

## Antecedent representational complexity eases maintenance cost in working memory

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**Background.** Working memory (WM) processes - encoding, maintenance and retrieval - are essential for sentence comprehension, especially for long-distance dependencies. It is an open question how representational complexity affects these processes. Some previous studies have argued that representational complexity increases encoding effort but decreases retrieval cost [1,2]. For example, it was found in [1] that reading time is longer when encoding a complex noun phrase *an alleged communist* than a simpler one *a communist*; but at a later retrieval region, retrieving the more complex noun phrase antecedent elicits faster reading time. However, it is unclear whether storing a more complex antecedent is beneficial for the maintenance process. The current study attempts to conceptually replicate the reported effects of antecedent complexity during encoding and retrieval and explore what happens during maintenance. Our results showed that 1) the encoding of modified NPs, which are more representationally complex, was slower and their retrieval faster, though the effects were inconsistent, and 2) their maintenance was facilitated.

**Experiment 1.** We tested how extracted NP complexity affects the three WM processes in subject and object relative clauses (SRC and ORC). In English, it is known that ORCs pose more processing difficulty [3]. The experiment had a 2 (SRC/ORC) x 2 (complex/simple NP) design (Examples in (1)). 93 participants from Prolific performed a self-paced reading task with 32 experimental items and 32 fillers. Each sentence was followed by a comprehension question targeting the dependency. Raw RTs were first log transformed and residualized based on sentence position. We examined the **encoding region** (extracted NP *survivors* and its spillover *who*), the **retrieval region** (RC verb *assisted*), and the **maintenance region** (words between the encoding and retrieval sites). Bayesian statistical analyses using *brms* [4] were performed, with RTs on the previous word, NP type and RC type (both sum-coded) as fixed effects and a full random effect structure. In the **encoding region**, no effect of NP type was detected on either word (Fig 1). In the **maintenance region**, RTs on adverb *dutifully* showed effects of NP type ( $\beta=-0.06$ , 95% CrI[-0.09, -0.04], complex < simple) and RC type ( $\beta=0.07$ , [0.04,0.10], SRC < ORC), and an NP x RC interaction ( $\beta=-0.05$ , [-0.09, -0.0001]), driven by a larger RT difference between ORCs with complex and simple NPs than their SRC counterparts. In the **retrieval region**, RTs on the verb *assisted* only showed an RC type effect that ORCs are more difficult ( $\beta=0.07$ , [0.04,0.11]). However, RTs on the spillover *last week* showed an NP type effect ( $\beta=-0.04$ , [-0.06,-0.02], complex < simple).

**Experiment 2.** One difference between the RCs at *dutifully* in Exp 1 is that for ORCs there are two referents to be maintained as distinct representations, whereas for SRCs the extracted NP is the only referent. In Exp 2 (n=83), we used the same design as Exp 1 with an additional embedding clause (*who Jennifer thinks*) so that additional referent(s) are present in both RC types. In the **encoding region**, we replicated the slowdown for complex NPs [1] on the noun *survivors* (Fig 2,  $\beta=0.04$ , [0.01,0.06]). In the **maintenance region**, RTs on *thinks* were faster in the complex NP conditions ( $\beta=-0.06$ , [-0.09,-0.04]). RTs on *dutifully* again showed an NP type effect ( $\beta=-0.05$ , [-0.07,-0.02], complex < simple) and an RC type effect ( $\beta=0.09$ , [0.06,0.12], SRC < ORC) but no interaction. In the **retrieval region**, we found NP type ( $\beta=-0.04$ , [-0.07,-0.02]) and RC type effects ( $\beta=0.05$ , [0.02,0.09]) in the same direction.

**Discussion.** We only replicated the slowdown of complex NPs [1] in the **encoding region** in Experiment 2. We also replicated the speed-up in the **retrieval region** of complex NPs in both experiments, albeit on different words (on the spillover in Exp 1 and the verb in Exp 2). In the **maintenance region**, we found facilitation effect thanks to NP complexity in both experiments, except for on the adverb *dutifully* in SRCs in Exp 1. We hypothesize that richer features on complex NPs make it easier to maintain distinct representations of the extracted NP and another intervening referent. This facilitation is shown on *thinks* and *dutifully* in Exp 2 and on *dutifully* in ORCs in Exp 1, all of which require maintenance of two or more distinct referents. When only one referent (*survivors*) is maintained, as in SRCs in Exp 1, it is unnecessary to make the representations distinct, resulting in no facilitation on *dutifully*.

**Materials. (Encoding region in red, maintenance region in green, retrieval region in blue)**

**(1) Experiment 1.**

SRC, complex: Those/ emotional / crash / survivors / who / dutifully / assisted / Sophia / last week / joined / the meeting.

ORC, complex: Those/ emotional / crash / survivors / who / Sophia / dutifully / assisted / last week / joined / the meeting.

SRC, simple: Those / survivors / who / dutifully / assisted / Sophia / last week / joined / the meeting.

ORC, simple: Those / survivors / who / Sophia / dutifully / assisted / last week / joined / the meeting.

Comprehension question: Was it Jane who assisted those survivors?

**(2) Experiment 2.**

SRC, complex: Those/ emotional / crash / survivors / who / Jennifer / thinks / dutifully / assisted / Sophia / last week / joined / the meeting.

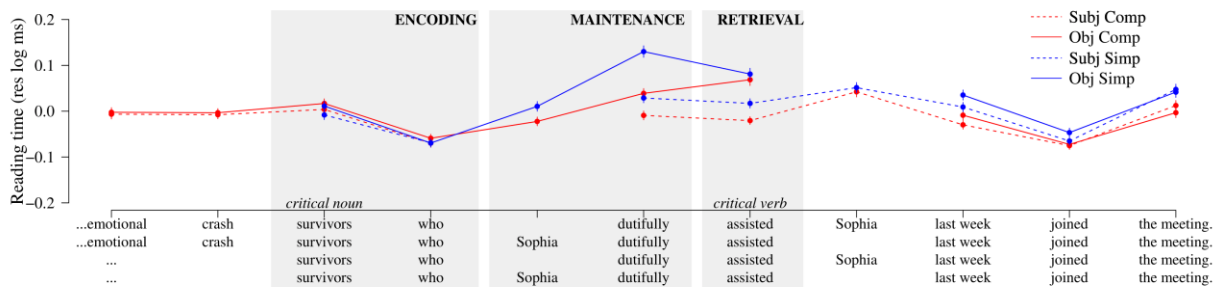
ORC, complex: Those/ emotional / crash / survivors / who / Jennifer / thinks / Sophia / dutifully / assisted / last week / joined / the meeting.

SRC, simple: Those / survivors / who / Jennifer / thinks / dutifully / assisted / Sophia / last week / joined / the meeting.

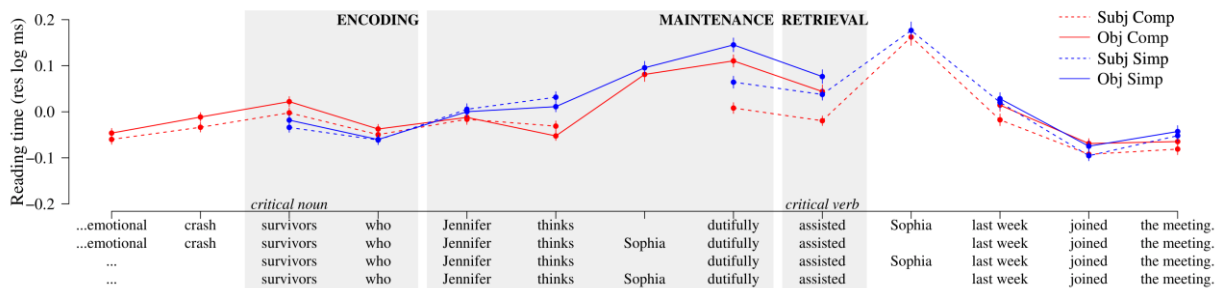
ORC, simple: Those / survivors / who / Jennifer / thinks / Sophia / dutifully / assisted / last week / joined / the meeting.

Comprehension question: Was it Jane who Jennifer thinks assisted those survivors?

**Figures.** (Logged RTs were residualized with previous word's logged RT and word position.)



**Fig 2.** Residualized logged RTs from Experiment 2. Error bars indicate +/- 1 standard error



**References.**[1] Hofmeister, 2011 [2] Hofmeister and Vasishth, 2014 [3] King and Just, 1991 [4] Bürkner, 2017