Go High or Go Low: Adaptation to Different Error Distributions in Sentence Processing

Shaorong Yan[1], Thomas A. Farmer[2], & T. Florian Jaeger[1] ([1]U of Rochester; [2]UC Davis)
syan13@ur.rochester.edu

Readers are sensitive to the statistics of linguistic input: e.g., expected words are read faster. Recent work suggests that readers can adapt their expectations when the statistics of language in a current context deviate from those of previously experienced input[1,2]. Expectation-adaptation has, however, typically been studied at one level of linguistic representation at a time. It is unclear what determines which linguistic representation readers will adapt. For instance, unexpected words can be caused by either lexical co-occurrence or syntactic context. Here, we investigate how readers attribute unexpected observations to different levels of processing.

In three eye-tracking experiments, we inspect how different types of prediction errors affect subsequent processing. We examine adaptation to garden-path effects (GP) elicited by an unexpected continuation of a syntactic ambiguity (reduced relative clauses, see Tab. 1). The adaptation effect is defined as the progressive decrease in GP as readers encounter instances of the unexpected continuation. Patterns of adaptation indicate what processes are adjusted: If lexical expectations are adapted, we expect to see changes in first-pass reading measures, which are more sensitive to lower-level properties (e.g., word frequency, lexical predictability). If syntactic expectations are adapted, changes should occur for regression-related measures (e.g. go-past times and second-pass reading times), which tend to reflect post-lexical processing, including syntax[3]. Analyses of reading times on the first word of the disambiguation region are presented in Tab. 2. (Whole disambiguation region analyses, not reported, replicate this pattern.)

Exp 1 (93 subj., 24 GPs+72 fillers)**:** Each GP sentence was disambiguated by a different word (see Tab. 1). Prediction errors should thus not be attributable to specific words, leading instead to changes in syntactic expectations. Confirming this prediction, we only found adaptation effects on regression-related measures (see Table 2), thus suggesting that the adaptation previously reported in self-paced studies[7] reflects post-lexical (syntactic) adaptation.

Exp 2 (60 subj., 36 GPs +84 fillers)**:** We examined whether the informativity of prediction errors for lexical processing affects the adjustment of syntactic expectations. We modified the materials of Exp 1 so that GP sentences were always disambiguated by the same word ("became"). Non-GP continuations were always disambiguated by another word ("and"). Unlike in Exp 1, here prediction errors might be attributed to either syntactic expectations or to (more specific) syntactically-conditioned lexical expectations. If readers do adapt lexical expectations, we should see adaptation in first-pass reading measures. Contrary to this prediction, however, expectation adaptation was only observed for regression-related measures.

Exp 3 (91 subj., 24 GPs +72 fillers) replicated these findings with different lexical materials (see Tab.1) that addressed some potential problems of Exp 2.

Discussion: In Exp 2 & 3 (unlike in Exp 1), prediction errors were informative of lexical expectations. Given that adaptation only occurred on regression-related measures, however, readers appear to have adjusted only (higher-level) syntactic expectations (same as in Exp 1). Crucially, this is not because first-pass measures are not malleable: previous work suggests that (sentential-context conditioned) lexical expectations *can* be adapted, as reflected in changes specific to first-pass measures[4]. The present results suggest that syntactically-conditioned lexical expectations are not readily adjusted when prediction errors can also be attributed to syntactic predictions. One possible reason is that one seldom needs to adjust syntactically-conditioned lexical expectations so that adjustment of syntactic expectations will be prioritized. Another possibility is that the attribution of prediction errors depends on the relative validity of predictions at different levels. It is rare that a specific lexical item can be predicted, but the syntactic category of the upcoming word can often be predicted[5]. The validity of lexical/pre-lexical level expectations is thus much lower than syntactic expectations. As a result, prediction errors will more likely be attributed to syntactic expectations.

Table 1. *Example Sentences for Exp1, 2, and 3. Structure: main verb (MV); relative clause (RC). Ambiguity Status: ambiguous (Amb); unambiguous (Unamb). Garden-path effect is defined as the interaction between Structure and Ambiguity Status. '/' signifies region boundaries adopted in analyses. Main regions of interest (i.e. disambiguation region) are bolded and colored.*

	Struc	Amb	Example Sentence
Exp 1	**MV**	Amb	The experienced soldiers /warned about the dangers /**before the midnight** /raid.
	RC	Amb	The experienced soldiers /warned about the dangers /**conducted the midnight** /raid.
	MV	Unamb	The experienced soldiers /spoke about the dangers /**before the midnight** /raid.
	RC	Unamb	The experienced soldiers who were /warned about the dangers /**conducted the midnight** /raid.
Exp 2	**MV**	Amb	The kitchen staff /served in the cafeteria /**and cleaned up** /afterwards.
	RC	Amb	The kitchen staff /served in the cafeteria /**became very content** /afterwards.
	MV	Unamb	The kitchen staff /ate in the cafeteria /**and cleaned up** /afterwards.
	RC	Unamb	The kitchen staff /fed in the cafeteria /**became very content** /afterwards.
Exp 3	**MV**	Amb	The kitchen staff /served in the cafeteria /**before their shift** /ended.
	RC	Amb	The kitchen staff /served in the cafeteria /**became very content** /afterwards.
	MV	Unamb	The kitchen staff /ate in the cafeteria / **before their shift** /ended.
	RC	Unamb	The kitchen staff /fed in the cafeteria /**became very content** /afterwards.

Table 2. *Coefficient (ß) and t-values from linear-mixed effect models for first-pass and second-pass reading times on the first word of the disambiguation region (**: p<.01; *: p<.05; ': p<.1).*

		First-pass Reading times		Second-pass Reading Times	
		ß	***t-value***	***ß***	***t-value***
Exp. 1	***Garden-path Effect***	22.59	1.76'	157.5	3.79**
	Adaptation Effect	-1.89	-1.01	-7.88	-2.52**
		ß	***t-value***	***ß***	***t-value***
Exp. 2	***Garden-path Effect***	44.99	1.48	112.6	4.99**
	Adaptation Effect	-0.39	-0.22	-3.0	-2.36*
		ß	***t-value***	***ß***	***t-value***
Exp. 3	***Garden-path Effect***	18.64	1.84'	183.4	5.51**
	Adaptation Effect	0.36	0.24	-11.4	-4.12**

References: 1. Kamide, 2012; 2. Fine et al., 2013; 3. Clifton et al., 2007; 4. Yan & Farmer, 2015; 5. Luke & Christianson, 2016.