

The effect of representational complexity on working memory processes

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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 (RT) is longer when encoding a complex noun phrase (NP, e.g., *an alleged communist*) than a simpler one (e.g., *a communist*); but at a later retrieval site, retrieving the more complex NP antecedent elicits faster RTs. However, the effect of complexity on encoding and the trade-off between encoding and retrieval have only been observed in a limited set of constructions. The current study investigates whether the reported effects can be generalized by comparing coordinated NPs (e.g., *those judges and lawyers*), with simple NPs (e.g., *those lawyers*). Different from the findings in [1], our results showed that the encoding stage of the coordinated NPs, which are syntactically and semantically more complex, was facilitated (faster RTs); and their maintenance, but not retrieval, was also facilitated.

Experiment 1. We tested how complexity of an extracted NP 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)). 94 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 *lawyers* and its spillover *who*), the **retrieval region** (RC verb), 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**, RTs on the extracted NP's final word *lawyers* showed an effect of NP type ($\beta=0.10$, 95% CrI[0.05, 0.15], complex < simple) (Fig 1). In the **maintenance region**, RTs on the adverb *harshly* showed an effect of NP type ($\beta=0.04$, [0.01,0.07]) and an NP x RC interaction ($\beta=-0.05$, [-0.09,-0.003]), driven by the fact that RTs for the complex NP conditions were faster in ORCs ($\beta=0.05$, [0.02,0.10]), but not in SRCs. In the **retrieval region**, RTs on the verb *admitted* only showed an RC-type effect that ORCs are more difficult ($\beta=-0.11$, [-0.15,-0.07]).

Experiment 2 One difference between the RCs at *harshly* 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=75), we used the same design as Exp 1 with an additional embedding clause (*who John thinks*) so that additional referent(s) are present in both RC types. In the **encoding region**, we replicated the faster RTs on *lawyers* in the complex NP conditions, ($\beta=0.08$, [0.03,0.14]) (Fig 2). In the **maintenance region**, RTs on *thinks* were also faster in the complex NP conditions ($\beta=0.04$, [0.01,0.06]). RTs on *harshly* showed an RC type effect ($\beta=-0.09$, [-0.13,-0.05], ORC>SRC) and a marginal RC x NP interaction ($\beta=0.05$, [-0.001,0.11]), driven by faster RTs for complex NP condition only in SRCs ($\beta=0.05$, [0.01,0.09]). In the **retrieval region**, there was again only an RC type effect on *admitted* ($\beta=-0.07$, [-0.12,-0.02], ORC > SRC).

Discussion. Both experiments showed a speed-up for the more complex NP in the **encoding region**, contrary to the slowdown effect in [1]. Further analyses ruled out lexical priming from *judges* as the source of the speed-up, as semantic similarity between the two conjunct nouns did not predict RTs at *lawyers*. In the **retrieval region**, there was no facilitation due to complexity, again contrary to [1]. We are currently conducting a conceptual replication of [1] using the original adjective-noun structure. In the **maintenance region**, 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 was shown on *thinks* in Exp 2 and on *harshly* in ORCs in Exp 1 and SRCs in Exp 2, all of which require maintenance of two distinct referents. The facilitation effect of the complex NP diminishes, however, when the maintenance difficulty is overloaded with the addition of a third referent, as on *harshly* in ORCs in Exp 2.

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

(1) Experiment 1.

SRC, complex: It seems / that / those judges / **and lawyers** / **who** / **harshly** / **reprimanded** / Andy / today / admitted / the error.

ORC, complex: It seems / that / those judges / **and lawyers** / **who** / **Andy** / **harshly** / **reprimanded** / today / admitted / the error.

SRC, simple: It seems / that / **those lawyers** / **who** / **harshly** / **reprimanded** / Andy / today / admitted / the error.

ORC, simple: It seems / that / **those lawyers** / **who** / **Andy** / **harshly** / **reprimanded** / today / admitted / the error.

Comprehension question (complex): Was it Andy who reprimanded those judges and lawyers?

Comprehension question (simple): Was it Andy who reprimanded those lawyers?

(2) Experiment 2.

SRC, complex: It seems / that / those judges / **and lawyers** / **who** / **John** / **thinks** / **harshly** / **reprimanded** / Andy / today / admitted / the error.

ORC, complex: It seems / that / those judges / **and lawyers** / **who** / **John** / **thinks** / **Andy** / **harshly** / **reprimanded** / today / admitted / the error.

SRC, simple: It seems / that / **those lawyers** / **who** / **John** / **thinks** / **harshly** / **reprimanded** / Andy / today / admitted / the error.

ORC, simple: It seems / that / **those lawyers** / **who** / **John** / **thinks** / **Andy** / **harshly** / **reprimanded** / today / admitted / the error.

Comprehension question (complex): Was it Andy who John thinks reprimanded those judges and lawyers?

Comprehension question (simple): Was it Andy who John thinks reprimanded those lawyers?

Figures. (Log RTs were residualized with previous word's log RT and word position.)

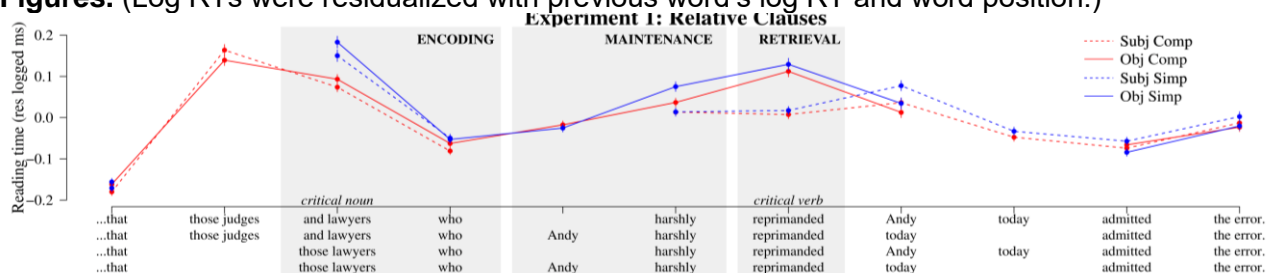


Fig 1. Residualized log RTs from Experiment 1. Error bars indicate +/- 1 standard error

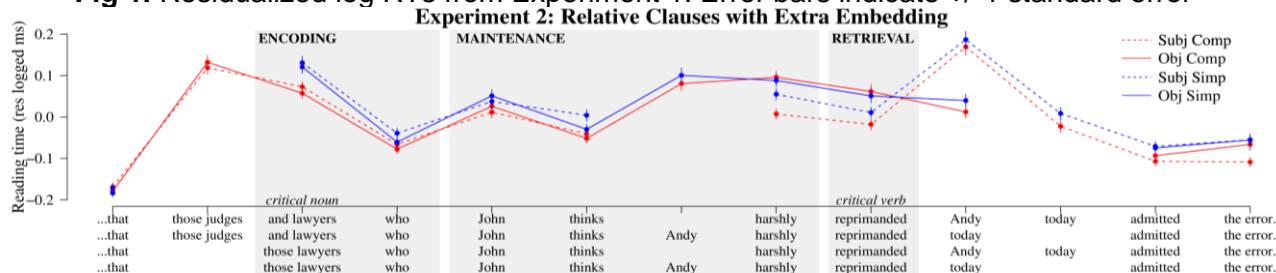


Fig 2. Residualized log RTs from Experiment 2. Error bars indicate +/- 1 standard error

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