EVIDENCE FOR EARLY APPLICATION OF BINDING THEORY AND LATE INTRUSION EFFECTS

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INTRODUCTION: Authors have previously argued that the parser "knows and obeys" binding theory during antecedent selection for reflexives (Nicol & Swinney, 1989). Sturt's "Defeasible binding" theory predicts that BT-grammatical antecedents are established during a "first-pass," and that intrusive antecedents can "take over" as illicit antecedent only in a temporally subsequent stage (Sturt, 2003). However, recent cue-based theories of memory retrieval predict that structurally illicit but feature matching ("intrusive") antecedents should immediately interfere with antecedent assignment (Jäger et al., 2017; Lewis & Vasishth, 2005; Parker et al., 2015, 2016; Parker & Phillips, 2017), and that intrusive antecedents are facilitated when the BT-grammatical antecedent fails to agree in some feature (Patil et al., 2016). The extant literature has relied on reading time and eye-tracking studies, but ERPs are well suited for measuring time course of processing and should converge with eye-tracking data. To date, only one ERPs study has measured intrusion effects in reflexive binding (Xiang et al., 2009), but it employed an unbalanced design and was primarily about negative polarity licensing. We turned Xiang et al into a 2x2 design, as in Patil et. al., (2016), to obtain an ERP time course test of BT-grammatical vs. intrusive binding.

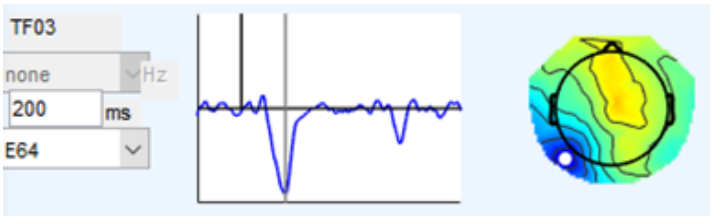
METHODS: Two ERP experiments were conducted (see table 1 and 2). Sentences were presented word-by-word centered on the screen (300ms duration+200ms ISI). Each sentence was followed by a comprehension question. Experiment 1 (N=24) sought to establish a baseline measure of the time course of agreement violation detection between BT-grammatical antecedent and reflexive, in the absence of intrusive antecedents (e.g. "The male soldier that the team treated in the military hospital introduced himself/herself to all the nurses"). In Experiment 2 (N=23) we introduced an intrusive antecedent (Table 1). We again measured (i) whether we observed the same BT-grammatical ERPs as in Exp 1, and also (ii) whether feature mismatches between the intruder and the reflexive modulated the same ERP as in Exp 1 or showed up in a separate (later) ERP, and (iii) whether there was an interaction such that the intrusive effect was facilitated by failure of BT-grammatical binding.

RESULTS: After artifact correction, main effects were constructed as difference waves (matching minus mismatching antecedent). The temporal and spatial dynamics of the brain response to agreement violations was factored with a temporo-spatial sequential PCA/ICA analysis (Dien, 2010, 2012). The "factor ERP" scores were used as dependent measures, but also used to constrain selection of time windows and electrode regions in the undecomposed voltage data, which was also analyzed as dependent measures, for convergence. In Experiment 1, in addition to a LAN factor (500ms), the BT-grammatical agreement violation was reflected in a modulation of the N170 visual cortex response (Vogel & Luck, 2000), analogous to Dikker et. al., (2009), see Fig 1. This effect was exactly replicated for BT-grammatical violations in Experiment 2 (Fig 2). However, there was no signal in the N170 component of intrusive antecedent agreement violation. Rather, this condition elicited two later ERP components (388ms and 496ms), none of which reached statistical significance (mirroring the results in (Xiang et al., 2009)). Analysis of the cue-based theory's predicted interaction between failed BT-grammatical binding and intrusive binding only revealed a main effect of BT-grammatical antecedents (Fig 3).

CONCLUSION: BT-grammatical binding is visible as early as 170ms. This is a new finding and shows that BT-grammatical binding is established much earlier than previously reported (Osterhout & Mobley, 1995). It is interpretable as grammatical predictions driving top-down sensory expectations about visual word forms (Dikker et al., 2009). Intrusive binding elicited later ERP effects (~500ms), but was variable across individuals (and therefore statistically weaker). There was no facilitation of intrusive binding when the BT-grammatical antecedent failed to agree, contra the predictions of cue-based memory retrieval models. The results support Sturt's 2-stage defeasible binding process theory.

		BT-GRAMMATICAL ANTECEDENTS	
		A. Incongruent grammatical	*B. Congruent grammatical*
INTRUSIVE ANTECEDENTS	*C. Incongruent intrusive*	The male soldier that Fred treated in the military hospital introduced herself to all the nurses.	The male soldier that Katie treated in the military hospital introduced himself to all the nurses.
	D. Congruent intrusive	The male soldier that Katie treated in the military hospital introduced herself to all the nurses.	The male soldier that Fred treated in the military hospital introduced himself to all the nurses.

Table 1: Design of Exp 2. Each cell had 30 trials.



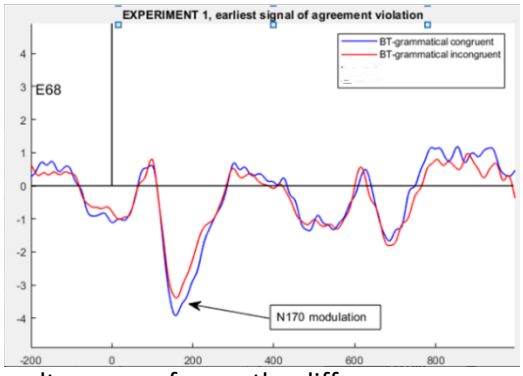


Figure 1: Left panel: Temporal PCA factor for Exp 1 BT-grammatical agreement violation difference wave (two spatial subfactors both sign. by t-test against 0). Right panel: corresponding undecomposed grand average absolute voltage waveforms; the difference incongruent-congruent, mean voltage 160-224ms peak channel E68 (defined by PCA/ICA) was statistically significant with t-test against zero ($t(23)=-5.69$, $p<0.00001$).

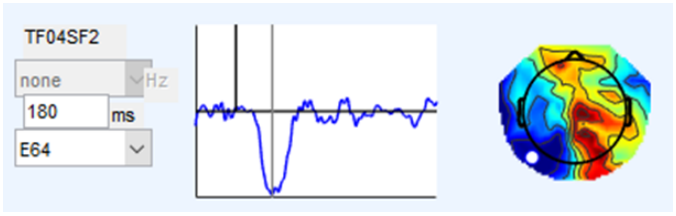


Figure 2, left: N170 effect in Exp2, BT-grammatical antecedents ($t(19)=4.79$, $p<0.001$. Corresponding voltage effect: $t(19)=-4.22$, $p<0.001$, t-tests against 0.

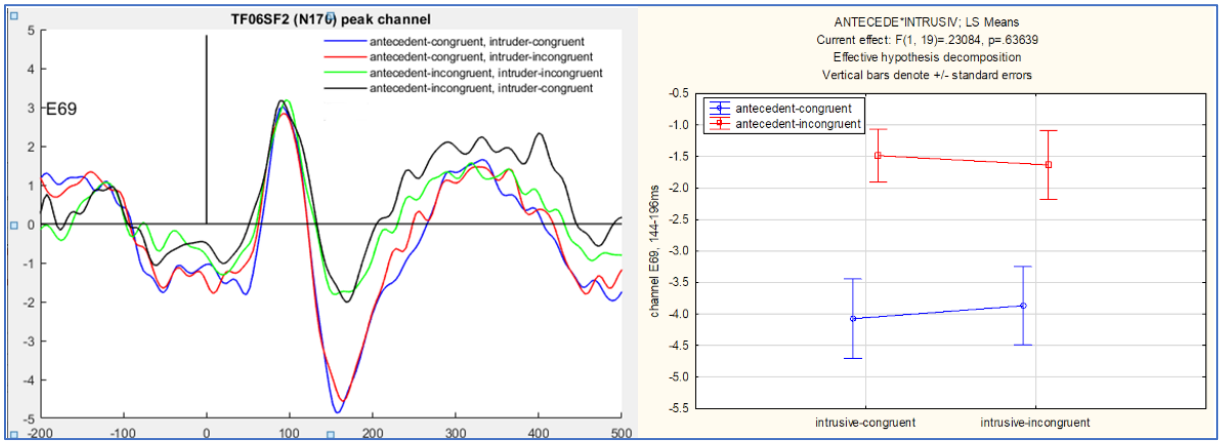


Figure 3: Analysis of absolute waves, full 2x2 ANOVA. Only a main effect of BT-grammatical antecedents was observed in the N170 component, no main effect of intruder or interaction between the two factors were observed. Intruder agreement violations had a later effect (~500ms), not shown here.