Longer encoding times facilitate subsequent retrieval during sentence processing

Hossein Karimi (Mississippi State), Michele Diaz (Penn State), Eva Wittenberg (UCSD)

Numerous studies have shown that modified words (i.e., *the injured and dangerous bear*) result in faster reading times compared to unmodified words (i.e., *the bear*) at a subsequent point where the retrieval of the head noun (*bear*) is triggered [e.g.,1-4]. This "modification effect" has been shown for both pre-modified (i.e., *the injured and dangerous bear*) and post-modified words (i.e., *the bear that was injured and dangerous*, [5]). Two main memory mechanisms have been proposed to explain the modification effect: (1) the *distinctiveness* account, according to which added semantic information result in representations that are more distinct from other representations in memory, rendering them less susceptible to interference. And (2) the *head-reactivation* account, which states that processing modifying words (e.g., *injured and dangerous*) causes the target word (*bear* as syntactic head of the noun phrase) to be re-activated in memory, leading to higher ultimate activation levels [e.g.,1,2]. This project challenges these accounts and provides evidence for a "time-induced attention" hypothesis: Modifying information provides more encoding time, which in turn heightens attention to the head noun, rendering encoding more robust and subsequent retrieval easier [6]. In the case of post-modified words, the processor necessarily spends more time ***maintaining*** the representation of the head noun when it is post-modified than when it is unmodified. In the case of pre-modified words, because the determiner (*the*) predicts an upcoming head noun, the processor spends more time ***expecting*** the head noun relative to unmodified words. Longer maintenance and expectation of the head noun's representation in memory may heighten attention to it, facilitating subsequent retrieval. **Design.** In addition to using UNMODIFIED (1a & 2a, see below), and PRE-, or POST-MODIFIED words (1b & 2b), we also included a CUE-GIVING (1c & 2c) condition in which modifying words were replaced with masking characters (Exps1&2) or symbols (Exps 3&4), but the determiner *the* (in the case of pre-modifiers) or the relative pronoun and the auxiliary verb *that was* (in the case of post-modifiers) were kept in English; as well as a NO-CUE condition in which these syntactic cues were replaced with masking characters/symbols as well (1d & 2d). Masking characters/symbols were used to ensure that readers spent a comparable amount of time on the head noun as in the PRE- or POST-MODIFIED conditions, without additional content. Note that the syntactic complexity of the whole noun phrase is maintained in the CUE-GIVING condition, but in the NO-CUE condition, head noun merely enjoys more encoding time. **Analysis.** Following [1], the residuals of an initial model (predicting log-transformed RTs by sentence type (filler vs. experimental), trial number, word length, word position, and RT on the preceding word) were used as the Dependent Variable to test the effects of the predictors of interest in maximal mixed-effects models, with UNMODIFIED condition as baseline. To minimize multiple comparisons, analyses were limited to an "early" region including the verb and the immediately following word, and a "late" region including the next four words. **Results.** In all experiments (self-paced reading, N=413, n=57), we replicated the standard modification effect on the late region. Critically, we also observed faster reading times on both the early and late regions for both CUE-GIVING and NO-CUE conditions relative to the UNMODIFIED condition (regardless of modifier position; see Figures 1-4). There were no significant accuracy differences between conditions in any of the experiments, eliminating shallow processing as a function of masking characters [10]. **Discussion**. These results call into question both accounts previously developed to explain the modification effect: The *distinctiveness* account states that ease of retrieval is predicated on additional semantic information; however, we found easier retrieval despite no information added by the masking symbols/characters. Similarly, the *reactivation* account cannot explain our data either, because the character/symbol masks necessarily could not trigger the integration needed to initiate head-reactivation [1,7-9]. Instead, our results suggest that sheer time spent expecting or maintaining a representation in memory, and the concomitant heightened attention, facilitates its subsequent retrieval, carrying important implications for the current memory-based theories of language processing by highlighting the role of encoding time and attention.

Example sentences with critical words highlighted. Symbols (■) were displayed in chunks, corresponding to word-by-word presentation. The experimental sentence for Experiments 1 and 2 can be constructed by replacing each symbol chunk with a random Korean character (participants were screened to be unfamiliar with Korean).

Exps 1 & 3	(1a) UNMODIFIED	*It was the bear that the hunters chased in the cold forest yesterday.*
	(1b) PRE-MODIFIED	*It was the injured and dangerous bear that the hunters chased in the cold forest yesterday.*
	(1c) CUE-GIVING	*It was the ■■■ ■■ ■■■■ bear that the hunters chased in the cold forest yesterday.*
	(1d) NO-CUE	*It was ■■ ■■■ ■■ ■■■■ bear that the hunters chased in the cold forest yesterday.*
Exps 2 & 4	(2a) UNMODIFIED	*It was the bear that the hunters chased in the cold forest yesterday.*
	(2b) POST-MODIFIED	*It was the bear that was injured and dangerous that the hunters chased in the cold forest yesterday.*
	(2c) CUE-GIVING	*It was the bear that was ■■■ ■ ■■■■ that the hunters chased in the cold forest yesterday.*
	(2d) NO-CUE	*It was the bear ■■ ■■ ■■■ ■ ■■■■ that the hunters chased in the cold forest yesterday.*

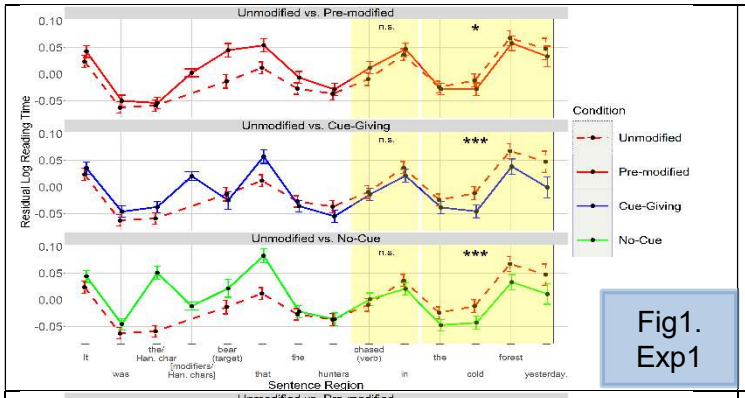

Fig1. Exp1

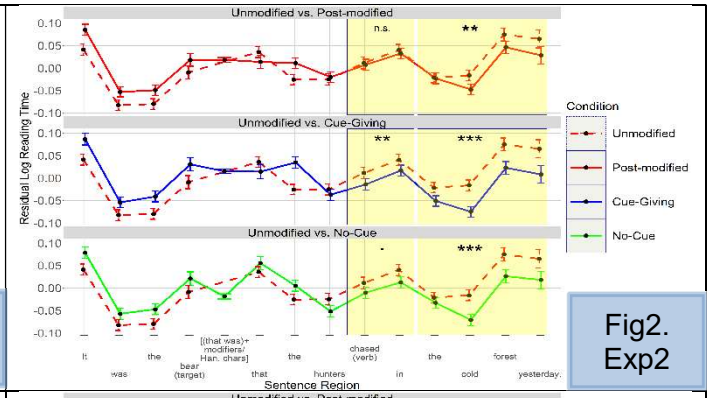

Fig2. Exp2

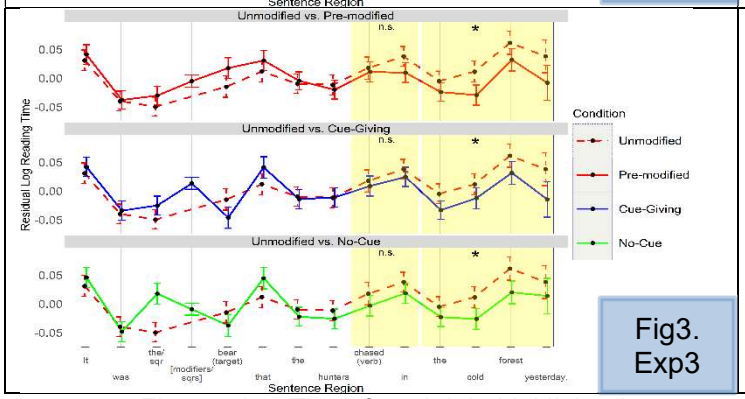

Fig3. Exp3

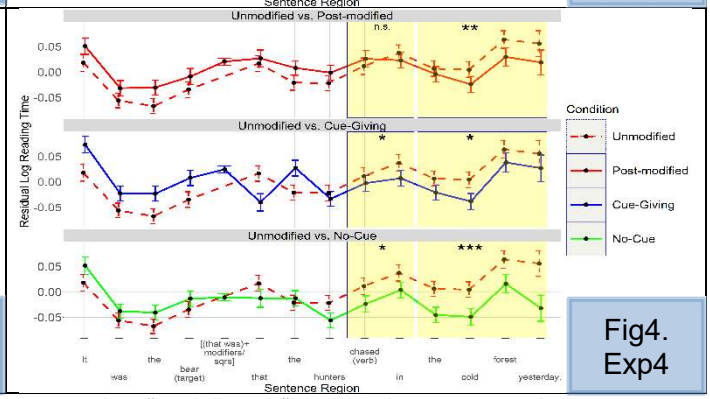

Fig4. Exp4

Figures 1-4. The left and right highlighted areas correspond to "early" and "late" regions, respectively.
Tables 1-4. Results for all experiments.

Table1. Exp1 Results. N=112

Region	Condition	*t*	*p*
Early "*chased in*"	Pre-modified	1.72	.08
	Cue-Giving	-1.24	.21
	No-Cue	-1.09	.27
Late "*the cold forest yesterday*"	Pre-modified	-2.15	.03
	Cue-Giving	-3.96	<.001
	No-Cue	-4.51	<.001

Table2. Exp2 Results. N=113

Region	Condition	*t*	*p*
Early "*chased in*"	Pre-modified	-1.01	.31
	Cue-Giving	-2.78	.005
	No-Cue	-1.84	.06
Late "*the cold forest yesterday*"	Pre-modified	-3.29	.001
	Cue-Giving	-6.03	<.001
	No-Cue	-4.99	<.001

Table3. Exp3 Results. N=89

Region	Condition	*t*	*p*
Early "*chased in*"	Pre-modified	-1.37	.17
	Cue-Giving	-.90	.36
	No-Cue	-1.21	.22
Late "*the cold forest yesterday*"	Pre-modified	-2.46	.01
	Cue-Giving	-2.33	.02
	No-Cue	-2.45	.01

Table 4. Exp4 Results. N=99

Region	Condition	*t*	*p*
Early "*chased in*"	Pre-modified	-.88	.42
	Cue-Giving	-1.98	.04
	No-Cue	-2.42	.01
Late "*the cold forest yesterday*"	Pre-modified	-2.81	.005
	Cue-Giving	-2.11	.03
	No-Cue	-5.03	<.001

References.

1. Hofmeister, P. (2011). *Language and Cognitive Processes.*
2. Hofmeister, P., & Vasishth, S. (2014). *Frontiers in Psychology*
3. Karimi, H., & Ferreira, F. (2016). *Psychonomic Bulletin & Review.*
4. Karimi, H., Swaab, T. Y., & Ferreira, F. (2018). *JML*.
5. Karimi, H., Diaz, M., & Ferreira, F. (2019). *JEP:LMC*.
6. Corley, M., & Hartsuiker, R. J. (2011). *PloS one*.
7. Lewis, R. L., & Vasishth, S. (2005). *Cognitive science.*
8. Lewis, R. L., Vasishth, S., & Van Dyke, J. A. (2006). *Trends in cognitive sciences*
9. Jäger, L. A., Engelmann, F., & Vasishth, S. (2017). *JML*.
10. Ferreira, F. Bailey, K.G.D & Ferraro. V. (2002). *Current Directions in Psychological Science*.