Cross-Lingual Transfer of Cognitive Processing Complexity

Findings of EACL 2023

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What is Cross-Lingual Transfer?

Humans use similarities between languages to facilitate learning.

pain, pan, pane,
pão, pâine, pa

brood, brot, brød,
bröd, braud, bread

chlieb, chléb, chleb, hljeb, хляб, хлеб, хліб

leib, leipää

Cross-Lingual Transfer in Multilingual Models

Shared vocabulary (sharing subwords across languages)

minister **minis**tre **minis**tru
miniszter **minis**tar **minis**ta

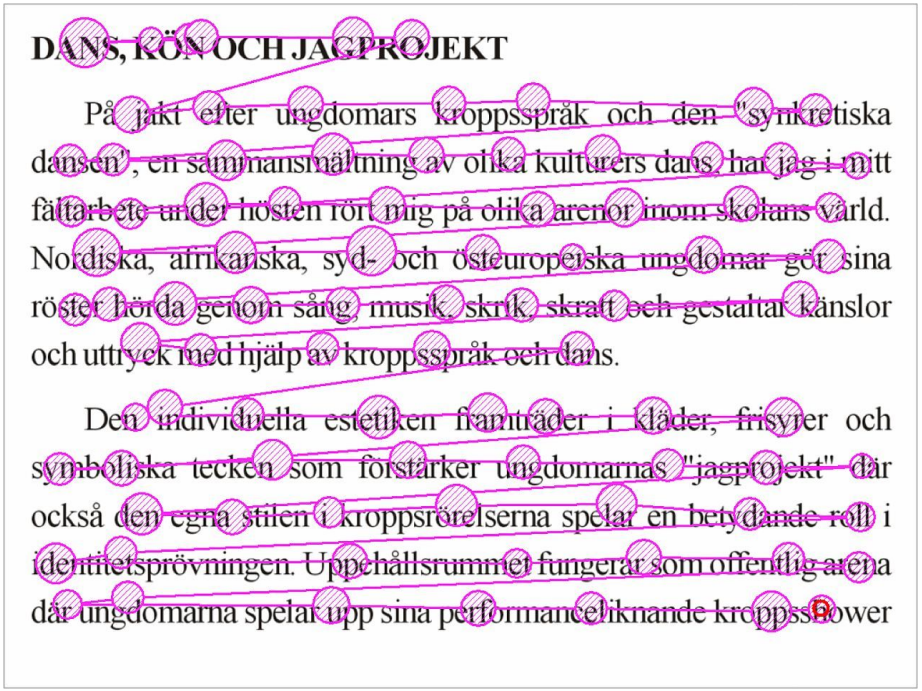
Structural similarity between languages

He is happy.
Il est heureux.

→ We want to analyze the **sensitivity** of multilingual language models to **structural information**

Structural Sensitivity in Humans

- Eye-tracking patterns are sensitive to structural information (**cross-lingual phenomenon**).
- Complex structure → More cognitive processing effort → Longer reading time



Source: https://en.wikipedia.org/wiki/Eye_tracking

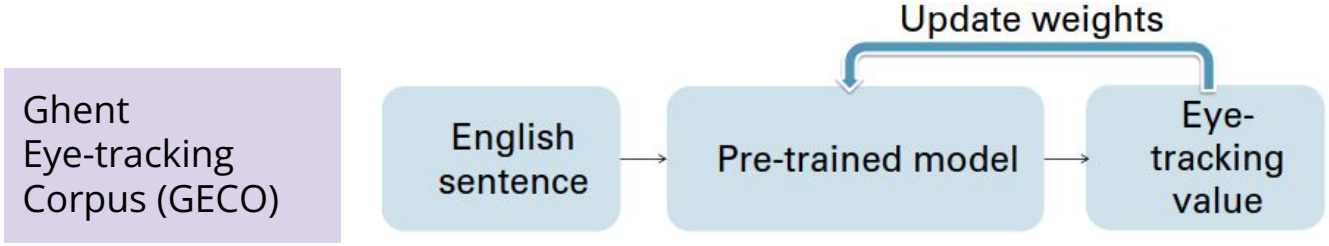
Research Questions

Correlation between structural complexity and eye-tracking patterns is **similar across languages**.

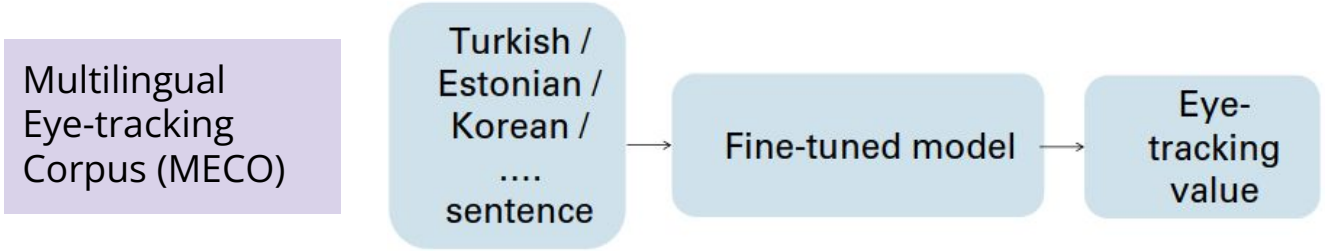
- Can the multilingual model XLM-R learn this correlation **from a single language** and predict eye-tracking patterns for **unseen languages**?
- If yes, can its performance be explained by **sensitivity to structural complexity**?

Experimental Setup: Model Training & Testing

Step 1. Fine-tune XLM-R to predict eye-tracking patterns of **English readers**



Step 2. Test the model on **13 typologically diverse languages**



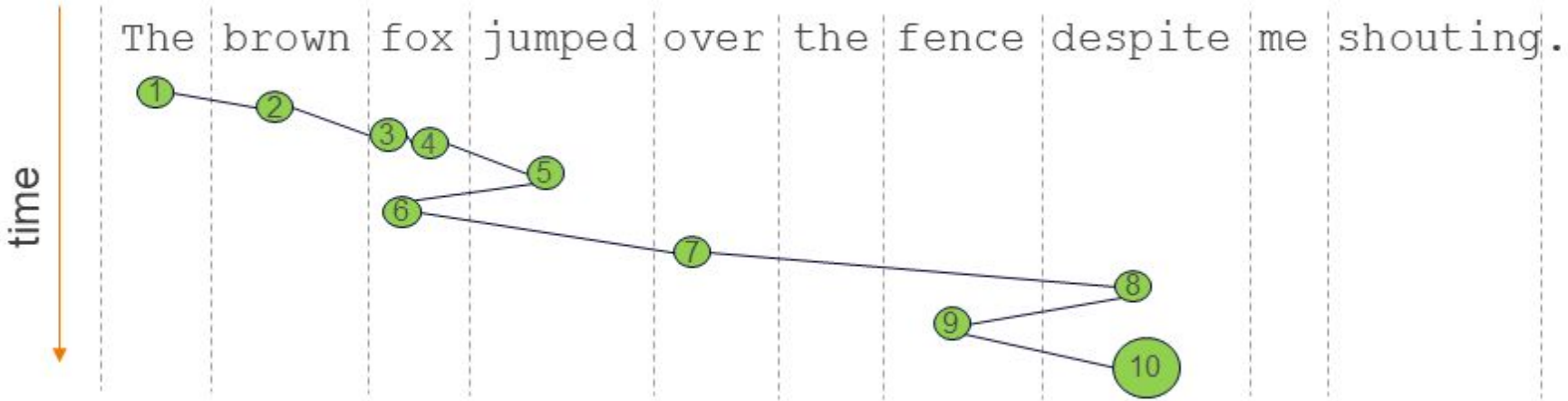
Cross-Lingual Transfer Results: Examples

English: In ancient Roman religion and myth, Janus is the god of beginnings and gates.

Finnish: Muinaisen roomalaisen mytologian mukaan Janus oli alkujen ja porttien jumala.

Turkish: Antik Roma inanı şlarında ve mitlerinde, Janus ba şlangıçların ve kapıların tanrısıdır.

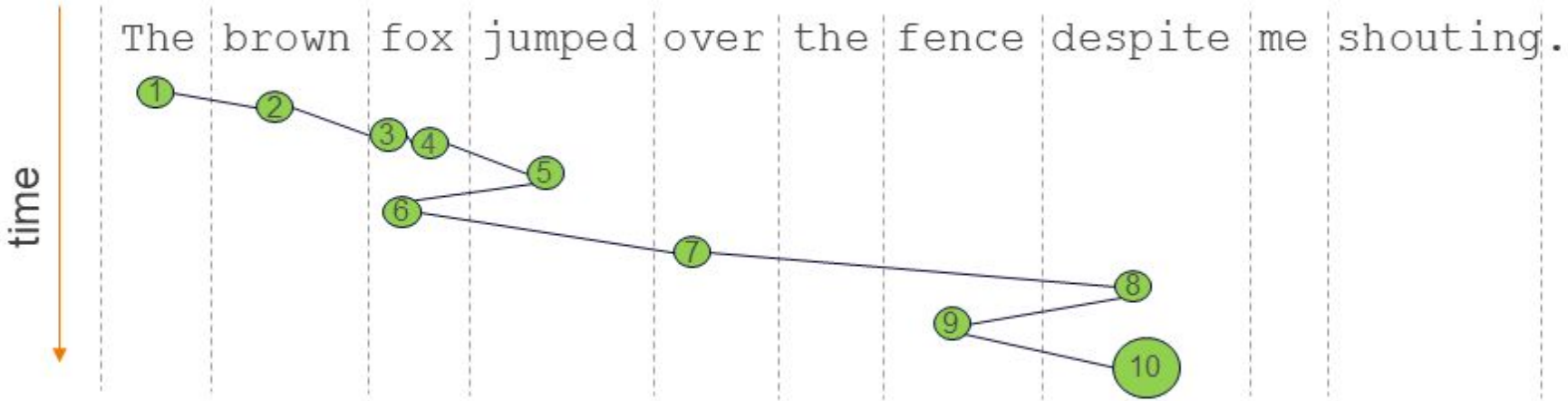
Experimental Setup: Eye-Tracking Metrics



Fixation Count: Total number of fixations

Source: https://connect.tobii.com/s/article/How-reading-metrics-work?language=en_US

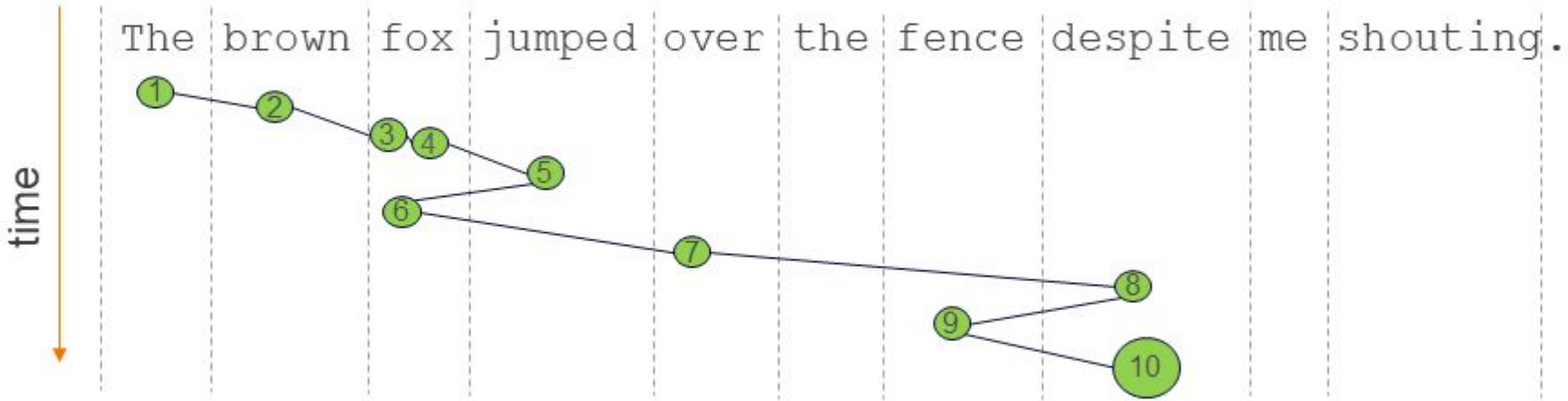
Experimental Setup: Eye-Tracking Metrics



First-Pass Duration: Duration of all first fixations on words

Source: https://connect.tobii.com/s/article/How-reading-metrics-work?language=en_US

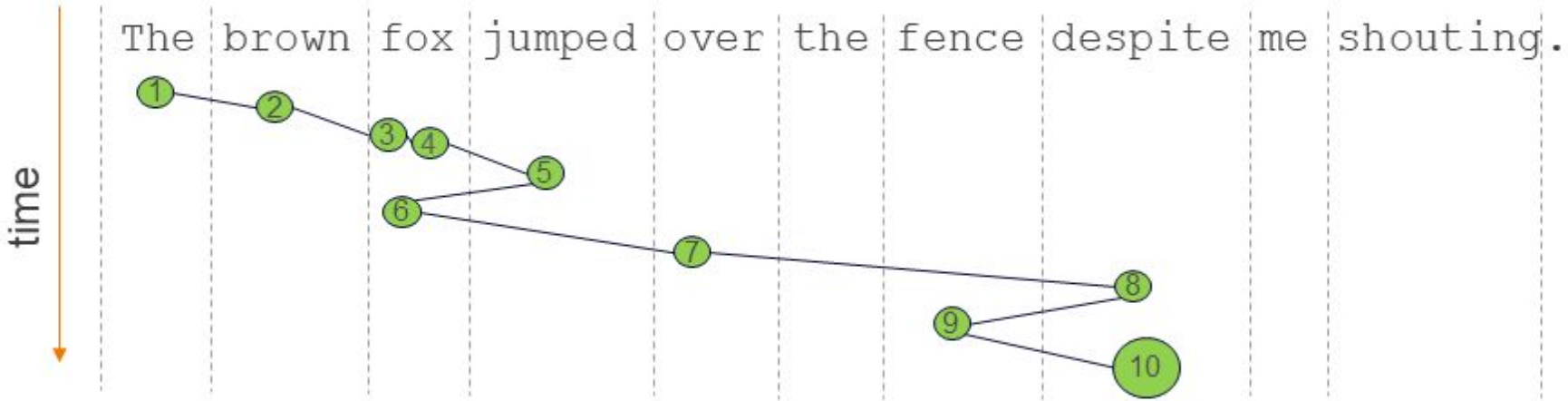
Experimental Setup: Eye-Tracking Metrics



Regression Duration: Duration of all regressions within the sentence

Source: https://connect.tobii.com/s/article/How-reading-metrics-work?language=en_US

Experimental Setup: Eye-Tracking Metrics

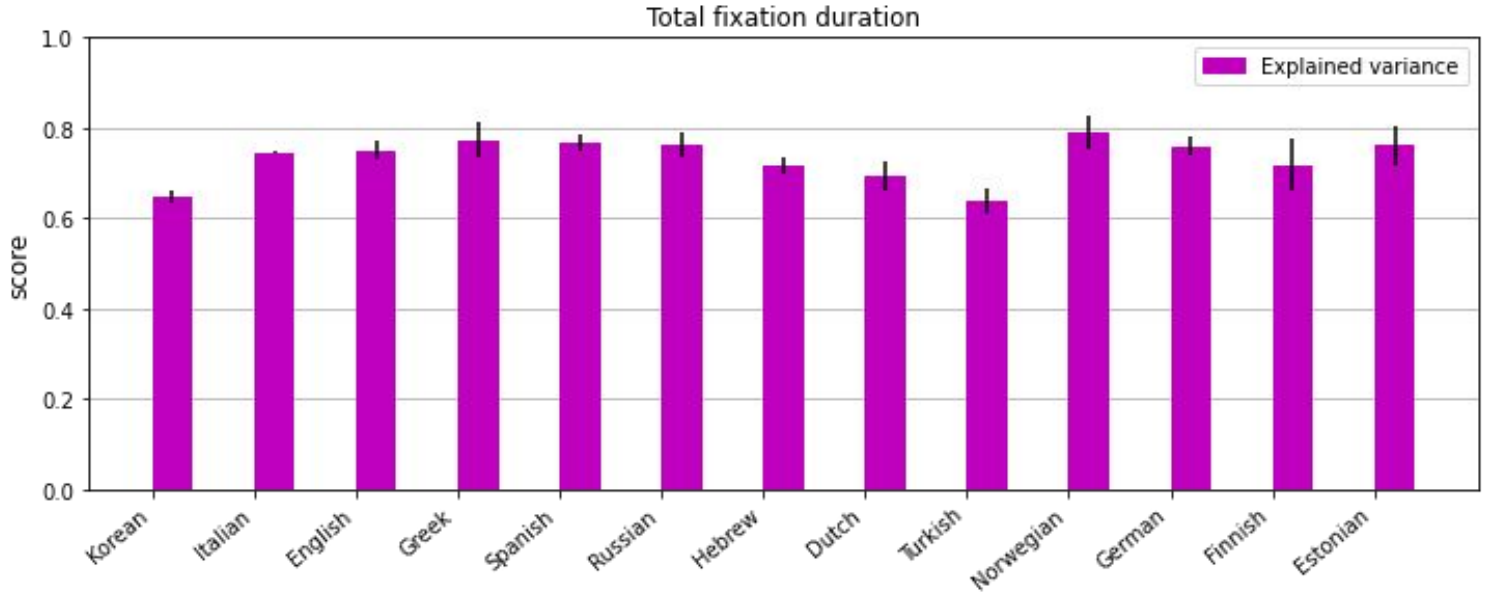


Total Fixation Duration: Total duration of all fixations

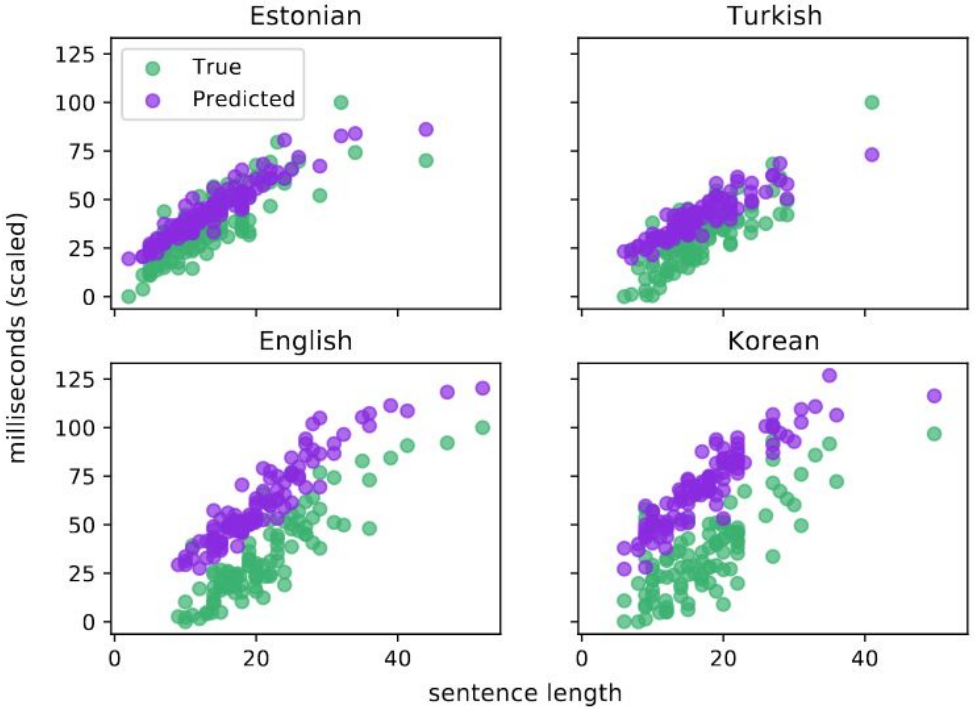
Source: https://connect.tobii.com/s/article/How-reading-metrics-work?language=en_US

Prediction Performance: Total Fixation Duration

Evaluation metric: Explained variance



Prediction Performance: True vs. Predicted Values



Sensitivity to Structural Complexity: Features

Length	Sentence length
	Word length
Frequency	Average word frequency
	Number of low frequency words
Morpho-Syntactic	Lexical density
Syntactic	Parse tree depth
	Average dependency link length
	Maximum dependency link length
	Number of verbal heads

Sensitivity to Structural Complexity: Examples

English: In ancient Roman religion and myth, Janus is the god of beginnings and gates.

Prediction: **43** Sentence length: **14** Word length: 4.6 Word freq: 5.6
Avg. dependency link length: 2.15

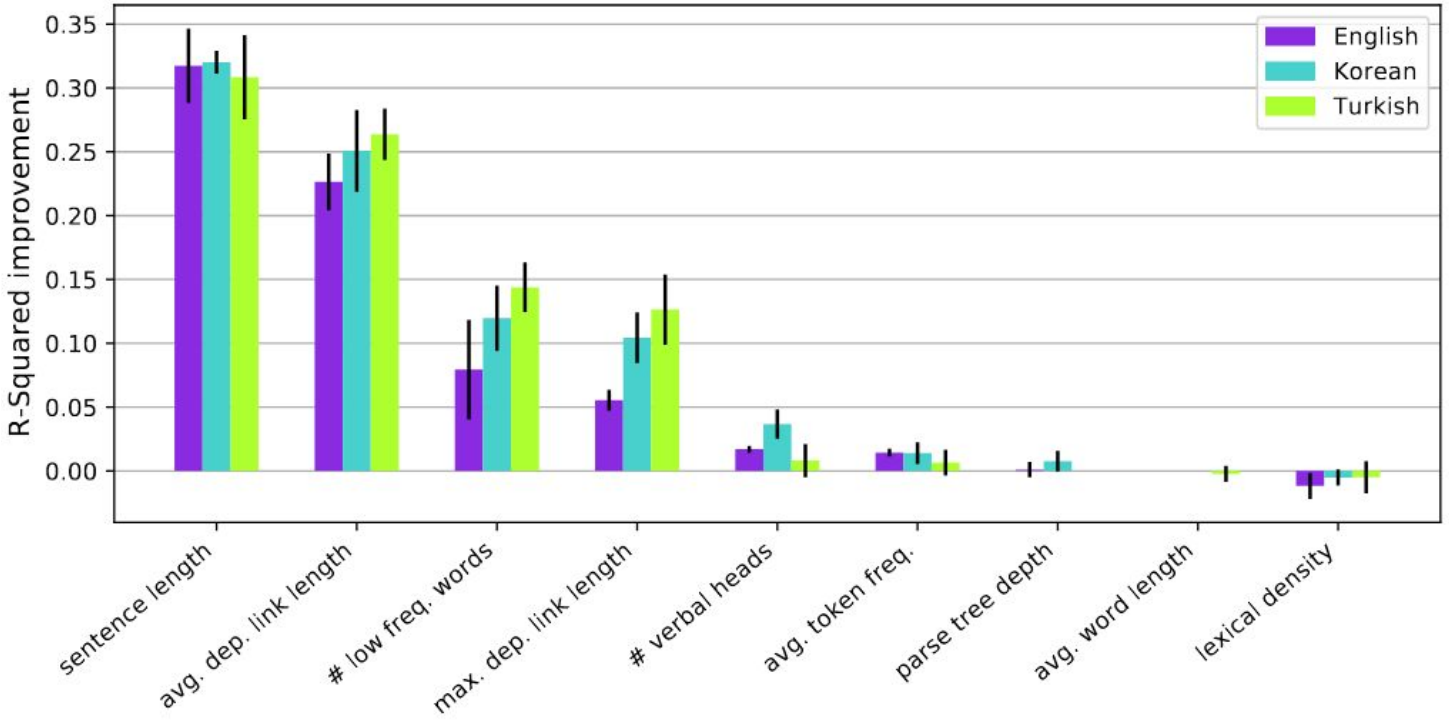
Finnish: Muinaisen roomalaisen mytologian mukaan Janus oli alkujen ja porttien jumala.

Prediction: 39 Sentence length: 10 Word length: 6.8 Word freq: 4.4
Avg. dependency link length: **2.78**

Turkish: Antik Roma inanı şlarında ve mitlerinde, Janus ba şlangıçların ve kapıların tanrısıdır.

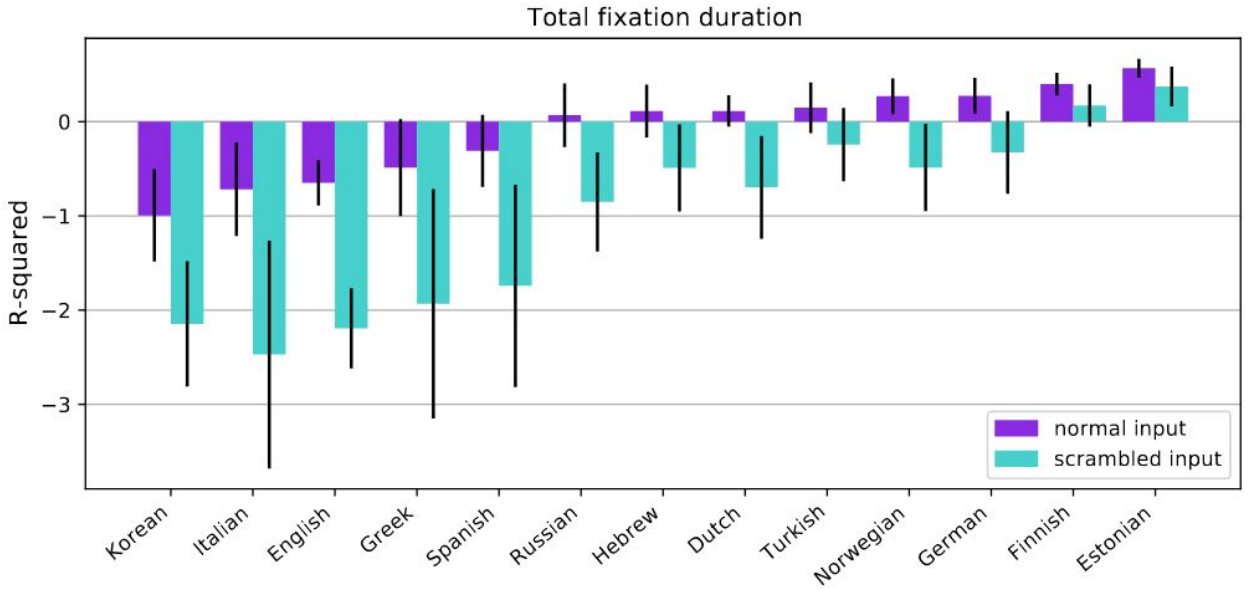
Prediction: 33 Sentence length: 10 Word length: **7.6** Word freq: **3.5**
Avg. dependency link length: 1.90

Sensitivity to Structural Complexity: Probing



Sensitivity to Structural Complexity: More than length?

Control experiment: Normal vs. randomized word order



Conclusions

- XLM-R can predict eye-tracking patterns for **13 languages**, despite being fine-tuned only on **English** data
- The model has a bias towards **sentence length**...
- ...but also encodes more complex structural information, e.g. **dependency structure** + **word order**

Future work: Account for individual differences between readers + Predict word-level eye-tracking metrics