The distributional learning of recursive structures

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Recursion vs. recursive structures

- The ability for recursion, i.e. the infinite self-embedding of a particular type of linguistic element or grammatical structure, is claimed to be universally available (e.g. Hauser et al. 2002).

- But not all structures can be used recursively: Languages differ regarding the depth, structure, and syntactic domains of recursive structures (e.g. Pérez-Leroux et al. 2018).

Within- and cross-linguistic differences in recursive structures

- For possessive structures, some structures allow productive and infinite embedding, whereas other structures suffer various restrictions and cannot be embedded freely.

(1) English allows free embedding with *–s,* but not with *of* :

a. that man'*s* neighbor'*s* computer

b.? the computer *of* the neighbor

c. *the computer *of* the neighbor *of* the man

Within- and cross-linguistic differences in recursive structures

(2) German allows free embedding with *von* ('of'), but not with *–s:*

a. das Buch *von* dem Nachbarn *von* dem Mann
the book of the neighbor of the man
'the book of the neighbor of the man'

b. Vater*s* Buch *Mann*s* Buch
father's book man's book
'father's book' 'man's book'

c. *das Mann*s* Nachbar*s* Buch
the man's neighbor's book'
'the man's neighbor's book'

(Weiss 2008)

Within- and cross-linguistic differences in recursive structures

(3) Chinese allows free embedding with *de*, but not without it:

a. na ren *de* linju *de* shu
that man GEN neighbor GEN book
'that man's neighbor's book'

b. na ren linju
that man neighbor
'that man's neighbor'

c. *na ren linju shu
that man neighbor book
'that man's neighbor's book'

(Li & Thompson 1981)

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- What kind of experience and how do children make use of it, then?

- An existing proposal: Explicit evidence of recursive embedding in the input is necessary for the acquisition of recursive structures (e.g. Roeper 2011).

How do children learn which structures can be used recursively in their language?

- But explicit evidence is vanishingly rare in the input:

e.g. 107 recursive possessives in 3.1 million English utterances, 70% conformed to a simple format: <proper name>'s + <common noun>'s + name;

No *de*-recursion in three Mandarin corpora. (Giblin et al. 2019)

How do children learn which structures can be used recursively in their language?

- Yet despite the paucity of explicit evidence in the input, children still acquire recursive structures:

  e.g. 4-year-olds can comprehend and produce multi-level recursive possessives (Giblin et al. 2019; Li et al. 2020).

- Furthermore, there is a logical problem of learning recursive structures: No N-level embedding logically entails even N+1 level embedding, not to mention infinite embedding.

Problem

- What learning mechanism enables children’s acquisition of recursive structures?

Proposal

- Productivity is a prerequisite for recursion.
- Similar to the case of English determiners, where productivity is defined as the interchangeability of *a* and *the* in combination with nouns (Yang 2013).
- For a possessive structure such as X's-Y or Y-of-X, productivity means the interchangeability of structural position: the possessum can productively appear in the possessor position. Therefore, the possessum can also take its own possessum, thus building recursive structures.

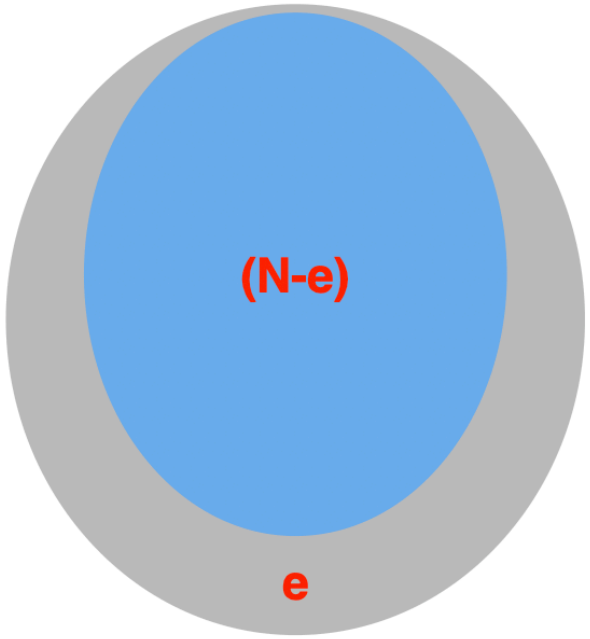
Proposal

- e.g.

…’s car	car’s …
…’s mom	mom’s …
…’s cat	cat’s …
…’s daddy	daddy’s …
…’s toy	toy’s …
…’s house	house’s …
…’s room	room’s …
…’s owner	owner’s …
…’s ball	ball’s …
…’s game	
…’s mess	
…’s color	

Proposal

- The Tolerance/Sufficiency Principle (TSP):



A rule that holds for *(N-e)* items is productive iff $e \leqslant \theta_N = N/\ln N$, where N pertains to the child learner's modest, and likely high-frequency, vocabulary (Yang 2016).

- Applying the TSP: The recursion of a possessive structure (X's-Y or Y-of-X) is licensed if a sufficiently large proportion—á la the TSP—of nouns attested in the Y position in the input is also attested in the X position in the input.

Proposal

- Applying the TSP: $e \leqslant \theta_N = N/\ln N$
- *R:* A noun that appears in the possessum position can also appear in the possessor position.
- *N*: Number of nouns in the child learner's modest vocabulary that appear in the possessum position.
- *e*: Number of nouns in the child learner's modest vocabulary that appear in the possessum position but do not appear in the possessor position.

Proposal

- e.g.

…’s car	car’s …
…’s mom	mom’s …
…’s cat	cat’s …
…’s daddy	daddy’s …
…’s toy	toy’s …
…’s house	house’s …
…’s room	room’s …
…’s owner	owner’s …
…’s ball	ball’s …
…’s game	
…’s mess	
…’s color	

$N = 12$

Threshold $= N - N/\ln N = 12 - 4 = 8 < 9$

An item that appears in position Y can also appear in position X.

The structure can be used recursively.

Corpus study

Language	Corpora	Number of words in the input corpora	Structures examined	Recursivity
Mandarin Chinese	19 corpora in CHILDES database	1.7 million	X de Y	Yes
			X Y	No
English	CHILDES database	5.5 million	X' Y	Yes
			Y of X	No
German	5 corpora in CHILDES database	3.5 million	X's Y	No
			Y von X	Yes

Method

1. A vocabulary representative of three-year-olds (established vocabularies for Mandarin (Hao et al. 2008) and English (Carlson et al. 2013); the most frequent 50 nouns in the input for German).

- We do not assume children only know some 50 nouns, but we are only concerned with those attested in possessor/possesum positions.

2. For each structure, calculate the number of nouns *N* in that vocabulary that appear in the possessum position in the input.

- Our analyses combined automatic search with manual inspection.
- The identities of the nouns do not matter under the TSP.

Method

3. Calculate the TSP threshold based on (2): $N - N/\ln N$.

4. Calculate the number of nouns in that vocabulary that appear in both the possessor position and the possessum position.

5. Compare the result in (4) against the TSP threshold.

Prediction

- For the recursive structures, the number of nouns that appear in both the possessor position and the possessum position exceeds the TSP threshold.

- For the non-recursive structures, the number of nouns that appear in both the possessor position and the possessum position does not exceed the TSP threshold.

Result

Language	Mandarin Chinese		English		German	
Structure	X de Y	X Y	X's Y	Y of X	X's Y	Y von X
Recursivity	Yes	No	Yes	No	No	Yes
N in Y	41		59			40
N in X & Y						
TSP threshold	30		45			29
Productive?						

Result

Language	Mandarin Chinese		English		German	
Structure	X de Y	X Y	X's Y	Y of X	X's Y	Y von X
Recursivity	Yes	No	Yes	No	No	Yes
N in Y	41		59			40
N in X & Y	35		46			34
TSP threshold	30		45			29
Productive?	Yes		Yes			Yes

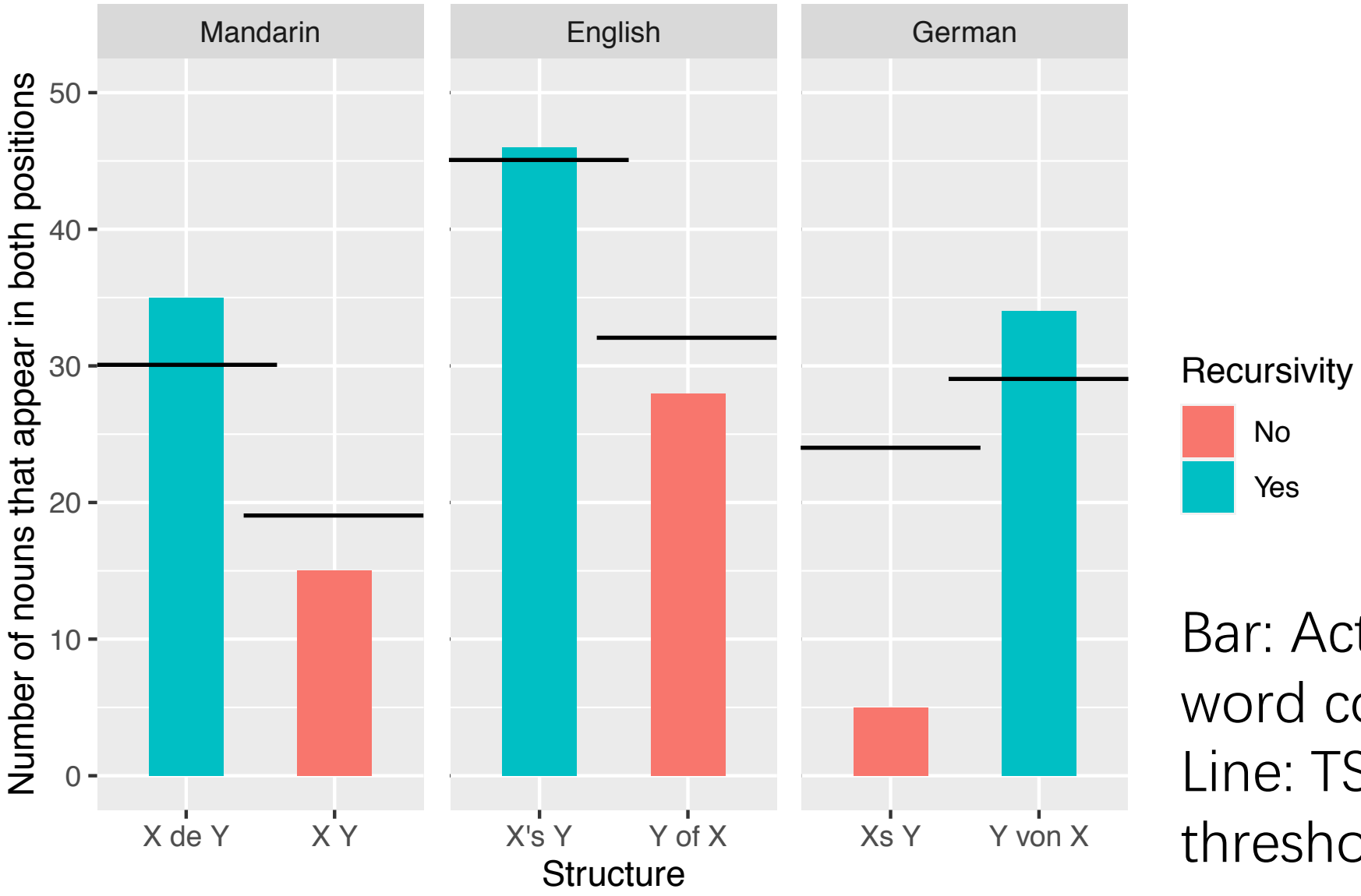
Result

Language	Mandarin Chinese		English		German	
Structure	X de Y	X Y	X's Y	Y of X	X's Y	Y von X
Recursivity	Yes	No	Yes	No	No	Yes
N in Y	41	27	59	43	34	40
N in X & Y	35		46			34
TSP threshold	30	19	45	32	24	29
Productive?	Yes		Yes			Yes

Result

Language	Mandarin Chinese		English		German	
Structure	X de Y	X Y	X's Y	Y of X	X's Y	Y von X
Recursivity	Yes	No	Yes	No	No	Yes
N in Y	41	27	59	43	34	40
N in X & Y	35	15	46	28	5	34
TSP threshold	30	19	45	32	24	29
Productive?	Yes	No	Yes	No	No	Yes

Result



Bar: Actual word count; Line: TSP threshold

Distributional learning of recursive structures

- There is reliable distributional information at first level in the input to be used for the acquisition of recursive structures. Recursive structures can be learned without explicit evidence of deep embedding.

- This also addresses the logical problem of learning recursive structures that no N-level embedding entails deeper embedding: This way of distributional learning predicts that a rule is either infinitely recursive or must stop at level one.

- We are in the process of using artificial language learning experiments to further demonstrate that children learn recursive structures in this way.

Conclusion

- Productivity, as a necessary condition for recursion, can be acquired from level-1 input data for specific syntactic domains, given that the child can recognize the relevant syntactic (e.g., noun) and semantic categories (e.g., possessor/possessum).

- Explicit evidence for deep embedding is not necessary for the acquisition of recursive structures.

Final remarks

- We do not claim that children acquire the ability of recursion, or Merge, through this mechanism; rather, we are interested in how children learn in which syntactic domains this ability can be applied and where not.

- Our analysis and methods lend themselves to other structures such as recursive adjective or PP embedding (e.g. Grohe in prep; Grohe, Schulz & Yang 2020).

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