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Quantifiers more or less quantify on-line: ERP evidence for partial incremental interpretation

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ABSTRACT

Event-related brain potentials were recorded during RSVP reading to test the hypothesis that quantifier expressions are incrementally interpreted fully and immediately. In sentences tapping general knowledge (*Farmers grow crops/worms as their primary source of income*), Experiment 1 found larger N400s for atypical (*worms*) than typical objects (*crops*). Experiment 2 crossed object typicality with non-logical subject noun phrase quantifiers (*most*, *few*). Offline plausibility ratings exhibited the crossover interaction predicted by full quantifier interpretation: *Most farmers grow crops* and *Few farmers grow worms* were rated more plausible than *Most farmers grow worms* and *Few farmers grow crops*. Object N400s, although modulated in the expected direction, did not reverse. Experiment 3 replicated these findings with adverbial quantifiers (*Farmers often/rarely grow crops/worms*). Interpretation of quantifier expressions thus is neither fully immediate nor fully delayed. Furthermore, object atypicality was associated with a frontal slow positivity in few-type/rarely quantifier contexts, suggesting systematic processing differences among quantifier types.

Introduction

It is often important to specify amounts or quantities when communicating about objects and events. The number words in, *three balls and two strikes*, uttered during a baseball game provide quantitative information of critical importance to the parties involved. Natural languages have many ways to express quantity including grammatical determiners broadly construed, e.g., *one*, *two*, *all*, *every*, *some*, *most*, *many*, *a few*, *nearly all*, *more than half*, that modify nominal expressions, e.g., *outs*, *runners on base*, *pitchers* (Barwise & Cooper, 1981; Keenan & Stavi, 1986) and adverbs of quantification (Lewis, 1975), e.g., *often* and *rarely* in sentences like, *Batters rarely bunt with two strikes*, where they express information about the quantity or frequency of occurrences of events or event-like entities.

It is uncontroversial that quantifier expressions systematically contribute to the overall meaning of the phrases and sentences in which they occur: *two outs with one runner on base* describes one sort of situation, *one out with two runners on base* describes quite another. However, the time course of quantifier interpretation in real-time comprehension remains poorly understood. We conducted three rapid serial visual presentation (RSVP) reading experiments using event-related brain potentials (ERPs) to investigate *when* (immediately vs. delayed) and *to what extent* (fully vs. partially), the information afforded by simple quantifier expressions is integrated with world knowledge and incorporated into message-level representations during sentence comprehension.

Incremental interpretation and world knowledge

Sentence comprehension is rapid – skilled young adults can read for comprehension at rates of around 4–5 words per second (Just & Carpenter, 1980; Rayner, 1978).

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Comprehension is also generally thought to be incremental, i.e., lexical information is processed when a word is first encountered and then rapidly integrated with ongoing message-level representations at latencies on the order of hundreds of milliseconds. Incremental processing contrasts with a wait-and-see processing strategy on which multiple words may be buffered with interpretation delayed or deferred until other, perhaps critically informative words are encountered, e.g., at a clause or sentence boundary, with lexical and structural representations determined after what may be a substantial delay perhaps on the order of seconds (for recent overviews of incremental comprehension from different perspectives see Altmann and Mirkovic (2009), Hagoort and van Berkum (2007), Rayner and Clifton (2009)). A special case in the broader debate about incremental interpretation concerns the role of real-world or background knowledge (among the many other relevant factors). The details of how and when background knowledge constrains real-time comprehension are not fully understood although there is evidence from on-line measures that it can be brought to bear very rapidly. For example, Hagoort and colleagues recruited the N400 ERP to investigate the time course of the contribution of factual knowledge and conceptual knowledge to incremental comprehension (Hagoort, Hald, Bastiaansen, & Petersson, 2004). The N400 is a large (~5 μV) negative-going waveform typically beginning around 200 ms and peaking around 400 ms poststimulus (Kutas & Hillyard, 1980). The N400 is elicited by a variety of potentially meaningful stimuli including written and spoken words as well as pictures. N400 amplitude has been found to vary with a range of stimulus properties such as the frequency and concreteness and number of orthographic neighbors of the eliciting lexical item and is sensitive to a wide range of contextual factors involving aspects of word meaning, sentence meaning, and discourse context (for a review see Kutas, Van Petten, and Kluender, 2006). Perhaps the best-known finding is that words that are a poor semantic fit in context elicit a larger N400 than suitable control words, e.g., *Sue got up early and walked her* [*jet*/*dog*], though the more general finding is that larger N400 amplitudes are associated with words that are unexpected in context (Kutas & Hillyard, 1984). Hagoort et al. (2004) noted that in Holland the trains are yellow and crowded, facts generally known to the Dutch, so for two sentences like, *The Dutch trains are* [*white*/*sour*] *and crowded*, Dutch people will know that both are false but for different reasons. The first is false because attempting to integrate the word *white* into the evolving representation of the sentence as an attribute of Dutch trains involves a failed correspondence with a well-known empirical fact. The second is false because attempting to integrate the word *sour*, an attribute of edible things, into the representation of the sentence as an attribute of the (inedible) Dutch trains involves a semantic feature mismatch. Hagoort and colleagues reasoned that if background knowledge of trains and semantic knowledge of word meanings contribute to comprehension in different ways or at different times, processing the semantically anomalous word, *sour* should differ from the factually incorrect word, *white*. They found, however, that both sentences elicited a large N400 in comparison with the word, *yellow* in the true sentence, and, crucially, the N400 waveforms for the critical word in both false sentences did not differ in amplitude or latency. They interpreted this as evidence that background knowledge and lexical semantic information are integrated into the evolving interpretation on the same time-scale and rapidly, i.e., within about 300 ms. It is has not gone unnoticed that this argument is based on the failure to detect a difference and the question of whether background information is deployed as quickly as other types of information, e.g., lexical or conceptual information stored in semantic memory, remains somewhat controversial. Not withstanding temporally fine grained questions, on-line measures such as eye-movements (e.g., Ferguson & Sanford, 2008; Filik, 2008; Rayner, Warren, Juhasz, & Liversedge, 2004; Warren & McConnell, 2007; Warren, McConnell, & Rayner, 2008) and ERPs (e.g., Ferguson, Sanford, & Leuthold, 2008; Hagoort et al., 2004; Nieuwland & Kuperberg, 2008; Nieuwland & Van Berkum, 2006) make a strong case that background knowledge is rapidly activated and deployed incrementally during comprehension.

Semantic underspecification

At the same time, there is a cross-current to strong hypotheses about incremental interpretation, supported by a growing inventory of phenomena indicating that comprehenders may not fully process all the semantic information afforded by the verbal input and that the resulting message-level representations may be "partial" (Frazier & Rayner, 1990), "shallow" (Barton & Sanford, 1993), "underspecified" (Sanford & Sturt, 2002), or "good enough" (Ferreira, Bailey, & Ferraro, 2002). So-called semantic illusions, i.e., failures to detect false or semantically anomalous information, are a touchstone phenomenon, and may be observed in the lab by asking questions like, "How many animals of each type did Moses take on the ark?" (Erickson & Mattson, 1981) or "What is the holiday where children go door to door, dressed in costumes, giving out candy?" (Reder & Kusbit, 1991). The key findings are that people often fail to notice that Moses did not take the animals at all (it was Noah), and there is no such holiday (although on Halloween children often get candy). Other paradigms provide additional evidence that shallow semantic processing may be more widespread than first supposed. Frazier and Rayner (1990) used eye-movement data to argue that different meanings of lexically ambiguous words, e.g., *bank*, the financial institution vs. *bank,* the side of a river, are resolved immediately whereas sense differences, e.g., *newspaper* as the paper product in the driveway vs. the institution with an editorial policy are not. In their account, the representation of *newspaper* is initially underspecified with sense selection deferred until it becomes relevant for interpretation. Christianson, Hollingworth, Halliwell, and Ferreira (2001) found that after reading temporarily ambiguous garden-path sentences, e.g., *While Anna dressed the baby played in the crib*, people often responded "Yes" to the question, *Did Anna dress the baby*, even though this interpretation of the agent–action–patient thematic roles is inconsistent with globally correct syntactic structure. Sturt and colleagues (Sturt, Sanford, Stewart, & Dawydiak, 2004; Ward