The ERP correlates of thematic role assignment for passive versus active sentences

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ABSTRACT

The current study investigates the ERP correlates of reading passive versus active sentences to provide insight into how comprehenders assign thematic roles and to advance our understanding of the processing mechanisms involved in real-time language processing. This study uses ERPs to investigate how English speakers assign thematic roles while building the structure and meaning of grammatical passive versus active sentences, in which both nouns are equally plausible agents and patients. In two separate experiments, participants exhibited a frontal positivity in response to passive versus active sentences at the point they encountered the past participle form of the lexical verb (e.g., *The policeman was tackling the robber/tackled by the robber* …). Such frontal positivities have previously been associated with processing grammatical sentences that involve increased syntactic or discourse complexity, rather than structural revision or reanalysis (e.g., Kaan & Swaab, 2003). This suggests that the online revisions necessary for comprehending passive sentences do not involve structural revisions per se, but rather revisions to the expected agent role initially assigned to the sentence-initial noun. These findings expand the scope of ERP research on the assignment of thematic roles and the processing of the morphosyntactic cues that disambiguate such role assignment.

1. Introduction

Explaining how people identify who does what to whom in a sentence, as well as what types of linguistic information inform these decisions and the timing of such decisions during real-time language comprehension, forms a core component of many cognitive and neurocognitive models of sentence processing (e.g., Bornkessel-Schlesewsky & Schlesewsky, 2009; Kuperberg, 2007; Trueswell, Tanenhaus, & Garnsey, 1994). Such models acknowledge that identifying a sentence's argument structure, and assigning the thematic roles of agent and patient in particular, involve the interaction of lexical-semantic and morphosyntactic information. Yet most neurophysiological research (EEG/ERP) has focused exclusively on how lexical-semantic information, including noun animacy and verb argument information, leads people to identify the argument structure of a sentence and assign semantic-thematic roles while constructing the structure and meaning of a sentence (see Bornkessel-Schlesewsky & Schlesewsky, 2009; Kuperberg, 2007, 2013, for review). Such research has largely overlooked how word order and verbal morphology may also influence thematic role assignment during real-time language processing, even though such morphosyntactic information provides potentially informative cues about

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how to interpret a sentence. Further, much of this ERP research relies on violation paradigms involving ungrammatical or implausible sentences, or stimuli that include highly semantically constrained sentences, even though such sentences are relatively rare in naturalistic speech (Frisson, Harvey, & Staub, 2017; Luke & Christianson, 2016).

We therefore present results from two ERP experiments involving the comprehension of passive versus active sentences among monolingual English speakers to address open questions in the literature regarding the assignment of semantic-thematic roles to advance our understanding of the neural correlates associated with different mechanisms involved in real-time language processing. Both active and passive sentences are grammatical (and semantically plausible) in English. However, passive sentences are less frequent than active sentences (Roland, Dick, & Elman, 2007) and involve a non-canonical patient-first ordering of thematic roles (Ferreira, 2003). As such, they represent a syntactic construction that is known to lead to processing difficulties during comprehension (e.g., Ferreira, 2003; Street & Dabrowska, 2010). However, less is known about the precise time course by which comprehenders assign thematic roles while building the structure of simple transitive active and passive sentences (e.g., *The policeman was tackling the robber/The policeman was tackled by the robber*) and whether comprehenders immediately assign the role of agent to the sentence-initial noun phrase (here: *the policeman*), only to subsequently revise this assignment upon encountering verbal morphology that unambiguously identifies a sentence as a passive construction. As explained in greater detail below, the present study, thus, uses neurophysiological evidence to provide novel insight into the extent to which comprehenders rely on algorithmic processing routines, in which they use morphosyntactic information to build a full syntactic parse of an utterance, versus heuristic processing routines, in which they use real world knowledge and prior linguistic experience to construct a "good enough" interpretation of the utterance (e.g., Christiansen & Chater, 2016; Christianson, 2016; Ferreira & Patson, 2007).

By directly comparing the real-time processing—as measured by ERPs—of these two sentence types, this study goes beyond previous ERP research by investigating how people anticipate and assign thematic roles when such roles are identified via word order and morphosyntactic cues rather than plausibility and semantic information. This study expands the scope of ERP research on the processing of semantic-thematic roles to examine (1) if and how English speakers assign thematic roles in grammatical and plausible sentences, even in the absence of highly semantically constraining contexts and (2) the neural correlates of processing grammatical and plausible, yet infrequent and noncanonical, syntactic constructions in real time. The results have important implications for our understanding of how people use prior linguistic knowledge to build the structure and meaning of a sentence in ways that facilitate the efficient and rapid processing of linguistic input (e.g., Christiansen & Chater, 2016; Christianson, 2016; Ferreira & Patson, 2007; Kuperberg, 2013).

1.1. Thematic roles and "good enough" processing

The comparison of passive versus active sentences provides an avenue to investigate open questions in the ERP literature on thematic role assignment, while also providing novel insight into the use of heuristic versus algorithmic processing routines during online comprehension. English speakers exhibit lower comprehension accuracy and longer response times for passive versus active sentences when answering comprehension questions about the assignment of agent and patient roles (e.g., Ferreira, 2003; Street & Dabrowska, 2010), suggesting that their processing routines do not always lead to a correct interpretation of the sentence. Difficulties emerge regardless of whether sentences contain biased, yet reversible, agents and patients (e.g., *The man was bitten by the dog*), nonreversible agents and patients (e.g., *The cheese was eaten by the mouse*), or symmetrical agents and patients (e.g., *The man was visited by the woman*) (Ferreira, 2003). Further, even though passive sentences are difficult, Ferreira (2003) reported no corresponding comprehension difficulties with equally infrequent and syntactically complex subject-cleft sentences. This suggests that difficulties with passive sentences arise when people adopt a heuristic noun-verb-noun strategy during comprehension, automatically identifying the first argument in a sentence as a proto-agent because this is the most frequent thematic-role order in English, even though, in passive sentences, the first noun is the patient of the verb (see also Bornkessel-Schlesewsky & Schlesewsky, 2009).

However, Ferreira (2003) points out that participants still correctly interpreted passive sentences more often than not, with comprehension accuracy ranging from 71 to 92% across experiments and sentence type (i.e., reversible biased, nonreversible, symmetrical). This indicates that comprehenders still conduct full syntactic parses a significant portion of the time, building the appropriate syntactic and thematic-role structure of the utterance, and may revise those initial parses that were based on heuristic or "good enough" strategies (see also Street & Dabrowska, 2010). However, based on behavioral data and end-of-sentence comprehension data alone, it is difficult to pinpoint the time-course with which comprehenders assign thematic roles, and the type of revisions comprehenders undertake upon realizing that they are reading a passive and noncanonical sentence, rather than a prototypical agent-first active sentence. As outlined in greater detail below, ERP methodology provides the ability to address precisely these questions and in so doing, advance our understanding of if, how, and when comprehenders employ heuristic versus algorithmic processing routines during real-time language comprehension.

1.2. ERP components and language processing

To date, ERP researchers have identified two primary components that index related, yet distinct, processes associated with thematic role assignment, the N400 and the P600. The N400 is a negative going waveform that begins around 300 ms post stimulus

relations between nouns in a sentence based on a select set of core factors including animacy, voice, case marking and linear position (but see Chow, Lau, Wang, & Phillips, 2018, for arguments that thematic role assignment is delayed in online processing). Mismatches that arise while computing such prominence information or linking thematic roles to the lexical requirements of the main verb (e.g., encountering an inanimate noun—a prototypical patient—in a structural position usually reserved for an agentive argument in English) result in an N400 effect. Importantly, comprehenders do not initially take plausibility information into account when computing prominence and linking relations (Bornkessel-Schlesewsky & Schlesewsky, 2009). According to the eADM, only at a later stage do comprehenders take plausibility and real world knowledge into account, leading to a P600 effect when such information conflicts with previously computed prominence and argument linking information.

The P600 is a positive-going waveform that begins around 500 ms post-stimulus onset and extends over several hundred milliseconds and is maximal over posterior sites. This waveform is traditionally associated with the relative difficulty of syntactic integration and reanalysis, in response to both grammatical violations (e.g., Friederici, Mecklinger, & Hahne, 1996; Hagoort, Brown, & Groothusen, 1993; Osterhout & Holcomb, 1992), and the reinterpretation of grammatical, yet unexpected, garden-path sentences (e.g., Frisch, Schlesewsky, Saddy, & Alpermann, 2002; Gouvea, Phillips, Kazanina, & Poeppel, 2010; Osterhout & Holcomb, 1992; Qian, Garnsey, & Christianson, 2018).[1]

P600 effects have also been observed in response to semantic violations, when such violations lead to implausible thematic relationships between verbs and their arguments (see Kuperberg, 2007, for review). Kuperberg and colleagues found a P600 at the verb in sentences like "For breakfast the eggs would *eat* …" because *eggs* is not a plausible agent of *eat*, even though it would be a plausible patient (Kuperberg, Kreher, Sitnikova, Caplan, & Holcomb, 2007; Kuperberg, Sitnikova, Caplan, & Holcomb, 2003). Such P600 responses can arise even without a clear semantic relationship between the verb and the preceding noun, as in "For breakfast the eggs would *plant…*" (Kuperberg et al., 2007; but see; Kim & Osterhout, 2005), highlighting that such effects are driven by selection restrictions in verb-argument structure (e.g., whether a verb requires an animate or inanimate object), rather than semantic fit per se (see also Hoeks, Stowe, & Doedens, 2004; Paczynski & Kuperberg, 2012; Szewczyk & Schriefers, 2011; Van Herten, Chwilla, & Kolk, 2006; Weckerly & Kutas, 1999).

To account for the "semantic" P600, Kuperberg (2013) proposed that comprehenders make predictions about the links between words in a sentence (e.g., assigning semantic-thematic roles) based on the conceptual features of those words. The semantic P600 arises when subsequent input requires revisions to the predicted event structure of the utterance and the corresponding thematic-semantic roles assigned to earlier nouns in the sentence. This proposal parallels the processes thought to underlie P600 effects for syntactic violations and garden-path sentences, in that P600 effects reflect the need to update the mental representation of an entire utterance, rather than of individual words, when incoming input renders the previous mental representation untenable (Brouwer, Fitz, & Hoeks, 2012). However, most research on the semantic P600 has relied on incongruous or highly implausible sentences. It remains an open question whether downstream revisions to thematic role assignment would similarly elicit a posteriorly-distributed P600 effect when such reanalysis stems from encountering a semantically plausible, yet noncanonical syntactic structure, as is the case with passive versus active sentences, especially when the sentence-initial noun is animate and equally plausible as an agent or patient (as in the sentences tested in the present study).

Although not specifically associated with the assignment of semantic-thematic roles, one final component that is relevant for the present study is the frontal positivity. This is a positive-going waveform that begins around 500 ms post-stimulus onset and extends over several hundred milliseconds and is maximal over anterior sites. This waveform generally emerges in response to processing grammatical but syntactically complex sentences (e.g., Friederici, Hahne, & Saddy, 2002; Hagoort, Brown, & Osterhout, 1999; Kaan & Swaab, 2003; see also Van Petten & Luka, 2012, for review of research linking frontal or anterior positivities to semantic predictive processing). For instance, Kaan and Swaab (2003) reported a frontal positivity at the disambiguating verb in sentences containing a complex noun phrase, like "I cut the cake beside the pizzas that *were* bought by Jill", in which it is temporarily ambiguous whether the relative clause modifies the head noun (i.e., *cake*) or the local noun (i.e., *pizzas*), compared to sentences in which the relative clause unambiguously modifies a simple noun phrase, like "The man in the restaurant doesn't like the hamburgers that *were* on his plate." Such frontal positivities do not emerge in response to sentences containing grammatical violations, leading researchers to argue that this frontal positivity reflects the "aftermath of increases in discourse complexity and/or of increases in syntactic complexity" (Kaan & Swaab, 2003, p. 106), rather than structural revision or repair processes per se. In the context of good-enough processing frameworks (e.g., Christianson, 2016; Ferreira & Patson, 2007), a frontal positivity would thus reflect the processing of more complex (and possibly noncanonical) constructions in general, suggesting that comprehenders are relying less on algorithmic or syntactic processing mechanisms—which would more likely lead to a posterior P600 associated with reanalysis and repair—and relying more on heuristic processing routines.

1.3. Present study

To provide novel insight into the timing and use of syntactic algorithms versus processing heuristics during real-time language

comprehension, the present study investigates how and when speakers assign thematic roles and build the corresponding syntactic structure for active versus passive sentences in English. In so doing, the present study also addresses open questions in the ERP literature regarding how comprehenders assign thematic roles during real-time language processing, even when processing grammatical and plausible sentences that are not highly semantically constrained (e.g., Frisson et al., 2017; Luke & Christianson, 2016). In two experiments, we investigated the comprehension of grammatical and semantically plausible active and passive sentences in English (e.g., *The policeman was tackling the robber/tackled by the robber* …), as a window into how comprehenders use morphological cues (i.e., *-ing* vs. *–ed*) and word order information (agent-first vs. patient-first) to anticipate the likely structure and meaning of a sentence. Critically, symmetrical passive sentences, in which the first noun is equally plausible as the agent or the patient, present readers with an unexpected and noncanonical ordering of thematic roles, independent of semantic constraints that would bias them towards one interpretation over another (Ferreira, 2003; Street & Dabrowska, 2010).

If passive sentences elicit a posteriorly-distributed P600 effect at the lexical verb (i.e., *tackled*) relative to active sentences, this would suggest that the cognitive effort associated with comprehending passive sentences includes the need to engage in structural reanalysis at the point one encounters morphosyntactic information that unambiguously marks the sentence as a passive construction. Such results would parallel previous ERP research involving the syntactic reanalysis of garden-path sentences (e.g., Frisch et al., 2002; Gouvea et al., 2010; Osterhout & Holcomb, 1992; Qian et al., 2018) and ERP research that characterizes a posterior P600 effect as reflecting the need to update the mental representation of a sentence's event structure (e.g., Kuperberg, 2007, 2013). Alternatively, if passive sentences elicit a frontal positivity, this would suggest that the cognitive effort associated with comprehending passive sentences stems from incorrectly identifying the sentence-initial noun phrase as the agent of the sentence, as this is the prototypical agent-patient order in English (Ferreira, 2003), thereby implicating heuristic processing routines in the comprehension of passive sentences. Such results would parallel previous ERP research linking frontal positivities to the processing of potentially ambiguous sentences that involve greater syntactic or discourse complexity (e.g., Friederici et al., 2002; Hagoort et al., 1999; Kaan & Swaab, 2003).

Although not necessarily predicted by the distinction between algorithmic versus heuristic processing in good-enough processing frameworks (e.g., Ferreira, 2003), other ERP research on the assignment of thematic roles has reported an N400 in response to atypical thematic-role assignments stemming from conflicts in prominence information and lexical requirements imposed by different verbs (e.g., Bornkessel-Schlesewsky & Schlesewsky, 2008; 2009). Thus, if passives elicit an N400 effect at the lexical verb, this would imply that the cognitive effort associated with comprehending passive sentences, in which a noncanonical ordering of thematic roles is disambiguated via morphosyntactic information, is similar to the processing of atypical thematic-role assignments, when disambiguated via prominence information and lexical requirements associated with verbs.

2. Experiment 1

2.1. Methods

2.1.1. Participants

Thirty-three functionally monolingual English speakers from a large American university participated in the experiment and received course credit for their participation. All participants provided informed consent prior to beginning the study, in accordance with approved IRB procedures for the study. Eight participants were excluded due to significant early exposure to a language besides English (2), testing session errors (5), or excessive artifacts in the raw EEG (1). All results are based on the remaining 25 participants (2 males; 23 females; mean age: 19.2 years, range: 18–23). All participants were right-handed (Grey, Tanner, & Van Hell, 2017), as determined by an abridged version of the Edinburgh Handedness Inventory (Oldfield, 1971), had normal or corrected-to-normal vision, and no reported history of any neurological impairment.

2.1.2. Materials

The first set of critical stimuli consisted of 72 active/passive sentence pairs. All sentences contained two animate nouns, both of which could be a logical agent or patient of the action in the sentence. Active sentences contained a progressive verb construction consisting of *was* plus a progressive participle, as in example (1). Passive sentences contained a passive construction consisting of *was* plus a past participle, as in example (2). All sentences were disambiguated as an active or passive sentence at the lexical verb (underlined below). There was no significant difference in frequency between the active (i.e., *tackling*) versus passive (i.e., *tackled*) verb forms (SUBTLEX-US corpus; Brysbaert, New, & Keuleers, 2012; $t(70) = 0.86$, $p = .345$).[2]

(1) The policeman was tackling the robber just as police backup arrived.
(2) The policeman was tackled by the robber just as police backup arrived.

To ensure that both nouns were equally plausible as agents and patients, 80 English native speakers residing in the United States were recruited via the online platform Prolific (https://www.prolific.co/) to complete a plausibility rating task. Using a 7-point Likert

The policeman tackled the robber; Second noun in stimulus as agent: *The robber tackled the policeman*). The 72 critical items were divided into four lists so that each participant rated 36 critical items (and only one version of any given item) and 36 filler items, which consisted of 18 plausible and 18 implausible SVO sentences, presented in randomized order. The critical items were judged as equally plausible, regardless of which noun was presented as the agent (First noun in stimulus as agent: $M = 5.62$, $SD = 0.89$; Second noun in stimulus as agent: $M = 5.45$, $SD = 0.88$; $t(71) = 1.25$, $p = .217$), thus limiting the potential impact of semantic plausibility on participants' ERP responses or comprehension accuracy.

The second set of experimental stimuli consisted of 72 grammatical/ungrammatical sentence pairs, which were included as a point of comparison. Grammatical versions contained a modal verb followed by a bare verb stem, as in (3). Ungrammatical versions contained a modal verb followed by a progressive participle, as in (4). All sentences were identifiable as grammatical or ungrammatical at the lexical verb (underlined below).

(3) The nurse should confront the friend who lied to her.
(4) The nurse should confronting the friend who lied to her.

The 72 active/passive sentences and 72 grammatical/ungrammatical sentences were split into two lists, so that participants saw 36 items in each condition but only one version of any given sentence. These 144 items were presented in a pseudo-randomized order along with 72 filler items. Filler items included nine grammatical and 18 ungrammatical sentences containing simple intransitive verbs (e.g., *The athlete was running outside despite the severe thunderstorm warning; *The pharmacist must biked to work today because his car is broken*), 18 grammatical sentences containing a form of the verb *be* followed by a locative phrase (e.g., *The books were under the table in the bedroom*), nine grammatical and nine ungrammatical sentences containing pseudopassive constructions (e.g., *The stadium was packed with fans from all over the country; *The boss was confuse because of the email that he received*), and nine ungrammatical sentences containing transitive verbs (e.g., *The committee members might requested an extension for the proposal*). All ungrammatical filler items were rendered ungrammatical by using an incorrect form of the lexical verb, such that across the experiment as a whole, participants encountered both grammatical and ungrammatical sentences containing progressive participles, past participles, and bare verb stems. Across the entire experiment, participants encountered 72 ungrammatical sentences and 144 grammatical sentences. Participants encountered 36 passive sentences altogether, for a ratio of 1:5 passive versus non-passive sentences across the entire experiment. The 216 sentences were divided into four experimental blocks of 54 sentences each, with an equal number of critical active and passive sentences, critical grammatical and ungrammatical sentences, and filler sentences in each block.

After one-third of the items (24 active/passive sentences; 24 grammatical/ungrammatical sentences; 24 filler sentences) participants answered a Y/N comprehension question probing the content of the sentence they had just read. For eight active and eight passive sentences, this question probed the assignment of agent/patient roles (e.g., *Did the robber tackle the policeman?/Did the policeman tackle the robber?*). For the remaining active/passive sentences, and all other sentences, this question probed other information in the sentence (e.g., *Did the friend lie?*). These questions provided a measure of comprehension performance and helped keep participants alert. Half of the questions required a yes response and half required a no response.

2.1.3. Procedure

Participants completed the experiment in one 2-h session. After signing the consent form, they filled out a language background questionnaire and the abridged version of the Edinburgh Handedness Questionnaire. They also completed an updated version of the Author Recognition Task (Acheson, Wells, & MacDonald, 2008) as a measure of print exposure, as this has been shown to correlate with the production of passive sentences (Montag & MacDonald, 2015). Participants were seated in a comfortable chair and instructed to relax and minimize movement and eye-blinks while reading. Stimuli were presented using E-Prime v2.0 (Psychology Software Tools, 2012). Each trial began with a blank screen, presented for 750 ms, followed by the word *Ready?*, which remained on the screen until participants pressed any key on the button box. This gave participants sufficient time to blink and rest their eyes before each trial. A fixation cross then appeared on the screen, followed by a stimulus sentence, presented one word at a time. The fixation cross and each word appeared on the center of the screen for 350 ms, with a 100 ms blank screen appearing between each word. The final word of each sentence appeared with a full stop. For sentences accompanied by a Y/N comprehension question, after the final word disappeared from the screen, the full comprehension question then appeared on the screen and remained there until participants responded by pressing Y or N on a button box (response hand was counterbalanced across participants). At the end of each experimental block, participants had time to rest. They then pressed any key on the button box to start the next block. Prior to the main task, participants completed 12 practice items. After the EEG task, participants completed an automated operation span task (Unsworth, Heitz, Schrock, & Engle, 2005) as a measure of working memory.[3]

2.1.4. Data acquisition and analysis

During the sentence reading task, scalp EEG was recorded from 32 Ag/AgCl electrodes (extended 10–20 system; Jasper, 1958)

attached to an elastic cap (Brain Products ActiCap, Germany) at a sampling rate of 500 Hz. EEG was amplified using a Neuroscan Synamps RT system and was filtered online with a 0.05–100 Hz bandpass filter and offline with a 30 Hz half-amplitude low-pass filter (24 dB/octave roll-off). Scalp electrodes were referenced during recording to a vertex reference and re-referenced offline to the average activity of the right and left mastoids. Eye movements were monitored for ocular artifacts via bipolar montages of additional electrodes placed above and below the left eye and at the outer canthus of each eye. Impedances were kept below 10 kΩ (which is below the recommendation for active electrodes).

Preprocessing and offline data analysis was done in ERPlab (Lopez-Calderon & Luck, 2014). ERPs, time-locked to the onset of the critical word (underlined in examples (1)–(4)), were averaged offline for each participant at each electrode (relative to a 200 ms prestimulus baseline) within each condition (active vs. passive; grammatical vs. ungrammatical). All artifact-free trials were included in the analyses, with trials removed for eye-blinks (defined as vertical peak-to-peak EOG amplitude exceeding 50 μV on either eye electrode within 200 ms time windows, analyzed in 50 ms steps across the epoch) and artifacts (defined as vertical peak-to-peak amplitude exceeding 120 μV on any single electrode within 200 ms time windows, analyzed in 50 ms steps across the epoch). A total of 8.1% of trials were excluded due to eye blinks, excessive muscle artifacts or drift, and this number did not differ reliably across conditions. In accordance with previous reports and visual inspection of the data, we computed mean amplitude measures for each condition in the 300–500 ms (N400/LAN), 500–700 ms (P600) and 700–900 ms (late positivity) time windows (see Kaan & Swaab, 2003). Mean ERP amplitudes were entered into separate ANOVAs for active/passive sentences and grammatical/ungrammatical sentences, with sentence type (active vs. passive; grammatical vs. ungrammatical) as a repeated-measures factor. To investigate the topographic distribution of any effects, the midline electrodes were analyzed separately from the lateral electrodes. For midline electrode analyses, electrode was entered as a repeated-measures factor (Fz vs. Cz vs. Pz) alongside sentence type. Data from the lateral scalp electrodes were grouped into the following regions of interest (ROIs), based on the ROIs reported in Brothers, Swaab, and Traxler (2015, 2017): Left-anterior (FP1, F3, F7), Left-central (FC1, FC5, C3), Left-posterior (CP5, CP1, P3), Right-anterior (FP2, F4, F8), Right-central (FC2, FC6, C4) and Right-posterior (CP6, CP2, P4). For lateral electrode analyses, hemisphere (left vs. right) and anteriority (anterior vs. central vs. posterior) were entered as repeated-measures factors alongside sentence type. We applied the Greenhouse-Geisser correction for homogeneity of variance for data with more than one degree of freedom in the numerator and corrected p-values are reported. For all analyses, if the omnibus ANOVA revealed a significant ($p < .05$) interaction involving the factor sentence type, we conducted follow-up analyses to investigate the nature of the interaction.

2.2. Results

2.2.1. Comprehension accuracy

Participants were highly accurate in their answers to the comprehension questions overall, across both experimental and filler items, $M = 93.6\%$, $SD = 3.9$, 95% CI [91.7, 95.2]. A t-test comparing comprehension accuracy on active versus passive sentences that tested the assignment of thematic roles revealed that participants were more accurate on active ($M = 88.0\%$, $SD = 14.2$, 95% CI [82.1, 93.9]) than passive sentences ($M = 73.0\%$, $SD = 15.6$, 95% CI [66.6, 79.4]; $t(24) = 4.00$, $p = .001$, $d = 1.01$).

2.2.2. ERP results

Active/passive sentences. Visual inspection suggests a frontal positivity in the 500–700 ms time window for passive sentences compared to active sentences (see Fig. 1). The ANOVA results are presented in Table 1. In the 300–500 ms time window, there was a significant interaction between sentence type and anteriority over lateral electrodes, but follow-up ANOVAs revealed no significant effects in any region (anterior: $F(1, 24) = 3.55$, $p = .072$; central: $F(1, 24) = 0.52$, $p = .479$; posterior: $F(1, 24) = 0.06$, $p = .813$). In the 500–700 ms time window, there was a significant effect of sentence type that was qualified by a significant interaction between sentence type and anteriority over lateral electrodes because the positivity for passive sentences relative to active sentences showed an anterior-central distribution (anterior: $F(1, 24) = 7.91$, $p = .010$, $\eta_p^2 = .248$; central: $F(1, 24) = 6.95$, $p = .014$, $\eta_p^2 = .225$; posterior: $F(1, 24) = 1.04$, $p = .318$, $\eta_p^2 = .042$). Similarly, there was a significant interaction between sentence type and electrode over midline electrodes because the positivity for passive sentences showed an anterior distribution (Fz: $F(1, 24) = 6.86$, $p = .015$, $\eta_p^2 = .222$; Cz: $F(1, 24) = 0.98$, $p = .332$, $\eta_p^2 = .039$; Pz: $F(1, 24) = 0.13$, $p = .727$, $\eta_p^2 = .005$). In the 700–900 ms time window, there were no significant effects or interactions.

Grammatical/ungrammatical sentences. Visual inspection suggests a widely distributed positivity that is greatest at posterior electrodes in the 500–700 and 700–900 ms time windows (a P600) for ungrammatical versus grammatical sentences (see Fig. 2). The ANOVA results are presented in Table 2. In the 300–500 ms time window there was a significant interaction between sentence type and electrode over midline electrodes, but follow-up ANOVAs revealed no significant effects at any electrode (Fz: $F(1, 24) = 2.69$, $p = .114$, $\eta_p^2 = .101$; Cz: $F(1, 24) = 0.18$, $p = .671$, $\eta_p^2 = .008$; Pz: $F(1, 24) = 0.66$, $p = .426$, $\eta_p^2 = .027$). In the 500–700 ms time window there was a significant effect of sentence type over lateral electrodes because ungrammatical sentences exhibited a widely-distributed positivity relative to grammatical sentences. In the 700–900 ms time window there was a significant effect of sentence type that was qualified by a significant interaction between sentence type and anteriority, because the enhanced positivity for ungrammatical sentences showed a central-posterior distribution (anterior: $F(1, 24) = 1.86$, $p = .186$, $\eta_p^2 = .072$; central: $F(1, 24)$
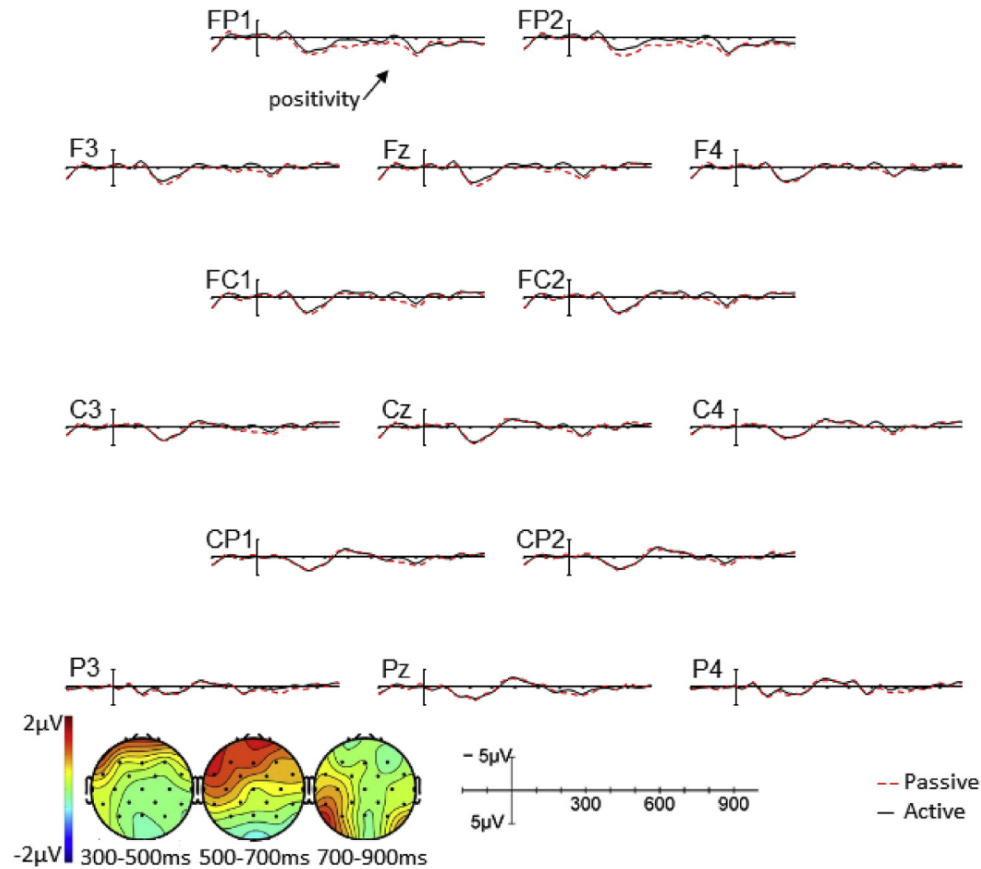
Fig. 1. Grand mean ERPs for active (black solid) and passive (red dotted line) sentences in Experiment 1. Onset of the verb is indicated by the vertical calibration bar; each tick mark represents 100 ms of time. Negative voltage is plotted up. In this and subsequent figures, ERP waveforms were filtered with a 15 Hz low-pass filter for plotting purposes only. Topographical maps show the scalp distribution of activity in the passive minus active conditions, averaged for the 300–500 ms, 500–700 ms and 700–900 ms time windows. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 1
F-statistics from the grand average ANOVAs on mean amplitudes for active/passive sentences (Experiment 1).

	df	300–500 ms		500–700 ms		700–900 ms	
		F	η_p^2	F	η_p^2	F	η_p^2
Midline							
Sent. type	(1, 24)	0.10	.004	2.42	.091	0.05	.002
Sent. type x Electrode	(2, 48)	2.48	.094	6.09*	.202	0.20	.008
Lateral							
Sent. type	(1, 24)	1.20	.048	5.59*	.189	0.56	.023
Sent. type x Hemi.	(1, 24)	1.79	.069	2.98†	.111	3.04†	.113
Sent. type x Ant.	(2, 48)	7.01**	.226	6.81*	.221	1.02	.041
Sent. type x Hemi. x Ant.	(2, 48)	0.22	.009	0.26	.011	0.74	.030

†$p < .1$ *$p < .05$ **$p < .01$.
Sent. type = sentence type; Hemi = hemisphere; Ant. = anteriority.

2.3. Discussion

To summarize the findings, participants exhibited a positivity that was maximal over anterior electrodes for passive versus active sentences in the 500–700 ms time window. In contrast, participants exhibited a P600 that was maximal over posterior electrodes for ungrammatical versus grammatical items in the 500–700 ms and 700–900 ms time windows. This suggests that the revisions par-
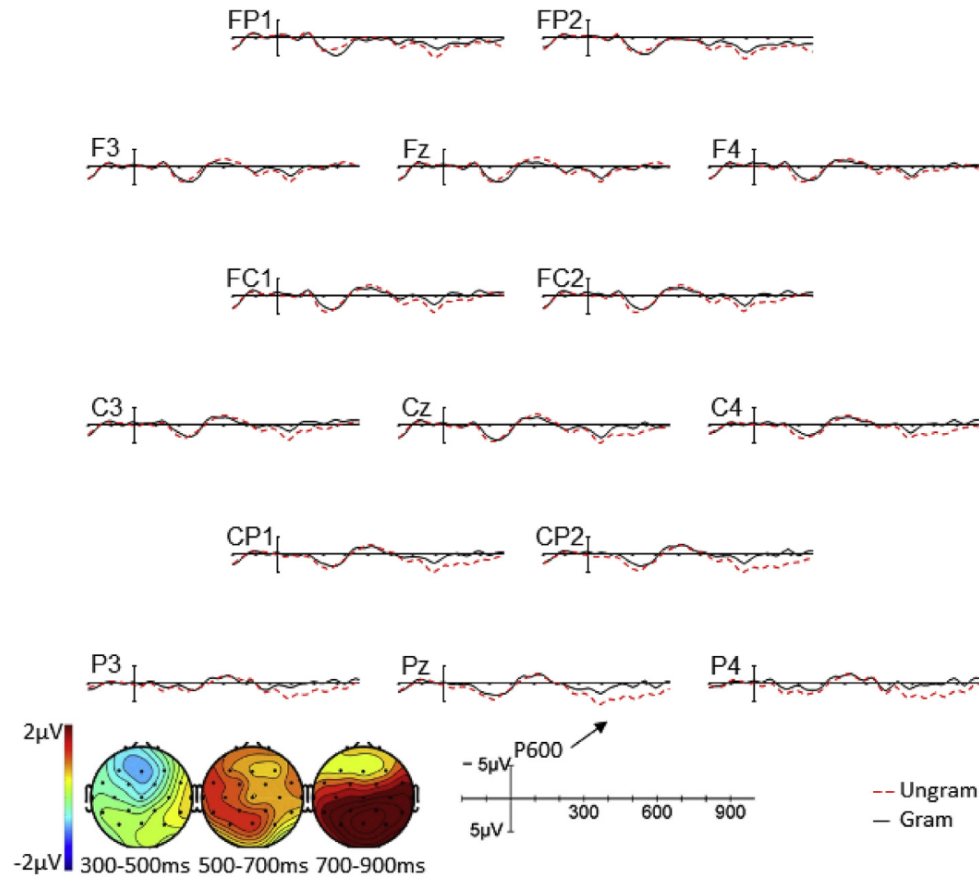
Fig. 2. Grand mean ERPs for grammatical (black solid) and ungrammatical (red dotted line) sentences in Experiment 1. Onset of the verb is indicated by the vertical calibration bar; each tick mark represents 100 ms of time. Negative voltage is plotted up. Topographical maps show the scalp distribution of activity in the ungrammatical minus grammatical conditions, averaged for the 300–500 ms, 500–700 ms and 700–900 ms time windows. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 2
F-statistics from the grand average ANOVAs on mean amplitudes for grammatical/ungrammatical sentences (Experiment 1).

	df	300–500 ms		500–700 ms		700–900 ms	
		F	η_p^2	F	η_p^2	F	η_p^2
Midline							
Sent. type	(1, 24)	0.53	.022	2.87	.107	7.90*	.248
Sent. type x Electrode	(2, 48)	4.61*	.161	1.29	.051	19.65***	.450
Lateral							
Sent. type	(1, 24)	0.00	< .001	4.87*	.169	10.62**	.307
Sent. type x Hemi	(1, 24)	1.94	.075	1.55	.061	3.21†	.118
Sent. type x Ant.	(2, 48)	1.22	.048	0.01	< .001	9.29**	.279
Sent. type x Hemi. x Ant.	(2, 48)	0.01	.004	0.20	.008	0.01	.001

†$p < .1$ * $p < .05$ **$p < .01$ ***$p < .001$.
Sent. type = sentence type; Hemi = hemisphere; Ant. = anteriority.

Given discussions emphasizing the need for replicability and reproducibility in psychological research, and the novelty of our findings, before considering the implications of these results, we deemed it important to replicate the finding of a frontal positivity for passive sentences with different experimental parameters, to minimize the possibility that this effect reflects some sort of task-specific strategy (see discussion on the importance of replication in Luck & Gaspelin, 2017). Previous research has shown that the presence of ERP components, and their amplitude, can vary based on the ratio of grammatical versus ungrammatical sentences (Coulson, King, & Kutas, 1998) and whether participants focus primarily on syntactic versus semantic processing (Hahne & Frederici, 2002). In Ex-

3. Experiment 2

3.1. Methods

3.1.1. Participants

Thirty-five functionally monolingual English speakers from the same population as Experiment 1 participated for course credit. Thirteen participants were excluded due to significant early exposure to a language besides English (4), being left-handed (1), testing session errors (4), or excessive artifacts in the raw EEG (4). All results are based on the remaining 22 participants (10 males; 12 females; mean age: 19.1 years, range: 18–21). All participants were right-handed, had normal or corrected-to-normal vision, and no reported history of any neurological impairment.

3.1.2. Materials

Materials were identical to those in Experiment 1, except that only the grammatical versions of the 72 grammatical/ungrammatical sentences were used. All ungrammatical filler items were replaced with their grammatical counterparts by using the appropriate form of the lexical verb.

3.1.3. Procedure; data acquisition and analysis

The procedure and data acquisition and analysis were identical to Experiment 1. A total of 10.2% of trials were excluded due to eye blinks, excessive muscle artifacts, or drift; this number did not differ reliably across conditions.

3.2. Results

3.2.1. Comprehension accuracy

Participants were highly accurate in their answers to the comprehension questions, across experimental and filler items, $M = 92.7\%$, $SD = 10.1$, 95% CI [88.2, 97.1]. A t-test comparing comprehension accuracy on active/passive sentences that tested the assignment of thematic roles revealed that participants were significantly more accurate ($t(21) = 2.13$, $p = .045$, $d = 0.46$) on active ($M = 85.8\%$, $SD = 16.0$, 95% CI [78.7, 92.9]) than passive sentences ($M = 78.4\%$, $SD = 15.5$, 95% CI [71.5, 85.3]). These accuracy rates did not differ significantly from those in Experiment 1 (overall: $t(45) = 0.43$, $p = .672$; active sentences: $t(45) = 0.50$, $p = .620$; passive sentences: $t(45) = 1.19$, $p = .241$).

3.2.2. ERP results

Active/passive sentences. Visual inspection suggests a positivity in the 500–700 ms time window for passive sentences compared to active sentences (see Fig. 3). The ANOVA results are presented in Table 3. In the 300–500 ms time window, there were no significant effects or interactions. In the 500–700 ms time window, there was a significant interaction between sentence type and hemisphere over lateral electrodes because the positivity for passive sentences relative to active sentences showed a left hemisphere distribution (left: $F(1, 21) = 5.35$, $p = .031$, $\eta_p^2 = .203$; right: $F(1, 21) = 1.63$, $p = .216$, $\eta_p^2 = .072$). In the 700–900 ms time window, there were no significant effects or interactions.

Combined active/passive results from Experiments 1 and 2. We directly compared the mean ERP amplitudes for passive versus active sentences in Experiments 1 and 2, entering experiment (Experiment 1 vs. Experiment 2) as an additional factor. There was no significant 2-way interaction between sentence type and experiment, nor were any higher order interactions involving both factors statistically significant (all $ps > .2$; all $\eta_p^2 < .037$). The critical interaction between sentence type and anteriority in the 500–700 ms time window from Experiment 1 was significant in this combined analysis. As seen in Figs. 1 and 3, the positivity for passive sentences was larger at anterior sites in both experiments, even if this interaction did not reach significance in Experiment 2. Similarly, the interaction between sentence type and hemisphere in the 500–700 ms time window from Experiment 2 was also significant in this combined analysis. As seen in Figs. 1 and 3, the positivity for passive sentences was larger at left hemisphere sites in both experiments, even if this interaction was not statistically significant in Experiment 1. Due to increased statistical power in the combined analyses, the marginally significant interactions between sentence type and electrode, sentence type and hemisphere, and sentence type and anteriority in the 300–500 ms time window were also statistically significant because of a larger positivity for passive versus active sentences at anterior and left hemisphere sites in both experiments. Finally, there was a significant interaction between sentence type and hemisphere in the 700–900 ms time window, but follow-up ANOVAs revealed no significant effects in either hemisphere (left: $F(1, 45) = 0.16$, $p = .693$, $\eta_p^2 = .003$; right: $F(1, 45) = 0.59$, $p = .446$, $\eta_p^2 = .013$) (see Appendix A for the complete results). In a final analysis, t-tests comparing the difference in mean ERP amplitude between passive and active sentences for each individual lateral-electrode ROI and each midline electrode in the 500–700 ms time window—where a significant positivity was found for passive sentences in each experiment individually – for Experiment 1 versus Experiment 2 similarly revealed no significant difference in the magnitude of the positivity for passive sentences between the two experiments (all $ts < 1.25$; all $ps > .2$).
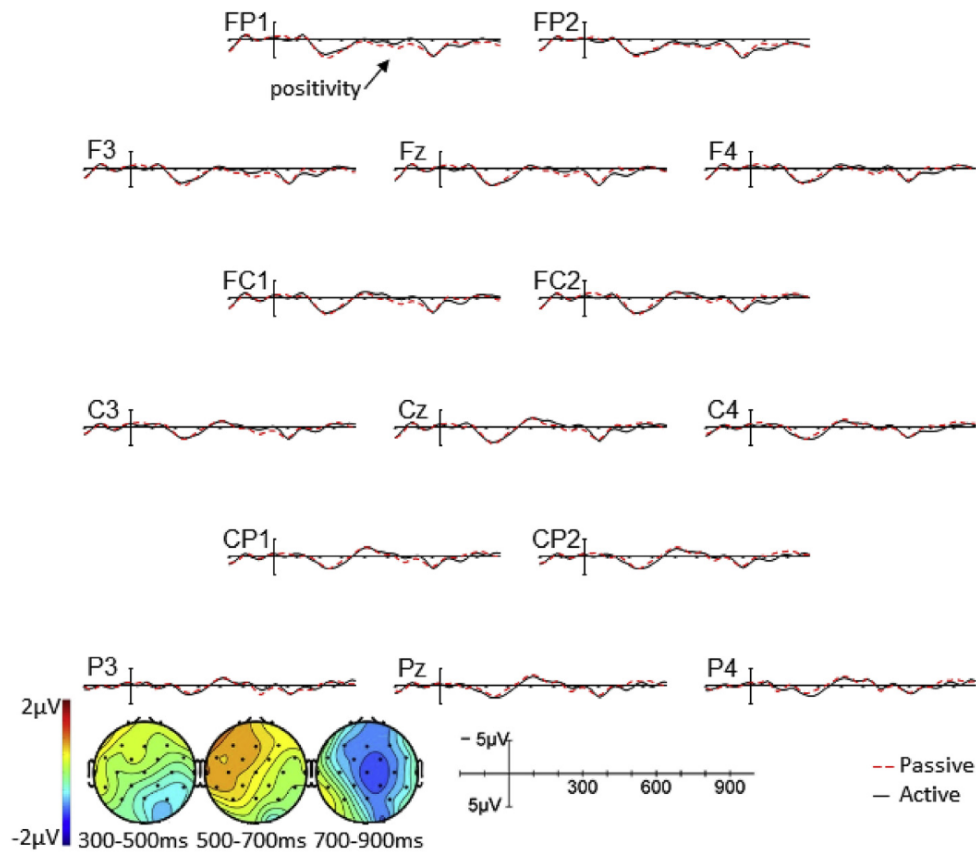
Fig. 3. Grand mean ERPs for active (black solid) and passive (red dotted line) sentences in Experiment 2. Onset of the verb is indicated by the vertical calibration bar; each tick mark represents 100 ms of time. Negative voltage is plotted up. Topographical maps show the scalp distribution of activity in the passive minus active conditions, averaged for the 300–500 ms, 500–700 ms and 700–900 ms time windows. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 3
F-statistics from the grand average ANOVAs on mean amplitudes for active/passive sentences (Experiment 2).

	df	300–500 ms		500–700 ms		700–900 ms	
		F	η_p^2	F	η_p^2	F	η_p^2
Midline							
Sent. type	(1, 21)	0.00	< .001	3.23†	.133	3.91†	.157
Sent. type x Electrode	(2, 42)	2.64	.112	1.32	.059	0.39	.018
Lateral							
Sent. type	(1, 21)	0.18	.008	3.74†	.151	1.32	.059
Sent. type x Hemi.	(1, 21)	3.02†	.126	5.72*	.214	2.39	.102
Sent. type x Ant.	(2, 42)	2.91†	.122	0.67	.031	0.44	.020
Sent. type x Hemi. x Ant.	(2, 42)	0.87	.040	0.19	.009	1.80	.079

†$p < .1$ * $p < .05$.
Sent. type = sentence type; Hemi = hemisphere; Ant. = anteriority.

symmetrical passive sentences at the point readers encountered the lexical verb, which unambiguously identified the sentence as a noncanonical passive construction rather than a prototypical agent-first active sentence. This ERP response for passive sentences exhibited an anterior distribution in Experiment 1, contrasting with participants' responses to ungrammatical sentences, which was associated with a posterior-distributed P600 effect. In Experiment 2, this positivity for passive sentences exhibited a left-hemisphere distribution and was descriptively strongest in anterior electrodes, even when the passive sentences were embedded in a stimulus set that contained only grammatical and plausible sentences. The combined analysis confirmed that the positivity for passive sentences was strongest at anterior electrodes and left-hemisphere electrodes, with no significant main effect or interaction as a function of

when reading entirely grammatical and semantically plausible sentences. Paralleling previous research, participants in both experiments exhibited lower comprehension accuracy for passive versus active sentences, although their comprehension of passive sentences was still relatively high and comparable to the comprehension accuracy for passive sentences reported by Ferreira (2003). This suggests that these online processing difficulties – as demonstrated by participants' ERP responses—occurred within the context of accurate comprehension (as indexed by the behavioural responses to the comprehension questions), and that this frontal positivity, thus, indexes the temporary difficulty of revising earlier expectations about the sentence, rather than signalling complete comprehension failure per se.

More importantly, participants exhibited a frontal positivity rather than a posterior P600 effect, thus differing from research reporting a P600 effect at the point of syntactic disambiguation in garden-path sentences (e.g., Frisch et al., 2002; Gouvea et al., 2010; Osterhout & Holcomb, 1992; Qian et al., 2018). This suggests that the cognitive effort associated with comprehending passive sentences does not stem from the need for reanalysis and repair processes. Rather, we hypothesize that the participants predictively assigned prototypical agent-patient roles via word order, adopting a heuristic noun-verb-noun strategy in which the first noun is the assumed agent of the sentence, as proposed by Ferreira (2003). The frontal positivity elicited at the lexical verb indexes the need to revise this initial role assignment once participants realized they were reading a noncanonical passive sentence. Further, because the critical sentences in these experiments contained nouns that are equally plausible as the agent and patient, these initial predictions—and any subsequent revisions—could not be based on plausibility and real-world knowledge, but rather are specifically connected to the predictive assignment of thematic roles. As such, these results provide neurophysiological evidence to support models of sentence comprehension, such as good-enough processing (e.g., Christianson, 2016; Ferreira & Patson, 2007), that incorporate heuristic strategies as a key component. Further, this frontal positivity appeared immediately at the point of disambiguation, thus providing a crucial link between good-enough processing frameworks and recent work on predictive processing (e.g., Van Petten & Luka, 2012) by demonstrating how the implementation of such heuristic strategies—as a means to efficiently process upcoming input during comprehension—can lead one to actively predict not only upcoming words, but also core relationships between words during real-time language comprehension (see also Christiansen & Chater, 2016; Kuperberg, 2013).

The presence of a frontal positivity rather than a posterior P600 effect suggests that revisions for passive sentences at the point of disambiguation involved revising this initial thematic role assignment rather than structural revision. However, we acknowledge that one cannot entirely rule out the possibility that structural revisions were also involved on some level, as predictively assigning the role of agent to the sentence-initial noun would presumably also entail predicting an active sentence structure.[4] Thus, future research should consider how English speakers process active sentences in which the sentence-initial noun does not turn out to be a prototypical agent at the point one encounters the verb. Such research would provide additional evidence to support the hypothesis that speakers may adopt heuristic processing strategies along the lines of those outlined above during real-time sentence comprehension.

The present findings stand in contrast to other recent ERP research on the assignment of semantic-thematic roles, especially within the context of research on predictive processing, which generally reports a posterior P600 effect in response to lexical-semantic information, when such information leads to thematic-role assignments that conflict with comprehenders' real world knowledge (Chow, Smith, Lau, & Phillips, 2016, 2018; Kim & Osterhout, 2005; Kuperberg et al., 2003, 2007), or an N400 in response to atypical thematic role assignments on the basis of factors like animacy and case marking (Bornkessel-Schlesewsky & Schlesewsky, 2008; 2009). However, as highlighted in the Introduction, the majority of this previous research has relied on semantically incongruous sentences and, in the case of Chow et al. (2016, 2018), *wh*-constructions or object relative clauses in English, in which the lexical verb appears in clause-final position, even though SVO is the dominant word order in English. In contrast, the present study involved canonical noun-verb-noun constructions in which both nouns were animate and equally plausible as either the agent or the patient of the action. As such, the present study reflects the time course of and revisions associated with thematic-role assignment when English speakers process canonical and plausible noun-verb-noun sentences in the absence of constraining (and potentially incongruous) semantic information.

4.1. Conclusion

The assignment of semantic-thematic roles constitutes a core component of many current models of language comprehension (e.g., Bornkessel-Schlesewsky & Schlesewsky, 2009; Kuperberg, 2007; Trueswell et al., 1994). By focusing on the processing of grammatical and plausible passive versus active sentences, this study has uncovered novel evidence regarding the nature of thematic role assignment during real-time language comprehension, especially with regard to how the assignment and processing of agent/patient roles proceeds in the absence of grammatically anomalous or semantically incongruous sentences. The presence of a frontal positivity in response to passive versus active sentences in the present study—in contrast to the bulk of previous research, which has reported a posterior P600 or an N400 effect as a result of lexical-semantic manipulations in the input (see Kuperberg, 2013, for review)—suggests that the assignment of semantic-thematic roles proceeds rapidly and that subsequent revisions to the initial assignment of agent and patient roles may not always involve structural reanalysis and repair per se. In so doing, the present study provides a critical link between research on how comprehenders rely on prior linguistic and real-world knowledge to facilitate comprehension, and the growing body of behavioral and neurophysiological research that stresses the important role that multiple

CRediT authorship contribution statement

Carrie N. Jackson: Conceptualization, Methodology, Investigation, Writing - original draft. **Heidi Lorimor:** Conceptualization, Methodology, Writing - review & editing. **Janet G. van Hell:** Conceptualization, Methodology, Resources, Writing - review & editing, Supervision, Funding acquisition.

Declaration of competing interest

None.

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Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jneuroling.2020.100886.

Appendix A

Table A1
F-statistics from the grand average ANOVAs on mean amplitudes for passive/active sentences in Experiment 1 versus Experiment 2

	df	300–500 ms		500–700 ms		700–900 ms	
		F	η_p^2	F	η_p^2	F	η_p^2
Midline							
Sent. type	(1, 45)	0.05	.001	5.36*	.106	0.91	.020
Sent. type x Exp.	(1, 45)	0.06	.001	0.00	< .001	1.68	.036
Sent. type x Electrode	(2, 90)	4.64*	.093	6.63**	.128	0.28	.006
Sent. type x Exp. x Electrode	(2, 90)	0.50	.011	1.39	.030	0.30	.007
Lateral							
Sent. type	(1, 45)	1.23	.027	9.07**	.168	0.02	.001
Sent. type x Exp.	(1, 45)	0.38	.008	0.29	.006	1.66	.036
Sent. type x Hemi.	(1, 45)	4.68*	.094	8.45**	.158	5.39*	.107
Sent. type x Ant.	(1, 45)	9.29*	.170	5.73*	.113	0.73	.016
Sent. type x Exp. x Hemi.	(1, 45)	0.08	.002	0.24	.005	0.04	< .001
Sent. type x Exp. x Ant.	(1, 45)	0.50	.011	1.62	.035	0.74	.016
Sent. type x Hemi. x Ant.	(1, 45)	0.08	.002	0.23	.005	2.00	.043
Sent. type x Exp. x Hemi. x Ant.	(1, 45)	0.90	.020	0.21	.005	0.28	.006

†$p < .1$ * $p < .05$ **$p < .01$ ***$p < .001$.
Sent. type = sentence type; Hemi = hemisphere; Ant. = anteriority.

References

Acheson, D. J., Wells, J. B., & MacDonald, M. E. (2008). New and updated tests of print exposure and reading abilities in college students. *Behavior Research Methods, 40*(1), 278–289. https://doi.org/10.3758/BRM.40.1.278.

Bornkessel-Schlesewsky, I., & Schlesewsky, M. (2008). An alternative perspective on "semantic P600" effects in language comprehension. *Brain Research Reviews, 59*(1), 55–73. https://doi.org/10.1016/j.brainresrev.2008.05.003.

Bornkessel-Schlesewsky, I., & Schlesewsky, M. (2009). The role of prominence information in the real-time comprehension of transitive constructions: A cross--linguistic approach. *Language and Linguistics Compass, 3*(1), 19–58. https://doi.org/10.1111/j.1749-818X.2008.00099.x.

Brothers, T., Swaab, T. Y., & Traxler, M. J. (2015). Effects of prediction and contextual support on lexical processing: Prediction takes precedence. *Cognition, 136,* 135–149. https://doi.org/10.1016/j.cognition.2014.10.017.

Brothers, T., Swaab, T. Y., & Traxler, M. J. (2017). Goals and strategies influence lexical prediction during sentence comprehension. *Journal of Memory and Language, 93,* 203–216. https://doi.org/10.1016/j.jml.2016.10.002.

Brouwer, H., Fitz, H., & Hoeks, J. (2012). Getting real about semantic illusions: Rethinking the functional role of the P600 in language comprehension. *Brain Research, 1446,* 127–143. https://doi.org/10.1016/j.brainres.2012.01.055.

Brysbaert, M., New, B., & Keuleers, E. (2012). Adding part-of-speech information to the SUBTLEX-US word frequencies. *Behavior Research Methods, 44*(4), 991–997. https://doi.org/10.3758/s13428-012-0190-4.

1017/S0140525X1500031X.

Christianson, K. (2016). When language comprehension goes wrong for the right reasons: Good-enough, underspecified, or shallow language processing. *Quarterly Journal of Experimental Psychology, 69*(5), 817–828. https://doi.org/10.1080/17470218.2015.1134603.

Coulson, S., King, J. W., & Kutas, M. (1998). Expect the unexpected: Event-related brain response to morphosyntactic violations. *Language & Cognitive Processes, 13*(1), 21–58. https://doi.org/10.1080/016909698386582.

Ferreira, F. (2003). The misinterpretation of noncanonical sentences. *Cognitive Psychology, 47*(2), 164–203. https://doi.org/10.1016/S0010-0285(03)00005-7.

Ferreira, F., & Patson, N. D. (2007). The 'good enough' approach to language comprehension. *Language and Linguistics Compass, 1*(1-2), 71–83. https://doi.org/10.1111/j.1749-818X.2007.00007.x.

Friederici, A. D., Hahne, A., & Mecklinger, A. (1996). Temporal structure of syntactic parsing: Early and late event-related brain potential effects. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22*(5), 1219–1248. https://doi.org/10.1037/0278-7393.22.5.1219.

Friederici, A. D., Hahne, A., & Saddy, D. (2002). Distinct neurophysiological patterns reflecting aspects of syntactic complexity and syntactic repair. *Journal of Psycholinguistic Research, 31*(1), 45–63. https://doi.org/10.1023/A:1014376204525.

Frisch, S., Schlesewsky, M., Saddy, D., & Alpermann, A. (2002). The P600 as an indicator of syntactic ambiguity. *Cognition, 85*(3), B83–B92. https://doi.org/10.1016/S0010-0277(02)00126-9.

Frisson, S., Harvey, D. R., & Staub, A. (2017). No prediction error cost in reading: Evidence from eye-movements. *Journal of Memory and Language, 95*, 200–214. https://doi.org/10.1016/j.jml.2017.04.007.

Gouvea, A. C., Phillips, C., Kazanina, N., & Poeppel, D. (2010). The linguistic processes underlying the P600. *Language & Cognitive Processes, 25*(2), 149–188. https://doi.org/10.1080/01690960902965951.

Grey, S. E., Tanner, D., & Van Hell, J. G. (2017). How right is left? Handedness modulates neural responses during morphosyntactic processing. *Brain Research, 1669*, 27–43. https://doi.org/10.1016/j.brainres.2017.05.024.

Hagoort, P., Brown, C., & Groothusen, J. (1993). The syntactic positive shift (SPS) as an ERP measure of syntactic processing. *Language & Cognitive Processes, 8*(4), 439–483. https://doi.org/10.1080/01690969308407585.

Hagoort, P., Brown, C. M., & Osterhout, L. (1999). The neurocognition of syntactic processing. In C. M. Brown, & P. Hagoort (Eds.). *The neurocognition of language* (pp. 273–316). Oxford: Oxford University Press.

Hahne, A., & Friederici, A. D. (2002). Differential task effects on semantic and syntactic processes as revealed by ERPs. *Cognitive Brain Research, 13*(3), 339–356. https://doi.org/10.1016/S0926-6410(01)00127-6.

Hoeks, J. C., Stowe, L. A., & Doedens, G. (2004). Seeing words in context: The interaction of lexical and sentence level information during reading. *Cognitive Brain Research, 19*(1), 59–73. https://doi.org/10.1016/j.cogbrainres.2003.10.022.

Jasper, H. H. (1958). The ten-twenty system of the international federation. *Electroencephalography and Clinical Neurophysiology, 10*, 371–375. https://doi.org/10.1016/0013-4694(58)90053-1.

Kaan, E., & Swaab, T. Y. (2003). Repair, revision, and complexity in syntactic analysis: An electrophysiological differentiation. *Journal of Cognitive Neuroscience, 15*(1), 98–110. https://doi.org/10.1162/089892903321107855.

Kim, A., & Osterhout, L. (2005). The independence of combinatory semantic processing: Evidence from event-related potentials. *Journal of Memory and Language, 52*(2), 205–225. https://doi.org/10.1016/j.jml.2004.10.002.

Kuperberg, G. R. (2007). Neural mechanisms of language comprehension. *Brain Research, 1146*, 23–49. https://doi.org/10.1016/j.brainres.2006.12.063.

Kuperberg, G. R. (2013). The proactive comprehender: What event-related potentials tell us about the dynamics of reading comprehension. In B. Miller, L. Cutting, & P. McCardle (Eds.). *Unraveling the behavioural, neurobiological, and genetic components of reading comprehension* (pp. 176–192). Baltimore: Paul Brooks Publishing.

Kuperberg, G. R., Kreher, D. A., Sitnikova, T., Caplan, D. N., & Holcomb, P. J. (2007). The role of animacy and thematic relationships in processing active English sentences: Evidence from event-related potentials. *Brain and Language, 100*(3), 223–237. https://doi.org/10.1016/j.bandl.2005.12.006.

Kuperberg, G. R., Sitnikova, T., Caplan, D., & Holcomb, P. J. (2003). Electrophysiological distinctions in processing conceptual relations within simple sentences. *Cognitive Brain Research, 17*(1), 117–129. https://doi.org/10.1016/S0926-6410(03)00086-7.

Kutas, M., & Hillyard, S. A. (1980). Reading senseless sentences: Brain potentials reflect semantic incongruity. *Science, 207*(4427), 203–205. https://doi.org/10.1126/science.7350657.

Lopez-Calderon, J., & Luck, S. J. (2014). ERPLAB: An open-source toolbox for the analysis of event-related potentials. *Frontiers in Human Neuroscience, 8*, 213. https://doi.org/10.3389/fnhum.2014.00213.

Luck, S. J., & Gaspelin, N. (2017). How to get statistically significant effects in any ERP experiment (and why you shouldn't). *Psychophysiology, 54*(1), 146–157. https://doi.org/10.1111/psyp.12639.

Luke, S. G., & Christianson, K. (2016). Limits on lexical prediction during reading. *Cognitive Psychology, 88*, 22–60. https://doi.org/10.1016/j.cogpsych.2016.06.002.

Montag, J. L., & MacDonald, M. C. (2015). Text exposure predicts spoken production of complex sentences in 8-and 12-year-old children and adults. *Journal of Experimental Psychology: General, 144*(2), 447–468. https://doi.org/10.1037/xge0000054.

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia, 9*(1), 97–113. https://doi.org/10.1016/0028-3932(71)90067-4.

Osterhout, L., & Holcomb, P. J. (1992). Event-related brain potentials elicited by syntactic anomaly. *Journal of Memory and Language, 31*(6), 785–806. https://doi.org/10.1016/0749-596X(92)90039-Z.

Paczynski, M., & Kuperberg, G. R. (2012). Multiple influences of semantic memory on sentence processing: Distinct effects of semantic relatedness on violations of real-world event/state knowledge and animacy selection restrictions. *Journal of Memory and Language, 67*(4), 426–488. https://doi.org/10.1016/j.jml.2012.07.003.

Psychology Software Tools, Inc [E-Prime 2.0]. (2012). Retrieved from http://www.pstnet.com.

Qian, Z., Garnsey, S., & Christianson, K. (2018). A comparison of online and offline measures of good-enough processing in garden-path sentences. *Language, Cognition and Neuroscience, 33*(2), 227–254. https://doi.org/10.1080/23273798.2017.1379606.

Roland, D., Dick, F., & Elman, J. L. (2007). Frequency of basic English grammatical structures: A corpus analysis. *Journal of Memory and Language, 57*(3), 348–379. https://doi.org/10.1016/j.jml.2007.03.002.

Street, J., & Dabrowska, E. (2010). More individual differences in language attainment: How much do adult native speakers of English know about passives and quantifiers? *Lingua, 120*(8), 2080–2094. https://doi.org/10.1016/j.lingua.2010.01.004.

Szewczyk, J. M., & Schriefers, H. (2011). Is animacy special?: ERP correlates of semantic violations and animacy violations in sentence processing. *Brain Research, 1368*(12), 208–221. https://doi.org/10.1016/j.brainres.2010.10.070.

Trueswell, J. C., Tanenhaus, M. K., & Garnsey, S. M. (1994). Semantic influences on parsing: Use of thematic role information in syntactic ambiguity resolution. *Journal of Memory and Language, 33*, 285–318. https://doi.org/10.1006/jmla.1994.1014.

Unsworth, N., Heitz, R. P., Schrock, J. C., & Engle, R. W. (2005). An automated version of the operation span task. *Behavior Research Methods, 37*(3), 498–505. https://doi.org/10.3758/BF03192720.

Van Herten, M., Chwilla, D. J., & Kolk, H. H. (2006). When heuristics clash with parsing routines: ERP evidence for conflict monitoring in sentence perception. *Journal of Cognitive Neuroscience, 18*(7), 1181–1197. https://doi.org/10.1162/jocn.2006.18.7.1181.

Van Petten, C., & Luka, B. J. (2012). Prediction during language comprehension: Benefits, costs, and ERP components. *International Journal of Psychophysiology, 83*(2), 176–190. https://doi.org/10.1016/j.ijpsycho.2011.09.015.

Weckerly, J., & Kutas, M. (1999). An electrophysiological analysis of animacy effects in the processing of object relative sentences. *Psychophysiology, 36*(5), 559–570.

13