The Interface of Syntax, Semantics and Psycholinguistics: An Investigation of Operator Scope

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1 Introduction

The goal of this paper is to explore an on-line processing theory of discourse comprehension which makes use of the grammatical construct of modality. Previous investigations of discourse processing have relied upon studies using the integrative device of anaphora (Halliday and Hasan, 1976). A close examination of the kinds of discourses previously investigated reveals that the sorts of inferences required to discern the antecedent to a pronoun rely on pragmatic world knowledge only, to the exclusion of grammatical knowledge (cf., Leonard, Waters & Caplan, 1997; Hirst & Brill, 1980; among others). For example, Garrod and Sanford (1994) indicated that either *Bill* or *his friend* in the context sentence below can serve as an antecedent to *he* in a continuation sentence. E.g., *Bill$_1$ wanted to lend his friend$_2$ some money. He$_2$ was hard up and really needed it.* Another possible anaphoric relation would be: *However, he$_1$ was hard up and couldn't afford to.* Assignment of co-reference in these sentences is dependent upon the sentential context. This contextual information refers to what we know about when it is appropriate to need or lend money, and who can be a possible lender. In other words, this is knowledge that is acquired with cultural experience. The question we pose here is whether we can see empirical effects of constructs that come from a different source: the grammar. A discourse processing model that also takes grammatical constructs into account has better predictive power than one that relies exclusively on experiential knowledge, due to potential cross-linguistic predictions. That is, a model which relies solely on world knowledge is bound to fail cross-linguistically, since cross-cultural norms can vary tremendously.

In the present study, we explored how modality constrains discourse anaphora. Roberts (1987, 1989) developed a theory of Modal Subordination, in the framework of Discourse Representation Theory (Kamp,1981; Heim,1982). Before we explain the phenomenon of how modality constrains anaphoric possibilities, let us first define mood. The mood of an utterance is an indication about the speaker's commitment to the truth of a proposition in the actual world—that is, it tells us whether or not a proposition is asserted. Factual mood indicates that the Common Ground must be updated, since a true proposition has been added to the discourse context set (Stalnaker, 1978). On the other hand, non-factual mood indicates that a proposition is introduced as a hypothetical notion, and subsequent propositions might rely on the assumption that the discourse continues *as if that previous proposition were true*. Factual mood is marked by indicative grammatical mood, whereas non-factual mood has many possible lexical sources: modal auxiliaries (e.g., *would, should, can, may*, etc.), modal adverbs (*perhaps, possibly, maybe*, etc.), non-factive propositional attitude verbs (e.g., *wonder, consider, muse*, etc.). We call these lexical items the class of modal operators (Heim, 1982; Asher, 1987). According to Roberts, these operators define scopal domains, which are represented in the Discourse Representation Structure as subordinate boxes. In contrast, the descriptive content of propositions uttered in factual mood is always entered at the matrix level of the DRS. Thus, factual mood does not add structure to a DRS, unlike non-factual mood.

The scopal domains of modal operators thus segment a discourse structure. Roberts (1987, 1989) uses this theoretical construct to account for an observation, originally noted in Karttunen (1976), that indefinite NPs do not form felicitous antecedents to pronouns when they are contained in sentences in non-factual mood but their pronouns are in sentences that mark factual mood. E.g.,

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(1) John might write a novel$_1$. #It$_1$ ends quite abruptly.

The pronoun in the continuation sentence is asserted to exist but its antecedent is hypothetical, due to the presence of the modal auxiliary *might* in the context sentence. In order for the anaphoric relation to be felicitous, the pronoun must also be contained in a hypothetical or non-factual clause:

(2) John might write a novel$_1$. It$_1$ could end quite abruptly (given what we know about John).

The meaning of the discourse above is: John might write a novel, *and if he did*, it could end quite abruptly. Roberts (1987, 1989) accounts for the anaphora in the following way: an antecedent is 'accessible' to a pronoun if it is at the same or superordinate level to the pronoun. Thus, in (2) both the antecedent and pronoun are at the same level of the DRS; these are both contained in non-factual boxes. However, in (1), the antecedent is subordinate to the pronoun and hence inaccessible. The empirical contrast between these two discourses forms the heart of the present investigation.

The goal of this paper was to empirically study the contrast in anaphoric felicity in discourses similar to those in (1) and (2). It is important to investigate this phenomenon for at least two reasons. First, while child language acquisition studies have shown that modal markers such as auxiliaries are acquired late developmentally (e.g., Noveck & Simon, 1996, among others), to our knowledge there are no empirical studies regarding the on-line processing of modality (in isolated sentences or in discourse context) by normal adults (for an exception, see Dwivedi 1996). Second, to date, the majority of studies on pronoun resolution (Badecker & Straub, 2002; among others) have examined antecedents that happen to be names. Although these studies have yielded important findings, a host of different questions emerge when another class of NPs is examined, namely, indefinite NPs.

We used the neurophysiological measure of Event Related Potentials (ERPs). This methodology measures voltage changes due to electrical activity of the brain during cognitive processing. It is particularly useful due to its high temporal resolution (on the order of milliseconds) and due to the fact that different ERP signatures are associated with different kinds of linguistic processing. For example, lexico-semantic processing is assumed to be marked by a negative-going wave, called the N400 (Kutas & Hillyard, 1980, 1983). This component is elicited roughly 200 to 400 ms after a semantically anomalous word is processed (*He spread the warm bread with socks*) in contrast to an acceptable word (*He spread the warm bread with butter*), and has centro-parietal topography. Recently, the N400 has been found in anomalies constructed at the discourse level (St. George et al., 1997; van Berkum et al., 1999). In addition, syntactic or structural processing has been identified with a later positive-going wave, the P600. This waveform has been found for garden path sentences, as well as those with morpho-syntactic anomalies (e.g., *The cat will eating.* vs. *The cat will eat*, Osterhout & Holcomb, 1992). Recently, this component has been subdivided into notions of structural revision and repair, where frontal positivity is associated with the former, and posterior positivity with the latter (Friederici et al., 2002, Kaan & Swaab 2003a,b). To our knowledge, the P600 has not been found at the discourse level.

It is an open question how the brain would process the anomaly in (1). On the one hand, the meaning of the pronoun in the continuation sentence does not match that of its antecedent; one is asserted to exist, and the other is not. This meaning mismatch might result in an N400 effect. On the other hand, Roberts' (1987, 1989) structural account of the accessibility of an antecedent in discourse might lead one to believe that a P600 effect would be found.

We addressed the foregoing questions in the following way: we created two-sentence discourses where the first (context) sentence displayed non-factual mood and contained a potential NP antecedent (the direct object). The second (continuation) sentence contained a pronoun and either did or did not contain a modal auxiliary. The ERPs were measured at the pronoun, modal (when present), verb, and verb +1 positions. We predicted an empirical difference between these two continuation sentences at the verb position, since it is at that point that the processor has enough information to assign or verify co-reference. However, this particular comparison is confounded by the fact that the target (continuation) sentence containing a modal auxiliary is compared to one lacking a modal, e.g. *It might end quite abruptly* vs. *It ends quite abruptly*. A Control condition was constructed in order to ensure that the effects obtained are indeed due to context, and not the fact that two different kinds of sentences are being compared. Thus, each continuation sentence—both those containing modals and those

without modals-- was preceded by two different kinds of contexts: Hypothetical and Control. This within-subjects study was defined by two independent variables: type of context (Hypothetical (H) or Control (C)) and type of continuation sentence (Modal (M) or Non-modal (N)), and measurements occurred at the Verb (V) position. Table 1 lists the 4 conditions explicitly; the critical word is bolded for clarity. Note that only Condition HNV is anomalous or infelicitous.

Table 1: *Overview of Experimental Conditions*

Condition	Context sentence	Target sentence
HMV	John is considering writing a novel.	It might **end** quite abruptly.
HNV	John is considering writing a novel.	#It **ends** quite abruptly.
CMV	John is reading a novel.	It might **end** quite abruptly.
CNV	John is reading a novel.	It **ends** quite abruptly.

This design allowed for two direct comparisons, first between the non-modal sentence in the hypothetical context (HNV), which should show anomaly and the non-modal sentence in the control context (CNV), which should not, and second, between the non-modal sentence and the modal sentence in the hypothetical contexts--HNV vs. HMV-- again, only the former should exhibit anomaly. In addition, a Filler Anomalous condition was included, where real-world violations where used, in order to elicit a classic N400 response for comparison purposes.

2 Methods

2.1 Participants: 23 native speakers of English (13 female, mean age 20.9 years, range 18 to 28 years) were recruited at McGill University and paid for their participation. All subjects had normal or corrected-to-normal vision and were right handed, and none reported any neurological impairments, history of neurological trauma or use of neuroleptics. Also, none of them had participated in the pilot ratings task (see below).

2.2 Materials: Hypothetical Conditions: Hypothetical context sentences were constructed in order to ensure non-factuality, such that they always contained a marker of non-factual mood (such as a modal adverb *possibly, likely, perhaps*, etc. and/or a non-factive propositional attitude verb such as *consider, muse, wonder*, etc.). In addition, the context sentence also used a verb of creation, (e.g., *paint, bake, write*) in order to further bias for a non-specific (or non-existent) reading of the indefinite NP (Diesing, 1992). The continuation sentence always contained a pronoun referring back to the indefinite NP antecedent. This pronoun appeared in a sentence that either contained or did not contain one of 5 epistemic modals: *would, might, may, must, should*. In order to minimize potential confounding factors of frequency and repetition, twenty high frequency verbs were used (Francis & Kucera, 1982). Note that it was impossible to match the frequency of the verbs and modals closely, as modals are closed-class items with extremely high frequencies of occurrence. However, data suggest that ERP differences in frequency within the category of "high frequency" words are minimal (van Petten & Kutas, 1990).

Control Conditions: The Control context did not exhibit any non-factuality markers. Therefore, no modal adverbs or non-factive propositional attitude verbs were used in the control contexts. Instead, sentences contained verbs of using (such as read, show, enjoy) which presuppose the existence of their direct objects. The Control context sentence was followed by the same modal and non-modal continuation sentences as in the Hypothetical condition.

Filler sentence pairs: In order to reduce the chance of participants adopting particular reading strategies, 100 filler sentence pairs were also included. Half of the fillers controlled for the fact that the modal sentences in the targets were always semantically coherent. Thus, these additional filler sentences used auxiliaries not used in the target sentences (e.g., *could, can, ought to, did, will*) and were anomalous, but for reasons independent of grammatical constraints across sentences. Instead, these represented violations of real-world knowledge. An example of such a "Filler Anomalous" discourse is:

Celine will come to the party. She ought to bring skyscrapers. These discourses were included in order to compare classic N400-like effects.

The other 50 filler sentence pairs controlled for verb repetition and consisted of two-sentence discourses containing anaphora that used 10 high frequency verbs, which were not used in the target sentences, repeated 5 times each. These were necessary to include since our targets contained high frequency modals, which were repeated several times. Since we predicted no anomaly in sentences with modal auxiliaries, we needed to ensure that the lack of an N400 or P600 effect here was due to the acceptability of the modals, and not due to the fact that these are repeated high frequency items. Thus, these "Filler Control" sentence pairs were constructed such that the continuation sentence contained a pronoun and a high frequency verb, e.g., *The director was deciding which scene to keep. He cut the sad scene.*

In order to ensure that subjects paid attention to the stimuli, forced-choice content questions were asked about S2, following the 50 filler control sentences. The two alternatives were shown on the left- and right-hand side of the computer screen, and participants had to press the corresponding button on a response pad to indicate the correct answer. The position of the correct answer was counterbalanced across trials. Participants responded by using a Stim System Switch Response Pad (*NeuroScan*).

In sum, the experiment consisted of the following items: 100 modal continuation sentences, which were preceded by a Hypothetical or Control context sentence (100 HMV + 100 CMV), 100 non-modal sentences which were preceded by a Hypothetical or Control context sentence (100 HNV + 100 CNV) and 100 fillers (50 Filler Anomalous and 50 Filler Control). This resulted in 500 discourse pairs. In order to reduce repetition effects, the stimuli were divided into two counterbalanced lists, such that each participant saw an equal number of sentence pairs from each condition. Each list contained 300 sentence pairs in total, and consisted of 100 filler sentence pairs and half of each of the four experimental sentence pairs. Each participant saw one list only, with sentences presented in a pseudo-random fixed sequence with the constraint that no more than two sentence pairs of the same type could follow one another.

2.3 Pretests: We evaluated the acceptability of a preliminary version of the 500 discourses by conducting a norming study. See Dwivedi et al. (2005) for the procedure. In all, the ratings confirmed the intended readings of the experimental and filler items.

2.4 Procedure: For the experimental test, participants were tested individually in one session, which lasted approximately 2.5 hours. Short breaks were given when required. Following the application of the EEG electrodes, subjects were seated in front of a computer screen approximately one meter away. All stimuli were presented in a 26 point white Arial font in the centre of a SVGA computer monitor with a black background. Each context sentence (S1) was presented in its entirety; participants pressed a button to indicate when they were ready for the continuation sentence (S2). Following an ISI of 600 ms, the continuation sentence was presented one-word-at-a-time in the centre of the screen with each word presented for 300 ms followed by an ISI of 300 ms. This presentation rate minimized eye movement artifacts in the EEG recordings and allowed for time-locking the EEG recording to the presentation of each word. Between each sentence pair there was a 3 second delay to make sure the participants read the sentences as distinct pairs. Participants were instructed to silently read the context sentence, to press a button when it had been read, and to read each individual word of the subsequent sentence. Participants were instructed not to speak, move, or blink their eyes during the presentation of the stimuli. Practice trials were included to accustom participants to the task. When required, participants responded to a comprehension question using a hand held pad. This question appeared 100 ms after the last word of certain sentence pairs.

2.5 Electrophysiological Measures: A commercially available nylon EEG cap containing silver/silver chloride electrodes (Quik-Cap) was used for EEG recording. The EEG was recorded from six midline electrode sites and 22 lateral sites. A cephalic (forehead) location was used as ground. All sites were referenced to the left ear during acquisition and re-referenced off-line to a linked ear reference. EOG was recorded from electrodes placed at the outer canthi of both eyes (horizontal EOG) and above and below the left eye (vertical EOG). EOG artifacts were corrected off-line for all subjects using a rejection criterion of ± 50 μV. EEG was sampled continuously with critical EEG epochs time-locked to the onset of each target word of S2: the pronoun, the modal (when present), the verb, and the word after the verb (i.e., V + 1 position; this was never the final position in the sentence). As predicted, only the verb position yielded significant results, as reported below. EEG data were amplified using

Neuroscan NuAmps in a DC-100 Hz bandwidth using a 500 Hz digitization rate. Single trial epochs were created using a -100 to 1100 ms window around the eliciting stimulus and processed off-line using Neuroscan Edit 4.3 software. For each participant, ERP averages were computed for the critical words in all target continuation sentences. The mean voltage amplitude of the -100 to 0 ms period of each averaged waveform was calculated and served as the 0 μV baseline for post-stimulus activity. The mean amplitude of each waveform was computed in 50 ms intervals from 300 to 1100 ms post-stimulus, yielding sixteen mean amplitudes. These effects were examined across six midline sites (i.e., Fz, FCz, Cz, CPz, Pz and Oz) and scalp regions of interest as defined in the Results section.

3 Results

3.1 Electrophysiological analyses.

We conducted a series of within subject ANOVAs with the factors Context (Control, Hypothetical), Modal (Modal, Non-Modal), Electrode location/region (specified below), and Time Interval (300-350, 350-400, . . . 1000-1050, 1050-1100 ms post-stimulus). Two broad sets of analyses were conducted, one involving the midline sites and one involving regions of interest (ROIs). Given the regional differences, ROIs were calculated by collapsing data from electrode sites into the following ROIs: left anterior (F3, F7, FT7), right anterior (F4, F8, FT8), left posterior (TP7, CP3, T5, P3), and right posterior (TP8, CP4, T6, P4). Due to space limitations, in this paper we only report the brain region (left anterior) that yielded empirical responses to the anomalous condition, HNV. For the complete set of findings, please refer to Dwivedi et al., (2005).

The ERP analyses reported below used SPSS v.11.0 statistical software and employed the Greenhouse-Geisser (1959) non-sphericity correction for effects with more than one degree of freedom in the numerator. Following convention, unadjusted degrees of freedom are reported, along with the Greenhouse-Geisser epsilon value (ε) and adjusted *p*-value. Mean square error values reported are those corresponding to the Greenhouse-Geisser correction. All significant main effects are reported first, followed by the highest order interaction effects involving Context and/or Modal. All analyses included planned comparisons between the HNV and CNV and between the HNV and HMV conditions using simple effects. Unless otherwise stated, interactions were further assessed using simple effects analyses and pair wise comparisons with alpha = .05. For example, a Context x Modal interaction was decomposed by examining simple effects of Context at each level of Modal, and then by examining the Modal factor at each level of Context.

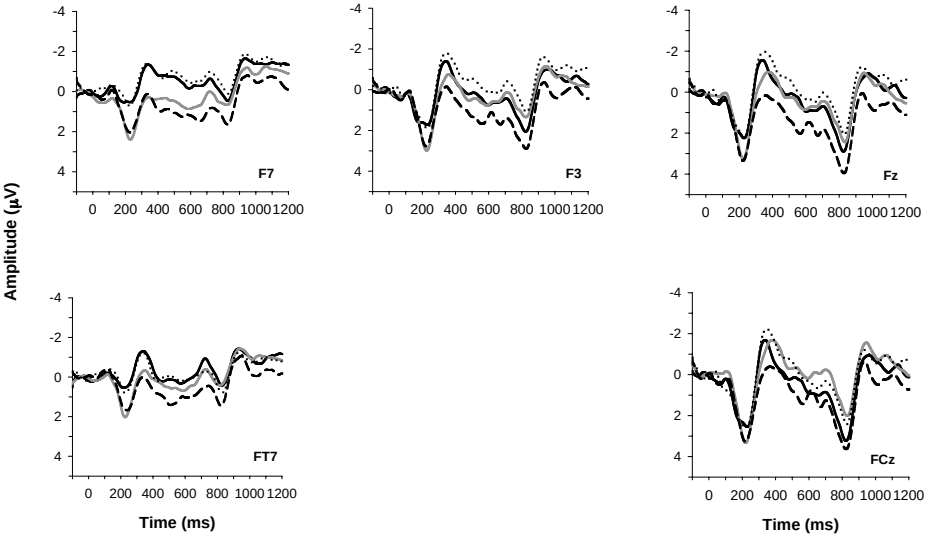

Figure 1. Grand average ERP waveforms for left anterior and frontal midline electrode positions. HMV: dotted line; HNV: dashed line; CMV: dark solid line; CNV: light solid line.

3.2 Left Anterior. As illustrated in Figure 1, the ERP waveforms over the left anterior region were characterized by a positivity evident only in the anomalous condition (i.e., HNV) and a sustained negativity at the verb when it had been preceded by a modal (HMV and CMV). The ANOVA yielded significant main effects of Modal (F (1, 22) = 11.94, MSE = 18.86, p = .002) and Time (F (15, 330) = 21.17, MSE = 8.34, p < .001, ε = .275), and a Modal X Time interaction (F (15, 330) = 4.78, MSE = 1.39, p = .001, ε = .313).

Importantly, there was a Context X Modal (F (1, 22) = 7.02, MSE = 12.58, p < .02) interaction. Simple effects revealed that the HNV waveform was significantly more positive than the HMV and the CNV waveforms. This effect was also revealed by the planned comparison of the HNV and CNV conditions, which yielded a main effect of Context (F (1, 22) = 10.85, MSE = 8.45, p = .003) Simple effects conducted on this comparison indicated that the time course of the difference between HNV and CNV was significant as early as the third time period (i.e., 400 ms), which shows an early effect of contextual information. In other words, the non-factual mood associated with the Hypothetical context sentence is processed as early as 400 ms after the verb in non-modal continuation sentences.

4 Discussion

In the present study, ERPs were recorded while participants read well-formed vs. anomalous discourses displaying anaphora in hypothetical and control contexts. We examined the ERPs elicited by the verb in the continuation sentence which either contained a modal or did not (non-factual vs. factual mood). We found that the anomalous discourse condition, HNV, was more positive-going in the left anterior region, as well as along the frontal midline sites, compared to the control (CNV) and the well-formed hypothetical context (HMV) conditions. This difference in waveform activity was present as early as 400 ms after the verb. In addition, the left anterior region displayed a sustained negativity for the two modal conditions: HMV and CMV. We discuss each of these findings in turn.

First, the neurophysiological results confirmed the grammatical intuitions, as well as the behavioral evidence found in Dwivedi (1996), that discourses in the form of Condition HNV are anomalous, compared to HMV and, crucially, Condition CNV. We also explored whether the anomaly was structural or semantic in nature, by examining the type of ERP effect elicited. Interestingly, the response to this anomaly can be characterized as a P600, with no evidence of N400 effects. That is, a localized left frontal positivity, which extended out to the midline, emerged 400 ms after the verb for the HNV condition relative to the CNV and HMV conditions. Consistent with previous studies that examined isolated sentences (Frisch et al., 2002, Kaan and Swaab, 2003b; Friederici et al., 2002; Hagoort et al., 1993), we interpret this finding to indicate a process of revision of preceding structure. However, in the present study, we conceive of the structural revision as taking place at the discourse level, not the sentential level. Furthermore, the nature of this structure is dictated by modal information (i.e., in terms of the scope of modal operators).[1] To our knowledge, this is the first time that such P600-like effects have been found across discourse.

Thus, the "meaning mismatch" in discourses like condition HNV, resulted in a P600-effect, not an N400 effect. In light of previous studies that have reported N400 effects in discourse context (e.g., van Berkum et al., 1999; St. George et al., 1997), it may seem somewhat surprising that such an effect failed to emerge in the present study. However, a brief comparison of the stimulus characteristics across studies may easily explain the discrepancies. We claim that these previous ERP studies conflated

[1] Since we did not set out to specifically test for a particular type of structural revision, we leave questions regarding the specific nature of this process for further research. One possibility is that the processor goes back to the context sentence and interprets the indefinite object as a specific NP, instead of non-specific. In terms of DRT, this would amount to "moving" the position of the NP from a subordinate box to the matrix or top level. This idea complements the proposal made in Saddy et al. (2004) where the P600 component was hypothesized to indicate re-analysis regarding the scope of positive polarity items in the scope of negative operators. In the present experiment, the relevant operator is the class of modal operators. Future experiments are planned that will test just this prediction.

notions of "real-world knowledge" with semantic knowledge, in contrast to the present approach, where semantic knowledge consists of grammatical principles governing the composition of the meaning of sentences (see Chierchia & McConnell-Ginet, 1990).

The speed with which the discourse structure was consulted was an interesting finding of the present experiment. The HNV waveform began to significantly differ from the CNV waveform as early as 400 ms. What this means is that 400 ms after the processor perceived the verb, it detected the anomaly. In other words, the parser had to have searched the discourse structure for an appropriate antecedent and discovered that the antecedent was found in the wrong kind of location, as dictated by its inaccessible (subordinate) position due to the non-factual mood of the previous sentence. Thus, it appears that modal information does indeed organize discourse structure, and that this information is available very quickly. This points to an "incrementalist" approach regarding discourse comprehension, where it is assumed that the discourse structure is continuously updated during comprehension.

Finally, we found left frontal negativity for modal conditions in both the hypothetical and control contexts (HMV and CMV). We interpret this negativity in terms of the findings of Kluender and Kutas (1993) and others (Mecklinger et al., 1995; Münte, Shlitz, & Kutas, 1998) who claim that this sort of negativity represents an increase in working memory load. In the present work, it may be argued that sentences containing modals (HMV and CMV) require more working memory resources than sentences that do not (HNV and CNV) because of the extra "meaning" that these closed-class elements add to sentences. That is, sentences with modal auxiliaries carry the extra inference of possibility or necessity relative to sentences without them (Kratzer, 1981). We note here that semantic and structural complexity are closely intertwined issues. Thus, this semantic complexity could result in an extra processing load (cf. Gennari & Poeppel, 2003), and/or, the structural complexity that ensues at the level of discourse structure once modals are processed, could also tax working memory resources.

In conclusion, the main contribution of the present study was to show that during pronoun resolution, a discourse structure representing modality was immediately consulted. Furthermore, left frontal positive-going waveforms indicated that the form of that representation is structural in nature. The finding that modality is relevant at the level of discourse structure is consistent with previous results in the literature that claim that the tense or temporal structure of a discourse shows empirical effects (see, among others, Trueswell & Tanenhaus, 1991; Zwaan, 1996; Gennari, 2004). In addition, the results also suggest that sentences containing modal auxiliaries compared to sentences without these closed-class items are structurally and/or semantically more complex. Moreover, the findings support the linguistic formulation of modal subordination and Discourse Representation Theory as conceived of by Roberts (1987, 1989) and Heim (1982) and Kamp (1981).

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