Beyond Surprising: English Event Structure in the Maze

Lisa Levinson, University of Michigan

Are there event structure properties of the lexical representations of verbs that influence reading times above and beyond the probabilistic distribution of those verbs and their arguments?

Background: Previous behavioral studies have found "costs" for lexical semantic verb representations due to the number of sub-events [1]–[4] and event types[4], even in lexical decision where contextual prediction does not play a role. It remains unclear, however, the extent to which this semantic complexity affects sentence processing. Structural verb biases vary both within and across languages *independent of* the event structure of the verbs themselves[2], [5]. Event structural properties thus might not travel through the same "causal bottleneck" [6] of surprisal, but rather make an independent contribution to processing. Prior findings cannot tease apart these factors; while based on stimuli that are controlled for a variety of probabilistic factors, they have not been recently re-evaluated in the context of (a) probabilities from less sparse language models, (b) measures more closely correlated with reading times[7], [8], (c) statistical modeling of multiple stimulus properties, and (d) more focal behavioral tasks such as grammatical maze[9], [10].

Experiment 1 sought to replicate effects of crossing event complexity and transitivity in English (exp 2 of [11]), with added analyses to evaluate the relative contribution of event complexity vs. surprisal. Stimuli (1)-(4) cross verb type (change-of-state (COS) vs. activity) with number of arguments. Transitives in the COS alternation (causatives) are assumed to have more complex events than intransitives (inchoatives)[12]–[14], as well as both activity variants, predicting a pairwise effect in COS verbs and an interaction independent of transitivity itself. Wh-question frames ensured that direct objects would be apparent prior to verb presentation.

Methods: 90 American English speakers completed a self-paced moving window task (with acceptability judgments) presented online via IbexFarm[15].

Results: LME models [16], [17] comparable to those in [11] supported replication of the predicted interaction (β = .04, se = .015, p < .05) and pairwise effect in COS verbs (β = .03, se = .01, p < .01) at verb+1 (Fig 1). LMEs were then fit with additional fixed effects of syntactic surprisals based on verb transitivity probabilities in VALEX[18] and full context lexical surprisals from pre-trained GPT-2[19]. While model comparison showed GPT2 significantly improved model fit (LRT p < .01), neither syntactic surprisal nor event structure did. This may be due to the dispersed and small effects observed via SPRT.

Exp 2: 60 participants completed a grammatical maze task on IbexFarm with the same stimuli, implemented with A-maze [20] using GRNN[21].

Results: As predicted, maze exhibited more focal effects, with no apparent spillover (Fig 2). Even with the full model, the predicted pairwise effect (β = .13 (255ms), se = .03, p < .0001) and interaction (β = .16 (280ms), se = .03, p < .001) were significant at the verb. GPT2 (but not syntactic surprisal) significantly improved model fit (LRT p < .0001), but the event structure interaction also significantly improved fit over GPT2 alone (LRT p < .0001).

In conclusion, these results support an independent contribution of event structure complexity to incremental processing above and beyond surprisal in the slower but more incremental maze task. Comparison of methods suggests that such effects may only be separable with more focal and larger effects that allow for teasing apart multiple fine-grained contributions to sentence processing.

Stimuli (matched across conditions for acceptability and verb frame entropy)

	Sentence		Verb Type	Arguments	Subevents
(1)	What did the explosion	sink near the harbor?	COS	2	2
(2)	When did the boat	sink near the harbor?	COS	1	1
(3)	What did the professor	read for the seminar?	Activity	2	1
(4)	When did the professor	read for the seminar?	Activity	1	1

Exp 1 & 2 full models: log RTs with fixed effects of verb type:num args, scaled and centered [verb frequency, length, syntactic surprisal, GPT2 surprisal], random effects of subjects and items.

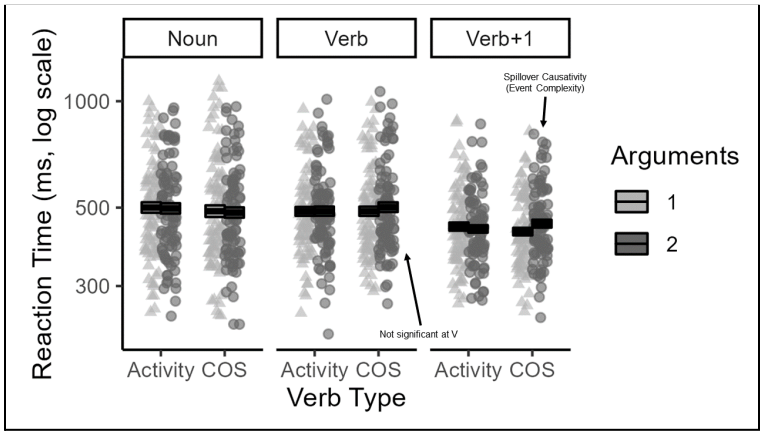

Figure 1: Experiment 1, SPRT. Interaction and pairwise effect emerge at Verb+1 spillover (preposition).

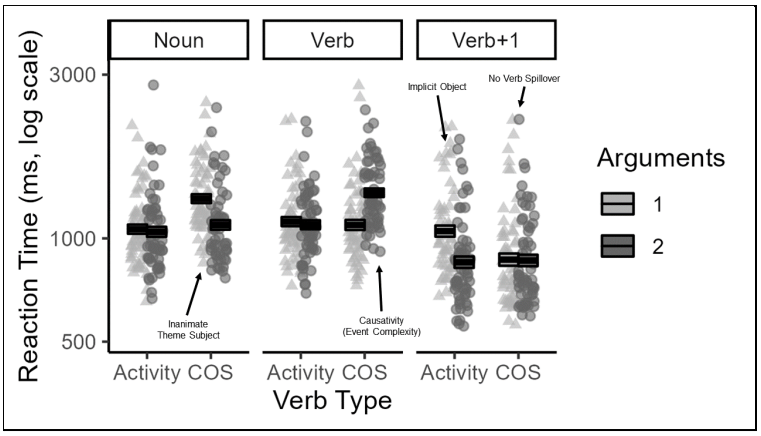

Figure 2: Experiment 2, Maze. Interaction and pairwise effect of event structure at verb. Effect at prior noun likely due to inanimate theme subjects of inchoative verbs, does not spillover to verb. Effect at verb+1 (preposition in all conditions) likely due to implicit object with intransitive activity verbs, also found in [11] and experiment 1 verb+2. No spillover of verb effect to verb+1.

[1] G. McKoon and J. Love, Language and Cognition, 2011. [2] G. McKoon and T. MacFarland, Language, 2000. [3] G. McKoon and T. Macfarland, Cognitive Psychology, 2002. [4] S. Gennari and D. Poeppel, Cognition, 2003. [5] M. Rappaport Hovav, in Perspectives on Causation, 2020. [6] R. Levy, Cognition, 2008. [7] J. Hale, presented at the NAACL, 2001. [8] J. Hale, Language and Linguistics Compass, 2016. [9] K. I. Forster, C. Guerrera, and L. Elliot, Behavior Research Methods, 2009. [10] N. Witzel, J. Witzel, and K. Forster, J Psycholinguist Res, 2012. [11] L. Levinson and J. Brennan, in Morphological Metatheory, 2016. [12] L. Pylkkänen, Introducing Arguments. 2008. [13] A. Alexiadou, E. Anagnostopoulou, and F. Schäfer, in Phases of Interpretation, 2006. [14] M. Rappaport Hovav and B. Levin, in The Theta System, 2012. [15] A. Drummond, Ibex farm. Online server, 2013. [16] D. Bates and M. Maechler, 2009. [17] A. Kuznetsova, P. B. Brockhoff, and R. H. B. Christensen, Journal of Statistical Software, 2017. [18] A. Korhonen, Y. Krymolowski, and T. Briscoe, presented at the LREC, 2006. [19] A. Radford et al., OpenAI blog, 2019. [20] V. Boyce, R. Futrell, and R. P. Levy, Journal of Memory and Language, 2020. [21] K. Gulordava, P. Bojanowski, E. Grave, T. Linzen, and M. Baroni, arXiv:1803.11138 [cs], 2018.