ERP evidence for telicity effects on syntactic processing in garden-path sentences

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Abstract

Verbs contain multifaceted information about both the semantics of an action, and potential argument structures. Linguistic theory classifies verbs according to whether the denoted action has an inherent (telic) end-point (fall, awaken), or whether it is considered homogenous, or atelic (read, worship). The aim of our study was to examine how this distinction influences online sentence processing, investigating the effects of verbal telicity on the ease of syntactic re-analysis of Object reduced relative clauses. Event-related brain potentials (ERPs) were recorded from 22 English speakers as they read sentences in which the main verb was either telic or atelic, e.g., "The actress *awakened/ worshipped*by the underlined writer left in a hurry". ERPs elicited by telic and atelic verbs, the preposition "by" introducing the second argument (Agent), and the second argument itself, e.g., "writer", were compared. Additionally, participants were grouped according to receptive syntactic proficiency: normal (NP) or high (HP). ERPs from the NP group first diverged at the second argument, with the atelic condition eliciting larger amplitude negativity at the N100, and continuing to the P200 interval. In contrast, ERPs from the HP group first diverged earlier in the sentence, on the word "by". ERPs elicited by "by" in the atelic condition were also characterized by increased negativity, in this case significant at P200 and Anterior Negativity between 320-500ms post stimulus onset. Our results support the postulated conceptual/semantic distinction underlying the two verb categories, and demonstrate that world-knowledge about actions designated by verbs and syntactic proficiency are reflected in on-line processing of sentence structure.

1. Introduction

Verbs contain multifaceted information about both the semantics of a denoted action and potential argument structures. Linguistic theory classifies verbs according to whether the denoted action has an inherent (telic) end-point (*fall, awaken*), or whether it is considered homogenous, or atelic (*read, worship*). Telicity, a semantic feature of the verb, is a major component of verbal event structure, relating verbal semantics to syntactic frames. Event structure of the verb is closely tied to its argument structure: for example, presence of a resultant state in telic verbs is related to increase in the number of obligatory arguments (Ramchand,

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2008). Interactions between event structure, especially telicity, and grammatical phenomena have been described in many typologically distinct languages, including English, Dutch, Russian, Bengali, Icelandic and Scottish Gaelic (for a survey of relevant studies, see Folli & Harley, 2006). The time course of such interactions between the semantics of the verb and the sentence structure in online language processing is the topic of the present study.

1.1_ERP components

We address the question of what effect verbal telicity has on sentence processing by recording event-related potentials (ERPs) elicited during comprehension of reduced relative clauses. Earlier work has demonstrated that specific ERP components indexing syntactic and semantic processing include increased amplitudes of N100, early left anterior negativity (ELAN), left anterior negativity (LAN), N400 and P600. Increased amplitude in early negativity, such as N100 (Neville-1991), has been described as a result of phrase structure violations in visual paradigm experiments. It has also been observed for syntactic violations presented in the auditory modality (Friederici, 1995). Yamada and Neville (2006) demonstrated that scalp distribution of this component is affected by the semantics of the preceding word: in Jabberwocky sentences, increase in negative amplitude of N100 is distributed evenly over frontal and central areas; in English sentences with grammatical violations it has frontal distribution. This increase has not been observed in sentences with both semantic and grammatical violations (Friederici et al., 1999). Also, several studies reported right-hemispheric distribution of this component. In Yamada and Neville (2006), stimulus sentences presented in English, which required integrated processing of syntax and semantics, elicited increased negativity during the P200 interval over the right hemisphere as compared to the left. The same study did not observe such asymmetry for Jabberwocky sentences, which required only syntactic processing. Osterhout and Nicol (1999) observed more negative-going ERPs within 150-300 ms over the right hemisphere in response to semantically implausible verbs (e.g. the cat *baked* the cake), which was argued to be the onset of the N400 effect. Additionally, the same study noted that the linear additive model of syntactic and semantic violation effects predicted more positive ERPs between 200 and 500 ms over the right hemisphere, as compared to the ones observed when difference waves were computed using the four conditions – i.e., interaction of syntactic and semantic violations elicited more right-lateralized negativity over the P200 interval than either type of violation on its own.

Later negative components include a left-lateralized anterior negativity (LAN, between 300 and 500 ms after the onset of a critical word) and the N400. The latter is characterized by medial and posterior distribution of negativity around 400 ms after the onset of a critical word, and has been connected with indexing of both semantic violations (Kutas and Hillyard, 1980, 1984), and pragmatic violations (Hagoort et al., 2004). Studies of German have also demonstrated that N400 is sensitive to thematic interpretation of the arguments. For example, Frisch & Schlesewsky, 2001, demonstrated that double subjects elicit N400 only when both arguments are animate (but not when one of them is animate and the other inanimate), showing that semantic animacy information can be used to interpret thematic relations in a sentence. Also, the study of Case assignment to an ambiguous NP in German by Hopf, Bayer, Bader, & Meng, 1998, elicited an enhanced N400 component in response to the sentence-final verb assigning morphological Dative, rather than structural Accusative case to the ambiguous NP. The authors interpreted the findings to suggest that ERP responses to garden-path effects are not restricted to late positivity (P600), but can selectively reflect reanalysis that is based on a second access to formal lexical information by way of an enhanced N400 component. LAN, on the other hand, has been shown to index discrepancies in morpho-syntactic information (Osterhout & Mobley 1995, Hagoort & Brown 2000). It is also a part of a biphasic pattern LAN-P600 (Osterhout et al 1994, Hagoort 2003a), correlated with the "cost" of syntactic processing and garden-path recovery.

The P600 component is widely found as a response to various syntactic violations, including word order (Kemmerer et al., 2007, Osterhout, Holcomb, & Swinney, 1994). Some research suggested that this component is primarily elicited by the inclusion of a grammaticality judgment task (Kuperberg, 2003, Yamada & Neville, 2007), or a monitoring process triggered by a conflict, e.g. when an unexpected linguistic item is encountered where another item is highly expected (Kolk et al., 2003). Both Osterhout & Holcomb, 1992, 1993, and Yamada & Neville, 2007, overtly probsed the grammaticality of the sentences, leading to a suggestion that it is, in fact, the combination of ungrammaticality in the sentence and the probe type which leads to a P600 component emergence in the data. Also, morphosyntactic ambiguities of Case (such as a Case-ambiguous noun occurring as the first argument in a sentence, as in Frisch, Schelsewsky, Saddy, & Alpermann, 2002) and number agreement (e.g. Kaan & Swaab, 2003) have been shown to elicit a P600 component. Kutas, Van Petten, & Kluender (2006) summarize the various interpretations of P600 to include the inability of a parser to assign the preferred structure to the input, a controlled process of syntactic re-analysis or repair, syntactic integration, or linguistic parsing difficulties. Because our stimuli did not contain sentences with syntactic violations, or morphosyntactic ambiguities, or require grammaticality judgments, we did not predict differentiation in the amplitude of this component, and adopted the experimental design with a natural speed of presentation (500 ms between words) at the expense of a longer inter-word interval.

Finally, a few studies (Yamada & Neville, 2007, Osterhout, Holcomb & Swinney, 1994) have identified additional intervals of increased negative amplitude in ERPs in ungrammatical sentences around 200ms after the onset of the critical word relative to grammatical condition (the component is usually termed P200, since overall ERP morphology typically includes a positive peak around 150-250ms post-onset of the stimulus). Yamada & Neville (2007) showed that this later "negative grammaticality effect" was distributed similarly to the effect at 100ms, i.e. anteriorly for English sentences with full semantics; Osterhout, Holcomb, & Swinney (1994) also reported a similar component for the PZ electrode site. While this component is not well-investigated in the ERP literature on sentence processing, it does seem to be related to increased negativity at 100ms, and as such can serve as another index of ease of syntactic integration during online sentence processing.

Existing models of language processing concerning the interaction of semantic and syntactic information fall into two main categories: syntax-first, or structure-driven models (Friederici, 2002, Frazier, 1978), and lexically driven parallel-processing models (e.g. Tannenhaus & Carlson, 1989, Trueswell & Tannenhaus, 1994, McClelland et al, 1989). The predictions of these models differ with regard to the components elicited by different types of ungrammaticality: syntax-first models predict early effects of syntactic bias on language processing in ambiguous and garden-path sentences, whereas lexically-driven models predict strong and early effects of semantics, such as an influence of thematic roles on syntactic processing (Osterhout, Holcomb, & Swinney, 1994). Since the theory of event structure operates at the interface of syntax and semantics, it can serve as a testing ground for predictions of both sets of language processing theories.

1.2 Research of telicity effects in online sentence processing

The design of the present study was based on previous behavioral evidence of telicity affecting sentence processing, as the sampling of the studies below demonstrates. For example, O'Bryan (2003) showed independent effects of telicity and transitivity on response times in a word maze experiment with reduced relative clauses using 4 types of verbs: transitive telic (e.g. *accuse*), optionally transitive telic (e.g. *trip*), transitive atelic (e.g. *carry*), and optionally transitive atelic (e.g. *lecture*). The subjects were asked to complete a grammatical sentence choosing one word at a time (only one of the two words offered allowed for the sentence to continue as

grammatical). The sentences contained Object reduced relative clauses, such as "The actress awakened by the writer left in a hurry". There was a significant reaction time advantage on the "by" for telic verbs, and an independent advantage for the second argument for transitive verbs (both telic and atelic). The experiment thus demonstrated independent effects of telicity and transitivity on response times in a word maze task.

Behavioral results obtained by Seegmiller, Ingraffea, & Townsend (2003) were somewhat different. Their study measured single-word self-paced reading times in sentences with different types of verbs in reduced relative clauses, and failed to demonstrate any difference in garden path effects for relative clauses based on telic vs. atelic verbs. However, unlike in O'Bryan's experiment, the Subject reduced relative clauses (such as "The actor tripped on the stage broke the mood of the audience") did not require either argument role re-assignment or verb frame alternations[1] following the relative clause, possibly masking facilitation of such processing by telic verbs. Therefore, the current study used Object relative clauses, requiring both verb frame alternation and argument role re-assignment, as stimuli (see Methods section and Appendix I).

Friedmann, Taranto, Shapiro, & Swinney (in press) compared sentences with unergative (intransitive atelic) and unaccusative (intransitive telic[2]) English verbs using a cross-modal priming technique, and found a priming effect for non-alternating unaccusatives (intransitive telic verbs), but not for unergatives (intransitive atelics). The difference in results between alternating and non-alternating unaccusatives in the above study might have been due to variable animacy of the arguments in the stimuli of this particular experiment; for this reason, we specifically use exclusively animate arguments in our design.

Osterhout, Holcomb, and Swinney (1994) have used ERP methodology to investigate the differences in verb subcategorization biases, e.g. preference for the use of clausal complement vs. direct object (*believe, know, remember*) and vice versa (*hear, forget, understand*). Verb bias ratings were obtained from Connine et al., 1984; intransitively biased verbs selected for the experiment were used with clausal complements in 66% of the responses, and transitively biased verbs selected were used with a direct object noun phrase on 68% of the responses. The study compared ERPs in grammatical sentences (which differed only in terms of subcategorization bias), and demonstrated differences in the processing of postverbal nouns, especially the increased negativity during the P200 interval for the less-frequently used subcategorization type. The authors suggested that the verb subcategorization information can be applied very rapidly, and that the parser can use it to resolve local ambiguities. At the time, no theoretical account proposing why such biases would affect sentence processing was available, and the authors suggested the need for further research into verb structure, which could take into account semantic or thematic properties of verbs and their influence on the parsing process.

1.3 Aims of the present study

Our study aimed at testing an event-structural account of semantic and thematic properties of verbs, with specific goals to: 1) examine whether the distinction between telic and atelic verbs influences on-line sentence processing; 2) identify the temporal window of proposed differentiated processing; and 3) characterize the ERP indices for processing differentiation based on event structure. Our approach differed from the standard in that it did not employ any ungrammatical sentences per se; the comparisons were made between grammatical sentences, which differed only in the type of verb employed in the reduced relative clause. Thus, we did

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[1]Verb frame alternations are changes in the expected verb frame, e.g. from intransitive NP V to transitive NP V NP.
[2]Not all unaccusatives are telic: verbs such as *melt, cool, warm* can denote incomplete events - e.g. "melt somewhat, but not completely". Such gradient verbs were not used in the present study.

not expect to see large-scale indications of ungrammaticality. Yet, on the basis of previous behavioral studies (O'Bryan, 2003, Trueswell & Tanenhaus, 1994), we hypothesized some differentiation in ERP indices comparing various aspects of visual sentence processing, such as early phrase structure/syntactic processing (N100, cf. Yamada & Neville, 2007, Neville, 1991), lexical parsing/word-category assignment (ELAN, cf. Friederici, 1996), indexing of morphosyntactic information (LAN, cf. Hagoort & Brown, 2000, Neville, 1991) or ease of semantic integration (N400). The predicted differences in ERPs to telic vs. atelic verbs could occur on the function word "by", which explicitly indicated which NP expressed the true Agent in the sentence, and the second argument of the reduced relative clause - the Agent itself. No difference in waveform morphology on the actual verbs was expected, since verbs of both types had comparable frequencies in both present and past forms (see methods), and both telic and atelic verbs could occur in transitive and intransitive frames.

Previous research has demonstrated that temporal and amplitude measures of ERPs elicited during sentence processing differentiate neural functions of young adults with normal and high language proficiencies (e.g. Weber-Fox et al., 2003, Weber-Fox & Neville, 2001, King & Kutas, 1995). A similar phenomenon has been observed in priming experiments (cf. Sanz, 2000, describing differential processing of predicate telicity in Spanish sentences), where the difference in performance (RTs) in subject subgroups has been attributed to differentiated processing strategies. In order to control for the possibility of differential characteristics of neural functions and ERPs in high-normal vs. normal subjects, the subjects were divided into two proficiency groups (Normal Proficiency, or NP, and High Proficiency, or HP), separated according to receptive grammar skills (described in detail in methodology section).

2. Materials and methods

2.1 Participants

Participants were 20 native monolingual English speakers, age 18-28, right-handed (self-report), with normal or corrected to normal vision, and no history of neurological or speech-language impairments. All participants were administered the Listening Grammar (LG) subtest of the Test of Adolescent and Adult Language, Third Ed. (TOAL-3, Hammill, Brown, Larsen, & Wiederholt, 1994) to provide a baseline measurement of perceptual language and grammar processing ability. The LG subtest was used because it closely imitates the processing requirements of the experimental task (as compared to other subtests), and was administered to the participants in full[3]. The subjects were separated into groups according to whether their number of correct responses was above or below the mean (29.7) for the entire group. This method, rather than the standard scoring procedure, was used for several reasons. First, the population in the study was older than the one for which TOAL scores are normalized (24;11). Second, we were interested in a baseline measure of subjects' ability to deal with sentence length and syntactic complexity, neither of which increase linearly in the LG subtest. Thus, the mean number of correct answers was the most appropriate measure of the subjects' performance. The subject were thus divided into Normal Proficiency (NP group, N=12) and High proficiency (HP group, N=10) responders.

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[3]The Listening Grammar subtest of TOAL-3 requires subjects to select two sentences closest in meaning from the three sentences read aloud to them, e.g.:

A) Jane did not make the grade because she didn't do her best.

B) Although Jane did her best, she did not make the grade.

C) If Jane didn't make the grade, it wasn't because she didn't try. The correct answers in this case are B and C. Because the sentences are presented one after another, the subject has to rely on verbal working memory for retrieval of exact sentence meaning.

2.2 Materials

Thirty-five sentences were constructed based on O'Bryan's (2003) sentence set, with appropriate changes to accommodate for more stringent linguistic restrictions on argument animacy and verb type. The sentences allowed the use of either telic or atelic verbs in the reduced relative clause, while remaining semantically plausible (see Appendix A). The stimulus materials consisted of 70 stimulus sentences with reduced relative clauses, and 70 filler sentences of approximately the same length, with varying syntactic structures (e.g. "The young mother exercised every day by chasing her toddler", "The veterinarian hurried to help the farmer in the middle of the night"). Optionally transitive verbs for reduced relative clauses (35 telic and 35 atelic) were chosen based on Levin (1993), and cross-referenced with examples of allowable usage from multiple dictionary sources. The telic verbs chosen described complete (non-gradient) change, and no semelfactives or reciprocal verbs were used. Both subject and object of the verb were animate (in 34 out of 35 sentences, human). The selected telic and atelic verbs were compared for frequency in present and past forms using Francis-Kučera (1967) frequency tables. The mean frequencies of occurrence were comparable for telics (M=44.06, SD=51.9) and atelics (M=43.5, SD=55) in the present tense, as well as in the past (telics M=31.7, SD=39.5; atelics M=41.1, SD=93.6). There was no effect of frequency for either present tense forms (t<1) or for past tense forms (t<1).

Probe questions were constructed for all sentences in order to test comprehension, e.g. a sentence such as "The patient dressed by the therapist moved both legs" was followed by the question: "Was the therapist getting dressed?" The telic condition had 31 probe questions which tested correct assignment of argument roles, vs. 25 such questions for atelic condition. The correct responses to probe questions, "yes" or "no", were balanced for each condition and filler sentences, and the sentences were ordered in such a way that no more than three correct "yes" or "no" responses occurred in sequence.

2.3 Procedure

Participants signed an informed consent form, and completed a case history questionnaire. The electrode cap was fitted on each participant, and impedances lowered to less than 5kOhms. The participants were then seated in a sound-attenuating booth, about 150 cm away from a 48-cm monitor. The experimental procedure was explained, and participants were given a practice session, consisting of two simple sentences followed by comprehension questions. Participants were instructed to press the response key when they were ready to answer; no time constraints were given. Keypad yes/no response hands were counterbalanced between the right and left hands across subjects. After the practice session, all subjects acquired sufficient familiarity with the task to begin the experiment. The stimulus sentences were presented word-by-word on an LCD screen for 200 ms, with an interval of 300 ms between words. Sentence-final words appeared with a period. Each sentence was followed by a yes-no question, which appeared on the screen in full. After the subject responded to the question, the prompt "Ready?" appeared on the screen, allowing the subject to pause before initiating the next trial.

The sentences were divided into 4 blocks, each consisting of 35 sentences (17 or 18 sentences in each block were filler sentences). The stimulus sentences were distributed pseudo-randomly inside each block, so that no more than 3 reduced relative clause sentences followed each other. The order of block presentation was balanced between subjects. The total run time for stimuli presentation and responses varied between subjects, and ranged from 30 to 50 minutes.

Event-Related Brain Potential Recordings—EEG activity was recorded from the scalp using 32 Ag-Cl electrodes secured in an elastic cap (Quik-cap, Compumedics Neuroscan). Electrodes were positioned over homologous locations across the two hemispheres according to the criteria of the International 10-10 system (American Electroencephalographic Society,

1994). The specific locations of electrodes were as follows: midline sites FZ, FCZ, CZ, CPZ, PZ, OZ; medial lateral sites FP1/FP200, F3/F4, FC3/FC4, C3/C4, CP3/CP4, P3/P4, O1/O2; lateral sites F7/F8, FT7/FT8, T7/T8, TP7/TP8, P7/P8. Reference electrodes were placed over the left and right mastoids. Electroencephalographic activity was recorded referenced to the left mastoid; activity over the right mastoid was also actively recorded. All scalp electrodes were re-referenced to the average of the left and right mastoid off-line (Luck, 2005). The eye movements and blinks were monitored and recorded using electrodes placed over the right and left outer canthi (horizontal eye movement), and left inferior and superior orbital ridge (vertical eye movement). All electrode impedances were adjusted to 5 kOhms or less. The electrical signals were amplified with a bandpass of .05 and 100 Hz, and digitized online (Neuroscan 4.0) at the rate of 500 Hz[4].

2.4 Data Analysis

For ERP measures, trials with excessive eye movements or other forms of artifact were rejected (24.5%). Averages were computed from 100 ms pre-stimulus onset to 1000 ms post-stimulus for each of the comparison words: the verb in the reduced relative clause, the preposition "by" after it, and the following noun (the Agent). The 100 ms interval prior to onset served as the baseline for amplitude measurements of the ERPs. Statistical analyses included ERPs recorded at 26 scalp electrodes (medial sites FZ, FCZ, CZ, CPZ, PZ, OZ; fronto-temporal lateral and mid-lateral sites F3/F4, F7/F8, FC3/FC4, FT7/FT8, C3/C4; parieto-occipital lateral and mid-lateral sites CP3/CP4, TP7/TP8, P7/P8, P3/P4, O1/O2).

Measurements of peak amplitude were quantified in relation to the baseline voltage in each participant's averages. Each ERP component was measured using a temporal window approximately centered around its peak in the grand averaged waveforms. The components of interest (N100, P200, anterior negativity) were selected based on literature mentioned above, and the differences between groups and conditions which appeared in the data. Additionally, analyses of the mean amplitudes in successive 20-ms windows from 60 to 520ms were conducted to determine the time course of Telicity effects (see section 3.2.8.).

The ERPs elicited by the verb in the relative clause, on the "by" following the verb, and on the Agent were compared over three temporal windows. The comparisons were made for negative peak amplitudes between 100 and 200 ms (N100), positive peak amplitudes between 200 and 320 ms (P200), and peak and mean amplitudes between 320 and 500 ms (Anterior Negativity, or AN). Lateral and mid-lateral and central electrode sites were analyzed separately. For lateral and mid-lateral sites, repeated-measures analysis of variance (ANOVA) was conducted to determine the effects of telicity (telic vs. atelic condition) separately with three factors (Telicity [telic, atelic], Hemisphere [left, right], and Anterior/Posterior [fronto-temporal, parieto-occipital]). For the analysis of the medial sites, analysis of variance included two factors (Telicity [telic, atelic], and Anterior/Posterior [fronto-central, parietal]).

3. Results

3.1 Behavioral results

Accuracy of responses to probe questions was measured for telic, atelic, and filler sentences in both groups. Accuracy for the NP group for question probes to sentences with telic verbs (*M*=93%, *SD*=3%), atelic verbs (*M*=95%, *SD*=5%), and filler sentences (*M*=95%, *SD*=3%) was similar to the HP group results for telic (*M*=94%, *SD*=3%), atelic (*M*=98%, *SD*=2%), and

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[4]The ERP waveforms in Figures 1, 2 and 5 were additionally low-pass filtered at 30Hz with 48dB dropoff and zero phase shift, to more clearly represent the effects on the small scale for publication purposes.

filler sentences (*M*=95%, *SD*=3%). There was no significant effect of group on accuracy of responses to telic (*t*<1), atelic (*t*<1), or filler (*t*<1) question probes.

3.2 ERP Results

Because the decision to separate the subject pool into groups was based on an independent measure – baseline receptive syntactic proficiency, as indicated by subject's performance on TOAL LG subtest – we report group data even in cases where Group by Condition interactions were only marginally significant.

3.2.1 Telic vs. Atelic Verbs—The amplitude and peak latencies of the ERPs elicited by the verbs did not differ for the telic and atelic conditions. No effect of telicity was found over either N1 interval ($F(1, 20)<1$) or 320-520ms interval: ($F(1,20)=1.353$, $p=.259$, $e_p^2=.063$). Over the P2 interval the two groups combined demonstrated marginally significant Group × Telicity ($F(1, 20)=4.272$, $p=.052$, $e_p^2=0.176$) and Group × Anterior/Posterior ($F(1,20)=4.057$, $p=.058$, $e_p^2=.162$) effects. However, as Figures 1 and 2 illustrate, a Telicity effect was not significant for either group separately ($F(1, 11)=1.778$, $p=.209$, $e_p^2=.139$ in the NP group, and $F(1, 9)=2.594$, $p=.142$, $e_p^2=.224$ in the HP group), while Anterior/Posterior effects were significant in both groups, although different in effect size ($F(1, 11)=12.031$, $p=0.005$, $e_p^2=0.552$ in NP, and $F(1, 9)$, $p=.000$, $e_p^2=.061$ in HP group). Thus, statistical analysis demonstrated that while neither group had a Telicity effect on the verb, the verbs in the RRCs were processed somewhat differently by the two groups, providing corroborative evidence towards the differential processing strategies analysis of sentence processing in populations with different syntactic proficiencies.[5]

3.2.2 Preposition "by": Early Negativity (100ms - 200 ms)—The mean peak latency of this component was 150.5 ms (*SE*=2.8) and did not show any effect of condition or group in the two groups combined ($F(1,20)<1$). Also, no effect of telicity was found for the N100 peak amplitude either in the two groups combined (Group × Telicity $F(1, 20)=2.509$, $p=.129$, $e_p^2=.111$ over midline electrode sites; Group × Telicity $F(1, 20)=2.789$, $p=.111$, $e_p^2=.122$ over lateral and mid-lateral electrode sites), or in either group separately (HP group ($F(1, 9)<1$), NP group ($F(1, 11)<1$).

3.2.3 Preposition "by": Positive Peak between 200 and 320 ms (P200)—The mean peak latency of the P200 elicited by the preposition "by" was 265.3 ms (*SE*=5.4 ms) and was not different for the syntactic proficiency groups or the telicity conditions ($F(1, 20)<1$).

In the analysis of the peak amplitude of this component in the two groups combined, the Group × Telicity effect was significant over midline electrode sites ($F(1, 20)=6.262$, $p=.021$, $e_p^2=.303$), and marginally significant over lateral and mid-lateral electrode sites ($F(1, 20)=3.411$, $p=.08$, $e_p^2=.146$). Also, the Group × Telicity × Anterior/Posterior interaction was significant over midline electrode sites ($F(1, 20)=8.680$, $p=.008$, $e_p^2=.303$). The ERP waveforms elicited by the preposition "by" in the atelic and telic conditions are illustrated for the HP group in Figure 1, and for the NP group in Figure 2. As can be seen in Figure 3 (bottom), the waveforms elicited in the atelic condition in the HP group were more negative relative to those of the telic condition during the P200 interval (200-320 ms) over anterior medial and mid-lateral electrode sites. In the HP group the P200 amplitude elicited by the preposition following atelic verbs was more negative over midline electrode sites ($F(1, 9)=6.009$, $p=.036$, $e_p^2=.404$), and especially over anterior sites (Telicity × Anterior/Posterior $F(1,9)=6.205$, $p=.034$, $e_p^2=.408$),

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[5]Also of interest is the two-peak morphology of the P2 component in the HP group, as compared to the NP group; this difference in morphology provides additional evidence of differential processing of the verb in the two groups; the specific nature of the difference would require further investigation.

compared to the telic condition. The effects were similar over lateral/midlateral sites, with the P200 amplitude significantly more negative for the atelic condition (Telicity $F(1, 9)$=5.762, p=.04, e_p^2=.390). For the NP group, the Telicity effect was not significant ($F(1, 11)$=1.061, p=.188, e_p^2=.152 over midline electrode sites; $F(1, 11)$<1 over lateral and mid-lateral electrode sites).

3.2.4 Preposition "by": The Negative Component between 320 and 500 ms (AN)
—The mean peak latency of the negative amplitude between 320 and 500 ms (Anterior Negativity, or AN) was 437.2 ms (*SE*=4.9 ms) and was not different for the syntactic proficiency groups or the telicity conditions (two groups combined, $F(1, 20)$<1; NP group, $F(1,11)$=3.416, p=.092, e_p^2=.237; HP group ($F(1, 9)$<1).

In the analysis of the peak amplitude of this component in the two groups combined, Telicity × Anterior/Posterior effect was marginally significant over midline electrode sites ($F(1, 20)$=4.117, p=.056, e_p^2=.171). Group × Telicity × Hemisphere effect was marginally significant over lateral and mid-lateral electrode sites ($F(1, 20)$=3.965, p=.06, e_p^2=.165).

As can be seen in Figure 1, the waveforms elicited in the atelic condition by the preposition "by" in the HP group were more negative relative to the ones elicited by the telic condition over the 320-500 ms interval; the effect was especially prominent over anterior electrode sites. This effect was confirmed by the statistical analyses: in the HP group, the amplitude of anterior negativity in response to atelic verb was larger, although only marginally significant ($F(1,9)$=4.208, p=.07, e_p^2=.319); Telicity × Anterior/Posterior effect was also marginally significant ($F(1,9)$=4.333, p=.067, e_p^2=.325. Figure 4 illustrates that over the midline electrode sites, the HP group only had significantly more negative ERP amplitudes in the atelic condition. Anterior distribution of AN component in the HP group was confirmed by the analysis of Anterior medial electrodes (FZ, FCZ, and CZ), which revealed significant effect of Telicity ($F(1, 9)$=8.515, p=.017, e_p^2=.486). Over anterior lateral and midlateral electrode sites, Telicity × Hemisphere interaction was marginally significant in the HP group ($F(1,9)$=4.075, p=.074, e_p^2=.312). However, in the NP group, Telicity and Telicity × Anterior/Posterior effects were not significant over midline electrode sites ($F(1, 11)$<1); nor were Telicity or Telicity × Hemisphere effects significant over lateral and mid-lateral electrode sites (Telictiy, $F(1, 11)$ <1; Telicity × Hemisphere, $F(1, 11)$=1.777, p=.210, e_p^2=.139).

Figure 5 demonstrates group differences in multi-word ERP waveforms of the NP and HP groups, including "by", "the" and Agent Noun. While ERPs elicited by the telic and atelic conditions in the HP group begin to diverge on the "by", the NP group does not appear to have processing differences until the onset of the Agent noun.

Because ERPs to the two conditions in the HP group begin to diverge on the preposition "by", and this difference propagates over the rest of the RRC, further analysis of the single-word ERPs in the HP group is complicated by preceding differential processing. This difference in the ERPs to the two conditions in the HP group results in problematic baseline correction further downstream - at the Agent noun. Thus, while the single-word ERPs elicited by the article "the" and the Agent noun are included in Figure 1 for the purposes of comparison to the NP group in Figure 2, here we focus statistical analysis on the Agent noun on the NP group. The statistical analysis for the HP group, while reported, should be treated with caution due to the confound underlying baseline correction in this case.

3.2.6 Agent Noun: Early Negativity (100ms - 200 ms)—The mean peak latency of this component was 150.6 ms (*SE*=2.8) and did not show any effect of condition or group ($F(1,20)$ <1).

Statistical analysis of the mean amplitude of this component for the two groups combined yielded two significant interactions: Group $\times$ Telicity, $F(1,20)=6.217.509$, $p=.022$, $e_p^2=.237$, and Telicity $\times$ Anterior/Posterior, $F(1, 20)=4.6311$, $p=.051$, $e_p^2=.177$).

The ERP waveforms elicited by the Agent noun in the atelic and telic conditions are illustrated for the NP group in Figure 2. As can be seen in this figure, the waveforms elicited in the atelic condition were more negative relative to those in the telic condition during the N100 interval (100-200ms). Statistical analyses confirmed that this effect was specific to the normal proficiency group: there were no significant effects of condition in the HP group for either medial ($F(1, 9)<1$) or lateral and midlateral electrode sites ($F(1, 9)<1$) over this interval. Figure 6 (top) shows that the peak amplitude of N100 was more negative in NP group over lateral and mid-lateral electrode sites in sentences with atelic verbs, and the difference was especially pronounced over the right hemisphere. Figure 6 (bottom) shows that N100 was also more negative over the frontal sites in the atelic condition as compared to the telic condition (Telicity $\times$ Anterior/Posterior ($F(1, 11)=8.428$, $p=.014$, $e_p^2=.434$).

Over lateral and midlateral electrodes sites, the two groups combined showed significant Group $\times$ Telicity $\times$ Hemisphere effect ($F(1, 20)=6.025$, $p=.023$, $e_p^2=.232$) and Telicity $\times$ Hemisphere $\times$ Anterior/Posterior effect ($F(1,20)=5.579$, $p=.028$, $e_p^2=.218$); yet only the NP group showed the effect of Telicity ($F(1,11)=6.939$, $p=.023$, $e_p^2=.387$) and Telicity $\times$ Hemisphere ($F(1, 11)$ $=9.012$, $p=.012$, $e_p^2=.45$); HP group did not show Telicity or Telicity $\times$ Hemisphere effects ($F(1, 9)<1$ in both cases).

Figure 7 (top) illustrates that over the medial electrode sites the ERPs elicited by atelic sentences in the NP group were also significantly more negative as compared to those elicited by telic sentences, the effect being especially prominent over the anterior sites (Telicity ($F(1, 11)=8.431$, $p=.014$, $e_p^2=.434$). No such effect was observed the HP group, as Figure 6 (bottom) shows.

3.2.6 Agent Noun: Positive Peak between 200 and 320 ms (P200)—The mean peak latency of this component over lateral electrode sites in the two groups combined was slightly longer for the atelic condition (274ms, *SE*=4ms) than for the telic condition (268ms, *SE*=3.6ms), with trending statistical significance ($F(1,20)=4.28$, $p=.052$, $e_p^2=.176$). As Figure 8 (top) demonstrates, the effect in the two groups combined was due mainly to the differences in the HP group, which was confirmed by statistical analysis. In the HP group, the mean peak latency differed both between conditions (mean peak latency in telics - 261.4ms (*SE*=5.8ms), mean peak latency in atelics - 270.8, (*SE*=5.7ms), with trending statistical significance at $F(1,9)=3.948$, $p=.078$, $e_p^2=.305$), and between hemispheres (left hemisphere, 261.7ms (*SE*=5.7), right hemisphere, 270.5ms (*SE*=5.1 ms), $F(1,9)=10.076$, $p=.011$, $e_p^2=.528$). There were no significant effects of condition or hemisphere on mean peak latency of this component in the NP group.

Statistical analysis of the peak amplitude over lateral and mid-lateral electrode sites for the two groups combined has shown a significant effect of Telicity $\times$ Anterior/Posterior interaction ($F(1, 20)=4.663$, $p=.043$, $e_p^2=.189$), as well as marginally significant Group $\times$ Telicity $\times$ Hemisphere interaction ($F(1, 20)=3.747$, $p=.067$, $e_p^2=158$). The analysis of these effects in the HP group did not reach significance for either Telicity, Telicity $\times$ Hemisphere, or Telicity $\times$ Anterior/Posterior effects ($F(1, 9)<1$).

Figure 2 illustrates that not only the N100, but also the P200 component was more negative in the atelic condition as compared to telic condition in the NP group. This negativity was especially prominent over anterior electrode sites and over the right hemisphere: statistical analysis including lateral and midlateral electrode sites confirmed the observation that over the

P200 interval, sentences with atelic verbs elicited more negative ERP waveforms in the NP group (Telicity, $F(1, 11)=5.814$, $p=.035$, $e_p^2=.346$). Also, as Figure 7 (bottom) shows, the P200 component was less negative in the NP group over the right hemisphere in the telic condition, as compared to the atelic condition ($F(1,11)=4.666$, $p=.054$, $e_p^2=.298$).

The HP group did not show significant effects of telicity at the point of the Agent argument over the P200 interval ($F(1, 9)<1$).

3.2.7 The Negative Component between 320 and 500 ms (AN)—The mean peak latency of the anterior negativity elicited by the Agent noun was 422.8 ms ($SE=3.9$), and was not different for the proficiency groups or telicity conditions ($F(1,20)<1$). Neither peak amplitude nor mean amplitude of the ERP waveforms of either group demonstrated an effect of telicity (HP group, $F(1, 9)<1$; NP group, $F(1,11)<1$).

3.2.8. Consecutive Temporal Window analyses of Component Selection—In order to determine the time course of observed effects, we have conducted additional analyses of the mean amplitudes of the ERP waveforms in 20ms time windows on the CZ electrode. The CZ electrode was part of the array showing the condition differences over both "by" in the HP group, and the Noun in the NP group. We started the analyses at 60ms post onset of the stimulus, and proceeded to 520ms – the end of the Anterior Negativity interval, 20ms past the onset of the following word.

On the "by", significant Group × Telicity effects in the two groups combined were found over consecutive 240-260 ms and 260-280 ms windows ($F(1, 20)=6.632$, $p=.018$, $e_p^2=.249$, and $F(1, 20)=7.204$, $p=.014$, $e_p^2=.265$, respectively), and over the 320-340ms window (F(1, 20) $=4.572$, $p=.045$, $e_p^2=.186$). There was a marginally significant Group × Condition effect over the 440-460ms window ($F(1, 20)=4.087$, $p=.057$, $e_p^2=.170$). Those windows correspond to the P200 interval (200-320) and the Anterior Negativity interval (320-520) in the component analysis. In a step-down analysis, only the HP group demonstrated a Telicity effect over those intervals. Over the P2 interval, the effect was significant over both the 240-260ms and the 260-280 ms windows ($F(1, 9)=5.812$, $p=.039$, $e_p^2=.392$, and $F(1, 9)=6.562$, $p=0.031$, $e_p^2=.422$, respectively). For the Anterior Negativity interval, the HP group also showed a significant effect over both 320-340ms window ($F(1, 9)=5.458$, $p=.044$, $e_p^2=.378$) and 440-460ms window ($F(1, 9)=5.270$, $p=.047$, $e_p^2=.369$). Thus, the effects demonstrated in the component analysis over the P200 and Anterior Negativity intervals on the "by" in the HP group are consistent within the consecutive window analysis.

Additionally, the 160-180ms window (located within N100 interval) demonstrated Group × Telicity effect in two groups combined ($F(1, 20)=5.561$, $p=.029$, $e_p^2=.218$). However, in a step-down analysis, neither group demonstrated a significant effect over this interval ($F(1, 9) <1$; F(1,11) p>.07).

On the Agent noun, significant Group × Telicity effects were found over the 120-140ms, 140-160ms and 160-180ms windows within the N100 interval in the two groups combined ($F(1, 20)=7.697$, $p=.012$, $e_p^2=.278$; $F(1, 20)=13.181$, $p=.002$, $e_p^2=.397$; and $F(1, 20)=6.088$, $p=.023$, $e_p^2=.233$, respectively). Additionally, the 120-140ms window demonstrated a significant Telicity effect($F(1, 20)=5.269$, $p=.033$, $e_p^2=.209$). Over the P200 interval, Group × Telicity effects reached significance in the 240-260ms and 260-280ms windows ($F(1, 20)=7.665$, $p=.012$, $e_p^2=.277$, and $F(1, 20)=9.275$, $p=.006$, $e_p^2=.317$, respectively). There was also a marginally significant Telicity effect over the 500-520 ms window (($F(1, 20)=4.043$, $p=.058$, $e_p^2=.168$). No other significant effects were found over any of the small windows in the two groups combined (F(1, 20), p>.09). In a step-down analysis, only the NP group demonstrated a significant Telicity effect. During the N100 interval, the Telicity effect in the NP group was

significant over 120-140ms (F(1, 11)=9.956, p=.009, e_p^2=.475), and 140-160ms (F(1, 11) =12.729, p=0.004, e_p^2=.536), with marginal significance over the 160-180ms windows (F(1, 11)=4.439, p=.058, e_p^2=.290). During the P200 interval, the Telicity effect was significant over both the 240-260ms and 260-280ms windows (F(1,11)=11.838, p=.006, e_p^2=.518; F(1,11) =14.369.519, p=.003, e_p^2=.566, respectively). Over the 500-520 ms window, the NP group also showed a significant Telicity effect (F(1,11)=5.070, p=.046, e_p^2=.315). Thus, the effects demonstrated in the component analysis over the P200 and Anterior Negativity intervals on the Agent noun in the NP group are consistent with the results of consecutive window analysis. The HP group, on the other hand, did not demonstrate significant effects (F(1, 9) p>.142)

The window analysis demonstrated that the difference between conditions reaches significance within the intervals chosen for the component analysis. Also, since the windows in which effects reach significance are located centrally for the peak amplitudes of N100 and P200, and the differences between conditions were not significant at the borders of the component intervals, the 20ms consecutive window analysis supports the choice of 100-200, 200-320, and 320-520 windows for the component analysis.

3.3 Summary of Findings

Overall, both groups showed significant telicity effects: ERPs from the NP group first diverged at the second argument, with the atelic condition eliciting larger negativity at the N100, and continuing to the P200 interval. In contrast, ERPs from the HP group first diverged earlier in the sentence, on the preposition "by". HP group ERPs elicited in the atelic condition were also characterized by increased negativity relative to the telic condition, which became significant at the P200 interval (200-320ms), and continued into the later 320-500ms interval over fronto-central electrode sites.

4. Discussion

This study investigated the effects of verbal telicity on the ease of syntactic re-analysis of Object reduced relative clauses in populations with normal and high-normal syntactic proficiency. Comprehension of sentences with reduced relatives was high in both groups, and did not differ significantly between the two groups, suggesting successful recovery from garden-path effects in both populations. In the following sections, findings on the ERP effects of re-analysis of verbal structure and group (proficiency) effects are discussed separately.

4.1 ERP effects

Overall, our results reproduced previously reported ERP waveform components, with more negative ERPs elicited over anterior scalp regions for the atelic condition. Because we relate the comparative morphology of ERP waveforms to the processing load during the task, we consider the interpretation of our results in light of previous studies which compared two grammatical conditions as well as grammatical with ungrammatical sentences.

4.1.1 ERPs to the "by"—Over the 200-320 ms interval (P200), the more negative amplitudes of ERPs elicited by the atelic condition in the HP group were similar to ones observed by Osterhout, Holcomb, & Swinney (1994) in ERPs to grammatical sentences containing verbs with a mismatch between subcategorization biases and phrase structure. In our experiment, the mismatch would be between the (possible) intransitive use of the verb, and a preposition signaling a complex phrase structure requiring a transitive verbal frame – i.e. P200 in this case may be signaling the beginning of phrase structure re-analysis.

The negativity in the atelic condition in the HP group was also sustained over the 320-500ms interval, with larger anterior negativity elicited by the sentences with atelic verbs. A similar

effect (although more left-lateralized, and referred to as LAN) was described by King & Kutas (1995), who observed it in response to the late introduction of the verb in unreduced Object relative clauses (e.g. *The reporter who the senator harshlyattacked...*), and attributed this increase in negativity to the difficulty of thematic integration. While anterior negativity in King & Kutas was observed in Poor comprehenders as compared to Good comprehenders, the thematic integration argument applies to the present paradigm: the anterior negativity was only observed in the group that has already begun differential processing of the two conditions over the preceding interval, and may have had comparatively more difficulty in re-analyzing verbal phrase structure in the atelic condition. A similar effect (an enhanced N400 component) was observed in German by Hopf, Bayer, Bader, & Meng, 1998, where it was interpreted as indicating repeated access to formal lexical information in garden-path sentences.

4.1.2 ERPs to the Agent Noun—Over the 100-200ms interval (N100), the difference between the telic and atelic ERP waveforms in the NP group was similar to that reported for grammatical and ungrammatical sentences requiring phrase structure re-analysis (Neville, 1991; Yamada & Neville, 2007). The larger negativity in the atelic condition continued over the 200-320 ms interval (P200) in the NP group. The frontal and right distribution of these early components related to syntactic re-analysis was similar to the distribution previously reported for those components by Yamada &; Neville (2007), who attributed the frontal maxima to the ongoing processes of syntax-semantics integration. Our findings support their hypothesis that pre-existing semantic information (in our experiment, verbal telicity) may affect how the initial syntactic processing is carried out.

4.1.3 ERP Markers of Syntactic Proficiency—ERPs for telic and atelic conditions in the HP group differed on the "by", earlier than in the NP group, as indicated by a more negative P200 component appearing in the atelic condition in subjects with high syntactic proficiency. This result is consistent with a suggestion by Weber-Fox & Neville (2002) that high-proficiency subjects seemed to have more reliance on closed-class words.

ERP waveforms elicited in normal proficiency subjects – N100-P200 complex which was more negative for the atelic condition - are also attested in the literature. King & Kutas (1995) noted that a higher amplitude variability in N100-P200 complex (in Poor vs. Good comprehenders in the original study) can point to a strong attentional allocation component. Similarly, the data in the present study seems to suggest that normal proficiency subjects begin attentional allocation (to the semantics of the verb) and differential processing of telic and atelic conditions only after the second argument is introduced.

The difference in the mean peak latency of the P200 component on the Agent in the two groups is intriguing. It is possible that the integration of the Agent into the phrase structure (or thematic role assignment) in the HP group is facilitated by the fact that verb frame alternation had already been processed differentially by this group at the point of the preposition "by". Another possible explanation is that HP subjects relied on a higher verbal working memory capacity for a faster integration of the preceding verb and the Agent. Previous research on garden-path effects has suggested that susceptibility to the garden pathing can be a function of the reader's working-memory capacity (Just & Carpenter, 1992), which allows readers with large working memory capacities to keep more than one parsing possibility active, and then choose the appropriate interpretation as later sentence information becomes available. Additional evidence for this interpretation comes from Sanz' (2000) cross-modal priming experiment on telicity in Italian, which suggested that subjects that demonstrated higher proficiency in linguistic tasks employed a processing strategy which allowed for a faster retrieval of lexical items previously used in the sentence.

Given our findings of differentiated ERPs in both predicted locations in the sentence distributed between the two proficiency groups, it is possible to suggest that an anteriorly distributed negativity component with an onset at about 100 ms post-stimulus, and sustained over 200-320 ms for open-class words (Agent noun), or with an onset at 200 ms and sustained over 320-500 ms for closed-class words (preposition "by") correlates with the complexity of the syntax-semantics integration processes in online sentence processing. The right-hemispheric distribution of this negativity appears to be elicited in conditions with an increased semantic load during a particular integration task, e.g. while integrating an Agent into the alternating verbal frame structure (vs. only verbal phrase structure re-analysis on the "by"). A similar observation was made in Just et al.'s (1996) fMRI study, where an increased activation of the right hemisphere homologs of Wernicke's and Broca's areas was observed as a function of increased linguistic complexity in visually presented sentences.

In general, these results provide additional evidence that thematic roles defined by the verb affect parsing decisions (cf. Frazier & Rayner, 1982, MacDonald et al., 1994), but may do so differently depending on the parsing strategy employed by the comprehender, which in turn might be the function of linguistic (or syntactic) proficiency, or non-linguistic cognitive processes, such as verbal working memory.

ERP studies of the use of verbal working memory in verb gapping sentences in English (Kaan, Wijnen, & Swaab, 2004) and anaphor resolution in German (Streb, Henninghausen, & Rösler, 2004) reported somewhat similar components to the ones observed in the current study. In English, the word immediately following the verb gap ("Ron took the planks for the bookcase, and Bill ___ the HAMMER with the big head") elicited central-posterior negativity (100-300ms), followed by fronto-central positivity (300-500ms), in comparison to a control condition not involving gapping. In German, negativity between 0 and 250ms was observed in the condition requiring more working memory load (further distance of the anaphor from its antecedent) over central, parietal, and temporal electrode sites, with slight right lateralization; it was followed by a wide midline positivity around 400-600ms. These findings suggest that the effects observed in the two groups are related to the use of verbal working memory.

We would like to elaborate on why the two conditions – sentences with RRCs headed by telic and atelic verbs – were compared to each other, without an overt baseline condition. Because the research question concerned only the re-analysis of thematic roles during processing of verb frame alternations, sentences lacking verb frame alternations (non-garden-path sentences) could not constitute a true control condition for the experiment (cf. King & Kutas, 1995); and since the optionally transitive verb in the RRC could only be either telic or atelic, there is no semantic control available to compare to the two conditions in garden-path sentences. We have relied on two sources of data, while interpreting comparative waveforms in the two conditions: psycholinguistic experiments concerning processing of telic vs. atelic verbs, and ERP literature regarding the components indexing comparative difficulty of semantic and syntactic integration. Earlier psycholinguistic studies of verbal event structure (O'Bryan, 2003, Friedmann et al., in press, Sanz 2000, etc.) have reported that telic verbs facilitate interpretation of frame structure alternations in sentences with garden-paths in terms of reaction times during online processing; it is on these findings that we based our assumption that it is ERPs to the atelic verbs which would index additional processing demands. Such processing demands have been previously reported as negativities in ERP literature. Thus, we have interpreted the data in the present experiment assuming additional negativity in the atelic condition, rather than positivity in the telic condition.

However, an alternative interpretation of the data would suggest that RRCs with telic verbs elicit multi-word frontal positivity, which is especially robust (and starts earlier) in the HP

group. A similar effect is analyzed in King & Kutas (1995), where it is elicited by comparative ease of processing of Subject relative vs. Object relative clause; it is also more robust in the Good Comprehenders group (in King & Kutas (1995), subjects were grouped according to median split in their total comprehension scores). Thus, according to the related ERP literature, both approaches to the interpretations of the data (as negative modulation of ERPs in atelic condition, or slow positive component in the telic condition) demonstrate comparative ease of processing of RRCs with telic verbs, which is more robust, and happens earlier, in the group with the higher syntactic proficiency.

4.2 Interpretation of results in terms of linguistic theory and processing frameworks

As the ERP data demonstrates, subjects process alternations of the verbal phrase structure frame from intransitive to transitive in telic verbs using fewer processing resources compared to the same frame alternation in atelic verbs. The same frame alternations in atelic verbs, on the other hand, are somewhat more difficult to process, and elicit ERP waveforms which are typically associated with increased difficulty of early syntactic processing and thematic role integration.

Since other factors which could contribute to possible differences in sentence processing were controlled for in the design of the study – including argument animacy, frequency of verb occurrence, and transitivity (all verbs were optionally transitive), the results within proficiency groups are clearly due to the linguistic factor of telicity affecting sentence processing at the syntax-semantics interface. While there is evidence that relative frequency of occurrence of certain structures can influence ERP waveform morphology (cf. Osterhout, Holcomb, & Swinney, 1994), there is still the question of why certain constructions might be more frequent in the corpora, or preferred, when alternative ones are possible with the same verb. A relative cost of processing for such alternations can provide one explanation, which goes back to the question of the present study – what alternations are more costly than others, and why? The data in the present study can be best explained by a combination of event structure and parallel processing theories.

Figures 9a and 9b illustrate comparative changes in event and argument role structure in telic and atelic verbs undergoing frame alternations from telic to atelic. As can be seen in Figure 9a, telic verbs can alternate between their non-causal (intransitive) and causal (transitive) interpretation, while preserving the thematic role interpretation of the Object. An additional argument, when it is introduced in the "by" construction, is added to the existing verbal phrase frame as an external Agent (or causer), and does not necessitate re-assignment of thematic roles. Atelic verbs, on the other hand, initially assign both Agent and Undergoer roles to the first argument, which results in necessary thematic role re-assignment when the verbal frame changes from intransitive to transitive. Re-assignment of Agent and Undergoer roles between the subject and the object of the reduced relative clause thus appears to be a process which elicits more negative ERPs as compared to simple addition of an extra argument in a vacant thematic role.

An alternative approach to the linguistic analysis of the stimuli in the present experiment would consist of considering the difference between the conditions to arise not from the telicity of the verb, but from an addition of Agent argument role only. This position is represented, for example, in the Meaning Through Syntax (MTS) framework of McKoon & Ratcliff (2003), who use purely semantic event templates, assuming that verbs do not undergo frame structure alternations. If we re-frame our research question in the purely semantic terms of MTS, atelic intransitive to transitive alternation would be expressed as the change from $Y(ACT) \rightarrow x(ACT\ y)$; and the telic one as $Y(BECOME\ IN\ STATE) \rightarrow \alpha\ CAUSE\ (Y\ (BECOME\ IN\ STATE))$. Thus, from the semantic standpoint, our investigation complements research of McKoon & Ratcliff by testing what they consider "extensions beyond basic sense" of the verbs[6]. The present experiment takes the verbs from various semantic classes, which do allow this kind of

frame structure alternation (within MTS approach, all of these verbs would be classified as "internal causer" verbs in their intransitive form, and "external causer" verbs in their transitive form), and investigates the comparative difficulty of this alternation as might relate to the telic/atelic feature of the same verb (or its *Aktionsart*). In the garden-path stimuli of the present experiment, the semantics of argument structure (i.e. due to presence of an external causer) vary with the verb frame alternations, but the *Aktionsart* properties of the verb remain consistent. The conclusion we make based on the data pertains to the comparative difficulty of adding an external causer to telic vs. atelic verbs. Yet, within the MTS framework, both types of verbs in the present experiment would simply extend their argument structure templates to incorporate an external causer, and we would not expect to see any differences in the ERPs for the two conditions[7].

It thus appears that the linguistic interpretation of the ERP data would be mostly consistent with lexically-driven parsing models of sentence processing, which suggest that basic syntactic or phrase structure information available with the verb controls the initial stages of comprehension, but it can be quickly modified by the information coming later in the sentence. For example, the extended argument dependency model (eADM), as proposed in Bornkessel & Schlesewsky, 2006, is a good candidate for incorporating event structure into its processing system. The formulation of eADM includes simple template structures, processed in phase 1, and semantic features of both predicates and arguments, such as animacy and logical structure, processed in phase 2. While the linguistic formulation of the event structure framework advocates more cohesion between semantic and syntactic templates for the verb, as compared to the 2006 version of eADM, it is entirely possible that during processing, different parts of the predicate's event structure are activated at different times – this question can be explored further in investigating interaction of telicity (logical structure) vs. transitivity (number of arguments in a template) processing, as well as processing of Case in verbs of different event structures. The Memory, Unification, and Control (MUC) framework, as formulated by Hagoort (2003b, 2005) is another possible model that could incorporate event structure templates and alternations as suggested by the data in the present experiment. However, more cross-linguistic research on event structure processing, with additional data on working memory use during processing, would be needed to interpret the present findings within the MUC framework.

4.3 Conclusions, study limitations, and future work

The findings of the present study provide evidence for differential processing of telic and atelic verbs in reduced-relative clauses requiring verbal frame structure alternation during recovery from garden-path effect. These findings support the claim by Yamada & Neville (2007) that the processing of syntactic information of a newly incoming word interacts with the previous semantic context, and they are best explained by parallel models of online sentence processing, which propose continuous interaction of syntactic and semantic modules and a flexibility of the processing system (cf. Jackendoff, 2005, for a linguistic theory consistent with parallel processing models). The data in this study complements earlier findings (Osterhout, Holcomb, & Swinney, 1994; Yamada & Neville, 2007) by demonstrating one possible source of early interaction of syntactic and semantic modules: verbal event structure, which determines both

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[6]However, if the ability of the verb to incorporate an 'external causer' is just an extension of the verb's meaning, a question arises as to why only some verbs allow such alternations (this question is treated in Ramchand's 2008 theory of event structure, but not in the MTS framework); this question is a part of an interesting line of research, that of interaction of verb's transitivity (optional or obligatory), and its semantics and verbal event structure. Within that larger question, McKoon & Ratcliff mention that only some verbs of the semantic class "manner of motion" allow transitivity (external causer) alternations, but do not offer any further treatment to the issue.

[7]We would suggest that ungrammaticality effects demonstrated in McKoon & Ratcliff's psycholinguistic experiments might be due to the lack of full argument structure in the RRC used for those experiments (for example, the external causer is not at all mentioned in their stimuli, such as "*The horse raced ___ past the barn fell*"; in our stimuli the external causer is overtly specified: *The actress awakenedby the writer* left the room).

the phrase structure of the surrounding lexical material (more thoroughly treated in Ramchand, 2008), and argument structure by means of thematic role assignment. The results obtained in the present study thus contribute both to the investigation of online sentence processing, and linguistic theory development.

The results also offer ERP evidence that the behavioral "strategies" previously observed in priming paradigms (Sanz, 2000) have a neurological basis, which might be based on the subjects' syntactic proficiency (Weber-Fox et al, 2003) or verbal working memory capacity (King & Kutas, 1995). More research is needed to determine the underlying reason for differentiation of ERP waveforms.

There were several limitations to the design of the study. Subjects were not limited with respect to response times, since we were relying on previous behavioral research for such evidence, and were specifically interested in the ERP waveforms elicited by sentence processing. Additionally, it would have been interesting to compare the relative effect of obligatory transitivity on the processing of reduced relative clauses, which would have provided insight into the comparative processing cost of event and argument structure alternations; the design, however, was limited by fatigue factor for the subjects. Another limitation of the study concerns pragmatic plausibility of occurrence of certain verbs with specific arguments. While every effort was made to ensure a balanced set of stimuli, there remains a possibility that the differences in ERP components interpreted as the response to the "by" might constitute a late response to the likelihood of certain subject-verb combinations. There also remains a question about the specific reasons for the subjects' individual abilities affecting online processing of event structure, which is left for future investigation.

Because the original question in this study pertained only to the comparative difficulty of argument re-analysis in RRCs headed by telic vs. atelic verbs, the research question of the place of telicity in processing of simple sentences remains open. The present experiment only addresses a small part of a larger research question: the place of verbal telicity/*Aktionsart* in language processing. Further research regarding interaction of verbal telicity with transitivity, argument animacy, Case (in languages where Case is overtly represented in morphology), etc. would be needed to determine the role that verbal telicity plays in language processing.

Acknowledgments

Appendix

Appendix A

Verbs were classified as (a)telic and (optionally) transitive based on several linguistic diagnostics. Telic verbs were identified using the standard tests for telicity: (1) compatibility with 'in an hour'-type adverbial; (2) applicability of imperfective paradox ("Mary is awakening" does not entail "Mary awakened"). Optionally transitive telic verbs (alternating unaccusatives) were selected based on three additional diagnostics: (3) existence of a morphologically identical predicate that takes a direct object (The ball rolled. – *Simon* rolled the ball); (4) the ability to take a passive subject (The ball was rolled *by Simon*), (5) and the inability to occur with a resultative phrase (*The boy rolled scratched.) (Levin & Rappaport-Hovav, 1995). Atelic verbs were selected based on the following diagnostics: (1) compatibility with 'for an hour'-type adverbial; (2) inability to undergo causative alternation: (e.g. Jane

broke the cup – The cup *broke*); (3) inability to undergo middle alternation (e.g. The butcher *cuts* the meat. – The meat *cuts* easily.).

Stimulus sentences, with both atelic and telic verbs used in the reduced relative clause.

1. The infant bathed /changed by the mother cried loudly.

2. The actress worshipped / awakened by the writer left in a hurry.

3. The child observed / stopped by the teacher walked to class.

4. The student painted / tripped by the artist looked very embarrassed.

5. The artist coached / flipped by the gymnast impressed the audience.

6. The toddler washed / cleaned by the sitter kicked angrily.

7. The actor tutored / vanished by the magician decided to come back.

8. The dog followed / scratched by the cat jumped the fence.

9. The sparrow watched / recovered by the hawk flew into the bushes.

10. The astronomer celebrated / left by the colleagues found an asteroid.

11. The author volunteered / emailed by the publisher gave a lecture.

12. The victim delayed / suffocated by the thief stayed in the building.

13. The runner studied / phoned by the coach lost the race.

14. The killer sketched / gagged by the cop scared the public.

15. The firefighter led / sickened by the marshal waved to the crowd.

16. The kid splashed/disarmed by the neighbor complained loudly.

17. The bride decorated/undressed by the mother looked in the mirror.

18. The teenager lectured/evacuated by the policeman acted nervous.

19. The workers pushed /unionized by the politician protested wage cuts.

20. The athletes raced / quieted by the trainer got a second chance.

21. The groom awaited / married by the judge left the building.

22. The baby nursed / burped by the mother rolled over.

23. The jockey smelled / kicked by the horse walked away.

24. The patient exercised / dressed by the therapist moved both legs.

25. The volunteers counted/ noticed by the mayor stayed until evening.

26. The students applauded / qualified by the instructor got certificates.

27. The veterinarian doctored / murdered by the surgeon acted irresponsibly.

28. The officer chauffeured / saluted by the soldier received a medal.

29. The husband pressed /enrolled by the wife attended the course.

30. The prisoner taught / halted by the agent tried to escape.

31. The dancer rushed / returned by the host surprised the guests.

32. The professor hurried / interrupted by the dean served on the committee.

33. The activist investigated / choked by the policeman fell to the ground.

34. The customer shaved/cheated by the barber left no tip.

35. The freshman soaked/passed by the classmate acted annoyed.

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ERPs Elicited in the HP Group by the Verb, Preposition "by", definite Article, and Agent Noun: Relative Clauses with Telic and Atelic Verbs Compared
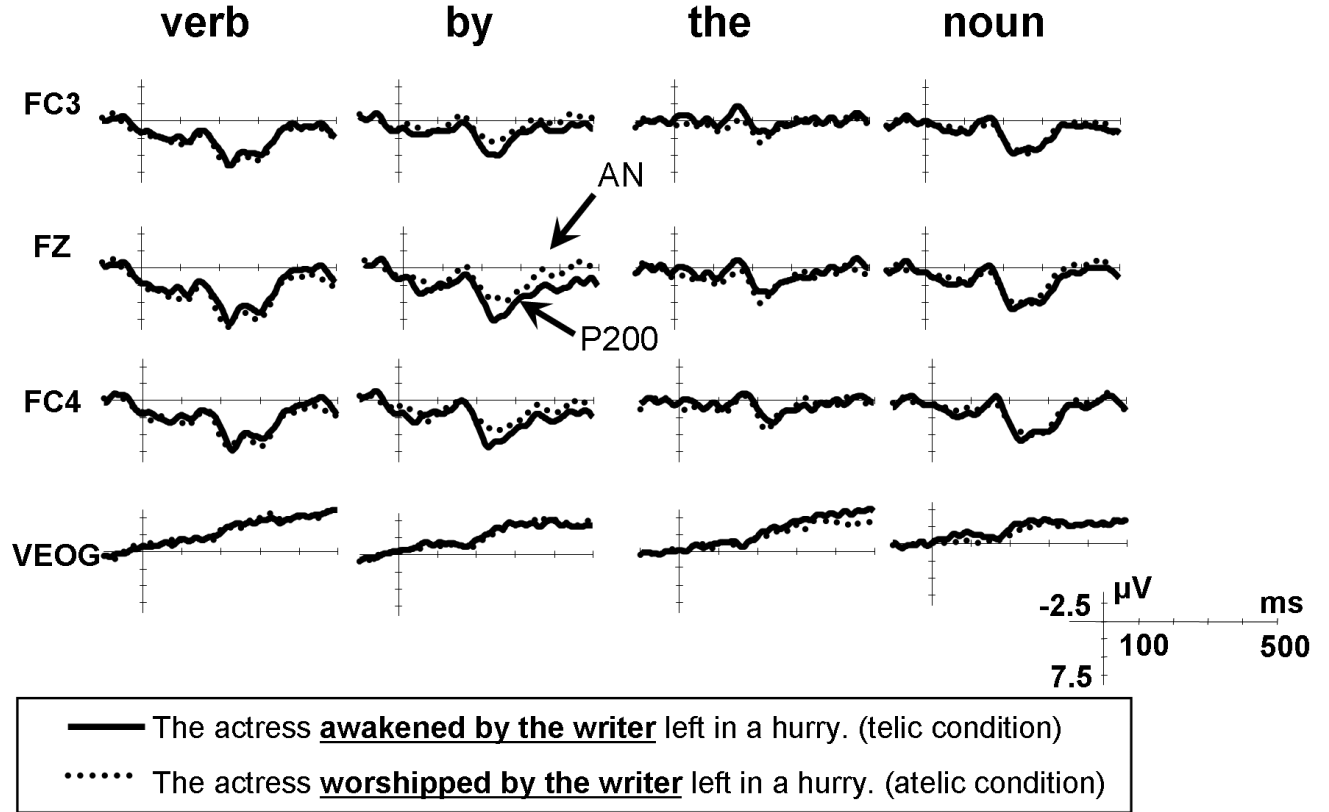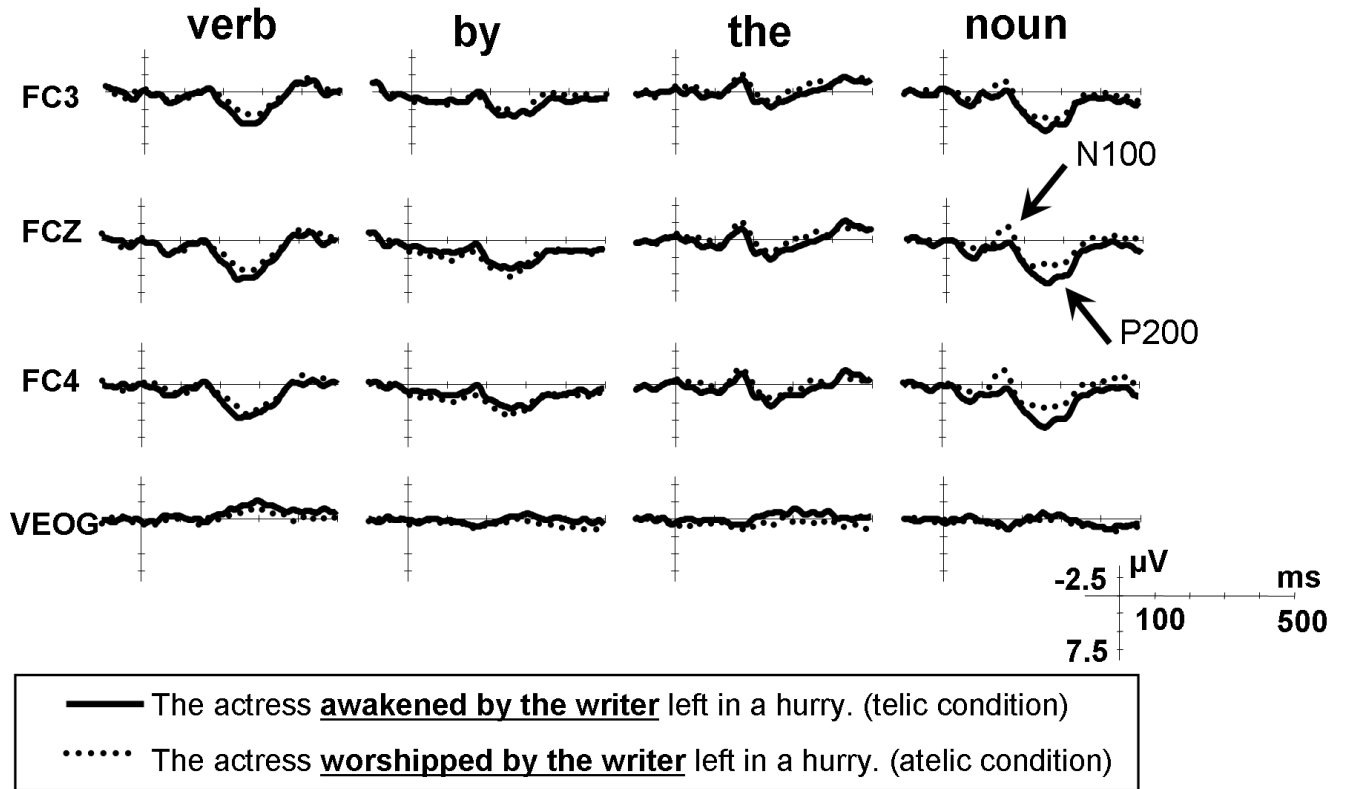
Figure 1.
ERPs elicited in the HP group by the verb, preposition "by", definite article, and Agent noun in reduced relative clauses with Telic and Atelic verbs, illustrating that P200 and Anterior Negativity components on the "by" were more negative in response to atelic condition. Negative potentials are plotted upward.

Figure 2.
ERPs elicited in the NP group by the verb, preposition "by", definite article, and Agent noun in reduced relative clauses with Telic and Atelic verbs, illustrating that N100 and P200 components on the Agent Noun were more negative in response to atelic condition. Negative potentials are plotted upward.
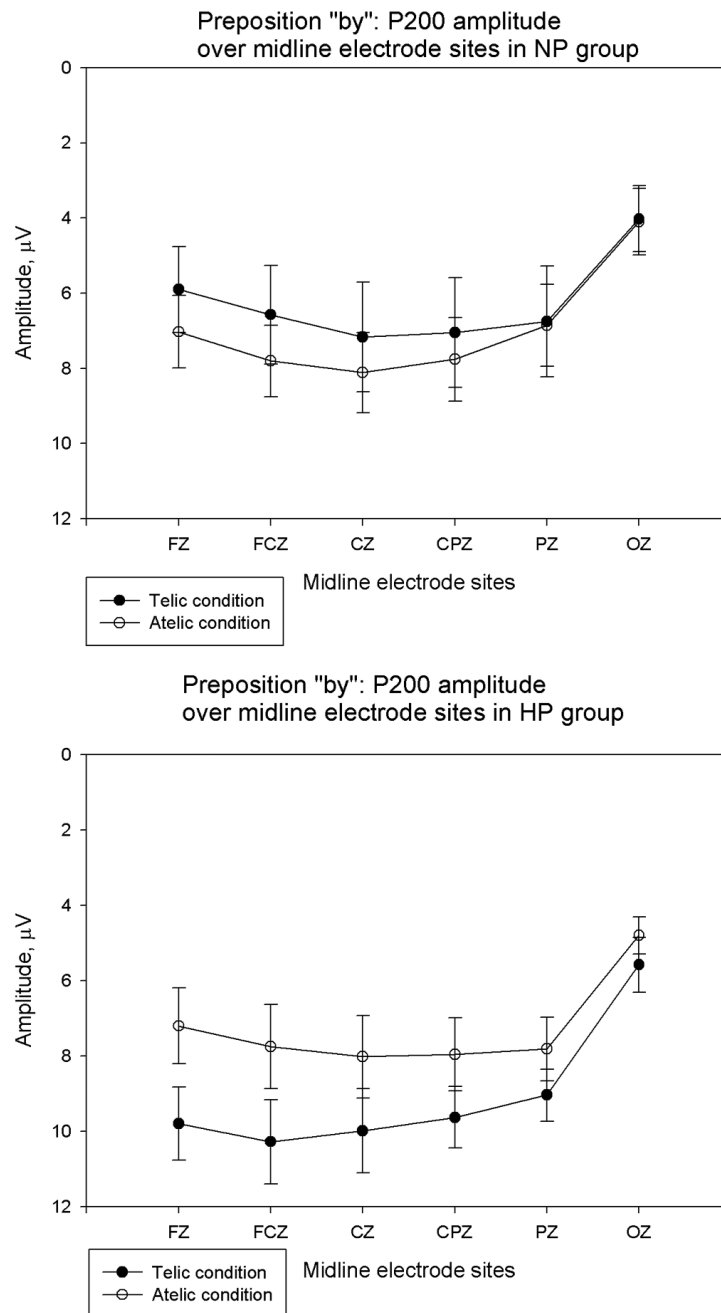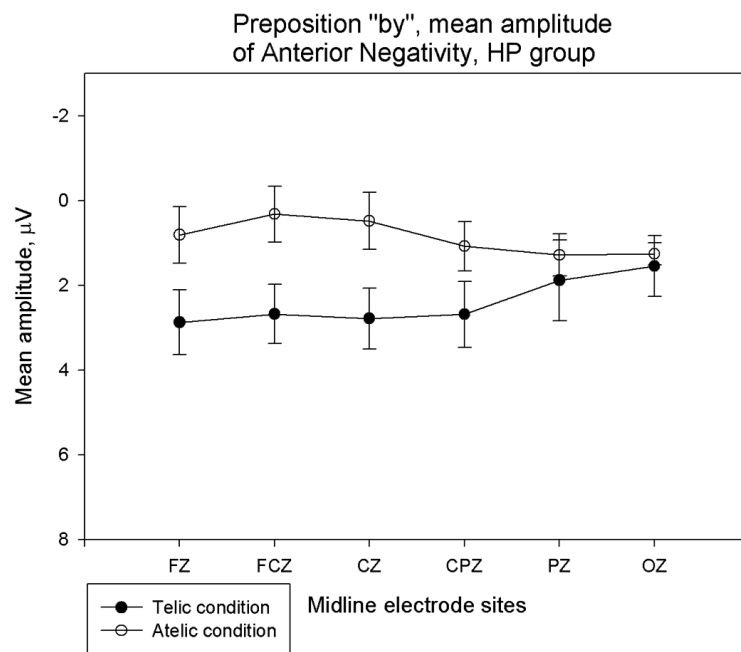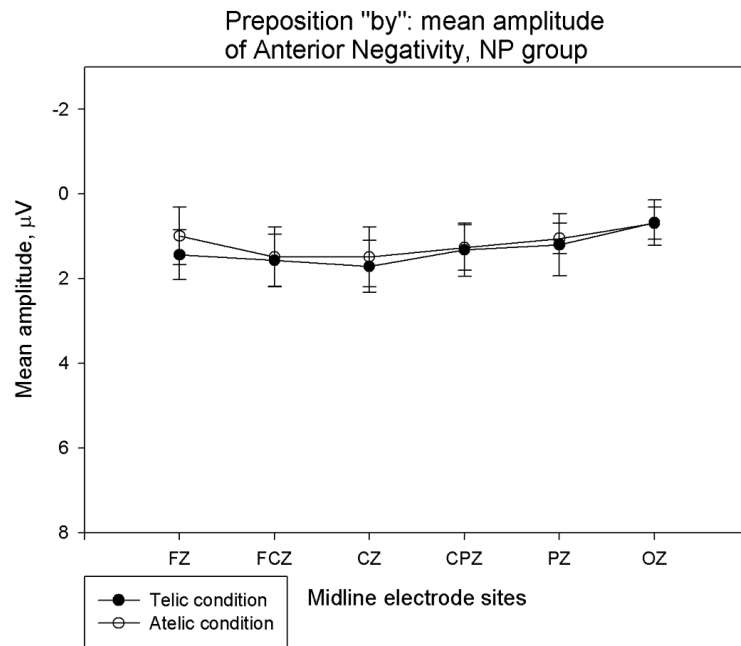
Figure 3.
Amplitude of P200 on the preposition "by" in reduced relative clauses with telic and atelic verbs over midline electrode sites in NP group (top), and HP group (bottom). Negative potentials are plotted upward.

Figure 4.
Mean amplitude of Anterior Negativity on the preposition "by" in reduced relative clauses with telic and atelic verbs over midline electrode sites in NP group (top), and HP group (bottom). Negative potentials are plotted upward.

ERPs Elicited in the NP and HP Groups by the Relative Clauses
with Telic and Atelic Verbs Compared
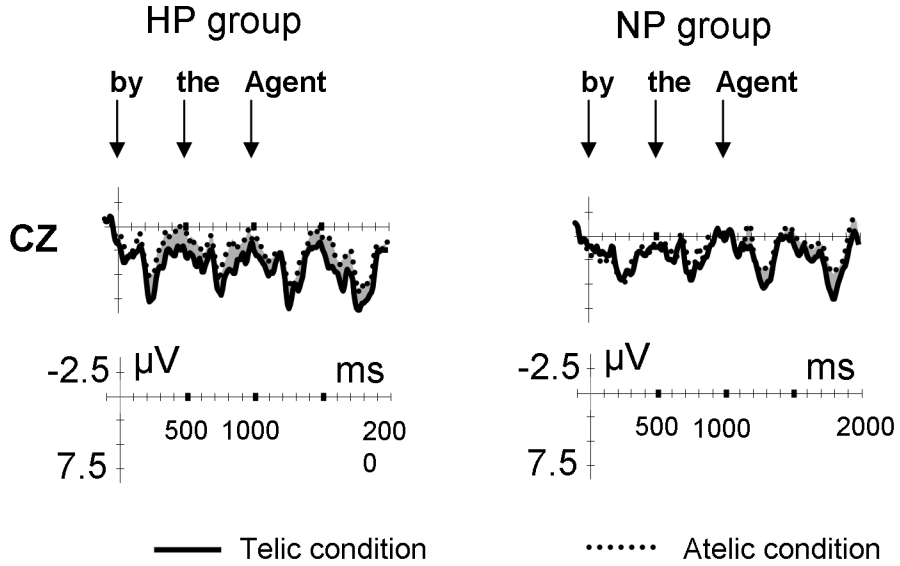
Figure 5.
ERPs elicited in the NP and HP groups by reduced relative clauses with Telic and Atelic verbs, illustrating sustained differential processing starting on the Agent noun in the NP group, and preposition "by" in the HP group. Negative potentials are plotted upward.
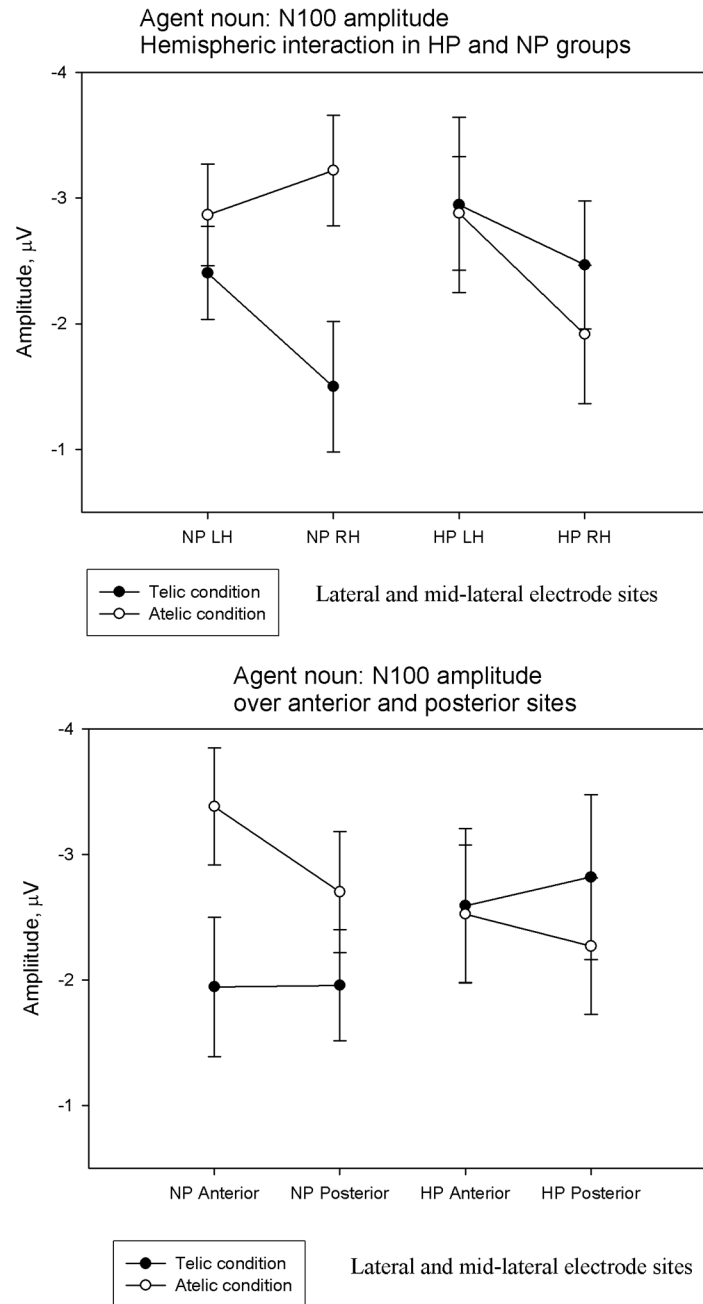
Agent noun: N100 amplitude
Hemispheric interaction in HP and NP groups

Agent noun: N100 amplitude
over anterior and posterior sites

Figure 6.
N100 peak amplitudes for NP and HP groups separated by hemisphere (top) and posterior-anterior electrode location (bottom), illustrating that N100 peak amplitudes were significantly more negative in the NP group over the right hemisphere, and over anterior sites. Negative potentials are plotted upward.
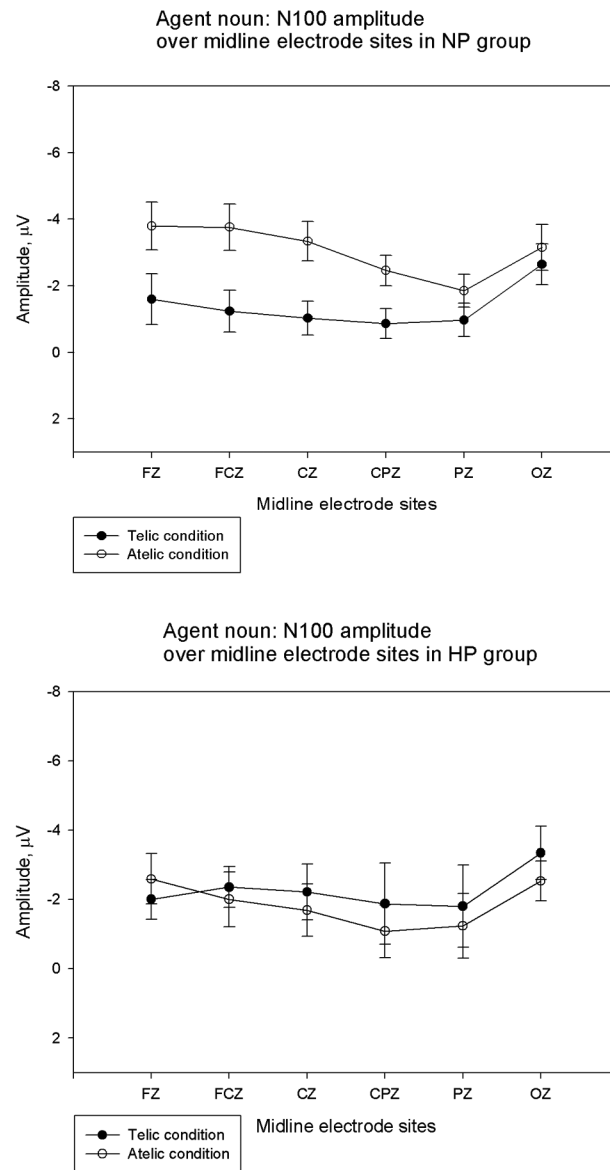
Agent noun: N100 amplitude
over midline electrode sites in NP group

Agent noun: N100 amplitude
over midline electrode sites in HP group

Figure 7.
N100 amplitude in response to the Agent noun over midline electrode sites in NP group (top), and HP group (bottom), illustrating that in NP group, the ERPs in response to atelic condition were significantly more negative, especially over fronto-central electrode sites. Negative potentials are plotted upward.
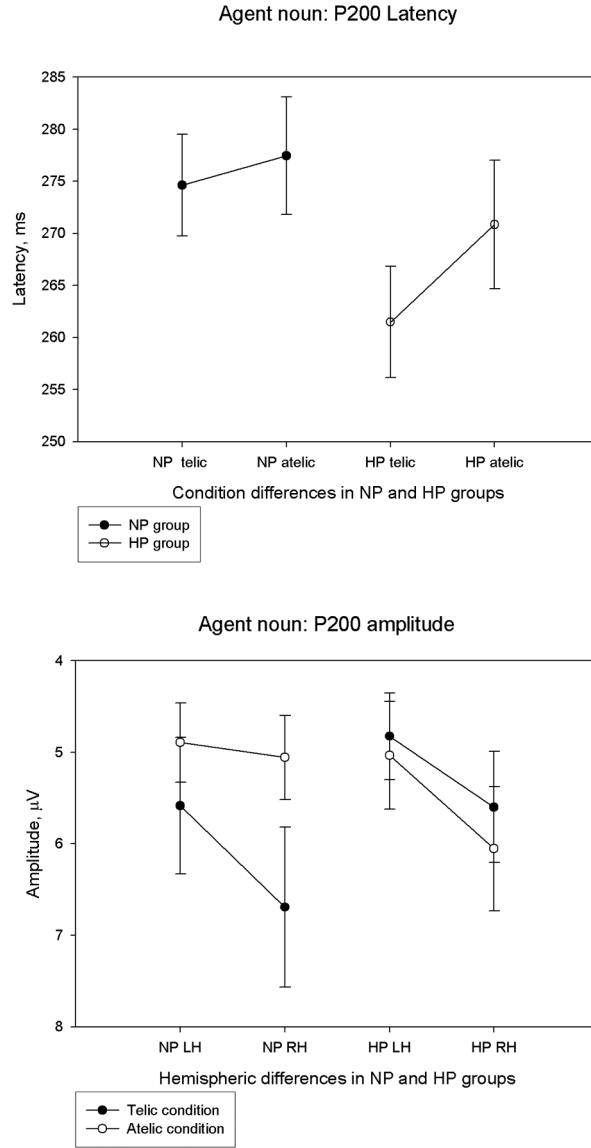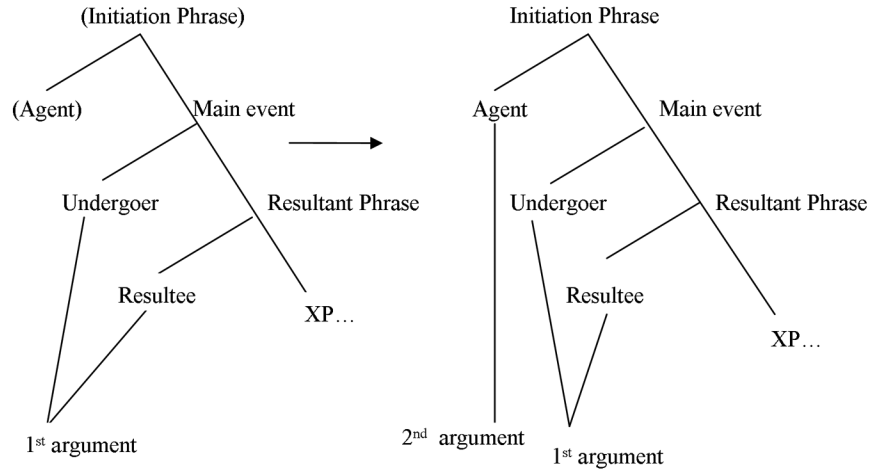
Figure 8.
P200 latency in NP and HP groups separated by condition (top), and P200 amplitude in NP and HP groups separated by hemisphere (bottom). Hemisphere interactions (bottom) illustrate that NP group had more negative P200 peak amplitude measures over the right hemisphere. Negative potentials are plotted upward.

Event and argument structure alternation in telic verb: from intransitive to transitive.

Event and argument structure alternation in atelic verb: from intransitive to transitive.
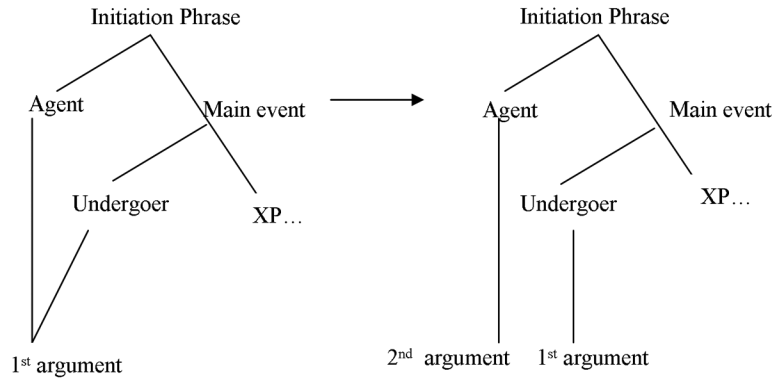

Figure 9.
Tree diagrams illustrating event and argument structure alternations from intransitive to transitive in telic verbs (top), and atelic verbs (bottom).