

The rational integration of noise and prior semantic expectation: Evidence for a noisy-channel model of sentence interpretation

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According to noisy-channel theories of sentence comprehension (e.g., Levy et al., 2009), listeners attempt to infer the most likely meaning from an utterance which may have been corrupted by noise such as deletions or insertions of words. These accounts therefore predict that the ultimate interpretation of a sentence should depend on the *proximity of plausible alternatives* under the noise model. In particular, if there is no plausible interpretation for an input string, then the closer a semantically plausible alternative is, the more comprehenders should rely on semantic cues for interpretation. Because previous models do not consider possible corruption of the linguistic signal by noise, they predict that the final interpretation is determined by syntax (e.g., Tanenhaus et al., 1995).

We investigated five English syntactic alternations (Levin, 1993): two “major-change” alternations – the active/passive and locative-inversion alternations – and three “minor-change” alternations: the transitive-intransitive alternation, the double-object (DO) / prepositional phrase object (PO) alternation for goals (“to” phrases), and the DO/PO alternation for benefactives (“for” phrases) (Table 1). If comprehenders rationally integrate the likelihood of noise with their prior semantic expectations, then semantic cues will have strongest influence on the interpretation of minor-change alternations. Thus, implausible DO structures like “The mother gave the candle the daughter” – which require only one deletion from the plausible PO (see 4b) – should be more likely to be interpreted according to semantics than implausible active structures like “The ball kicked the girl” – which require two deletions from the passive (see 1a).

We evaluated this prediction using a paradigm where participants answered a comprehension question about a sentence, whose answer indicated whether syntactic or semantic cues governed the interpretation (five experiments, 60 participants each; 20 items each). E.g., if the target sentence was “The ball kicked the girl”, then participants might be asked “Did the ball kick something/someone?”; “yes” indicates reliance on syntax; “no” – on semantics.

The noisy-channel prediction was borne out across the five alternations (Table 1). In particular, people relied on syntax more in the major-change alternations (93.4% (1)-(2)) than in minor-change alternations (56.1% (3)-(5); $p < .0001$). Furthermore, analysis of the minor-change alternations revealed that people rely on syntax more for structures requiring an insertion (66.1%) than those requiring a deletion (46.0%; $p < .0001$). This asymmetry is predicted by the Bayesian size principle (MacKay, 2003; Tenenbaum & Xu, 2007) because a deletion only requires a particular word to be randomly selected from a sentence, while an insertion requires its selection from (a subset of) the speaker’s vocabulary; the insertion of a specific word therefore has smaller likelihood.

Five follow-up experiments validated the assumptions of the noise model for each alternation. Participants were asked how likely a speaker would be to accidentally produce an implausible target sentence when intending to produce a plausible alternation. The results were as predicted: deletions were most expected, with insertions less expected, and multiple insertions/deletions still less expected.

In summary, we have demonstrated that comprehenders rationally integrate the likelihood of noise with prior expectations, and we have provided evidence for a particular noise model where deletions are more expected than insertions.

Construction/alternation	Example sentence	Plaus→Implaus changes	%Syntactic reliance
1a. Passive → Active:	The ball was/∅ kicked by/∅ the girl.	2 deletions	0.986
1b. Active → Passive:	The girl ∅/was kicked ∅/by the ball.	2 insertions	0.968
2a. Subj-loc → Obj-loc:	Onto/∅ the table jumped ∅/onto a cat.	1 deletion, 1 insertion	0.856
2b. Obj-loc → Subj-loc :	∅/Onto The cat jumped onto/∅ a table.	1 insertion, 1 deletion	0.933
3a. Intrans → Trans:	The tax law benefited ∅/from the businessman.	1 insertion	0.796
3b. Trans → Intrans:	The businessman benefited from/∅ the tax law.	1 deletion	0.625
4a. DO → PO-goal:	The mother gave the daughter ∅/to the candle.	1 insertion	0.620
4b. PO → DO-goal:	The mother gave the candle to/∅ the daughter.	1 deletion	0.478
5a. DO → PO-benef:	The cook baked Lucy ∅/for a cake.	1 insertion	0.568
5b. PO → DO-benef:	The cook baked a cake for/∅ Lucy.	1 deletion	0.276

Table 1: % syntactic reliance for the interpretation of implausible syntactic constructions, and the number of insertions & deletions that are needed to form a plausible alternation from the implausible version. E.g., 2 deletions are needed to form the implausible sentence “the ball kicked the girl” from the plausible “the ball was kicked by the girl”. Plausible (control) versions of these materials were also run in the experiment, and people always interpreted them according to their syntax & semantics (99%).