Journal of Memory and Language **45,** 200–224 (2001)
doi:10.1006/jmla.2000.2768, available online at http://www.academicpress.com on IDEAL®

Syntactic and Semantic Factors in Processing Gender Agreement in Hebrew: Evidence from ERPs and Eye Movements

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The interrelation between syntactic analysis of agreement and semantic processing was examined by recording eye movements and event-related potentials. Subject–predicate gender agreement was manipulated within Hebrew sentences. The subject was either animate or inanimate, with conceptual gender denoted by the subject's morphological structure. First-pass reading time was found to be longer for incongruent predicates than of congruent predicates but only if the predicate's gender was morphologically marked. Furthermore, this effect was larger in the animate than in the inanimate condition. Second-pass reading time was also prolonged by gender incongruity but this effect was not affected by either markedness or animacy. Gender incongruity enhanced the amplitude of an early negative potential (ostensibly ELAN), of a later negative potential (N400), and of a positive potential (P600). Like first-pass reading time, the congruity effect on the syntactically modulated P600 was significant only for marked predicates, but it did not interact with animacy. In contrast, the congruity effect on the semantically modulated N400 was significant only in the animate condition. The N400 was not affected by markedness. The congruity effect on the early negativity did not interact with either animacy or markedness. The interaction between semantic and syntactic processing and its time course are discussed within the framework set by interactive, constraint-based models for online sentence processing.

Key Words: gender agreement; eye movements; ERP; P600; N400.

The morphological structure of words appearing in a sentence is constrained by syntactic rules that use inflectional morphology to mark the grammatical roles of the words within the sentence. These syntactic constraints are agreement rules that involve various grammatical dependencies (such as gender, number, case, person, and definiteness) between sentential elements (such as the noun and its modifier as reflected in the agreement between a subject and its attribute). Although languages vary in the extent to which they use agreement rules, these rules constitute a general principle of the syntax of many languages.

A fundamental question concerning the processing of agreement rules is the extent to which this process is affected by semantic information. Although agreement relates to abstract grammatical relations, the inflections that determine the agreement also denote semantic properties, such as number and/or sex. Therefore, findings concerning the involvement of semantic factors in processing agreement are likely to contribute to the more general debate regarding the independence of the syntactic process. One view maintains that the syntactic processing is modular and that it interacts with other linguistic information only at the output level (e.g., Clifton, Speer, & Abney, 1991; Frazier, 1987). An alternative view posits mutual influence between the syntactic domain and multiple sources of linguistic constraints throughout the computation of sentence meaning (e.g., MacDonald, 1994; Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995). In the case of agreement rules, the proponents of the modular view suggest that agreement analysis is governed only by formal principles, which are applied, for example, via a process of inflection-feature checking. In contrast, proponents of the interactive, multiple-constraint-based models posit that agreement analysis is affected by the semantic properties of a word as well as its form.

This study was supported by a grant from the National Institute for Psychobiology in Israel, founded by the Charles E. Smith Family to A.D., and by Grant # 01994 from NICHD to S.B. through Haskins Laboratories. We thank Tamar Aharony, Gad On, Irit Shapira, and Nomi Wexler for their extensive help and assistance in preparing the stimuli and running the experiments.

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0749-596X/01 $35.00

The question whether the processing of agreement is, or is not, influenced by lexical-semantic factors has been examined using different experimental paradigms primarily in the context of language production. These studies focused on different types of agreement in different languages. The overall pattern of findings, however, is equivocal and apparently influenced by the language in which the study was conducted. For example, findings suggesting that the processing of subject–predicate number agreement in English is basically unaffected by semantic factors (Bock, 1995; Bock & Miller, 1991; Nicol, Forster, & Veres, 1997, Vigliocco, Butterworth, & Garrett 1996a; Pearlmutter, Garnsey, & Bock, 1999; but see Eberhard, 1999) are contradicted by evidence obtained for Italian, Spanish, Dutch, and French (Vigliocco, et al., 1996a; Vigliocco, Butterworth, & Semenza, 1995; Vigliocco, Hartsuiker, Jarema, & Kolk 1996b) as well as for gender agreement in Italian and French (Vigliocco & Franck, 1999). This inconsistency has been attributed to linguistic differences between the languages studied, such as the extent of use of agreement rules and their salience in each language (see, Vigliocco et al., 1996a, 1995, 1966b). The languages in which conceptual factors influenced the processing of agreement are relatively highly inflected, and the role of agreement as a syntactic tool in these languages is much more central than in English. This suggestion could be further supported by findings obtained in Hebrew. Although Hebrew, as a Semitic language, is very different from the above-mentioned Indo-European languages, like them, it is a highly inflected language: Agreement rules are important and form highly reliable syntactic cues. Converging evidence from remotely related languages may contribute to the ability to distinguish between language-specific and general psycholinguistic principles. Indeed, previous language comprehension studies in Hebrew showed that the syntactic analysis of subject–predicate agreement is susceptible to semantic influence (Deutsch, 1998; Deutsch, Bentin, & Katz, 1999). These findings form the starting point for the present investigation of possible semantic influence on processing agreement while reading Hebrew sentences.

Another factor that should be considered is whether the processing of agreement was examined in the course of language production or language comprehension. The comparison between the processing of agreement in language production and comprehension is not trivial. Whereas, in language production, the speaker needs to create the correct inflections in order to translate the grammatical roles of the words into syntactic structure, in language comprehension, the listener (or reader) needs to compute the agreement on the basis of given inflected forms in order to identify the grammatical role of the various words in the sentence. Unfortunately, studies of processing agreement during comprehension are scarce. In fact, except of our own previous study cited above, we are aware of only two studies examining agreement processing during sentence comprehension (Nicol et al., 1997; Pearlmutter et al., 1999). These studies, which were carried out in English, suggested that, at least in English, the processing of agreement in comprehension is, like in production, insensitive to conceptual information. Therefore, in addition to providing information for cross-linguistic comparisons, the present study, which focused on language comprehension processes, may enrich the very limited findings available on agreement computation in the course of language comprehension.

Most nouns and adjectives in Hebrew are inflected for gender and number. Verbs are also inflected for gender and number as well as for person and tense. The inflection is formed by the affixation of a suffix and or a prefix to a base form, often synthetically so that the morpheme binding entails changes in the phonological structure of the base form. The base to which the inflectional suffixes are appended is the masculine singular form in the nominal system and the masculine singular form in the verbal system. Hence, the masculine singular constitutes the *morphologically* unmarked form. The feminine-marking morpheme is usually one of the three possible suffixes, /**a**/, /**et**/, or /**it**/, used by both nouns and verbs. For instance, the feminine form of the noun “yeled” (masc. sing., “a boy”) is “yald**a**” (sing. fem., “a girl”); in the verbal system the feminine form of a verb such as “nopel” (masc. sing. present: “is falling down”) is “nopel**et**” (fem. sing.). The plural-marking morpheme is /**im**/ or /**ot**/, where /**im**/ is usually used for masculine forms and /**ot**/ for feminine forms. In the above example, the plural form of “yeled” (masc. sing.) is “ylad**im**” (masc. pl.) and the plural form of “yald**a**” (fem. sing.) is “ylad**ot**” (fem. pl.). Indeed, there are exceptional cases in which feminine nominal forms are not marked by one of the feminine inflectional markers. Furthermore, there are also a few cases in which the plural suffix /**ot**/ is used for masculine forms and the suffix /**im**/ for feminine forms. However, because most exceptional cases involve inanimate rather than animate nouns, these exceptions do not reduce the reliability of the inflections as markers of conceptual gender.

Being a highly inflected language, syntactic relations in Hebrew are denoted primarily by matching inflectional affixes (imposed by the agreement), relying far less on other structural factors such as, for example, word order.

The main agreement rules operating in Hebrew are between the subject and the predicate and the subject and the attribute.[1] The predicate and the attribute must agree with regard to gender and number with the subject (and also with regard to person if the predicate is a verb in the past, future, or imperative forms). In addition, the subject and attribute also agree with regard to article. For example, the sentence, “The cute boy is falling into the pond,” which translates into Hebrew as “Hayeled (sub.—article “ha” — masc. sing. “the boy”) hanexmad (attrib.—article “ha” — masc. sing. “cute”) nopel (pred.—masc. sing. present “is falling”) letoch habrecha (“into the pool”) becomes, when referring to a girl, “Hayald**a** hanexmad**a** nopel**et** letoch habrecha.” As can be seen in the example, the masculine singular forms (the noun, the adjective, and the verb) are morphologically unmarked, whereas the feminine forms are all marked by a suffix. Furthermore, whereas the subject (**ha**yald**a**) and the predicate (nopel**et**) agree only with regard to gender and number (the suffixes /a/ and /et/), the subject (**ha**yald**a**) and the attribute (**ha**nexmad**a**) also take the same article. Thus, in most sentential structures, the agreement rules provide a reliable cue for identifying the basic syntactic categories in the sentence and for constructing the subject–predicate structure. In addition to their role in specifying the relationship between words, the grammatical markers of inflectional morphology also convey semantic information. This information may pertain to concepts such as person, number, or, particularly relevant to the present study, the sex of animate nouns. Disentangling the effects of syntactic and semantic information conveyed by inflectional markers on processing the agreement is difficult. A possible solution is provided by gender agreement in languages like Hebrew whereby the same inflectional suffixes are used for marking the gender of both animate and inanimate nouns. It should be noted, however, that in Hebrew, with few exceptions, the sex correlates with the grammatical gender denoted by inflectional morphology. Hence, by using identical inflectional tools, it is possible to disentangle grammatical and conceptual consequences. Whereas gender agreement between subject and predicate reflects only grammatical matching for inanimate nouns, it is also associated with the semantic feature of sex when the nouns are animate.

Using this feature of Hebrew, Deutsch et al. (1999) used a syntactic priming paradigm to examine the sensitivity of syntactic agreement analysis to semantic factors. Participants read a list of sentences, half of which violated subject–predicate gender agreement and, therefore, were syntactically incongruent. The effect of a word’s semantic content on gender-agreement processing was assessed by comparing the effect of agreement violation in sentences in which the sentential subject was an animate noun and in sentences in which the subject was an inanimate noun. The working hypothesis was that the violation of gender agreement for

[1] Agreement rules are similarly applied, in other forms of grammatical relations, such as between an object and its attribute or a verb and its adverbial modifier. However, we do not specify these rules, as they are not crucial for the understanding of the present experiments.

animate nouns involves, in addition to the grammatical violation, a semantic mismatch between the biological sex denoted by the subject and the incongruent predicate. Therefore, if the processing of agreement is sensitive to semantic factors, then the interference effect induced by the violation of the agreement should be greater for sentences in which the sentential subject is animate than for sentences in which it is inanimate. The results showed, as expected, that the congruity effect on naming latency was larger when the same predicate was coupled with an animate subject than when it was coupled with an inanimate subject. In light of this result, it was suggested that semantic information interacts with the processing of subject–predicate agreement.

The results of Deutsch et al. (1999) support an interactive approach to agreement processing but they do not specify the time course of this interaction. Does the influence of semantic factors on agreement processing reflect mutual influences during lexical access and/or during the initial integration of the word within the context, or does it reflect processes that take place at later stages, such as more global processes of sentence integration? To answer this question and obtain a more comprehensive account for the interaction, the process of sentence comprehension needs to be examined throughout its progression. Examination of this type cannot be based only on off-line measures, such as naming latency. It requires on-line data collection of the process involved, using measures that allow for good temporal resolution.

Another common shortcoming of most paradigms used in studies of sentence processing is that they use stimulus presentation methods that disrupt the natural flow of reading (for example, “word-by-word” presentation). This shortcoming could have been particularly deleterious for examining the involvement of semantic information in processing the agreement. This is because the extent of semantic involvement might be biased by temporal factors, such as exposure time and rate of presentation. Therefore, examining the interaction between semantic and syntactic factors in the processing of agreement is likely to benefit from evidence obtained in a more natural setting.

Finally, additional limitation of conclusions based only on performance measures such as reaction time and accuracy is that they may reflect a composite effect of the processes under investigation. In particular, ascribing the longer reaction time required to name animate as opposed to inanimate incongruent predicates to the differential involvement of semantic factors in the two conditions was mainly based on the assumption that the manipulation of animacy reflects semantic factors (Deutsch et al., 1999). However, the validity of the interpretation of these results is likely to be enhanced by variables that are independently influenced by semantic and syntactic processes.

With the above concerns in mind, in the present study we recorded eye movements and brain event-related potentials (ERPs) while subjects read sentences. The subject–predicate gender agreement and semantic factors were manipulated in these sentences using the same procedure as in Deutsch et al. (1999). Both measures have been shown to provide reliable on-line measures of reading performance (see following review). In addition, the ERPs are expected to provide independent indexes of semantic and syntactic processes, and eye movements will enhance the ecological validity of the natural process of reading.

Following is a brief description of the main features of each of these two methods, with special focus on studies in which these methods were used to explore the syntactic process of agreement analysis and its interaction with semantic factors. Because the present study examined only the processing of subject–predicate agreement, the following survey will be limited to findings based on the investigation of this type of agreement.

Eye Movements in the Study of Subject–Predicate Agreement

The main advantage of the eye-movement technique is that data are collected in almost natural conditions—silent reading of complete sentences, with participants in control of their reading rate. The principal measure used in the investigation of reading processes is the duration of eye fixations on target words. Because the spatial location of each fixation is monitored on-line, this procedure has the capacity to distinguish between at least two major phases of reading: “first-pass duration” and “total fixation time” on a target. First-pass duration (also termed “gaze duration”) refers to the duration of all the fixations on the target word from the first time the reader’s eyes encounter it until the eyes move to preceding or following parts of the sentence. Because the first-pass duration often includes more than one fixation, it is possible to distinguish the “first fixation duration” from the subsequent fixations included in the first-pass duration. Total time refers to the summed duration of all fixations made on the target word, including later fixations resulting from regressive movements from subsequent words in the sentence or rereading of the sentence starting at words prior to the target. Operationally, it is possible to calculate the “second-pass duration,” which includes all fixations on the target area on a second encounter, but not the duration of the first pass. It should be noted that although it may be tempting to link lexical access, initial integration of a word in its local context, and sentence reanalysis directly with first fixation duration, first-pass duration, and total-time duration, such attempts are probably unwarranted. Nonetheless, it is commonly accepted (Rayner & Pollatsek, 1989; Reichle, Pollatsek, Fisher, & Rayner, 1998) that processes associated with single word analysis and on-line integration of the word into its immediate local context mainly affect the first-pass duration (as well as first fixation duration) and that later processes of global sentence integration and/or reanalysis of the sentence mainly affect the total time (as well as second-pass duration). Thus, the monitoring of eye movements may help throw light on the interaction between syntactic and semantic processes taking place during the on-line process of word identification and its integration in the immediate context, as well as processes that take place later, during sentence comprehension. The sensitivity of eye movements to subject–predicate agreement processing was reported in Hebrew (Deutsch, 1998) and in English (Pearlmutter et al., 1999). In these studies, participants were instructed to read sentences that were either syntactically (and semantically) intact or syntactically incorrect due to violation of the subject–predicate agreement in respect to gender and/or number. In the Hebrew study, when the predicate immediately followed the subject, both the first-pass duration (gaze duration) and the total time duration were longer during the processing of syntactically incongruent as opposed to congruent predicates. However, this congruity effect disappeared when an attributive phrase of five words was embedded between the subject and the predicate. Assuming that the “distance” manipulation implied the conceptual mapping of the sentential subject and its semantic analysis prior to reading the predicate, Deutsch (1998) suggested that the processing of agreement in Hebrew might be susceptible to on-line semantic and/or conceptual processes.

In the present study, we applied the animacy manipulation (Deutsch et al., 1999) to further explore the susceptibility of agreement processing to semantic factors, focusing primarily on the temporal aspects of this interaction. If semantic factors interact with the immediate, on-line process of agreement analysis, then the interaction between animacy and agreement congruity should emerge already in the first-pass duration. Specifically, the violation of gender agreement should interfere more with the first-pass duration of the predicate in animate as opposed to inanimate contexts. If, however, the immediate, on-line process of agreement analysis is restricted to form agreement and is opaque to other sources of information, then measures of first-pass duration should reflect the interference of agreement independently of the semantic features of the sentential subject. Specifically, the interaction between animacy and congruity should not emerge in the first-pass duration analysis, but rather in the total time and/or second pass, the measures associated with the reanalysis of the sentence triggered by difficulties in global sentence integration.

ERPs in the Study of Subject–Predicate Agreement

Event-related brain potentials reflect processing-induced changes in brain activity and provide an on-line index of processing with high temporal resolution. Therefore, ERPs may help charting the time course of various cognitive processes. In addition, because different cognitive processes modulate brain activity in different ways, the recording of ERPs can assist in separating qualitatively different processes by demonstrating their association with different ERP components.

ERPs have been used extensively in word perception and reading research and showed to be sensitive to semantic and syntactic factors during the course of comprehension (e.g., Ainsworth-Darnell, Shulman, & Boland, 1998; Neville, Nicol, Barss, Forster, & Garrett, 1991; Osterhout & Mobley, 1995; for a review see Kutas & Van Petten, 1994). The most documented component associated with semantic processing is the N400, a negative trough in the waveform, peaking at about 400 ms from stimulus onset. Its particular association with semantic processes was first demonstrated by Kutas and Hillyard (1980), who found that its amplitude is modulated by the semantic coherence of the final word in a sentence, but not by its physical match with the other words. Since its discovery, much effort has been invested toward understanding its association with lexical activity elicited by single-word processing (e.g., Bentin, 1987; Bentin, McCarthy, & Wood, 1985; Nobre & McCarthy, 1994; Rugg & Nagy, 1987; Van Peten & Kutas, 1990, 1991) and with contextual semantic processes (e.g., Holcomb & Neville, 1990; Kutas & Hillyard, 1984; Kutas, Lindamood, & Hillyard, 1984; Van Petten & Kutas, 1990). Although the precise cognitive mechanism underlying its sensitivity to semantic factors is not fully understood, there is ample evidence demonstrating its validity in indexing word-related semantic activity (Kutas, 1993; for a review, see Kutas & Van Petten, 1994). Particularly relevant to the present study is the fact that, in contrast to its sensitivity to semantic manipulations, N400 was not modulated by manipulation of syntactic factors (Ainsworth-Darnell et al., 1998; Gunter, Stowe, & Mulder, 1997; Kutas & Hillyard, 1983; Neville at al., 1991; Osterhout & Mobley, 1995). Hence, regardless of the exact interpretation of the mechanisms involved in its elicitation, the N400 has the capacity to distinguish between semantic and syntactic processes occurring during sentence comprehension.

Syntactic manipulations usually modulate two ERP components: One is the P600, a positive peak around 500–600 ms from word onset (Osterhout & Holcomb, 1992). This component [also labeled "syntactic positive shift" (SPS), Hagoort, Brown, & Groothusen, 1993], is usually largest at central and parietal sites (e.g., Coulson, King, & Kutas, 1998; Friederici, Hahne, & Mecklinger, 1996; Osterhout & Mobely, 1995), although one study reported a right anterior maximum (Osterhout & Holcomb, 1992). The other component is the LAN, a left anterior negativity initially reported by Kluender and Kutas (1993), which was later associated by some authors with syntactic processing (e.g., Friederici, Pfeifer, & Hahne, 1993; Neville et al., 1991). In some studies, the LAN was found between 200 and 500 ms from word onset (Coulson et al., 1998; Münte, Matzke, & Johannes, 1997; Münte, Heinze, & Mangun, 1993; Neville et al., 1991; Osterhout & Holcomb, 1992; Osterhout & Mobley, 1995; Rösler, Pütz, Friederici, & Hahne, 1993), whereas in others it was found even earlier, between 100 and 300 ms from word onset (Friederici et al., 1993, 1996; Hahne & Friederici, 1999; Neville et al., 1991). Given this considerable temporal variation, the earlier negative trough was separately labeled ELAN to reflect its early onset (Friederici et al., 1993; Hahne & Friederici, 1999).[2] The LAN and the P600 have been found to coexist in some cases (Coulson et al., 1998; Friederici et al., 1996; Gunter et al., 1997; Osterhout & Holcomb, 1992; Osterhout & Mobley, 1995; Neville et al., 1991; Rösler et al., 1993). The multitude of ERP manifestations of syntactic processing is probably accounted for by the variability in the syntactic rules manipulated in different studies.

Previous ERP studies of subject–verb agreement processing focused on number agreement.

[2] The difference in the onset of this early negativity may be associated with the time that the critical information becomes available (Friederici et al., 1996).

These studies were carried out in various languages, such as English (Coulson et al., 1998; Osterhout, McKinnon, Bersick, & Corey 1996; Osterhout, & Mobley, 1995), Dutch (Hagoort et al., 1993), and German (Münte et al., 1997). In all these studies, violation of agreement was associated with enhanced P600. Indeed, in two of these studies, LAN was also evident (Coulson et al., 1998; Osterhout & Mobley, 1995). However, the effects of violation of agreement on the size of the LAN (to be refered to as "modulation of the LAN") were found only under specific circumstances: In the Osterhout and Mobley (1995) study, the LAN was modulated when the participants performed an acceptability task, but not when they simply read sentences. In the Coulson et al., (1998) study, violation of agreement involved the inflection of *closed class* words (pronouns). When syntactic anomaly was induced by violation of agreement between the inflection of two *open class* words (constituting the subject and the predicate of the sentence) the modulation of the LAN was unstable or not evident at all, whereas the P600 was enhanced (Hagoort et al., 1993; Münte et al., 1997; Osterhout et al., 1996). In line with the relative higher consistency of the agreement effects on the P600, at least in the case of open class words, our predictions in the present study focused primarily on this ERP component.

Despite the apparently evident association between syntactic processing and the P600, the cognitive mechanism that underlies its modulation is still debatable. One question is whether the enhanced positivity in response to syntactic violations is uniquely related to syntactic processing or, alternatively, whether the P600 is a member of a late positive potentials (e.g., P300), which are sensitive to unexpected, task-relevant events (e.g., Coulson et al., 1998; Gunter et al., 1997; Hagoort et al., 1993; Osterhout et al., 1996). Although, this debate is not solved, it is usually agreed that, at the very least, the P600 can reliably index syntactic processing (Osterhout et al., 1996). Another question is what exactly is the syntactic process that modulates the P600: Is it the mere detection of ungrammaticality, or is it the reanalysis of ungrammatical or ambiguous structures? In light of its fairly late occurrence (500–600 ms after word onset) and its elicitation by disambiguating words in garden-path sentences, many researchers consider the P600 as being associated with additional processing of local ungrammaticality and/or global reanalysis of ungrammatical sentences.

On the basis of the differential association of N400 with semantic processes and the LAN and P600 with syntactic processes, we predicted different patterns of ERP in sentences in which the gender agreement correlates with semantic features (the animate condition) and sentences in which the manipulation of gender agreement has no semantic consequences (the inanimate condition). Specifically, we predicted that incongruent predicates would modulate all of the above components in the animate condition, whereas in the inanimate condition the incongruent predicates will modulate only the syntax-associated components.

Although the ERP data seem capable of providing a distinct index of brain activity involving semantic and syntactic processes, their interpretation in the context of natural reading is weakened because ERPs are usually recorded in unnatural reading conditions, namely when sentences are presented word by word at a fairly slow pace. This shortcoming is overcome by the eye-movement technique. Thus, in addition to the separate contribution of each of these techniques to the understanding of sentence comprehension processes, contrasting and converging evidence from both types of data is important for a general theory of reading. Furthermore, correspondence between the specific measures of eye movements (i.e., first-pass and second-pass) and specific ERP components, namely the LAN and the P600, may help illuminate the processes of syntactic analysis and sentence comprehension associated with each of these two components. In the following two experiments, we recorded eye movements (Experiment 1) and ERPs (Experiment 2) while participants read sentences in which agreement congruity for sentences including an animate or an inanimate subject was manipulated.

EXPERIMENT 1

Methods

Participants. Thirty-two adult native Hebrew speakers, students at the Hebrew University, participated in the experiment for course credit or payment.

Stimuli. The critical stimuli were 104 target words embedded in sentences. All sentences had a complex structure. Each began with a main clause of three to four words followed by a sentential object complement. An English example would be the following: "The woman saw that *the boy had fallen into the pool*." The target word in each sentence was the predicate of the sentential object complement clause ("had fallen"); it was never the last word of the sentence and it was always adjacent to its subject. Congruity and animacy were manipulated within the object-complement clause. Although the sentential object complement was located in a syntactically subordinate part of the sentence, it played an essential role in the sentence context, independent of the main clause. In fact, the subordinate clause carried the primary content of the sentence.[3] Each target word appeared in four different sentence-context conditions: (1) animate-congruent, (2) animate-incongruent, (3) inanimate-congruent, and (4) inanimate-incongruent. In the animate conditions, the subject of the sentence was an animate noun, and in the inanimate conditions, it was an inanimate noun. In the congruent conditions the target agreed with regard to gender with the subject and in the incongruent conditions it did not. The grammatical gender of all the subjects, predicates, and attributes, as well as the conceptual gender of all animate subjects, used in this study could be deduced on the basis of their morphological structure.

All targets were masculine forms. In order to control for specific effects of morphological markedness on the rules of agreement, 52 target predicates were singular (unmarked) verbal forms, such as "*napal*" ([he] fell), and 52 target predicates included the suffix "im" [i.e., denoting a plural (marked), form, such as "maksim**im**" ([they] fascinate].[4] The four experimental conditions with morphologically unmarked (1a–1d) and marked (2a–2d) predicates are illustrated in Table 1.

The resulting 416 sentences were divided into four experimental lists. Each list included 104 different sentences, 52 unmarked (masc. sing.) predicates, and 52 marked predicates (masc. pl.). Within each list, there were 26 sentences (13 in the "marked" and 13 "unmarked" form) in each of the four (animacy × congruity) conditions. The target words were rotated across lists so that each participant saw each target only once, but across participants, each target was presented in all animacy × congruity conditions (once in the marked and once in the unmarked form). Eight different participants were randomly assigned to each list.

Apparatus. Eye movements was recorded by a SR Research Ltd. (Canada) EYELINK eyetracker, a videobased tracking system that samples pupil location at the rate of 250 Hz.

The sentences were presented on a video monitor (EIZO FlexScan F563/T) and controlled by a 586 computer. Eye-movement data were collected by a second 586 computer interfaced to the eye-tracker and synchronized with the stimulus-control computer. Although viewing was binocular, only data from the right eye were used for analysis purposes. The spatial resolution of the eye-tracking system was less than half a degree. Participants were seated 46 cm

[3] This specific sentential structure was chosen because the eye-movement technique used in the experiment does not allow for target areas to be located at the beginning of a single sentence.

[4] Previous studies which examined the processing of subject–predicate agreement revealed morphological effects of markedness on the implementation of agreement rules in language production (Bock & Eberhard, 1993; Eberhard, 1997; Vigliocco et al., 1995). It has been suggested that the explicit appearance of an inflectional morpheme triggers the process of feature matching between the forms under agreement (Eberhard, 1997). Accordingly, the actual way agreement is processed may differ for marked and unmarked forms. Although the effect of markedness was not the main interest of the present study, we controlled for a possible markedness effect on the processing of agreement by creating two sets of stimuli in which the target word (the predicate), which is supposed to agree with the subject, is either morphologically marked (plural/masculine forms) or unmarked (singular/masculine forms).

TABLE 1
Examples of Sentences Used in the Four Experimental Conditions of Congruity × Animacy for Unmarked and Marked Predicates.

	Animate	Inanimate
Unmarked		
Congruent	"The woman saw that *the boy had fallen into the pond*." "Hʔiʃa raʔata ki *hayeled* (article "ha" + subject masc. sing. "the boy") napal (predicate masc. sing. "had fallen") letox habrexa."	"The woman saw that *the diamond had fallen into the pond*." "Hʔiʃa raʔata ki *hayahalom* (article "ha" + subject masc. sing. "the diamond") napal (predicate masc. sing. "had fallen") letox habrexa."
Incongruent	"The woman saw *that the girl had fallen into the pond*." "Hʔiʃa raʔata ki *hayald**a*** (article "ha" + subject fem. sing. "the girl") napal (predicate masc. sing. "had fallen") letox habrexa."	"The woman saw that *the necklace had fallen into the pond*." "Hʔiʃa raʔata ki *haʃarʃer**et*** (article "ha" + subject fem. sing. "the necklace") napal (predicate masc. sing. "had fallen") letox habrexa."
Marked		
Congruent	"I enjoyed seeing how *the actors were enchanting the tired audience*." "ʔani neheneti lirʔot keytzad *hasaxkan**im*** (article "ha" + subject masc. pl. "the actors") maksim**im** (predicate masc. pl. "enchanting") ʔet hakahal hasʕayef."	"I enjoyed seeing how *the movies were enchanting the tired audience*." "ʔani neheneti lirʔot keitzad *hasrat**im*** (article "ha" + subject masc. pl. "the movies") maksim**im** (predicate masc. pl. "enchanting") ʔet hakahal hasʕayef."
Incongruent	"I enjoyed seeing how *the actresses were enchanting the tired audience*." "ʔani neheneti lirʔot keytzad *hasaxkani**ot*** (article "ha" + subject fem. pl. "the actresses") maksim**im** (predicate masc. pl. "enchanting") ʔet hakahal hasʕayef."	"I enjoyed seeing how *the pictures were enchanting the tired audience*." "ʔani neheneti lirʔot keytzad *hatmun**ot*** (article "ha" + subject fem. pl. "the pictures") maksim**im** (predicate masc. pl. "enchanting") ʔet hakahal hasʕayef".

Note. The Hebrew examples with the English translations are shown.

from the video monitor, with 1.7 characters subtending a visual angle of 1°.

Procedure. The eye-tracking system was calibrated for each participant and the calibration was checked prior to the presentation of each sentence. Participants were told that sentences would appear on the video monitor one at a time and that they should read each sentence as they would normally do for comprehension. The participants were instructed to move their eyes to a green square (located at the bottom left-hand side of the monitor) after reading the sentence. In order to maintain participant alertness, a comprehension question occasionally appeared after a sentence to which they responded by pressing a "yes" or "no" button. Twenty-five percent of the sentences were followed by a question and participants had no difficulty answering them correctly (above 95% accuracy).

Each trial started with a fixation point on the right-hand side of the monitor, the location of which coincided with the location of the first letter in the sentence. Once the participant focused on the fixation point, the calibration was verified and the sentence was presented. Each experimental session began with 10 practice sentences (2 of which were followed by a question). Immediately following practice, the experimental sentences were presented in random order, using a different randomization for each participant. The 104 sentences were presented in two blocks of 52 sentences, with a short break between blocks.

Results

The assessment of the initial reading time of the target was based on gaze duration (i.e., first-pass duration) and duration of the first fixation, whereas the rereading and renalysis of the target was assessed by calculating the second-pass duration, i.e., the difference between total time and first pass. (We chose to conduct the statistical analysis on second-pass duration rather than on total time because second-pass duration is a "cleaner" measure of rereading, as it does not includes first-pass duration.) Because no other interesting eye-tracking effects, such as prolonged fixation on the word following the target word ("spillover" effects), were observed, no other measures are reported. Cutoff points of 140 and 800 ms were used to eliminate very short or very long single fixations. Trials with zero-fixations in first pass were not included in the computation of the first-pass or the total-time measures. Separate averages were calculated for each participant and item for marked and unmarked congruent and incongruent predicates, in the animate and inanimate conditions. For each of the three measurements, outliers longer than 2 *SD* (based on the mean calculated for each participant and for each item) in each condition were eliminated and the mean recalculated. Table 2 presents these data, averaged across participants.

Gaze duration (first pass) and first fixation. As revealed by Table 2, in the marked (masc. pl. pred.) condition, gaze duration was longer for incongruent predicates than for congruent predicates. This congruity effect was more conspicuous in the animate than in the inanimate condition. In contrast, in the unmarked condition, gaze duration was almost equal for predicates in the congruent and incongruent conditions, regardless of animacy. A congruity × animacy × markedness ANOVA across participants ($F1$) and across items ($F2$) showed a significant congruity effect [$F1(1, 31) = 15.79$, $MS_e = 1669$, $p < .001$; $F2(1, 102) = 16.08$, $MS_e = 2946$, $p < .001$] as well as a significant markedness effect [$F1(1, 31) = 20.21$, $MS_e = 1891$, $p < .001$; $F2(1, 102) = 11.07$, $MS_e = 3755$, $p < .001$]. The three-way interaction was not significant [$F1(1, 31) = 1.90$, $MS_e = 2312$, $p > .05$; $F2(1, 102) = 1.72$, $MS_e = 3544$, $p > .05$]. However, a significant congruity × markedness interaction was revealed, stemming from the fact that the congruity effect was significantly different in the marked (masc. pl.) and the unmarked conditions [$F1(1, 31) = 18.72$, $MS_e = 1359$, $p < .001$; $F2(1, 102) = 7.24$, $MS_e = 2946$, $p < .01$]. Because no congruity effects were observed for unmarked predicates, the effects of congruity and animacy and the interaction between the two were computed only for marked predicates by a two-way ANOVA in a repeated-measures design.[5]

The two-way ANOVA revealed a significant main effect of congruity [$F1(1, 31) = 24.35$, $MS_e = 2127$, $p < .001$; $F2(1, 51) = 19.83$, $MS_e = 3335$, $p < .001$] and no main effect of animacy [$F1(1, 31) = 1.50$, $MS_e = 1508$, $p = 0.23$; $F2(1, 51) = 2.15$, $MS_e = 3199$, $p = .15$]. The most important result was the significant interaction between congruity and animacy [$F1(1, 31) = 4.26$, $MS_e = 2766$, $p < .05$; $F2(1, 51) = 5.05$, $MS_e = 3667$, $p < .05$]. Planned comparisons showed that gaze duration was significantly longer for incongruent as opposed to congruent predicates in the animate condition [$F1(1, 31) = 21.20$, $MS_e = 5329$, $p < .001$; $F2(1, 51) = 23.89$, $MS_e = 6474$, $p < .001$], but not in the inanimate condition [$F1(1, 31) = 3.18$, $MS_e = 4457$, $p = .08$; $F2(1, 51) = 1.95$, $MS_e = 7529$, $p = .17$].

A similar pattern emerged for duration of the first fixation. Although the congruity effect in the animate marked condition was bigger than in the inanimate condition, this interaction did not reach statistical significance [$F1(1, 31) = 1.56$, $MS_e = 570$, $p = .22$; $F2(1, 102) = 3.11$, $MS_e = 1354$, $p = .08$].

Second-pass duration. Like gaze duration the second-pass duration was longer for incongruent predicates than for congruent predicates for the animate and the inanimate conditions. Unlike gaze duration, however, the congruity effect was conspicuous for marked and unmarked predicates for both types of subject (Table 2). A three-way (congruity × animacy ×

[5] The same two-way ANOVA for unmarked predicates indeed showed no significant main effects or interactions.

TABLE 2

Mean Latency (in Milliseconds) of Gaze Duration, First Fixation, Total Time, and Second Pass for the Congruent (Cong.) and Incongruent (Incong.) Predicates of Animate and Inanimate Sentences in the Marked and Unmarked Conditions

	Marked				Unmarked			
	Animate		Inanimate		Animate		Inanimate	
	Cong.	Incong.	Cong.	Incong.	Cong.	Incong.	Cong.	Incong.
Gaze duration	260	320	271	292	263	266	260	257
Congruity effect	**60**		**21**		**3**		**–3**	
First fixation	226	244	238	239	233	234	228	231
Congruity effect	**19**		**1**		**1**		**3**	
Total time	317	439	331	403	301	376	308	356
Congruity effect	**122**		**72**		**75**		**48**	
Second pass	57	120	60	111	38	111	48	99
Congruity effect	**63**		**51**		**73**		**51**	

markedness) ANOVA showed a significant congruity effect [$F1(1, 31) = 49.7$, $MS_e = 4539$, $p < .001$; $F2(1, 102) = 88.8$, $MS_e = 3025$, $p < .001$], which did not interact with markedness ($F1 < 1$, $F2 < 1$). Planned comparison showed that the congruity effect was significant for the marked as well as for the unmarked predicates, for animate and inanimate subjects [marked, animate: $F1(1, 31) = 12.7$, $MS_e = 9954$, $p < .001$, $F2(1, 51) = 25.6$, $MS_e = 12563$, $p < .001$; marked, inanimate: $F1(1, 31) = 17.9$, $MS_e = 5827$, $p < .001$, $F2(1, 51) = 15.1$, $MS_e = 12207$, $p < .001$ unmarked, animate: $F1(1, 31) = 20.5$, $MS_e = 8254$, $p < .001$, $F2(1, 51) = 24.1$, $MS_e = 8399$, $p < .001$; unmarked, inanimate: $F1(1, 31) = 16.0$, $MS_e = 5091$, $p < .001$, $F2(1, 51) = 15.2$, $MS_e = 10069$, $p < .001$].

Discussion

The results of Experiment 1 revealed a significant congruity effect induced by manipulating subject–predicate gender agreement. However, the manifestation of this effect in the various measures of fixation duration differs for marked condition (sentences in which the predicate included an inflectional suffix of a masculine plural form) and unmarked condition (sentences in which the target denoted a masculine, singular form). For the marked predicates, the congruity effect emerged in measuring first-fixation duration and first-pass duration as well as in the later measure of rereading (i.e., second-pass duration). Furthermore, the congruity effect tended to be bigger for conceptual gender (the animate condition) than for grammatical gender (inanimate condition). This tendency reached statistical significance only in the first-pass (gaze) duration. For the unmarked predicates, the congruity was observed only in the later second-pass duration, and it did not differ for the animate and the inanimate condition.

The emergence of the congruity effect in the measure of first pass in the marked condition suggests that the processing of agreement may take place already during the initial process of integrating a word in its immediate local context as part of the on-line process of word recognition in sentence reading. Furthermore, the results of the marked condition show that semantic information may be available and may affect the processing of agreement in its early processing. However, this analysis of agreement and the interaction with semantic information seems to be mediated by morphological factors, which probably enhance the prominence of the grammatical incongruity. When the predicate is not morphologically marked for gender and plurality, the syntactic incongruity maybe less prominent, at least on the level of feature matching, and therefore it emerges only later, during the continuous process of comprehension. The morphological factor may be less essential in the later processes of reanalysis of the unsolved incongruity, as indicated by the significant congruity effect for both marked and unmarked predicates on the second-pass measure, where no interaction with markedness is observed.

We resume the discussion of the implications of these findings to more general principles of the process of comprehension under General Discussion.

EXPERIMENT 2

Methods

Participants. Twenty-four native Hebrew speakers, students at the Hebrew University, participated in the experiment for course credit or payment.

Stimuli. In this experiment we used the same stimuli as in Experiment 1, with the addition of 12 new sentences in each experimental condition. This addition was necessary to increase signal-to-noise ratio following the within-subject averaging of the EEG epochs in each condition. Thus, the Experiment included 200 target words, each of which was embedded in 8 different sentences comprising the 8 experimental animacy × congruity × markedness conditions. The resulting 800 sentences were divided into 4 experimental lists. Each list included 200 different sentences, 100 with unmarked predicates and 100 with marked predicates. Within each list, there were 50 sentences (25 in the plural, marked and 25 singular, unmarked form's) in each of the four (animacy × congruity) conditions. As in Experiment 1, the target words were rotated across lists so that each participant saw each target only once, but across participants, each target was presented in all animacy × congruity conditions (once in the marked and once in the unmarked form). Six different participants were randomly assigned to each list.

Apparatus. The EEG was recorded from 32 tin electrodes mounted on a custom-made cap (ECI) and referenced to the tip of the nose. The recording sites were based on the 10-20 system with 12 additions (see Fig. 1). The EOG was recorded by 2 electrodes, 1 located over the outer cantus of the right eye and the other over the infraorbital region of the same eye, both referenced to the tip of the nose.

The EEG was continuously sampled at 250 Hz, amplified × 20,000 with an analog bandpass filter of 0.1 to 100 Hz, and stored for offline analysis. For ERP averaging, the EEG was parsed to 1000-ms epochs starting 100 ms before the target stimulus. Epochs with EEG or EOG exceeding $\pm 100\ \mu V$, or exceeding a level of variance (measured as a root-mean-square of amplitudes) individually determined for each subject, were excluded from averaging. The epochs were averaged separately for each stimulus condition, resulting in eight averaged ERPs per subject. The baseline was adjusted by subtracting the mean amplitude of the prestimulus period of each ERP from all the data points in the epoch. Frequencies lower than 0.5 Hz and higher than 7 Hz (-3 dB points) were digitally filtered out from the ERPs after averaging.[6]

Procedure. The experiment was run in an electrically shielded dimly lit and sound-attenuated room. Electrode impedance was kept below 5 kΩ throughout the experiment. The participants were instructed to read the sentences and try to memorize them for subsequent recognition tasks. No special instructions concerning the structure of the sentences were provided.

Sentences were presented word by word at the center of the screen within a rectangular frame. Each word was exposed for 600 ms, with an interval of 300 ms between each two successive words. Short function words appeared together with the following content word. A trial started with a fixation point at the center of the screen for 500 ms, which was replaced by the first word of the sentence. The session started with 16 practice sentences after which the 200 experimental sentences were randomly presented in three approximately equal blocks. At the end of each block participants were tested for recogni-

[6] The drastic low-pass filtering was necessary in order to reduce alpha activity which, in the present experiment, was relative high in all subjects. Note, however, that because the waveforms of interest in the present study (N400 and P600) are of very low frequency (2–4 Hz) and because the same filter bandpass was used for all conditions, the distortion effect of the low-pass filter was not large and did not affect the intercondition differences.

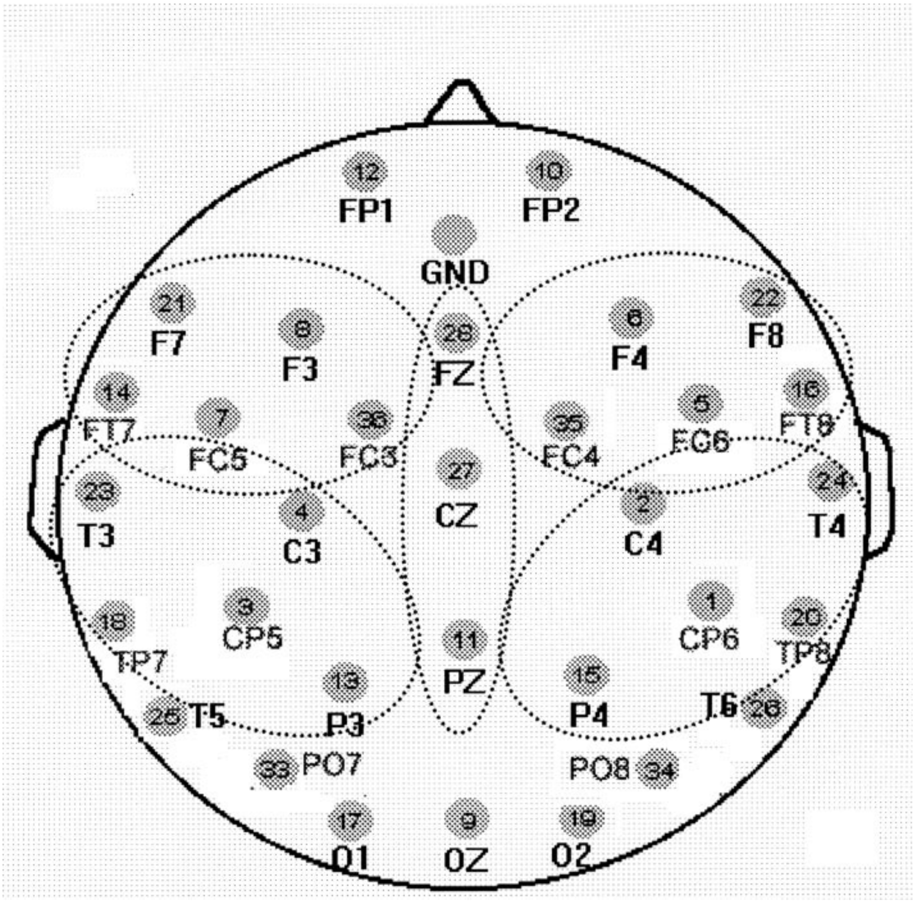

FIG. 1. The layout of the 32 scalp electrodes used for recording ERPs in this experiment. The regions of interest (ROIs see text for details) are encircled.

tion memory. The recognition test consisted of a list of 16 sentences, 50% of which had been presented in the preceding block, and the participants were instructed to mark these sentences.

Results

One participant was excluded from the analysis due to excessive eye movement. Hence, the following results are based on 23 participants who had at least 16 uncontaminated trials in each condition. Gender congruity between the subject and the predicate modulated the N400 and P600 components and an early negative potential with a latency ranging between 100 and 150 ms. These effects were observed primarily at the posterior-central and anterior locations (Fig. 2). In order to reduce the degrees of freedom to a manageable number, and based on accepted procedures as well as the observed scalp distribution of the effects, the ERPs were collapsed into five regions of interest (ROI): Frontal-Left (F7, F3, FC5, FC3, and FT7), Frontal-Right (F8, F4, FC6, FC4, and FT8), Posterior-Central Left (T3, C3, CP5, and P3), Posterior-Central Right (T4, C4, CP6, and P4), and Midline (FZ, CZ, and PZ). Henceforth these regions are labeled FL, FR, PCL, PCR, and ML, respectively.

The effects of congruity, animacy, and markedness were analyzed separately for each of the above components. The peak of the early negativity was defined as the most negative

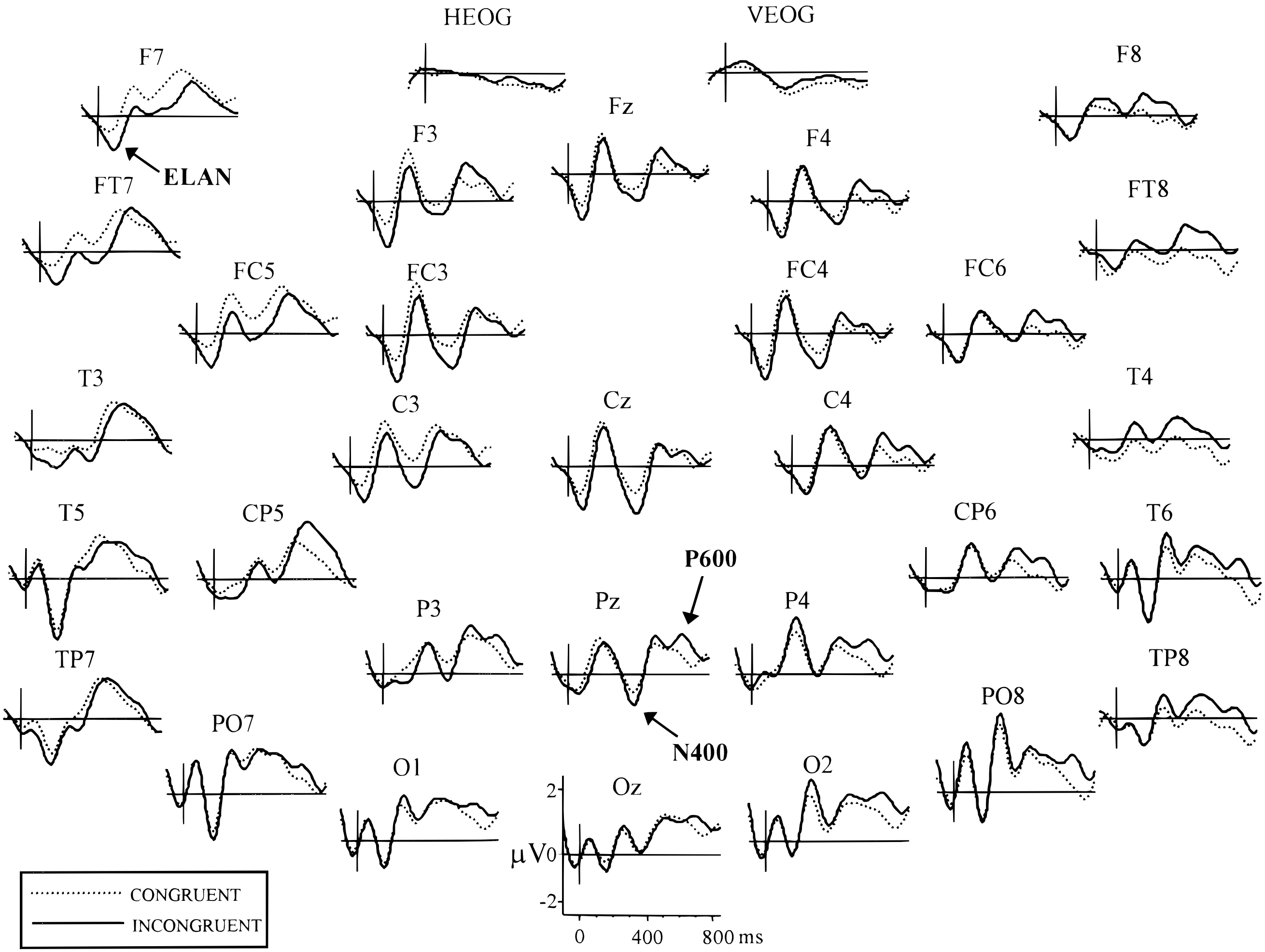

FIG. 2. ERPs elicited at all scalp locations by congruent and incongruent predicates. The data is averaged across markedness and animacy conditions.

amplitude between 80 and 250 ms from stimulus onset. The N400 was defined as the most negative peak between 250 and 550 ms from stimulus onset, and the P600 was defined as the most positive peak between 500 and 750 ms. In order to allow for examination of interhemispheric differences, the midline was excluded from one set of ANOVA for each component. A second set of ANOVA (except for left early negativity) examined the different effects at the midline sites.

Early negativity. As evident in Fig. 2 and Table 3, the amplitude of this negativity was larger for incongruent than for congruent predicates, and this effect was larger over the left hemisphere than over the right hemisphere. The characteristics of this effect were tested by a three-way ANOVA. In addition to congruity (congruent vs incongruent), the factors were anterior–posterior distribution (FL + FR vs PCL + PCR) and hemisphere (FL + PCL vs FR + PCR). This analysis showed that the congruity effect was not significant [$F(1, 22) = 3.17$, $MS_e = 36.0$, $p = .089$], but it interacted significantly with the hemisphere effect [$F(1, 22) = 8.82$, $MS_e = 7.9$, $p < .01$]. No other main effects or interactions were significant (for all $F < 1.00$).

The significant congruity × hemisphere interaction was examined by running separate ANOVAs of the congruity effect over the left and right hemispheres. These analyses revealed a significant main effect of congruity for the left [$F(1, 22) = 7.93$, $MS_e = 22.8$, $p < .01$], but not for the right [$F < 1.0$] hemisphere.

An additional ANOVA examined the effects of markedness, animacy, and their possible interaction with the congruity effect reported above. Neither of these two factors affected the early negativity [markedness: $F(1, 22) = 1.26$, $MS_e = 2.92$, $p = .27$, animacy: $F < 1$], and they did not interact with the effect of congruity [$F(1, 22) = 1.39$, $MS_e = 2.31$, $p = .25$, and $F < 1$ for congruity × markedness and congruency × animacy, respectively].

As indicated by Fig. 2, the early negativity elicited by incongruent targets seems to be larger over the Frontal-Left region than over any of the other regions. This pattern is similar to the pattern of the ELAN described above. However, the absence of an anterior/posterior effect on the early negativity and the similar congruity effect at anterior and posterior-central is inconsistent with the characteristics of the ELAN. In order to verify the extent to which we can ascribe the present early negativity to the same mechanisms associated with the ELAN, we analyzed the distribution of the present component in the incongruent condition, the condition in which the ELAN is elicited. This analysis compared the amplitude of this component over the four regions (FL, FR, PCL, and PCR). ANOVA showed that the difference between regions approached significance [$F(3, 66) = 2.56$, $MS_e = 0.49$, $p = .062$]. However, post hoc contrasts showed that the difference between FL and CPL was not significant [$F(1, 22) = 2.188$, $MS_e = 0.75$, $p = .153$].

TABLE 3

Mean Amplitude (in Millivolts) of the Early Negativity for the Congruent and Incongruent Predicates in Each of the Four ROI in the Left and in the Right Hemispheres

	Left hemisphere		Right hemisphere	
	FL	PCL	FR	PCR
Congruent	−1.438	−1.519	−1.704	−1.617
Incongruent	−2.210	−1.994	−1.810	−1.659
Congruity effect	**0.772**	**0.475**	**0.106**	**0.042**

P600. An initial ANOVA of the P600 included the following four factors: markedness (marked vs unmarked), congruity (congruent vs incongruent), animacy (animate vs inanimate), and ROI (FL, FR, PCL, and PCR). This analysis showed that the amplitude of the P600 was larger for incongruent predicates (2.7 μV, $SEM = 0.26$) than for congruent predicates (1.81 μV, $SEM = 0.27$) [$F(1, 22) = 8.5$, $MS_e = 17.2$, $p < .01$]. The main effect of ROI was also significant [$F(3, 66) = 7.52$, $MS_e = 3.9$, $p < .01$], whereas the effects of markedness and of animacy were not [$F(1, 22) = 1.69$, $MS_e = 19.9$, $p = .21$ and $F < 1$, respectively]. Most importantly, as with eye movements, the congruity × markedness interaction was significant [$F(1, 22) = 5.6$, $MS_e = 6.3$, $p < .05$], reflecting that the congruity effect was evident when the subjects and the predicates were marked as masculine plural forms (1.81 and 3.1 μV for congruent and incongruent predicates, respectively), but less so when they were unmarked (1.8 and 2.3 μV for congruent and incongruent predicates, respectively). This interaction is illustrated in Fig. 3 in which the data for marked and unmarked conditions are presented in two different panels. (See also Table 4.) No other interactions were significant.

The interaction between markedness and congruity and the scalp distribution of the congruity effect were further examined by ANOVAs run separately for the marked and unmarked conditions. The factors in these analyses were congruity, animacy, anterior–posterior distribution, and hemisphere. The most important result in these analyses was that the congruity effect was highly significant in the marked (masculine vs plural) condition [$F(1, 22) = 10.83$, $MS_e = 15.0$, $p < .005$] but not in the unmarked condition [$F(1, 22) = 2.22$, $MS_e = 8.5$, $p = .15$]. In addition, for both the marked and unmarked condition, the P600 was larger over left as opposed to over right hemisphere sites [2.7 μV (*SEM* = 0.25) and 2.4 μV (*SEM* = 0.39), $F(1, 22) = 4.23$, $MS_e = 4.69$, $p = .052$, for the marked condition; and 2.2 μV (*SEM* = 0.26) and 1.8 μV (*SEM* = 0.23), $F(1, 22) = 4.52$, $MS_e = 3.48$, $p < .05$, for the unmarked condition]. No other main effects or interactions were significant.

A similar pattern of effects was found in the analysis of the midline electrodes. The factors were markedness, congruity, animacy, and site (Fz, Cz, and Fz). This ANOVA revealed a significant effect of congruity [$F(1, 22) = 5.27$, $MS_e = 15.6$, $p < .05$], which interacted with markedness [$F(1, 22) = 6.37$, $MS_e = 7.8$, $p < .025$]. No other main effects or interactions were significant. Separate ANOVAs for the marked and unmarked conditions showed that the congruity effect on P600 was significant in the marked condition [$F(1, 22) = 11.16$, $MS_e = 11.6$, $p < .005$], but not in the unmarked condition [$F < 1$]. No other effects were significant.

N400. The analysis of the N400 was based on designs identical to those used for the P600. The four-factor ANOVA for markedness, congruity, animacy, and ROI revealed that the amplitude of the N400 was larger (i.e., more negative) in response to syntactically incongruent predicates (−2.67 μV, *SEM* = 0.36) than in response to syntactically congruent predicates (−1.74 μV, *SEM* = 0.18) [$F(1, 22) = 10.9$, $MS_e = 14.4$, $p < .01$]. In contrast to P600, there was no effect of markedness or of ROI [Fs < 1]; however, the effect of animacy was significant [$F(1, 22) = 4.97$, $MS_e = 18.6$, $p < .05$]. Most importantly, the congruity × animacy interaction was significant [$F(1, 22) = 4.60$, $MS_e = 21.8$, $p < .05$], reflecting the fact that the N400 was modulated by congruity significantly more in the animate condition [−2.7 μV (*SEM* = 0.36) and −1.0 μV (*SEM* = 0.32) for incongruent and congruent predicates, respectively] than in the inanimate condition [−2.65 μV (*SEM* = 0.49) and −2.47 μV (*SEM* = 0.28) for incongruent and congruent predicates, respectively]. This interaction is illustrated in Fig. 4, in which the data for animate and inanimate conditions are presented in two different panels. (See also Table 5.) No other first-order interactions were significant.

Separate ANOVAs for the animate and the inanimate conditions showed that the congruity effect was significant in the animate condition [$F(1, 22) = 13.3$, $MS_e = 19.1$, $p < .01$], but not in the inanimate condition [$F < 1$]. No other significant main effects or interactions were found in these analyses.

ANOVAs at the midline sites showed, again, a significant effect of congruity [$F(1, 22) = 9.97$, $MS_e = 13.1$, $p < .01$], and a significant effect of the congruity × animacy interaction [$F(1, 22) = 4.38$, $MS_e = 14.4$, $p < .05$], but no

TABLE 4

Mean Amplitude (in Microvolts) of the P600 Elicited by Congruent and Incongruent Predicates of Animate and Inanimate Sentences in the Marked and Unmarked Conditions (Averaged across the Four ROIs)

	Marked		Unmarked	
	Animate	Inanimate	Animate	Inanimate
Congruent	1.39	2.21	1.80	1.83
Incongruent	3.03	3.24	2.19	2.35
Congruity effect	**1.64**	**1.03**	**0.39**	**0.52**

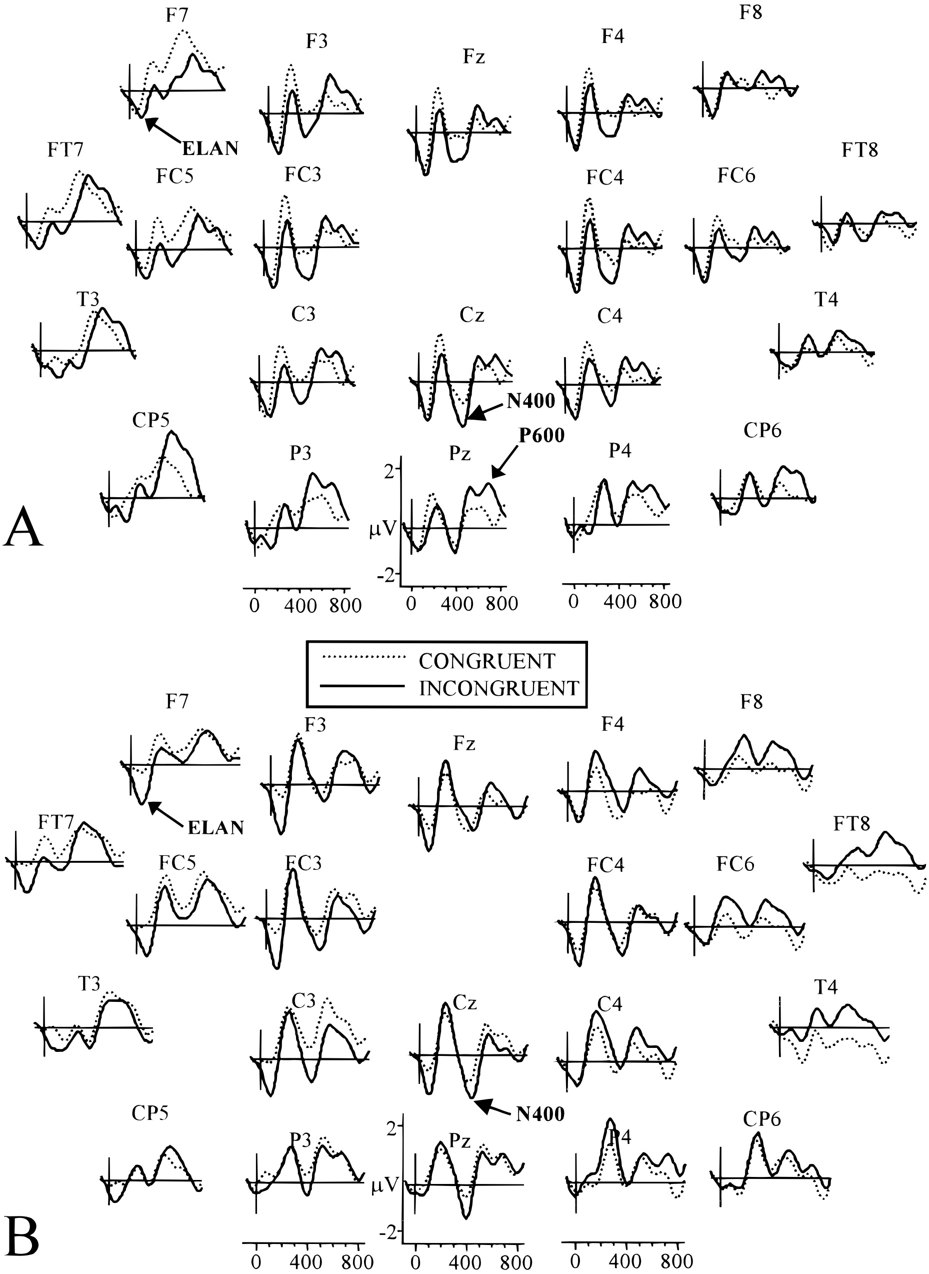

FIG. 3. The modulation of ERPs by syntactic congruity at selected channels for (A) marked predicates and (B) unmarked predicates. Note that the congruity effect on P600 is evident only for marked predicates and the N400 is modulated by congruency but not by markedness. The congruity effect on the early negativity (ELAN) is evident for both marked and unmarked predicates.

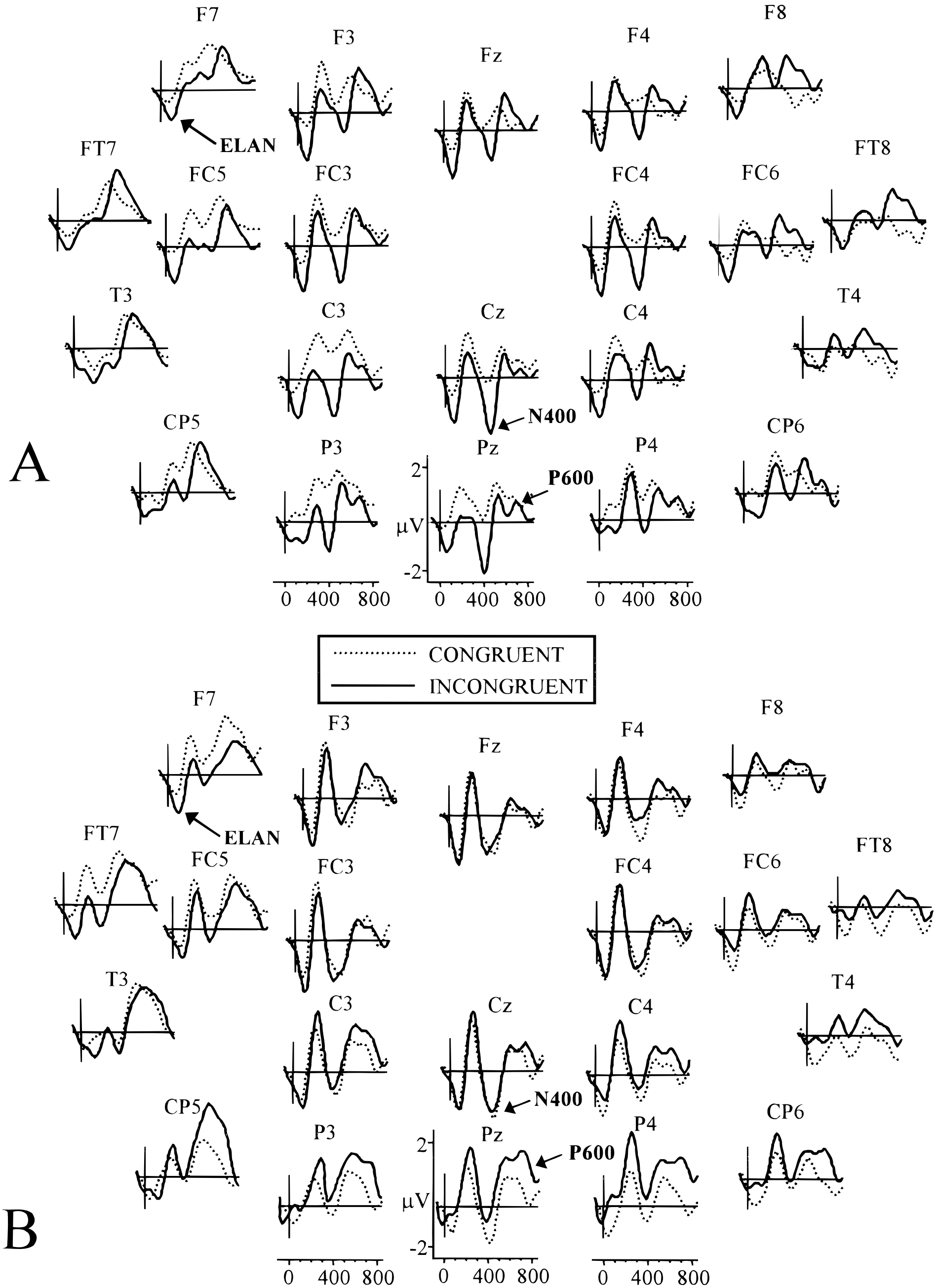

FIG. 4. The modulation of ERPs by syntactic congruity at selected electrodes in the (A) animate condition and (B) inanimate condition. Note that the N400 is significantly modulated by congruity in the animate condition, and in the inanimate condition it is similarly negative for congruent and incongruent predicates. Both the P600 and the early negativity (ELAN) are modulated by congruity in the animate and in the inanimate conditions.

TABLE 5

Mean Amplitude (in Millivolts) of the N400 Elicited by Congruent and Incongruent Predicates of Animate and Inanimate Sentences in the Marked and Unmarked Conditions (Averaged across the Four ROIs)

	Animate		Inanimate	
	Marked	Unmarked	Marked	Unmarked
Congruent	−1.13	−0.91	−2.56	−2.37
Incongruent	−2.32	−3.08	−2.60	−2.71
Congruity effect	**1.19**	**2.17**	**0.04**	**0.34**

other effects. Separate ANOVAs showed that the congruity effect was significant in the animate condition [$F(1, 22) = 14.02$, $MS_e = 13.6$, $p < .001$], but not in the inanimate condition [$F(1, 22) < 1.00$].

Discussion

The results of the ERP experiment showed that agreement incongruity modulated an early negativity (peaking between 100 and 150 ms from stimulus onset), the N400, and P600. The pattern of the interactions between this effect and the effects of animacy and markedness, however, was different for each component. The analysis of the early negativity showed no interactions between congruity and any of the other factors. The effect of congruity on P600 was not affected by animacy but it interacted with markedness; it was significant only for masculine-plural-marked predicates. In contrast, the effect of congruity on N400 interacted with animacy but not with markedness; it was significant in the animate but not in the inanimate condition. The differential effect of congruity, animacy, and markedness on the various ERP components reflects the involvement of syntactic, semantic, and morphological information in the analysis of agreement rules.

Before discussing these differential effects in detail, we need to address the discrepancy between the present data and previous reports of syntactic congruity effects on early negativity. Considering its very early latency, it was tempting to identify the present early negative component as the ELAN, reported, for example, by Friederici et al. (1993) and by Neville et al. (1991). Friederici and her colleagues had suggested that the ELAN may reflect the processing of word *category* information, as opposed to agreement and/or subcategorization information (Hahne & Friederici, 1999), and that its latency depends on whether the word's category information is available at the word's beginning or its end (Friederici et al., 1996). However, the atypical anterior–posterior distribution of the early negativity observed here and the absence of an interaction between the anterior–posterior distribution and the congruity effect counterindicate a straightforward interpretation of the present early negativity as reflecting the same mechanisms as the ELAN. It is possible that the LAN and ELAN are manifested primarily when word-category information is incongruent, whereas the modulation of the early negativity in the present study was peculiar to, and anchored in, processing of the *inflectional* structure of the word (marked by suffixes). Further research is required, therefore, to resolve this inconsistency.

GENERAL DISCUSSION

The aim of the present study was to examine the on-line processing of semantic and syntactic information during agreement analysis using converging evidence from eye movements and ERP, two time-continuous measures that complement each other. Across all experimental conditions, both methods revealed significant disruption of the normal on-line process caused by the violation of subject–predicate gender agreement. The effect of gender agreement incongruity was modulated by semantic and morphological factors. The interrelation between semantic and syntactic factors during the processing of agreement was examined by comparing the interaction of the syntactic congruity effect with animacy and markedness as manifested in the analysis of the different measures provided by the two methods.

Eye movements revealed a significant interaction between syntactic and semantic information as early as during the initial reading of the target word. This interaction was manifested by a larger incongruity effect on first-pass duration in the animate as opposed to the inanimate conditions. However, the interaction was observed, only in the marked condition; that is, for sentences in which the predicate denoted a masculine plural form. The manifestation of an interaction between animacy and congruity converges with previous findings in Hebrew, in which the processing of subject–predicate agreement was examined using a naming task (Deutsch et al., 1999). Furthermore, it is in accordance with findings obtained in other inflected languages (such as Italian, Spanish, French, and Dutch). All these studies suggest that unlike in English, the process of computing syntactic agreement in highly inflected languages is affected by semantic and/or conceptual factors. Furthermore, the present results that were obtained examining language comprehension converged with the results obtained examining language production in other highly inflected languages. This resemblance suggests that the linguistic properties of a language rather than differences between production and comprehension account for the discrepancies among different studies regarding the interrelation between semantic and syntactic processing of agreement. This suggestion is in line with the Nicol et al. (1997) and Pearlmutter et al. (1999) conclusion that, in English, the same principle guides the process of agreement construction in language production and in language comprehension.

The ability to distinctively measure the manifestation of semantic and syntactic processes in ERPs, unveiled a pattern of interactions between the markedness, the animacy, and the syntactic congruity effects which were relatively obscure in eye movements. Whereas, in eye movements, both animacy and markedness influenced the effect of syntactic incongruity on first-pass duration, each of these two factors affected a different ERP component; the congruity effect interacted only with markedness for the syntactically associated P600 and only with animacy for N400. Consequently the ERP data disentangled the semantic and syntactic processes that interacted during the initial reading of the word in context, as reflected by first-pass duration.

The absence of P600 sensitivity to animacy corroborated the view that the linguistic process indexed by this component is not sensitive to semantic information (e.g., Gunter et al., 1997; Osterhout & Mobely, 1995). More revealing is that the modulation of P600 by the various factors paralleled eye movements in the first-pass duration rather than the second-pass duration. The parallel between P600 and first-pass duration is intriguing because first-pass duration is associated with relatively early processes in word recognition, whereas the modulation of P600 was associated by several authors to a late process of sentence reanalysis, induced by inconsistencies at the message level encountered during sentence integration (Ainsworth-Darnell et al., 1998; Friederici et al., 1996; Gunter et al., 1997). Assuming that first-pass duration reflects the extraction of lexical information during word recognition and the on-line integration of a word within its context, the present results support the view that the P600 is also sensitive to initial on-line processing. Hence, the P600 may be responsive to the processes related to word recognition that are required for its immediate integration into the local syntactic structure, such as its morphological analysis (cf. Hopf, Bayer, Bader, & Meng, 1998).

In line with the above conceptualization, Osterhout et al. (1995) promoted the concept of a lexically driven parser for the mechanism that underlies the modulation of the P600. Additional evidence divorcing the P600 from its exclusive association with sentence reanalysis was provided in a recent study by Weckerly and Kutas (1999). The authors showed that the P600 is elicited by complex and infrequent syntactic structures, even if they are syntactically intact. Furthermore, the amplitude of that P600 was modulated by manipulating the animacy of the main and/or relative clause subjects, thereby creating more or less frequent sentence structures. Most importantly, this modulation was elicited by words appearing in multiple locations in the sentence, including words that appeared before the main verb of the sentence, which determined their thematic roles. Hence, Weckerly and Kutas's (1999) results support the hypothesis that the P600 is sensitive to the initial on-line process of sentence comprehension and that the P600 cannot be solely ascribed to a distinct later process of reanalysis induced by syntactic ambiguity or incongruity structures.

The sensitivity of the agreement analysis to lexical morphology is not surprising considering that gender is marked by a word's inflectional structure. However, morphological analysis per se is probably insufficient to modulate the P600. This position is suggested by results showing that manipulations of subject–predicate number agreement affected the P600 only if sentences were composed from real words (Münte et al., 1997). When similar manipulations used pseudowords, only the LAN was modulated. Indeed, simultaneous modulation of both the P600 and the LAN was observed in response to various manipulations of syntactic structures (Ainsworth-Darnell et al., 1998; Friederici et al., 1996; Gunter et al., 1997) as well as for the manipulation of agreement rules (Münte & Heinze, 1994; Osterhout & Mobley, 1995). However, when the agreement manipulation was between the subject and the predicate, as in the present study, thus affecting the sentence level (as opposed to the phrase level), the ERP modulation involved primarily the P600 (Hagoort et al., 1993; Münte et al., 1997; Osterhout et al., 1996, but see Osterhout & Mobely, 1995). This pattern might be interpreted as suggesting that, although both the LAN and the P600 may reflect processes occurring during the initial process of word reading within a text, the former component is probably associated only with the analysis of the word's morphological structure, whereas the latter seems to be associated with the activation of a lexical entry and the integration of a word into its immediate local structure.

The above line of argument apparently supports some aspects of a serial model of sentence comprehension by which phrase structures are constructed during an initial stage of syntactic analysis. According to such a model, the initial analysis is based solely on morphological information of word-class and not on agreement between inflected forms. However, such a model does not successfully describe the process of constructing subject–predicate structure in Hebrew because the process of defining the syntactic role of words and the construction of subject–predicate structure is primarily cued by agreement rules, based on *inflectional* morphology. Thus, we would expect that if the early negativity observed in the present study reflects "first-pass parsing" of constructing subject–predicate structure (in serial model terms), the interaction between inflectional markedness and congruity would be primarily manifest in this component. In contrast, the interaction between syntactic congruity and markedness was observed only in the P600 component. Thus, ascribing the observed early negativity to the initial process of constructing subject–predicate structure (i.e., adopting a serial model) implies that the on-line process of *inflectional* analysis may be precluded from the process of constructing subject–predicate structure in Hebrew.[7] In addition, if a serial model is adopted, we might ascribe the congruity effect to a feature-checking stage that takes place after the construction of a subject–predicate agreement. However, by making this assumption we would, once again, limit the role of the agreement in the on-line process of building the subject–predicate structure. Furthermore, if indeed the congruity effect reflected a secondary process of feature-checking stage, the markedness effect would be expected also in the second-pass measure of eye movements. In contrast, neither the main effect of markedness nor the interaction of this effect with syntactic congruity was found in the second-pass measure. Together, this pattern does not appear to be compatible with a serial model. Alternatively, we suggest that the present pattern of results fits better with an interactive model of sentence comprehension, in which no defined sequential processing stages on the time axis are postulated. Such an account does not exclude the possibility that the early negativity is associated with an *initial* process of syntactic analysis,

[7] The role of agreement may be different in other, less inflected languages, such as English, in which subject–predicate agreement may be of secondary importance to the construction of the phrase structures. In such languages, the agreement process can be based on analysis of derivational word structure and word order (Clifton et al., 1991; Frazier, 1987; see also Friederici, et al., 1996; Hahne & Friederici, 1999, for similar claims with respect to German).

which then continues and is completed later in time, as reflected by the P600.

The interaction between the effects of markedness and congruity on first-pass duration can be interpreted along the same lines as Eberhard's (1997) explanation of the increased probability of incorrectly assigning plural inflection to verbs following number-marked as opposed to unmarked nouns in language production. Accordingly, the on-line processing of the unmarked form, being the default of the system, would probably be simpler, since it does not entail morphological analysis of inflectional morphology. Therefore, the agreement violation, based on inflectional analysis may be less salient and thus interfere only later, in the course of sentence integration. In contrast, identifying an inflectional morpheme may trigger an immediate feature-matching process. Consequently, for marked predicates, gender disagreement affects gaze duration (i.e., first-pass) as well as second-pass duration, whereas incongruent unmarked predicates affected only second-pass duration. A similar argument can be made regarding ERPs. Assuming that the P600 is sensitive to the on-line processes of word recognition and integration of the word in its immediate context, it is not surprising that markedness interacted with gender congruity in modulating this component only for marked predicates.

The fact that markedness did not affect the modulating of the N400 suggests that the impact of morphological structure *per se* on semantic coherence is small. Furthermore, the fact that markedness did not interact with animacy highlights the centrality of the formal grammatical meaning of the inflectional suffixes in sentence analysis. The absence of these interactions is revealing because markedness also carries semantic information stemming, for example, from the fact that, in Hebrew, the masculine form is used when refering not only to males but also to a mixed group of men and women.

The present study was not designed to explore the effect of morphological markedness on the processing of agreement, and therefore, naturally, we did not examine all possible combinations of subject and/or predicate markings. However, the obtained results regarding the effect of morphological marking on on-line processing clearly suggest that this topic deserves a more detailed and systematic investigation. A comprehensive examination of the effect of marking the subject and/or predicate may be especially interesting in view of the fact that in Hebrew, unlike English, the order of subject and predicate in a sentence is free. Thus a further investigation is needed before any definite account for the markedness effect can be made.

Like markedness, animacy interacted with congruity in modulating gaze duration. Hence, it appears that semantic factors are considered as soon as the initial processing of the agreement in the course of sentence comprehension. Semantic information at this stage may play a role in providing additional cues to aid the process of assigning the syntactic roles of subject and predicates to words in the sentence; first, it may make the process of encoding the noun gender easier, because the sex of the animate noun renders the gender marking more conspicuous; and second, the fact that animate nouns usually take the thematic role of an agent may facilitate the process of assigning a subject role to an animate noun (Bates & MacWhinney, 1982, 1989). The salience of semantic information induced by animate subjects probably augmented the deleterious effect of gender incongruity.

Animacy did not affect the congruity effect on the P600 component, but it did significantly increase the effect on N400. This result is plausible because the modulation of the N400 is presumed to be semantically specific. Indeed, previous studies have demonstrated that pure syntactic violations do not affect the N400 (Gunter et al., 1997; Kutas & Hillyard, 1983; Neville et al., 1991; Osterhout & Mobley, 1995). Likewise, the violation of gender agreement in our study did not modulate the N400 in the inanimate condition, where the morphological marking had no semantic implication. Given that the N400 precedes the P600 in the order of their occurrence, this pattern also raises caveats for multistage, sequential models of sentence processing, models that suggest that semantic processes follow an initial, distinct phase of syntactic analysis. This order also contradicts an assumption that P600 is associated only with the initial phase of syntactic parsing. The issue of the sequence of semantic and syntactic processing (as manifested by ERP components) is less important, however, for constraint-based models for sentence processing (e.g., MacDonald, 1994; MacDonald, Pearlmutter, & Seidenberg, 1994; Tanenhaus et al., 1995; Trueswell & Kim, 1998). According to such models, the resolution of the syntactic structure of a sentence is governed by an interaction between syntactic and nonsyntactic processes that mutually constrain the initial online syntactic parsing. A fundamental property of constraint-based models is that this analysis is a continuous process rather than a sequential stage-based analysis. The dynamic of the interaction is determined by the relative strength of the available constraining information. In line with this assumption, and assuming that the P600 is indeed associated with the activity of a lexically driver parser, it is plausible that although it appears relatively late, it is still sensitive to initial processes of syntactic analysis.

In conclusion, the present results may better fit those models that postulate a simultaneous, multiple-constraint process for sentence comprehension than a serial-type model. According to our conceptualization, the initiation of the syntactic process may be manifested in the early negativity component. However, the process is continuous in time, including the basic construction of the subject–predicate structure, which is manifested in the P600, and the semantic analysis as manifested in the N400. The observed congruity effect may reflect the on-line difficulty in constructing the subject–predicate structure. For less salient morphosyntactic forms, such as the unmarked condition, incongruity may be realized later, thus manifested mainly in second-pass measure. It should be noted, however, that although such models do not deny the existence of distinct cognitive semantic and syntactic processes, a main feature of interactive models is the multiple constraining processes by which semantic and syntactic analyses affect each other. According to a strong version of this view an interaction between animacy and syntactic congruity effects should have been observed in the P600, as indeed it appeared in the eye-movement measures. The absence of such an interaction on P600 raises, therefore, some caveats regarding a strong version of the interactive, constraint-based models, caveats that should be addressed in further research.

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(Received June 30, 1999)
(Revision received September 30, 2000)
Published online May 30, 2001