

What do retrieval effects tell us about how dependencies are established in comprehension?

When parsing a sentence, comprehenders must at different points encode, store, and retrieve information encountered previously in order to establish dependencies between non-adjacent elements. These long-distance dependencies (hereafter LDDs) are abundant in language and include phenomena such as number or gender agreement, reflexive pronouns or ellipsis (Parker, Shvartsman, & Van Dyke, 2017). In order to deal with LDDs, comprehenders must make use of their memory. In this essay, I will review the research that has aimed to explore the mechanisms that operate in this process. I will focus on the evidence that has been provided by the study of how information is retrieved from memory. Studies using both the speed-accuracy paradigm and the research on interference effects will be covered. I will argue in favour of cue-based theories of memory use in establishing LDDs. I will show how the available evidence is in line with the predictions of cue-based theories. Next, I will present some recent findings that are inconsistent with this view. Finally, I will argue that these might nevertheless be accommodated into cue-based theories.

LDDs occur when there are relations between certain constituents that are separated by intervening material (Parker et al., 2017). Take the following example:

- 1) The horse that ran away during the snowstorm was called Brunellus.

In order to successfully parse (1), comprehenders must establish a link between the subject *the horse* and the auxiliary *was* even though these two constituents are not in immediate vicinity. They must encode the information needed when they encounter *the horse*, store it in memory during the intervening material, and then finally retrieve that information when the agreement with the auxiliary is required upon reaching *was*. This task has often been termed *dependency completion* (Vasishth, Nicenboim, Engelmann, & Burchert, 2019).

We shall now turn to how this process has been theoretically accounted for. In recent years, several theories that postulate cue-based retrieval as a core element. Among these are for instance the *direct access model* or the *activation model*. Whilst these have been argued to have different predictions in some cases, they both employ cue-based mechanisms (Vasishth et al., 2019). I will refer to these collectively as the cue-based theories. Let us look at the proposal by Lewis and Vasishth (2005) based on the Adaptive Control of Thought – Rational framework. The model proposes an incremental parser that relies on associative retrievals which are affected by activation decay as well as by similarity-based interference. Based on findings from memory research, this theory assumes that the capacity of the focus of attention is limited to only two items at the same time. Importantly, the model assumes that all items stored in memory are accessed at the same time in parallel as opposed to being searched through *serially* (Lewis, Vasishth, & Van Dyke, 2006).

Cue-based theories postulate that as constituents are encountered in course of the parse, they are encoded as *bundles of features*. For example, *the horse* from (1) is encoded as being singular, animate and as the local subject. This information is then kept in memory until it needs to be retrieved at the point of the verb to establish the dependency. Here, the theory claims that cues are “sent out” also coded as features, in this case [+singular] and [+subject] to search through all the previously encoded bundles all at the same time. The degree of overlap in features between what is stored and cued for determines which element is picked. In the case of (1), the match is perfect and the subject-verb agreement between *the horse* and *was* is established (Lewis et al., 2006). Evidence for the cue-based approach has been identified at both the encoding stage (Gordon, Hendrick, & Levine, 2002) and the storage interval (Chen, Gibson, & Wolf, 2005). In the following, we focus on the evidence coming from the last stage of the process – the retrieval of encoded information used in dependency completion.

UČO: 123456

In studying retrieval, one experimental paradigm has been used extensively, namely the speed-accuracy tradeoff (Parker et al., 2017). When information is retrieved from memory, there are two variables that we can measure – how accurate the comprehender is at getting the right information and how quickly they can access it. In order to measure both independently, the task has participants read sentences displayed using rapid serial visual presentation (RSVP), where they only see one word at a time for a specified period of time. They are then asked to make binary acceptability judgments about the sentences at different points during and after presentation. What we are then interested in is at what time comprehenders perform above chance at determining whether a given sentence is grammatical or not. The chance of making an accurate judgment is plotted as a function of time.

Let us look at possible predictions here. If information is accessed serially then with an increasing amount of intervening material *both* accuracy and speed of retrieval should suffer, given that the comprehender must work backwards through the intervening material. On the other hand, the cue-based theories predict a decline *only* in accuracy, since all elements kept in memory are accessed or considered at the same time.

In a series of experiments, McElree and colleagues (McElree, 2000; McElree, Foraker, & Dyer, 2003) set out to test these predictions using the SAT. Their participants were exposed to sentences with a filler-gap LDD, where the conditions differed in the amount of intervening material:

- 2) This was the book that the editor admired.
- 3) This was the book that the editor who the receptionist married admired.
- 4) This was the book that the editor who the receptionist who quit married admired.

What these researchers found was a pattern consistent with cue-based theories. An increase in the amount of intervening material did affect accuracy, however it did not have any effect on the speed of retrieval. This provided convincing evidence in favour of this approach. The same pattern of results was obtained for other types of LDDs, such as subject-verb dependencies (Van Dyke & McElree, 2011) and ellipsis (Martin & McElree, 2008).

Both inhibitory and facilitatory effects identified in the retrieval stage have been argued to be predicted by the cue-based approach (Engelmann, Jäger, & Vasishth, 2019). In this context, what we mean by inhibition or facilitation is when a certain type of manipulation causes either a slow down or an increase in the speed of processing at some point during comprehension, for example at a particular point of a stimulus sentence. This can be operationalised as either increased or decreased eye-fixations during reading or people's behaviour in self-paced reading tasks.

Van Dyke and McElree (2006) used the dual-task paradigm to test for inhibitory effects at the point where speakers have to retrieve antecedent elements from memory. Their participants were first asked to remember triplets of words (e.g. *table, sink, truck*). Next, they were presented with written stimuli sentences that were designed to be either interfering or non-interfering with the previously introduced memory load. For example:

- 5) It was the boat that the guy sailed in two sunny days. [non-interfering]
- 6) It was the boat that the guy fixed in two sunny days. [interfering]

When comprehenders reach the verb, they have to reach back into their memory to retrieve the clefted object. The prediction of cue-based theories is that there should be a difference between the conditions in the experienced difficulty of this retrieval, since if retrieval is based on cues and degree of feature match, there should be competition between the actual antecedent *boat* and the other nouns currently held in memory. This expected inhibition is due to the experienced *cue overload*

UČO: 123456

(Vasishth et al., 2019). This is because all these nouns match the selectional restrictions of the verb – one can fix either a boat or a truck. However, in the non-interfering condition, only the actual antecedent fully matches the cues of the verb *sailed*. This is exactly what Van Dyke and McElree (2006) found – reading times in the verbal region were slower in the interfering condition. A similar inhibitory effect was observed when the distractors were embedded in the stimulus sentences (Van Dyke, 2007).

Let us now turn to facilitatory effects. Wagers, Lau, and Phillips (2009) examined the phenomenon of agreement attraction. It has long been observed that in language production, speech errors of the following type often occur (Bock & Cutting, 1992):

- 7) *The editor of the history books were unavailable.

Agreement attraction is when there is an attractor word (*books*), which is linearly closer to a verb than its actual antecedent (*editor*) and with which the verb ends up agreeing, in this case in number. Similar phenomena have been observed for other types of agreement, such as gender in Slovak (Badecker & Kuminiak, 2007). In comprehension, sentences such as (7) have been found to cause illusions of acceptability. In Wagers et al.'s (2009) self-paced reading experiment, participants saw sentences such as these:

- 8) *The key to the cabinets were rusty.
 9) *The key to the cabinet were rusty.
 10) The key to the cabinets was rusty.
 11) The key to the cabinet was rusty.

What the researchers found was a significant effect of grammaticality in that ungrammatical sentences were read slower than grammatical ones. Crucially, there was an interaction of the two conditions. Those sentences where there was a match in number between the attractor and the verb (8) were read faster than those where there was no match. According to cue-based theories, when no perfect match exists to establish the dependency such as in the ungrammatical sentences (4) and (5), in those cases where there is at least a partial match, the models predict a speed up at the verb – a facilitatory effect (Vasishth et al., 2019). Since the predictions of the theory were in line with what Wagers et al. (2009) found, this study provided further evidence in favour of cue-based models. The same pattern of findings has since been replicated to hold cross-linguistically, for instance in Armenian (Avetisyan, Lago, & Vasishth, 2020).

Whilst, as we have seen, most findings in the literature on interference effects in retrieval support the cue-based approach, one apparent counterexample has been identified, namely antecedent-reflexive relations (Jäger, Mertzen, Van Dyke, & Vasishth, 2020). Dillon, Mishler, Sloggett, and Phillips (2013) conducted a study testing for facilitatory effects in this type of dependency. The researchers used ungrammatical sentences such as the following where facilitation should occur given the presence of a partially matching antecedent:

- 12) *The amateur bodybuilder who worked with the personal trainers amazingly injured themselves on the lightest weights.

They reported that no facilitation was observed at the point of the reflexive pronoun. Unlike in subject-verb agreement, the partial match did not cause a speed-up compared to the ungrammatical condition with no partial matching. What this apparent asymmetry between subject-verb agreement and antecedent-reflexive relations suggested that the cue-based approach could be wrong for the latter. A meta-analysis of the literature on retrieval interference confirmed the findings of Dillon et al. (2013)

UČO: 123456

in that facilitatory effects were confirmed only in subject-verb agreement (Jäger, Engelmann, & Vasishth, 2017).

However, a recent large-scale replication of the original Dillon et al. (2013) study found no difference in the profile of subject-verb agreement and antecedent-reflexive relations as far as facilitation was concerned – for both types of dependencies, sped up reading times were observed (Jäger et al., 2020). In their article, Jäger and colleagues also point out that the literature might suffer from having underpowered experiments. This is especially important for findings like that of Dillon et al. (2013) that make theoretical claims based on an *absence* of an effect. The picture that emerges is thus inconclusive in terms of the evidence from facilitatory effects.

More findings inconsistent with the predictions of the cue-based theory were reported by Dillon et al. (2014). This time, antecedent-reflexive relations were found to differ in their speed-accuracy profile in retrieval. In their study, they examined the Mandarin reflexive *ziji* using the multiple-response speed-accuracy tradeoff paradigm. *Ziji* is a long-distance reflexive pronoun, which may bound outside its local clause. Dillon et al. (2014) contrasted cases where *ziji* had an antecedent either in the local, embedded clause or the distant, matrix clause:

- 13) Zhangsan_i shuo fengbao_j hai-le ziji_{i/j}
 Zhangsan says storm harm-perf ziji
 “Zhangsan said the storm harmed him.”
- 14) Xiaoshuo_i shuo Zhangsan_j hai-le ziji_{i/j}
 Novel says Zhangsan harm-perf ziji
 “The novel said Zhangsan harmed himself.”

What they found was a locality effect in that the antecedent of *ziji* present in the distant clause was retrieved slower than one in the local clause. It thus appears that the retrieval profile of *ziji* antecedents resembles that predicted by serial search rather than cue-based access. The authors point out that in a cue-based theory, locality effects are explained by either time-based decay or interference. However, they argue that their findings represent a case where the locality effect for *ziji* antecedent retrieval cannot be explained by either of the two. They suggested that comprehenders first consider the local subject as the antecedent and that this is because syntactic locality outweighs semantic cues. This finding would suggest that the current theory needs to be amended to account for how syntactic positions can be modelled. The authors suggest adding the feature [+Local] as something that is encoded. They propose that finding the antecedent for *ziji* is a “series of serially executed, cue-based retrievals” (Dillon et al., 2014). The finding has since been replicated and found to be specific to the *ziji* reflexive in Mandarin specifically as opposed to other reflexive pronouns in the language by Dillon, Chow, and Xiang (2016).

In conclusion, the evidence gathered by studies using both the speed-accuracy tradeoff paradigm and those examining both inhibitory effects in retrieval suggests that the comprehenders are equipped with a parser that uses cues to match information about previously encountered constituents that are stored as bundles of features. So much so has been proven for such dependencies as subject-verb agreements. However, there is some evidence that in the case of antecedent-reflexive relations, the current theory might be inadequate. However, the studies showing a difference between subject-verb agreement and antecedent-reflexive relation dependencies in terms of their facilitatory effects have been inconclusive. Finally, the examination of how comprehenders retrieve antecedents for the Mandarin reflexive *ziji* suggests that the cue-based approach might need to be amended to account for locality effects by way of encoding information about syntactic position within the bundles.

UČO: 123456

Word count: 2409

References

- Avetisyan, S., Lago, S., & Vasishth, S. (2020). Does case marking affect agreement attraction in comprehension?. *Journal of Memory and Language*, *112*, 104087.
- Badecker, W., & Kuminiak, F. (2007). Morphology, agreement and working memory retrieval in sentence production: Evidence from gender and case in Slovak. *Journal of Memory and Language*, *56*(1), 65-85.
- Bock, K., & Cutting, J. C. (1992). Regulating mental energy: Performance units in language production. *Journal of memory and language*, *31*(1), 99-127.
- Chen, E., Gibson, E., & Wolf, F. (2005). Online syntactic storage costs in sentence comprehension. *Journal of Memory and Language*, *52*(1), 144-169.
- Dillon, B., Mishler, A., Sloggett, S., & Phillips, C. (2013). Contrasting intrusion profiles for agreement and anaphora: Experimental and modeling evidence. *Journal of Memory and Language*, *69*(2), 85-103.
- Dillon, B., Chow, W. Y., Wagers, M., Guo, T., Liu, F., & Phillips, C. (2014). The structure-sensitivity of memory access: evidence from Mandarin Chinese. *Frontiers in psychology*, *5*, 1025.
- Dillon, B., Chow, W. Y., & Xiang, M. (2016). The relationship between anaphor features and antecedent retrieval: comparing Mandarin ziji and ta-ziji. *Frontiers in psychology*, *6*, 1966.
- Engelmann, F., Jäger, L. A., & Vasishth, S. (2019). The effect of prominence and cue association on retrieval processes: A computational account. *Cognitive Science*, *43*(12), e12800.
- Gordon, P. C., Hendrick, R., & Levine, W. H. (2002). Memory-load interference in syntactic processing. *Psychological science*, *13*(5), 425-430.
- Jäger, L. A., Engelmann, F., & Vasishth, S. (2017). Similarity-based interference in sentence comprehension: Literature review and Bayesian meta-analysis. *Journal of Memory and Language*, *94*, 316-339.
- Jäger, L. A., Merten, D., Van Dyke, J. A., & Vasishth, S. (2020). Interference patterns in subject-verb agreement and reflexives revisited: A large-sample study. *Journal of Memory and Language*, *111*, 104063.
- Lewis, R. L., & Vasishth, S. (2005). An activation-based model of sentence processing as skilled memory retrieval. *Cognitive science*, *29*(3), 375-419.
- Lewis, R. L., Vasishth, S., & Van Dyke, J. A. (2006). Computational principles of working memory in sentence comprehension. *Trends in cognitive sciences*, *10*(10), 447-454.
- Martin, A. E., & McElree, B. (2008). A content-addressable pointer mechanism underlies comprehension of verb-phrase ellipsis. *Journal of Memory and Language*, *58*(3), 879-906.
- McElree, B. (2000). Sentence comprehension is mediated by content-addressable memory structures. *Journal of psycholinguistic research*, *29*(2), 111-123.
- McElree, B., Foraker, S., & Dyer, L. (2003). Memory structures that subserve sentence comprehension. *Journal of Memory and Language*, *48*(1), 67-91.g

UČO: 123456

Parker, D., Shvartsman, M., & Van Dyke, J. A. (2017). The cue-based retrieval theory of sentence comprehension: New findings and new challenges. *Language processing and disorders*, 121-144.

Van Dyke, J. A., & McElree, B. (2006). Retrieval interference in sentence comprehension. *Journal of Memory and Language*, 55(2), 157-166.

Van Dyke, J. A. (2007). Interference effects from grammatically unavailable constituents during sentence processing. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 33(2), 407.

Van Dyke, J. A., & McElree, B. (2011). Cue-dependent interference in comprehension. *Journal of memory and language*, 65(3), 247-263.

Vasishth, S., Nicenboim, B., Engelmann, F., & Burchert, F. (2019). Computational models of retrieval processes in sentence processing. *Trends in cognitive sciences*.

Wagers, M. W., Lau, E. F., & Phillips, C. (2009). Agreement attraction in comprehension: Representations and processes. *Journal of Memory and Language*, 61(2), 206-237.