

# Modeling garden path effects without explicit hierarchical syntax

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## Introduction

Syntactically ambiguous sentences can lead to misinterpretations, causing slower reading than unambiguous sentences at disambiguation point (garden path effect).

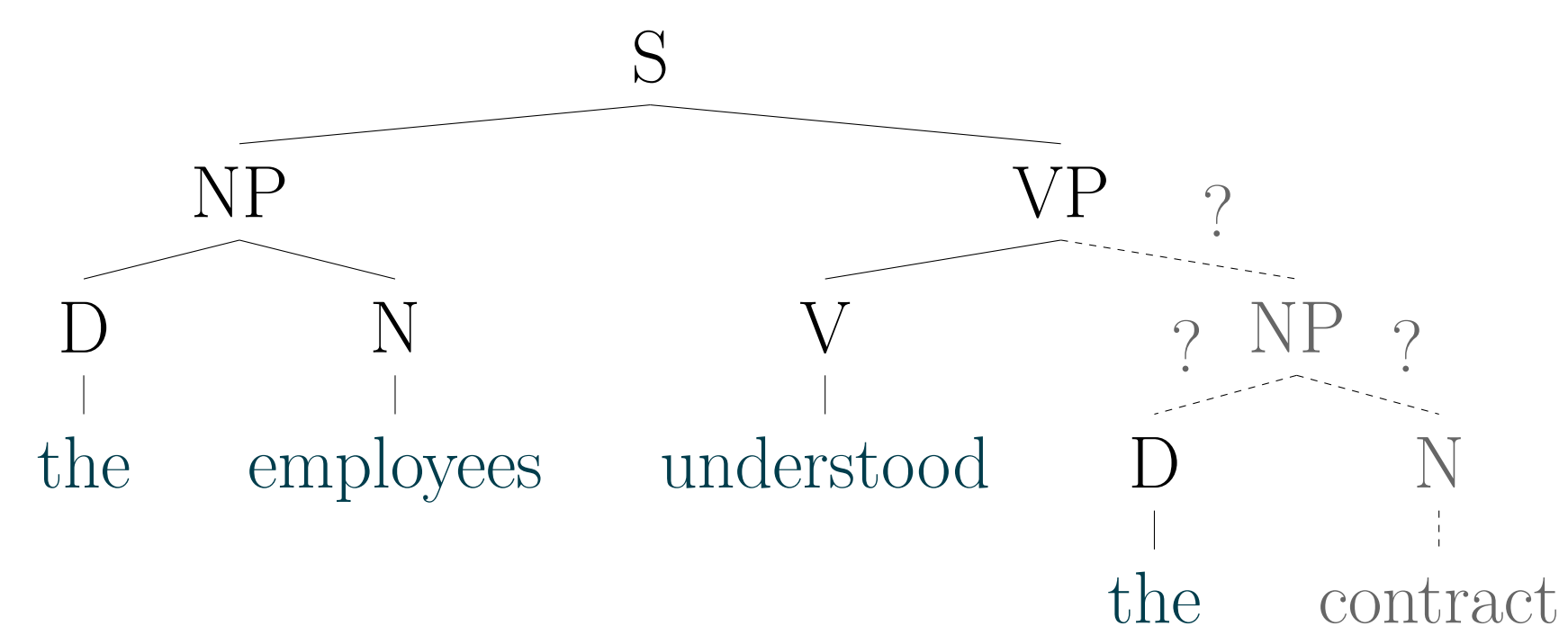
- Can models without explicit hierarchical syntax predict garden path effects?
- Can word predictability alone explain magnitude of garden path effects?

## Linking Hypothesis

Smith & Levy (2013): 1 bit surprisal = 3.75 ms reading time

$$\text{surprisal}(w_i) = -\log_2 P(w_i | w_1 \dots w_{i-1}) \quad (1)$$

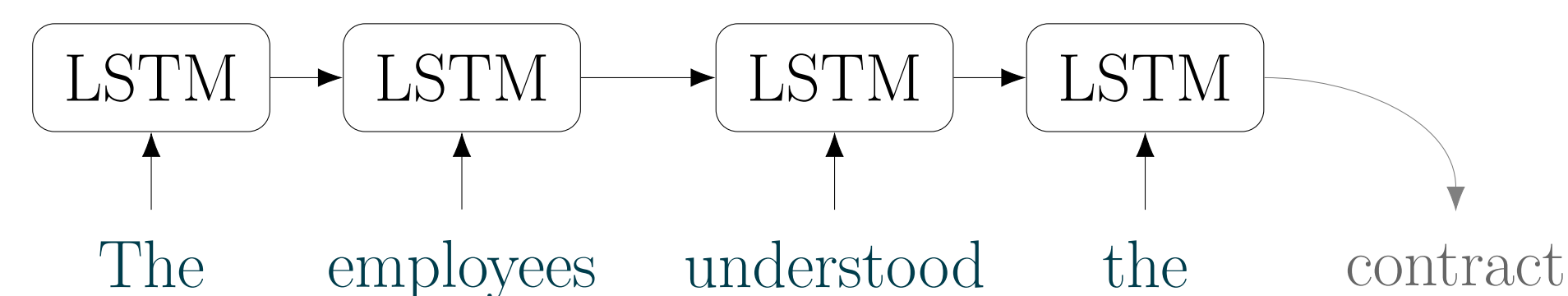
## Grammar-Based Language Models



Parser	Beam	Refined Grammar
Top-Down [4]	$\gamma = 10^{-11}$	0 PTB
Left-Corner [7]	$K = 5000$	5 PTB
Left-Corner [7]	$K = 5000$	3 Categorical Grammar [3]

Table 1: Model specs. All were trained on the Wall Street Journal corpus.

## Neural Network Language Models



Model	Layers	Units	Dropout	Epochs
Wall Street Journal	2	1500	0.65	40
Wikipedia (2M words)	2	1500	0.65	40
Wikipedia (90M words) [2]	2	650	0.65	40

Table 2: Model specs. The Units column indicates the number of units in each layer and the size of the word embeddings.

## NP/S Garden Paths

- Ambiguous      Disambiguation
- (1) The employees understood the contract would be changed soon to accommodate all parties.
- (2) The employees understood that the contract would be changed soon to accommodate all parties.
- Unambiguous

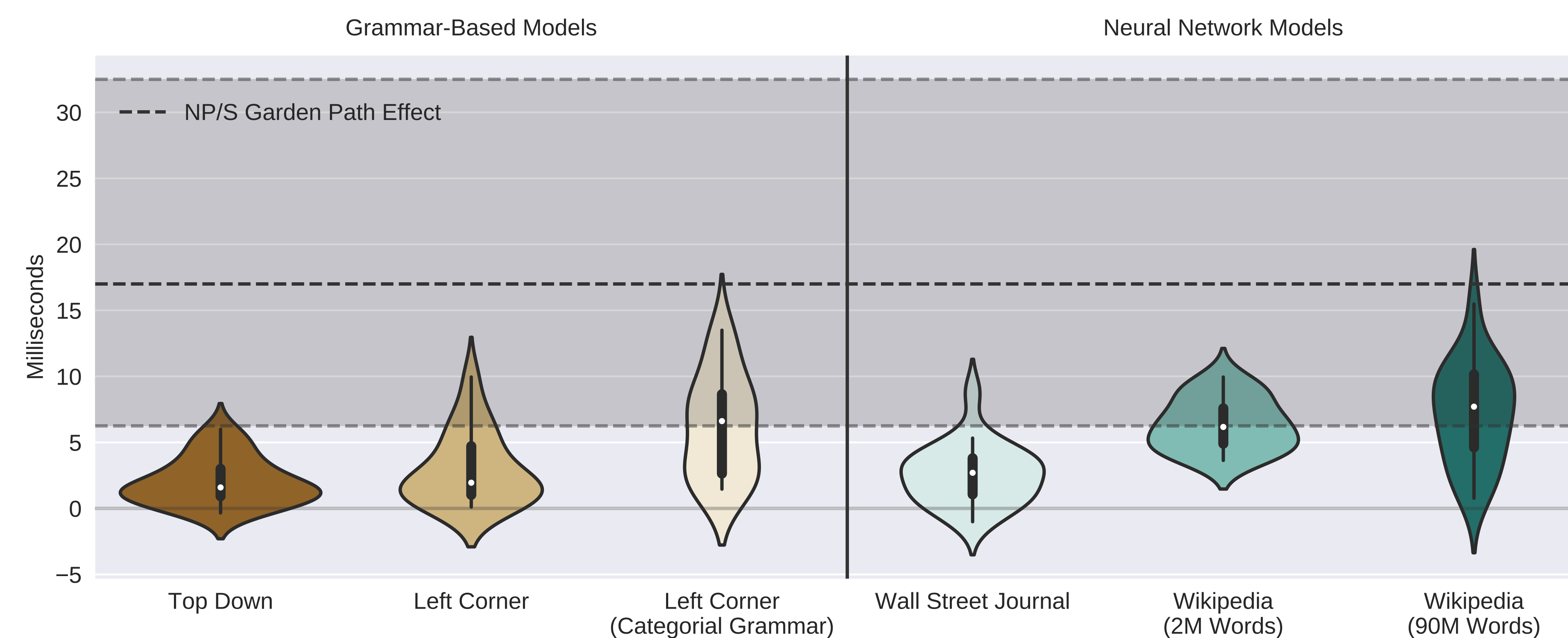


Figure 1:  $RT_{\text{Ambiguous}} - RT_{\text{Unambiguous}}$ . Grodner et al., (2003) mean effect shown with dashed line, Grodner et al. error bars shown by shading.

## NP/Z Garden Paths

- Ambiguous      Disambiguation
- (1) Even though the girl phoned the instructor was very upset with her for missing a lesson.
- (2) Even though the girl phoned, the instructor was very upset with her for missing a lesson.
- Unambiguous

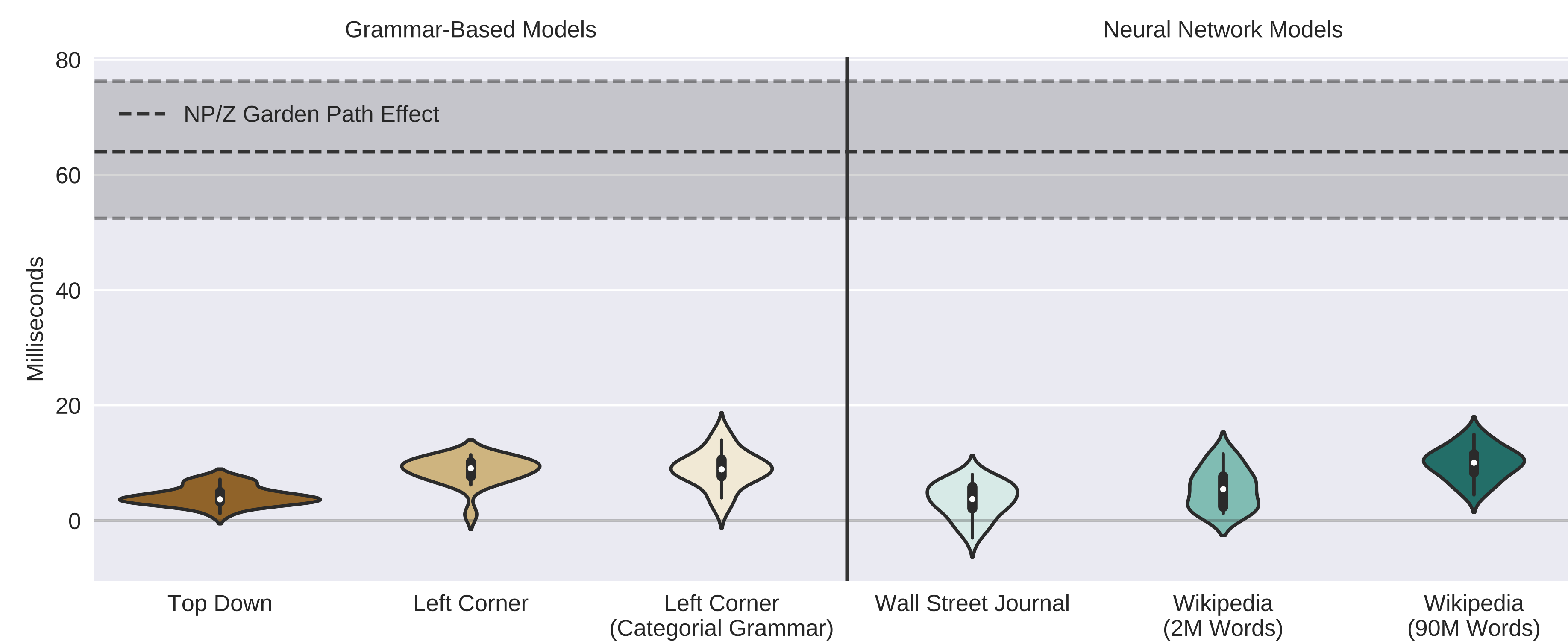


Figure 2:  $RT_{\text{Ambiguous}} - RT_{\text{Unambiguous}}$ . Grodner et al., (2003) mean effect shown with dashed line, Grodner et al. error bars shown by shading.

## Timecourse Predictions

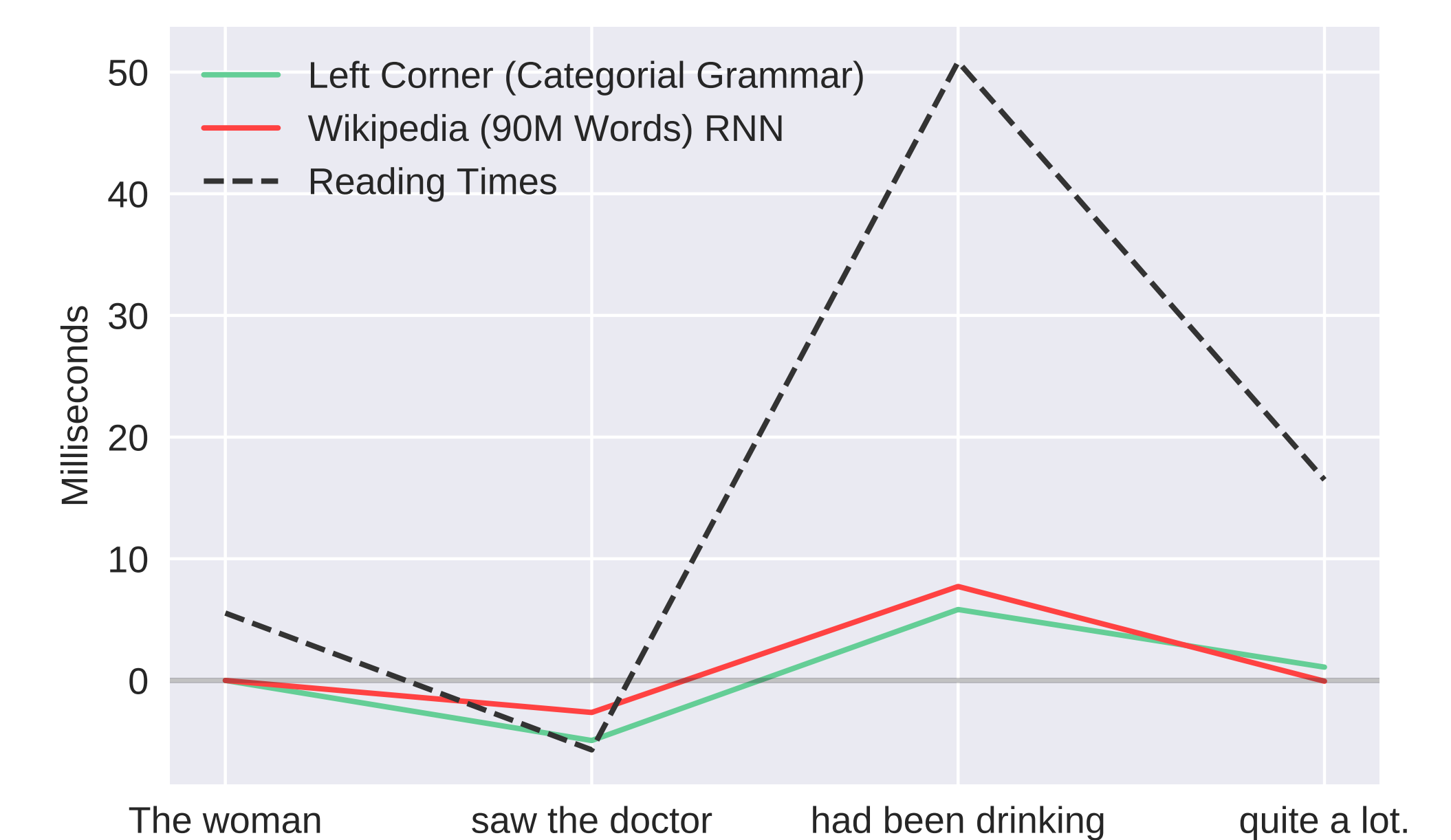


Figure 3: NP/S LM reading time predictions; mean effects reported by Sturt et al., (1999) are plotted with a dashed line.

Computational models make comparable human-like timecourse predictions for reading times outside the disambiguating region. The Sturt et al. garden path effect was much larger than that of Grodner et al. because Sturt et al. presented text region-by-region, so subjects were more strongly encouraged to adopt the incorrect interpretation prior to the disambiguation region.

## Conclusions

- NN predictions comparable to grammar predictions
  - All models correctly predict garden-path effect
  - Models severely underestimate size of NP/Z effect
- Therefore  $\left\{ \begin{array}{l} \text{Surprisal likely not enough} \\ \text{NP/Z repair mechanism may be needed} \end{array} \right.$

## References

- [1] Daniel J. Grodner, et al. Against repair-based reanalysis in sentence comprehension. *J. Psych. Res.*, 32(2):141-166, 2003.
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- [3] Luan Nguyen, et al. Accurate unbounded dependency recovery using generalized categorical grammars. In *Proceedings of COLING*, 2012.
- [4] Brian Roark. Probabilistic top-down parsing and language modeling. *Computational Linguistics*, 27(2):249-276, 2001.
- [5] Nathaniel J. Smith and Roger Levy. The effect of word predictability on reading time is logarithmic. *Cognition*, 128(3):302-319, 2013.
- [6] Patrick Sturt, et al. Structural change and reanalysis difficulty in language comprehension. *J. Mem. Lang.*, 40:136-150, 1999.
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