Quantified Sentences as a Window into Prediction and Priming: An ERP Study

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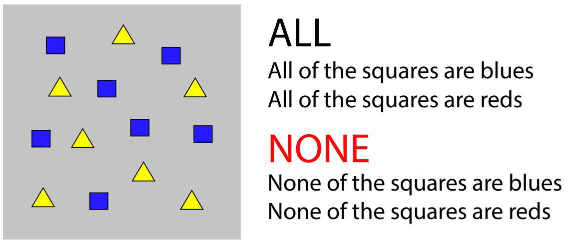
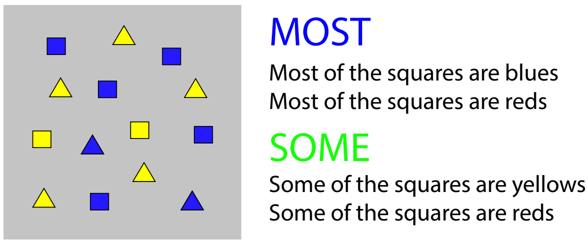
Overview In this study, we examined the processing of quantified sentences in an auditory/visual verification task to probe truth-value/quantifier-type influences on the N400 ERP response. Studies have demonstrated the N400 to be insensitive to truth-value/negation in verification paradigms (Fischler et al. 1983; Kounios & Holcomb 1992) while exhibiting modulations for subject/predicate relatedness (e.g., N400 for ROCK>BIRD in "A robin IS/IS-NOT a ROCK/BIRD). However, Nieuwland & Kuperberg (2008) argue such uses of negation are pragmatically unnatural, and when this is controlled, N400 amplitude can be modulated by truth-value (False>True). To unequivocally disambiguate truth-value and priming, we used quantified sentences associated with a visual scene relevant to verification. In light of our results, we also discuss evidence for early prediction effects tied to the truth-conditional properties of quantifiers; and for ERP markers of quantifier complexity.

Methods We presented quantified sentences (e.g., "All of the squares are blues") auditorily while participants simultaneously viewed arrays of colored shapes. Shape/color-combinations were used with four quantifier-types (ALL/NONE/MOST/SOME) to yield eight conditions varying quantifier/truth-value. Each visual stimulus consisted of fourteen colored shapes, with an even contrast ratio for ALL/NONE (7 yellow-circles/7 blue-squares) and opposing 2:5/5:2 ratios for MOST/SOME (e.g., 2 yellow-/5 blue-circles and 5 blue-/2 yellow-squares). False conditions used color/shape-predicates which were not present in the images (unprimed). These visual/auditory-pairs were presented to adult/native English-speakers (N=10) who provided (mis)match judgments following each trial. EEG was recorded continuously (32 channels, Biosemi-Active-2) and ERP mean amplitudes for successive 100 ms windows were examined for 1200 ms epochs (-200-0 ms baseline). Signals were time-locked to (i) the predicate onset to examine quantifier-type influences on truth-value and (ii) the onset of the quantifier to test for complexity effects for MOST.

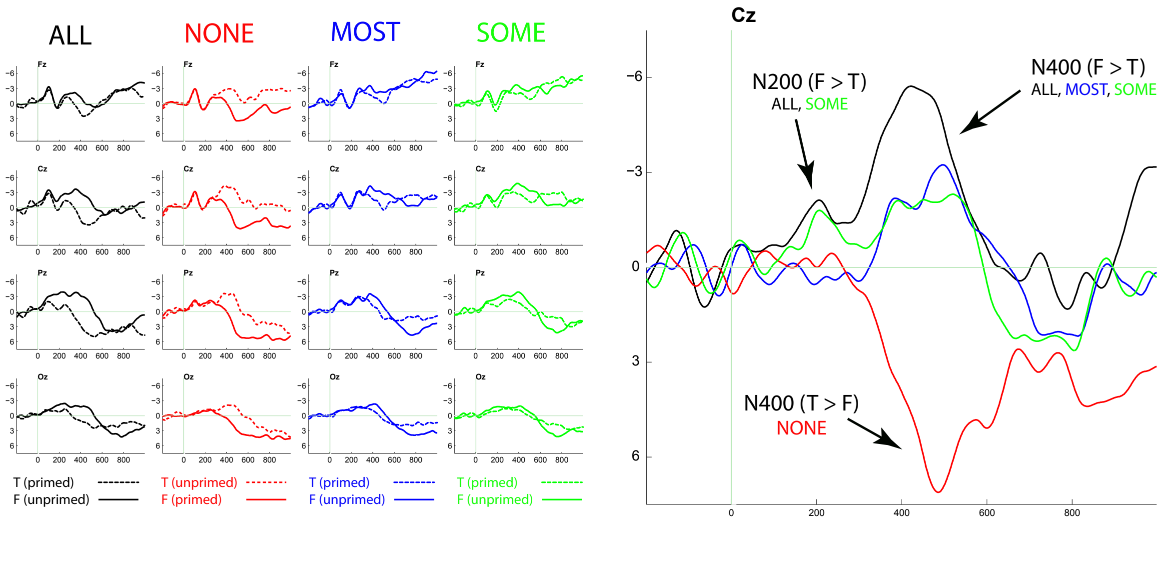




Results & Discussion Predicates showed opposite polarity N400 effects for ALL (False>True) relative to NONE (True>False). MOST/SOME yielded a N400 profile (False>True) similar to ALL (cf. Fig. 1). The flip[1] in N400 effects for NONE (True>False) vs. ALL/SOME/MOST (False>True) confirms the hypothesis that the N400 is driven by a conflict between the auditory continuation primed by the visual presentation (*blue*) and the predicate actually heard by the participant (*red*), independently of truth-value. Moreover, N400 effects were larger for ALL/NONE than MOST/SOME conditions. These differences in amplitude need further investigation, but might be explained by variations in the complexity of the two visual scenes (e.g. number of shape/color combinations) associated to distinct quantifiers (ALL/NONE vs. SOME/MOST). Interestingly, predicates showed an earlier negativity for ALL relative to NONE, and for SOME relative to MOST (False>True), peaking ~200ms. We relate this early negativity to Phonological Mismatch Negativities (PMMNs; Connolly & Phillips (1994)) and tie it to prediction effects, constrained by the truth-conditional properties of the quantifiers and the properties of the scene being inspected.

We propose the following hypothesis: **ALL** combined with priming for SQUARES restricts the space of expectations specifically to **blue**. False cases then give rise to PMMNs at the onset of an unexpected predicate (e.g. red); **NONE** only predicts **not blue**, so the hypothesis space at the onset of the predicate is too vague (e.g. red, green, yellow, ...) to cue early mismatches; **SOME** asks for sets of minimal cardinality (**blue triangles**, yellow squares). Priming for SQUARES thus leads to strong predictions for yellow and PMMNs in False conditions. Finally, **MOST** should restrict expectations to sets of maximal cardinality, and pattern as SOME. However, fMRI research (McMillan et al. 2005) has demonstrated that additional

[1]Note that the difference waves in Fig. 1b are always False - True.



(a) *(b)*

Figure 1: ERPs time-locked at predicate onset (a) All conditions, midline electrode (b) *False* - *True* difference waves

working memory resources are recruited in the processing of proportional quantifiers (MOST) which, unlike other quantifiers (ALL/NONE/SOME), require maintenance/comparisons of the cardinalities of sets to evaluate truth-conditions. The idea of additional working memory load associated to higher-order quantifiers is also supported by recent behavioral results collected by Szymanik (2016). In our own data, ERPs time-locked to the onset of the quantifiers revealed a positivity for MOST > ALL/NONE/SOME, beginning ~350-450 ms and sustaining for ~500 ms (cf. Fig. 2). This early positivity is consistent with complexity effects associated with initial encoding of higher-order quantifiers, and reflecting the need for continued maintenance of the cardinalities for the contrasting sets. Thus, we do not expect specific predictions to cue early mismatches.

Conclusion In pragmatically natural contexts N400s were driven by priming of the expected auditory continuation and were not modulated by truth-value, consistent with earlier findings (Fischler et al. 1983). We relate early (~200 ms) negativities for ALL/SOME to PMMNs modulated by anticipatory effects tied to the truth-conditional properties of the quantifiers. Future experiments grounded in these results could help understand the different ways prediction and priming modulate ERPs effects. Finally, our data suggest complexity effects for MOST may reflect initial encoding, and may not arise downstream during verification. To the best of our knowledge, the time-course of complexity effects associated with MOST has not previously been investigated using ERPs. Further experiments should specifically disentangle quantifier encoding from verification effects.

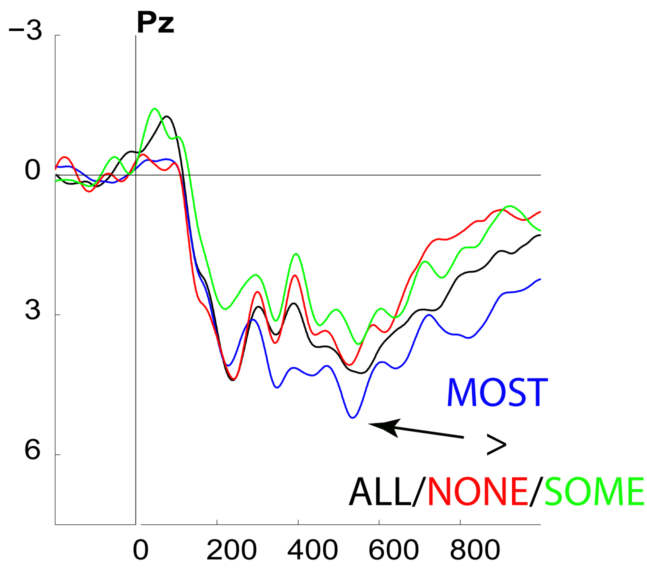


Figure 2: ERPs time-locked at quantifier onset

Connolly, J. F., Phillips, N. A. (1994). Event-related potential components reflect phonological and semantic processing of the terminal word of spoken sentences. *J. of CognitiveNeuroscience*. ● **Fischler I.**, Bloom P., Childers D., Roucos S., Perry N. (1983) Brain potentials related to stages of sentence verification. *Psychophysiology*. ● **Kounios J, Holcomb P.** (1992) Structure and process in semantic memory - evidence from event-related brain potentials and reaction-times. *J. of Experimental Psychology: General*. ● **McMillan, C. T.**, R. Clark, P. Moore, C. Devita, and M. Grossman (2005). Neural basis for generalized quantifier comprehension. *Neuropsychologia*. ● **Nieuwland MS, Kuperberg GR.** (2008) When the truth isn't too hard to handle: An event-related potential study on the pragmatics of negation. *Psychological science*. ● **Szymanik, J.** (2016). *Quantifiers and Cognition: Logical and Computational Perspectives.* Springer International Publishing.