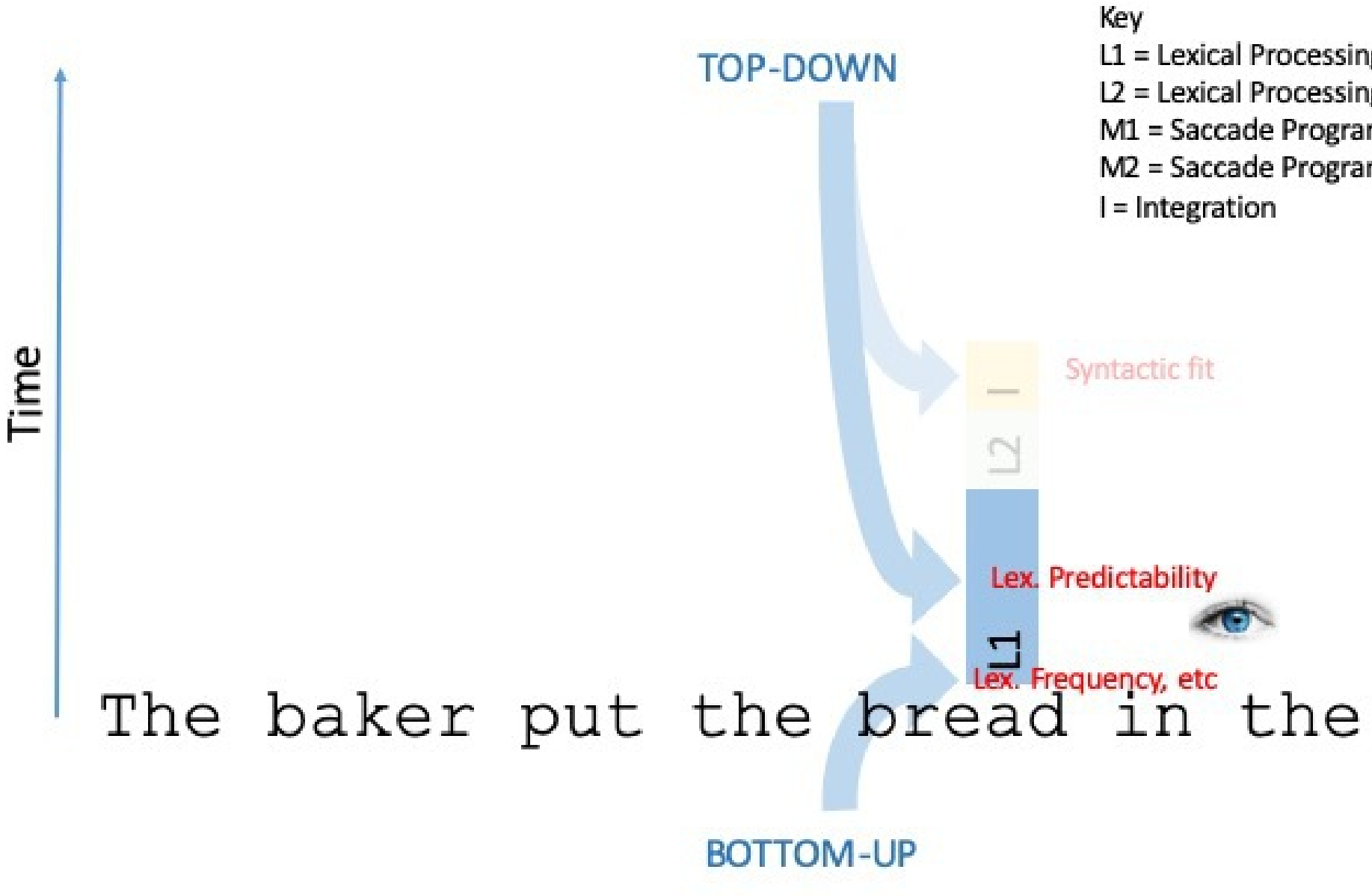
Time
Syntactic fit
L2
I
Lex. Predictability
L1
Lex. Frequency, etc
The baker put the bread in the
BOTTOM-UP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BOTTOM-UP

Does lexical predictability affect skipping for ungrammatical words? (Cutter et al, 2020)

Legal Predictable:

The baker put the bread in the hot oven.

Legal Unpred:

The baker put the pizza in the hot oven.

Illegal Predictable:

The dog buried his rather bone poo in the garden.

Illegal Unpredictable:

The dog buried his rather food poo in the garden.

Does lexical predictability affect skipping for ungrammatical words? (Cutter et al, 2020)

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Legal Unpred:

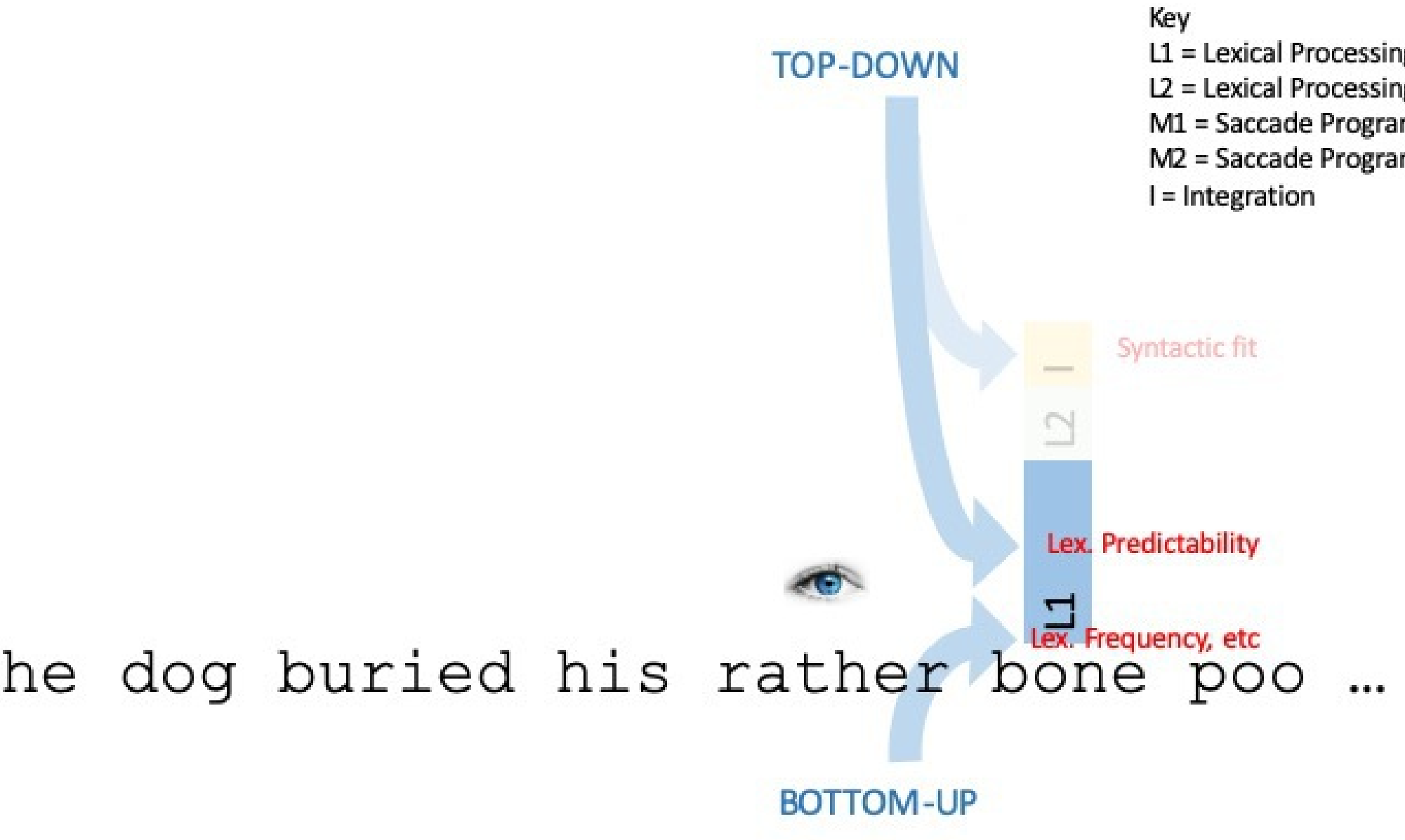
The baker put the pizza in the hot oven.

Illegal Predictable:

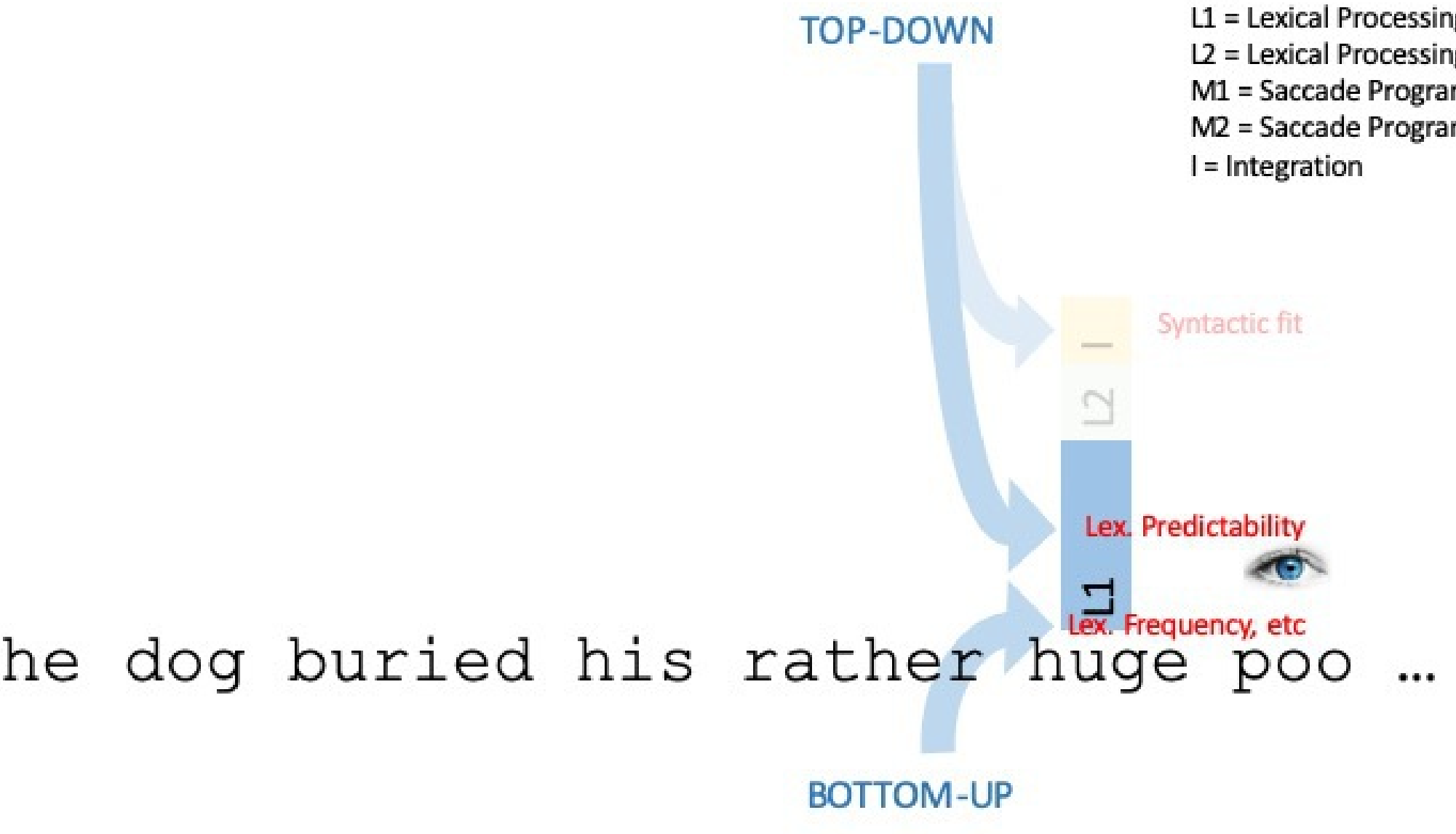
The dog buried his rather huge poo in the garden.

Illegal Unpredictable:

The dog buried his rather huge poo in the garden.



For frequency, see also Angele et al (2014), JEP:LMC



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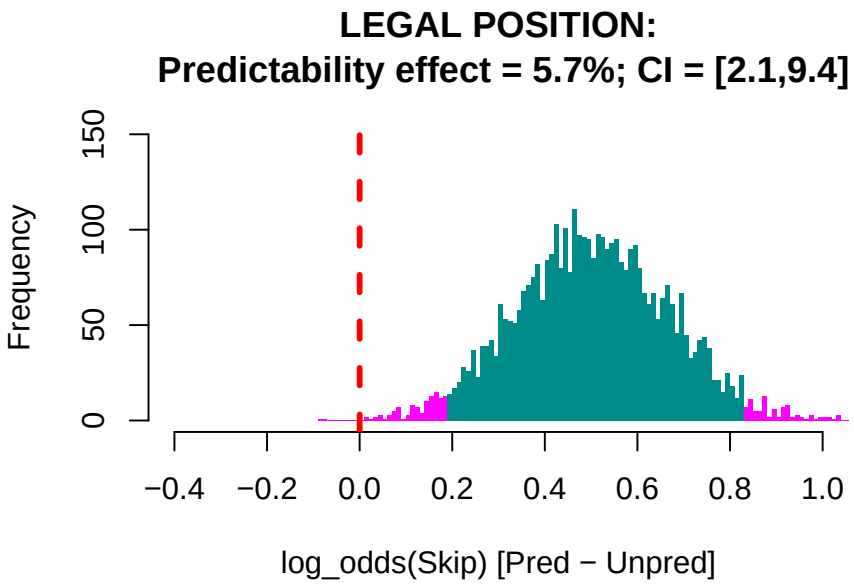
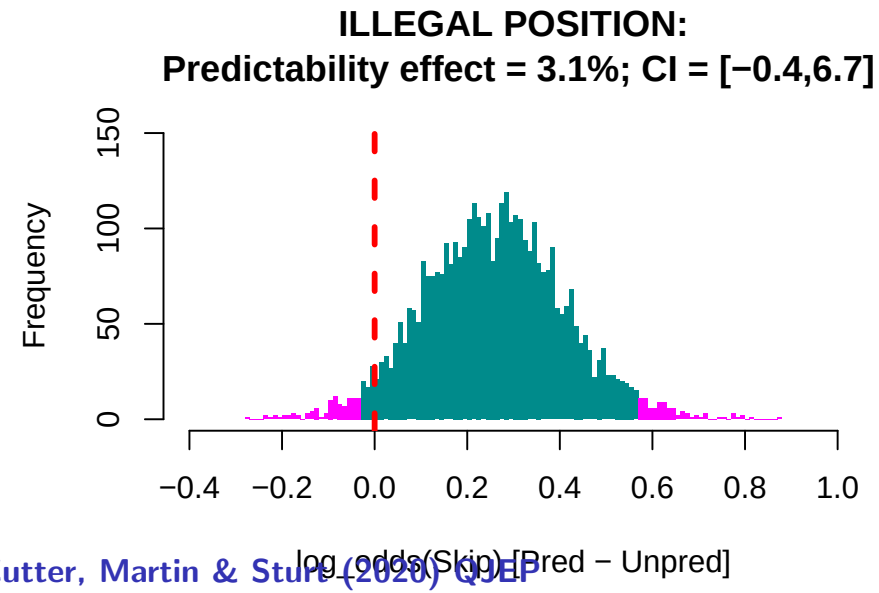
Predictability skipping effect



Legal Position

5.7% skipping effect

$P(b > 0) > .99$



Illegal Position

3.1% skipping effect

$P(b > 0) = .95$

Cutter et al (2020) Skipping study: Summary

- Readers may skip lexically predictable words more than unpredictable words, even in ungrammatical positions:
  - Explained in EZ-Reader, if we assume lexical pre-activation of word before integration into context.

Cutter et al (2020): Syntactic PoF effect?

SRC; Normal case

The tall guard who alerted Charlie was young.

ORC; Normal case

The tall guard who Charlie alerted was young.

.

.

.

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Cutter et al (2020): Syntactic PoF effect?

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Cutter et al (2020): Syntactic PoF effect?

SRC; Normal case

The tall guard who alerted Charlie was young.

ORC; Normal case

The tall guard who Charlie alerted was young.

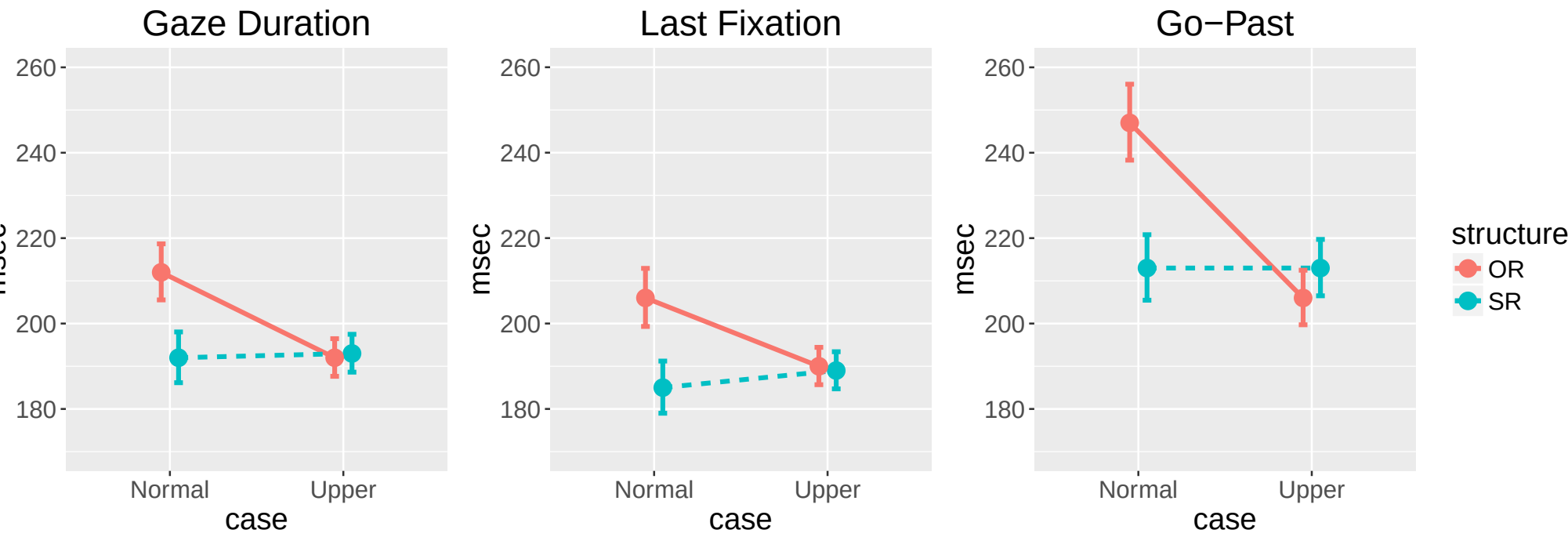
SRC; Upper case

THE TALL GUARD WHO ALERTED CHARLIE WAS YOUNG.

ORC; Upper case

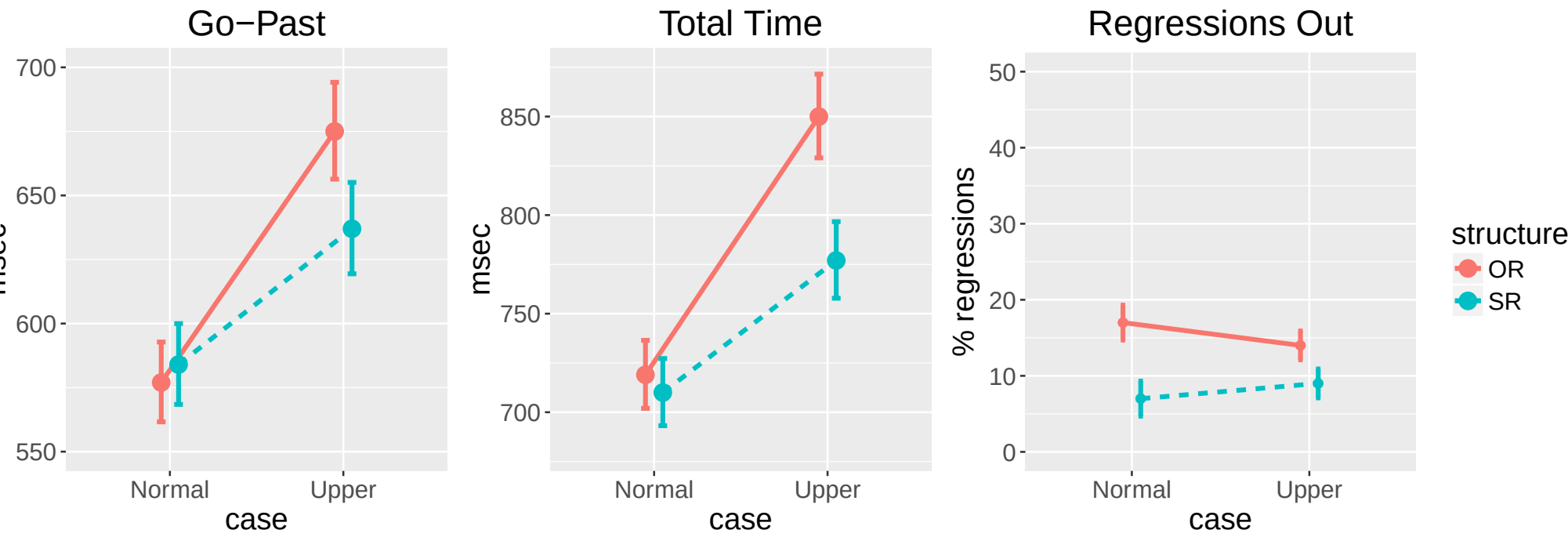
THE TALL GUARD WHO CHARLIE ALERTED WAS YOUNG.

Experiment 1: pre-target ("who")

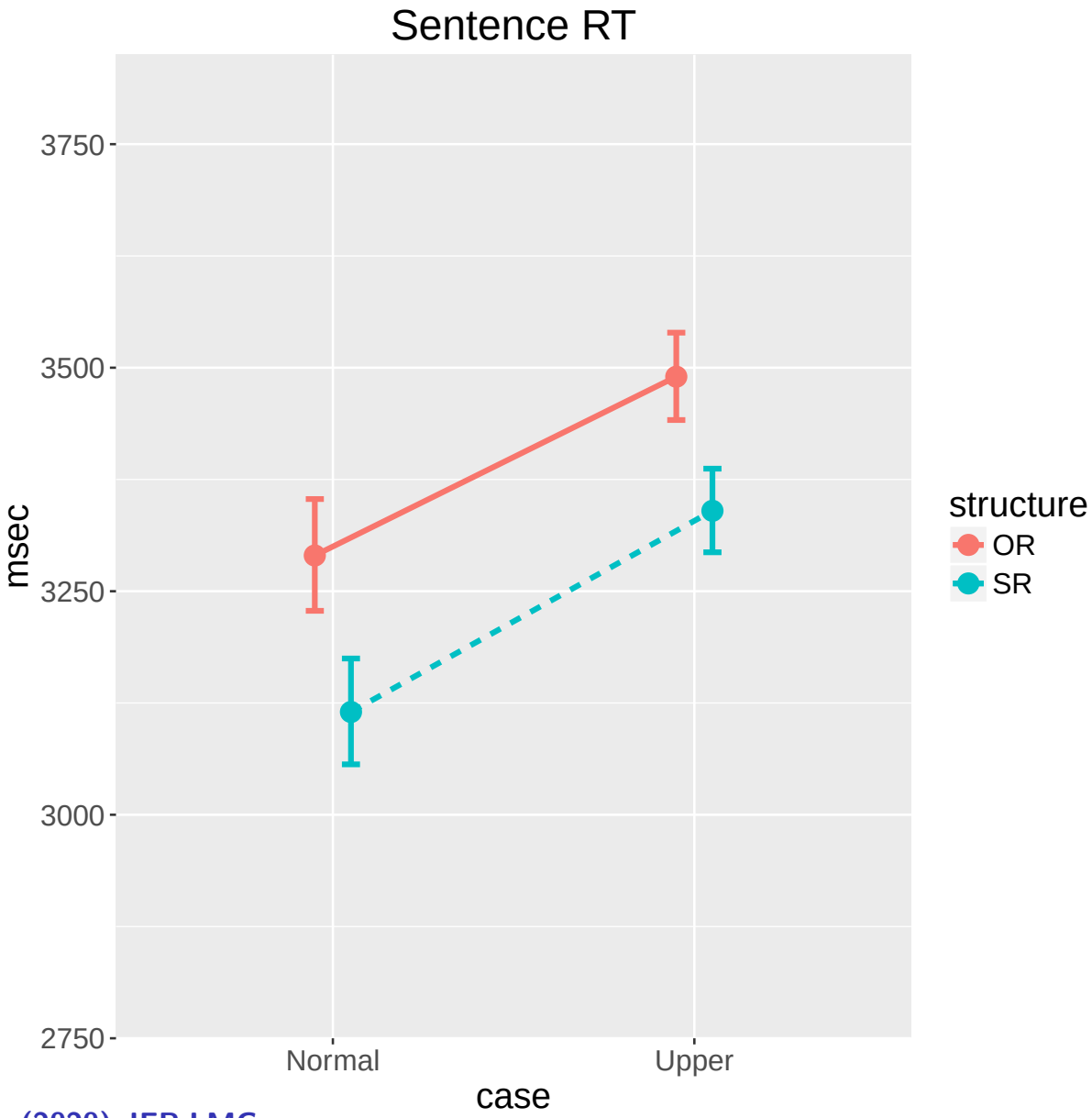


Cutter, Sturt & Martin (2020) JEP:LMC

Experiment 1: relative clause: "Charlie alerted"



Experiment 1: Whole sentence RT

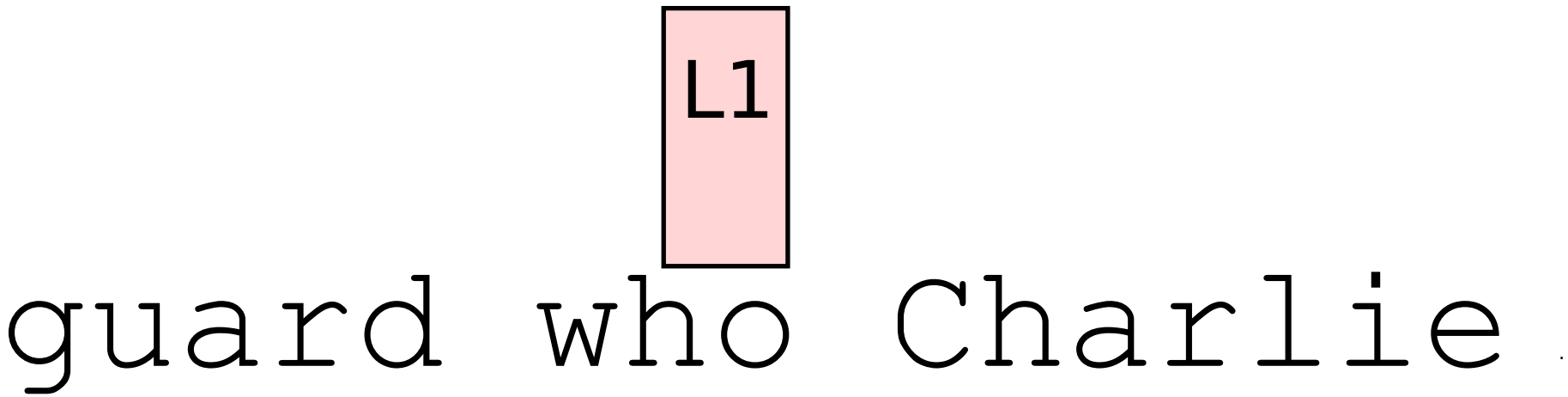


Cutter, Sturt & Martin (2020) JEP:LMC

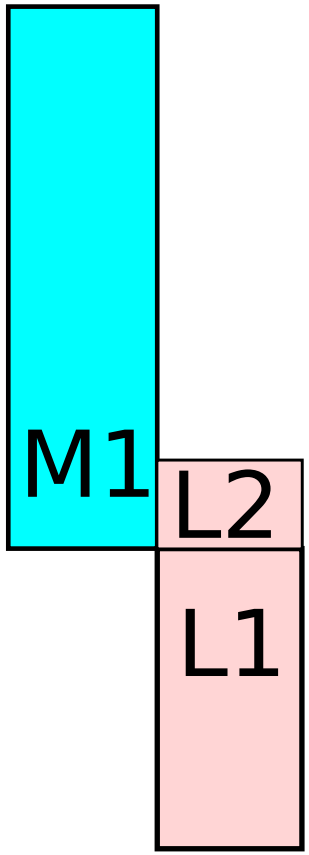
An EZ-Reader account?

guard who Charlie

Initial processing of “who”

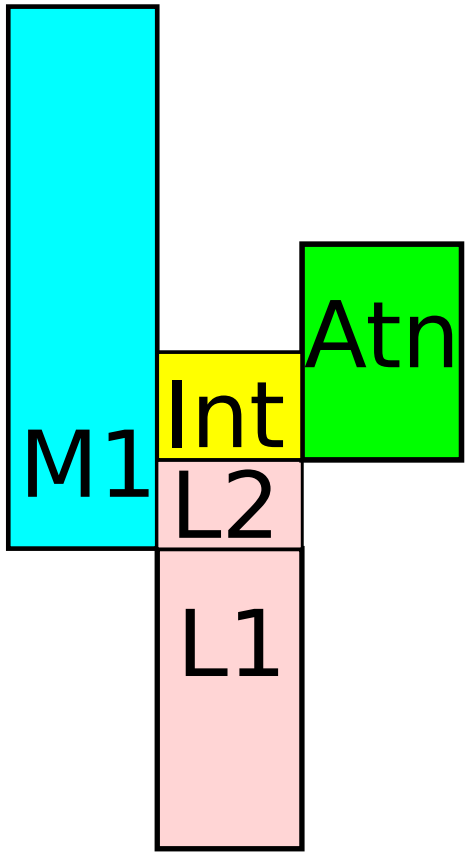


Lex acc of “who”; Saccade preparation M1



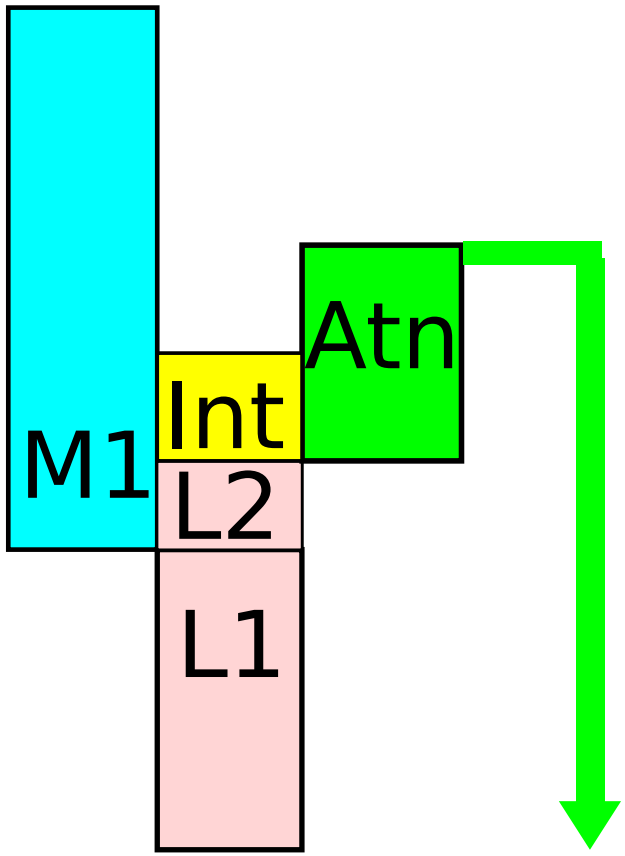
guard who Charlie

Integration of “who”; attention



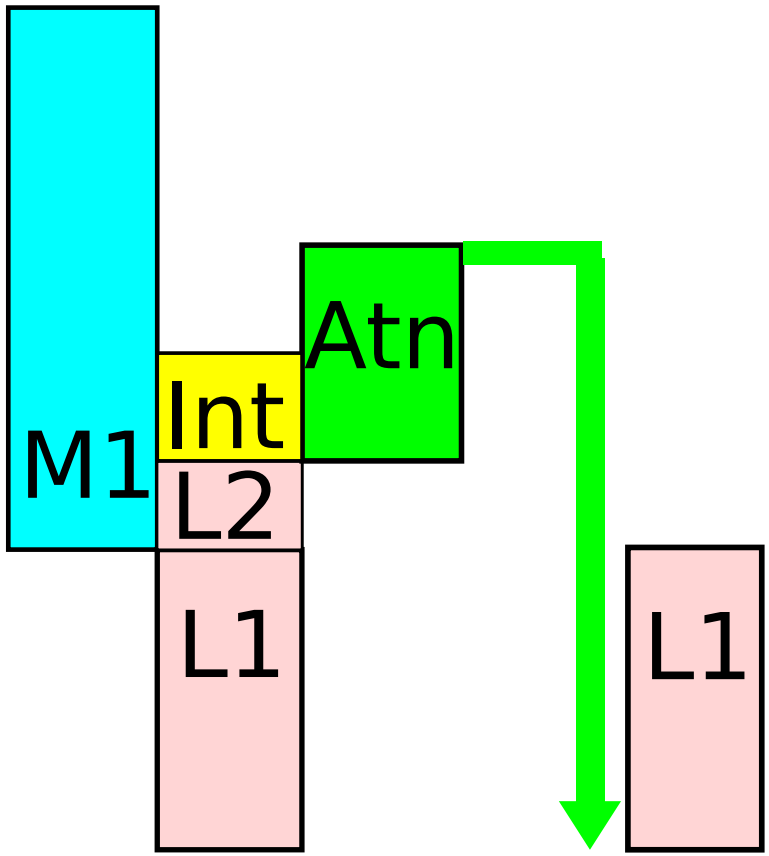
guard who Charlie

Attention shifts to “Charlie”



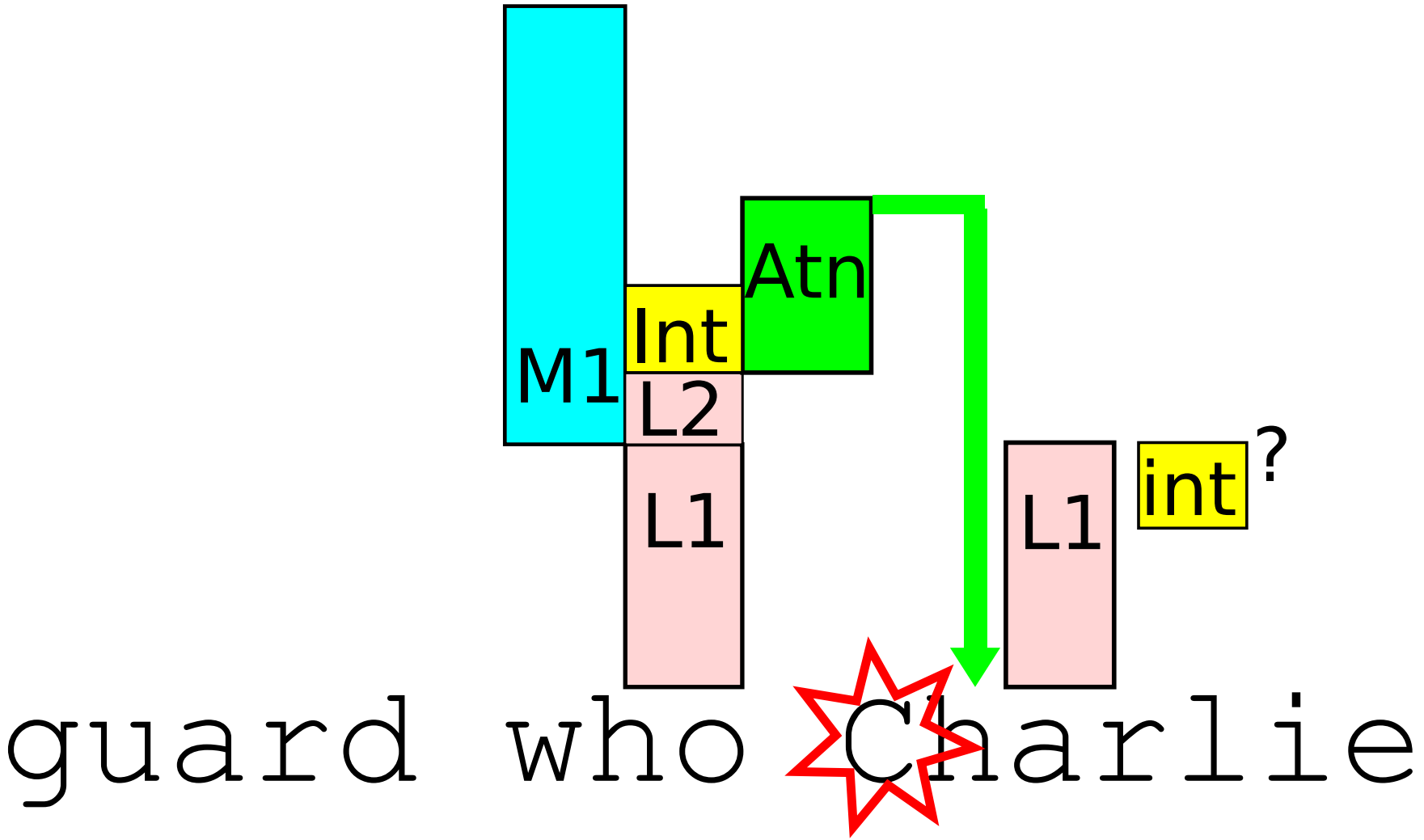
guard who Charlie

Initial processing of “Charlie”



guard who Charlie

Visual features clash with syntactic expectation



See also: form typicality (e.g. Dikker et al, 2010; Farmer et al 2011)

Cutter et al (2020) Summary

- Parafoveal-on-foveal effect of capital letter in the parafovea may have been due to prediction of visual features based on *syntactic prediction*
  - Participants predict subject relative clause: next word after "who" can't have capital letter
- Could have an explanation within serial attention shift model, given extra assumptions
- (similar in to "orthographic" PoF effects)

Phonological integration

He said losing against an Icelandic team was embarrassing

Legal Preview

He said losing against an Ethiopian team was embarrassing

Illegal Preview

He said losing against an Mongolian team was embarrassing

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Phonological integration

He said losing against an Icelandic team was embarrassing

Legal Preview

He said losing against| an GP:340ms Icelandic team was embarrassing

Illegal Preview

He said losing against| an GP:365ms Icelandic team was embarrassing

Conclusions

- Previous research:
  - Focus on reading process; little consideration of how structure guides interpretation
  - Focus on comprehension process: little consideration of how attention is allocated
- We attempt to bridge this gap by investigating the extent of structural sensitivity in parafoveal processing.
  - Predictability effects for ungrammatical words
  - Capitalization as a cue to structure
  - Phonological integration

Acknowledgements

LEVERHULME TRUST

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