

The Missing-VP/NP Illusion Through the Lens of Language Models: The Joint Effects of Exposure and Memory Capacity

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Grammaticality illusions arise when readers do not show the expected sensitivity to ungrammaticality in certain syntactic constructions. In English double center-embedded structures, for example, omitting the intermediate verb phrase (VP) can give rise to the missing-VP effect, whereby ungrammatical sentences are perceived as more comprehensible than their grammatical counterparts [1]:

- (1) a. *The patient who the nurse who the clinic had hired admitted met Jack.*
- b. **The patient who the nurse who the clinic had hired met Jack.*

In Chinese, a comparable missing-NP (noun phrase) effect has been reported [2] (see Supplementary Information). While the illusion can be attributed to memory limitations [1], its absence in verb-final languages such as German and Dutch suggests that exposure-based expectations play a role [3, 4]. In the present study, we disentangle the contributions of exposure and memory capacity by capturing the missing-VP/NP effect in neural language models, and investigating how data exposure and model capacity, as proxies for human language exposure and memory capacity, shape the grammaticality illusion.

In Experiment 1, we employ a set of pretrained large language models (LLMs) differing in architecture and scale. We test whether the illusion emerges under large-scale exposure to natural language by examining surprisal at critical regions in missing-VP/NP sentence pairs adapted from prior psycholinguistic experiments [1, 2, 4], with the illusion reflected in higher surprisal for grammatical than ungrammatical conditions. Focusing on the role of memory, we explore whether models with higher capacity (number of parameters) show closer alignment with human performance or instead more robust syntactic processing that eliminates the illusion. The results reveal that the Chinese missing-NP effect is reproduced, but the English missing-VP effect is absent (Fig. 1). There is no systematic relation between capacity and the strength of the illusion.

In Experiment 2, we train long short-term memory (LSTM) models on naturalistic corpora in each language under varied amounts of data exposure and model capacity (i.e., number of recurrent layers) and assess their surprisal patterns on the same missing-VP/NP sentence pairs. The LSTM models capture the grammaticality illusions in both English and Chinese (Fig. 2a, 2b). In English, there is a robust, stable missing-VP effect; in Chinese, the missing-NP effect increases with language exposure and is significantly stronger in deeper models. We apply the same LSTM modeling approach to German and Dutch, two languages in which the missing-VP effect is typically absent [3, 4], to show that LSTMs do not overgenerate the illusion. In both languages, the models converge toward the absence of the missing-VP illusion as exposure increases (Fig. 2c, 2d). Taken together, by combining LLM probing with controlled LSTM training, we capture the missing-VP/NP effect in neural language models and show the joint effects of exposure and memory capacity. The illusions are shaped by language exposure, with capacity contributing to their strength in non-uniform ways across languages.

References

- [1] Edward Gibson and James Thomas. Memory limitations and structural forgetting: The perception of complex ungrammatical sentences as grammatical. *Language and Cognitive Processes*, 14(3):225–248, 1999.
- [2] Nick Huang and Colin Phillips. When missing NPs make double center-embedding sentences acceptable. *Glossa: a journal of general linguistics*, 6(1), 2021.
- [3] Stefan L. Frank and Patty Ernst. Judgements about double-embedded relative clauses differ between languages. *Psychological Research*, 83(7):1581–1593, 2019.
- [4] Shravan Vasishth, Katja Suckow, Richard L. Lewis, and Sabine Kern. Short-term forgetting in sentence comprehension: Crosslinguistic evidence from verb-final structures. *Language and Cognitive Processes*, 25(4):533–567, 2010.

Figures

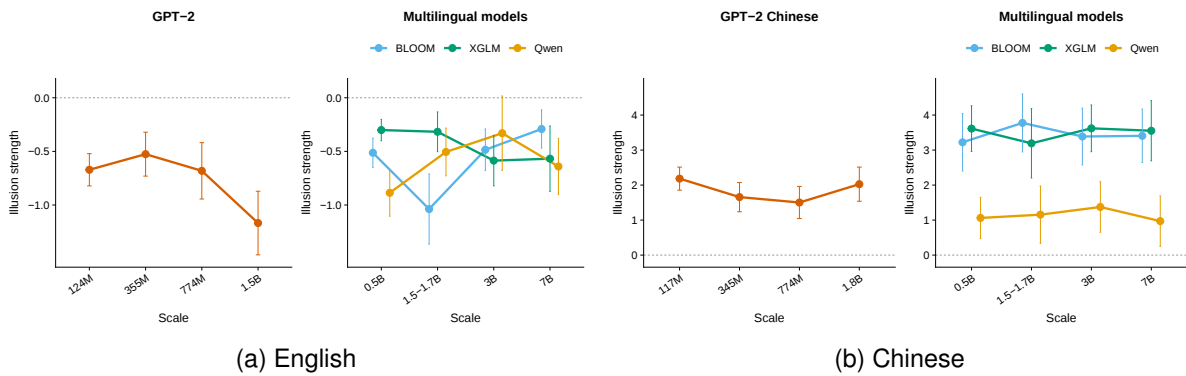


Figure 1: Illusion strength across scale (number of parameters) and model family in LLMs. Illusion strength is defined as the surprisal difference between grammatical (G) and ungrammatical (U) conditions ($G-U$).

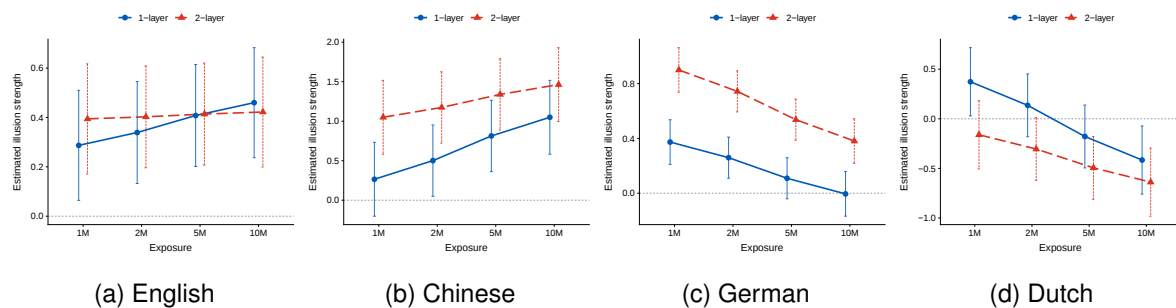


Figure 2: Estimated illusion strength across exposure and model depth in LSTM models. Exposure is defined as the number of training tokens, with smaller training pools nested within larger ones. Points show fixed-effect estimates from linear mixed-effects models with random intercepts for items, data pools, and random seeds; error bars indicate 95% confidence intervals.

Supplementary Information

Example items from Chinese, German, and Dutch are shown below. Boldface marks the critical region: the word immediately following the verb in the main clause in English, German, and Dutch, and the particle *de* preceding the final noun phrase in Chinese, glossed as DE.

Example Items

Chinese:

- (2a) 系主任很信任曾探望过已经研究文学一阵子的老教授一两次**的**助教。

*Xi-zhuren hen xinren ceng tanwang-guo yijing yanjiu wenxue yizhenzi de lao jiaoshou yi-liang-ci **de** zhujiao.*

department-chair very.much trust previously visited already study literature for.some.time DE old professor one-two-times DE teaching.assistant

'The department chair very much trusts the teaching assistant who previously visited the old professor who studied literature for some time once or twice.'

- (2b) *系主任很信任曾探望过已经研究文学一阵子的老教授。

**Xi-zhuren hen xinren ceng tanwang-guo yijing yanjiu wenxue yizhenzi de lao jiaoshou.*

German:

- (3a) *Der Anwalt, den der Zeuge, den der Spion betrachtete, schnitt, überzeugte **den** Richter.*

the lawyer who the witness who the spy observed interrupted convinced the judge

'The lawyer who the witness who the spy observed interrupted convinced the judge.'

- (3b) **Der Anwalt, den der Zeuge, den der Spion betrachtete, überzeugte den Richter.*

Dutch:

- (4a) *De timmerman die eergisteren de vakman die zaterdag de boer droeg bezeerde begeleid-
de **de** leerling in de tuin.*

the carpenter who two.days.ago the craftsman who on.Saturday the peasant carried hurt supervised the apprentice in the garden

'The carpenter who two days ago hurt the craftsman who carried the peasant on Saturday supervised the apprentice in the garden.'

- (4b) **De timmerman die eergisteren de vakman die zaterdag de boer droeg begeleidde de
leerling in de tuin.*