Phrase Length Matters: The Interplay between Implicit Prosody and Syntax in Korean “Garden Path” Sentences

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Abstract

■ In spoken language comprehension, syntactic parsing decisions interact with prosodic phrasing, which is directly affected by phrase length. Here we used ERPs to examine whether a similar effect holds for the on-line processing of written sentences during silent reading, as suggested by theories of “implicit prosody.” Ambiguous Korean sentence beginnings with two distinct interpretations were manipulated by increasing the length of sentence-initial subject noun phrases (NPs). As expected, only long NPs triggered an additional prosodic boundary reflected by a closure positive shift (CPS) in ERPs. When sentence materials further downstream disambiguated the initially dispreferred interpretation, the resulting P600 component reflecting processing difficulties (“garden path” effects) was smaller in amplitude for sentences with long NPs. Interestingly, additional prosodic revisions required only for the short subject disambiguated condition—the delayed insertion of an implicit prosodic boundary after the subject NP—were reflected by a frontal P600-like positivity, which may be interpreted in terms of a delayed CPS brain response. These data suggest that the subvocally generated prosodic boundary after the long subject NP facilitated the recovery from a garden path, thus primarily supporting one of two competing theoretical frameworks on implicit prosody. Our results underline the prosodic nature of the cognitive processes underlying phrase length effects and contribute cross-linguistic evidence regarding the on-line use of implicit prosody for parsing decisions in silent reading. ■

INTRODUCTION

The human language processing mechanism is sensitive to pervasive syntactic ambiguities encountered as the sentence unfolds in real time from left to right, and several sources of information, including prosody, can contribute to the disambiguation. The term *prosody* refers to the intonation and rhythmic grouping patterns in speech. Previous studies on spoken language processing have demonstrated that prosodic information can alter syntactic parsing preferences and sentence interpretations typically found in reading (Carlson, Clifton, & Frazier, 2001; Kjelgaard & Speer, 1999; Schafer, 1997). For example, a written sentence such as *When John phoned his old mother was happy* often results in initial misunderstandings (so-called *garden path* effects) at the disambiguating auxiliary *was*. The reason for this is a strong preference to interpret the syntactically ambiguous NP *his old mother* as the direct object of *phoned* rather than as the subject of a subsequent verb (which, however, is the ultimately correct analysis in our example above). When the same sentence is auditorily presented, a prosodic boundary after *phoned* (indicated by #) can alter the parsing preference before disambiguating lexical information is encountered, and thus prevent the garden path effect: *When John phoned # his old mother was happy* (Kjelgaard & Speer, 1999). There is evidence that speakers produce such overt boundaries at critical syntactic positions to facilitate the interpretation of otherwise ambiguous sentences (Schafer, Speer, Warren, & White, 2000). Moreover, there is reason to assume that readers mentally insert this boundary when recovering from the garden path effect (Kondo & Mazuka, 1996).

In addition to this kind of syntax–prosody alignment, *prosodic phrase length* has repeatedly been discussed as one potential source that induces overt prosodic phrasing (the presence of prosodic boundaries) in speech (Fernández, Bradley, Igoa, & Teira, submitted; Watson & Gibson, 2004; Jun, 1996, 2003; Fodor, 1998, 2002; Selkirk, 1986, 2000; Gee & Grosjean, 1983). For example, when a prenominal modifier is short as in (1a), it is likely to be placed within the same prosodic phrase with the following NP *professor*, whereas when the modifier is long as in (1b), *ugly* and *professor* tend to be broken up into separate prosodic phrases (Fodor, 1998, 2002):

(1a) *[[The ugly professor]'s # [daughter]]*;
(1b) *[[The horribly ugly]# [professor's daughter]]*.

As Fodor (1998, 2002) reports, length-driven prosodic phrasing in each phrase can lead to different decisions about the syntactic analysis of *ugly*. Phrase (1a) can be interpreted either as “the daughter of the ugly professor” or “the ugly daughter of the professor,” although the former is more typical. In contrast, phrase (1b) receives one strongly preferred interpretation over another: “the

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horribly ugly daughter of the professor." When the second NP becomes lengthened like *the horribly ugly professor's daughter-in-law*, *horribly ugly* modifies *professor* again (Fodor, 1998). This pattern of shift in interpretation suggests that constituent length, mediated by prosodic phrasing, can have an impact on a listener's syntactic analysis and reanalysis.

Prosodic phrasing is central not only to spoken but also to written language comprehension. While reading silently, readers activate much of the phonological information typical for spoken language, a phenomenon referred to as "phonological recoding" (e.g., Bader, 1998). This explains why, for example, rhyming words (*mud–blood*) show priming effects in reading studies (e.g., Tanenhaus, Flanigan, & Seidenberg, 1980). In addition to the sound pattern of word forms, silent readers also utilize *implicit prosody*—the subvocally activated prosodic representation of a sentence. Implicit prosody seems to be very similar to the overt prosody produced when reading aloud and has been found to influence comprehension processes (Fodor, 2002; Bader, 1998). According to Chafe (1988), readers "experience auditory imagery of specific intonations, accents, pauses, rhythms, and voice qualities, even though the writing itself may show these feature poorly if at all" (p. 397). It is widely assumed that implicit prosody is evoked because of a certain correspondence between visual input and phonological representation (e.g., Patterson & Coltheart, 1987). For instance, commas may represent prosodic boundaries in writing, as found in reading aloud (Hill & Murray, 2000), although this prosodic encoding process seems to depend on individual punctuation habits (Steinhauer & Friederici, 2001) and language-specific punctuation rules (Kerkhofs, Vonk, Schriefers, & Chwilla, 2008). Phrase length can influence prosody across modalities too. Speakers shift overt prosodic patterns, depending on phrase length (Fernández et al., submitted; Hirose, 2003). Likewise, silent readers seem to rely on phrase length to generate subvocal prosodic phrasing, which in turn affects syntactic parsing (Hwang & Schafer, 2009; Hirose, 2003).

However, implicit prosody in silent reading is difficult to investigate, and behavioral studies generally have to infer the prosodic phrasing pattern *indirectly* from processing difficulties that occur later in the sentence. Here, the continuous on-line measures of ERP studies have an advantage, as prosodic boundaries elicit a characteristic immediate ERP brain response. ERP evidence for implicit prosody has previously been reported in two punctuation studies by Liu, Wang, and Zhixing (2010) and Steinhauer and Friederici (2001), which demonstrate that a comma is processed similarly to a speech prosodic break (i.e., it exhibits comparable impact on sentence comprehension and elicits the same brain response). In contrast, implicit prosody triggered by phrase length has not yet been tested using ERPs. If length effects are, in fact, mediated by subvocal prosody, then ERPs should be able to reveal this. Therefore, extending a number of suggestive (but inconclusive) behavioral studies, the primary objective of the present work is to employ ERPs to determine whether and how phrase length influences implicit prosodic phrasing as well as the processing of a syntactic ambiguity. Moreover, by providing the first ERP data on prosodic and syntactic processing in Korean, the study also adds cross-linguistic evidence on the universality of such interactions. The following sections discuss previous experimental findings on phrase length effects and ERP correlates of prosodic and syntactic sentence processing. We then explain how and why the design of the current ERP study differs from similar behavioral studies. Results will argue that, during silent reading, the language processor makes active use of the respective prosodic representation of a sentence, which can be manipulated by changing phrase lengths.

Length Effects and Implicit Prosody

Different accounts have been proposed to explain the role of phrase length and implicit prosody in sentence processing. Although they share similar assumptions on the role of syntax-driven boundaries, their predictions differ as to whether length-driven boundaries can impact syntactic parsing decisions. One prominent proposal is the *implicit prosody hypothesis* (IPH; Fodor, 1998, 2002), according to which implicit prosodic boundaries influence the syntactic analysis in reading, *regardless* of whether they are triggered by syntax–prosody alignments or by long phrases. A competing proposal is the *rational speaker hypothesis* (RSH; Clifton, Carlson, & Frazier, 2006), which claims that phrase length is inversely associated with the syntactic effect of a prosodic boundary. That is, a prosodic boundary tends to be placed before or after a long phrase, yet the *syntactic* implications of such a length-driven boundary are small or absent compared with other boundaries. This is because the listener or reader should be able to realize that the boundary is motivated by phrase length rather than by syntactic phrase boundaries. Clifton et al.'s predictions were confirmed in a series of auditory studies in which phrase length (e.g., short vs. long proper names) was crossed with boundary position (*#1* vs. *#2*, indicating distinct NP groupings), as in {*Pat (#1) or Jay (#2) and Lee*} compared with {*Patricia Jones (#1) or Jacqueline Frazier (#2) and Letitia Connolly*}. The forced-choice disambiguating response patterns showed that syntactic ambiguity was significantly better resolved with shorter than longer phrases, presumably because listeners assumed that the prosodic boundary in the long context was justified by length but not syntactically motivated (Clifton et al., 2006). However, increased working memory load for longer names may have played a role, and the results for other structures were less consistent. The RSH has not yet been applied to implicit prosody. An ERP investigation of implicit prosody can provide an ideal test, because readers should know, without any ambiguity, the reasons why they projected a boundary, and ERP measures can monitor both this projection and how those boundaries are used for syntactic parsing.

On the other hand, the Implicit Prosody Hypothesis has been supported by studies that documented how the length of a relative clause (RC) affects the preferred *site* (underlined) for RC attachment (e.g., *Someone saw the servant (#1) of the actress (#2)*{*who cried* vs. *who was on the balcony*}[1]). These studies have attributed length effects to implicit prosody, that is, subvocal boundary placement (Fernández et al., submitted; Jun & Koike, 2003; Lovrić, 2003). However, other researchers have challenged the prosodic explanation for length effects reported in RC attachment studies. They argue that length manipulations employed did not control for referential or syntactic complexity in the critical region, thus resulting in possible confounds with discourse representation (Hemforth & Konieczny, 2002) and memory load (Gibson, Pearlmutter, Canseco-Gonzalez, & Hickok, 1996). Semantic plausibility may also have played a role. Indeed, in a test of Korean, Jun and Kim (2004) did *not* find a reliable effect of RC length on prosodic phrasing in production, although RC length did affect off-line attachment preferences. The conflicting results are consistent with a nonprosodic account for length effects.

As the results of Jun and Kim (2004) call into question the applicability of the implicit prosody hypothesis to Korean, Hwang and Schafer (2009) investigated the effect of length-driven implicit prosody on the syntactic analysis of Korean sentences in both a production study and a self-paced reading experiment. As these sentences have been adopted for the present study, the relevant conditions are shown in Table 1 and summarized in Example (2) below. The length manipulation contrasted long (7.5 syllables) and short (3.4 syllables) versions of cartoon characters' names (e.g., Korean equivalents of *Pooh* [short NP] vs. *Winnie the Pooh* [long NP] or *Piglet* [short NP] vs. *Little Piglet* [long NP]). To avoid nonprosodic confounds associated with length variation, the length-manipulated NP occurred only in the sentence-initial matrix subject position (i.e., outside the ambiguously parsed phrase or its potential attachment sites). Unlike a short subject NP (e.g., *Piglet*), a long subject NP (e.g., *Little Piglet*) was predicted to elicit a prosodic boundary, which should then influence the attachment preference for the subsequent ambiguous dative NP, such as *Robin* in (2). In *ambiguous* sentence conditions (such as (a) and (c) in Table 1), the dative NP "Robin" can be attached either to the verb of the matrix clause (i.e., *sold*) or to the verb of the RC (i.e., *picked*), resulting in two distinct sentence meanings. For simplicity, Examples (2a) and (2b) below present only the English translations of these two interpretations to illustrate this syntactic ambiguity (for further details, see Table 1).

(2) Word order in Korean: (Little) Piglet **Robin** Pooh picked the honeycomb sold.

(2a) Matrix verb attachment: (Little) Piglet **sold** [the honeycomb [that Pooh picked]] **to Robin**.

(2b) RC attachment: (Little) Piglet sold [the honeycomb [that Pooh **picked for Robin**]].

Although both interpretations are grammatical, Korean readers strongly prefer the simpler syntactic analysis in (2a) and interpret the dative NP *Robin* as the indirect object of the matrix verb, as shown in both an eye-tracking study (Koh, 1997) and a self-paced reading study (Kiaer, 2007; see also Kamide & Mitchell, 1999, for a similar preference in Japanese).[2] However, if a competing *second* dative NP further downstream (*Thige-eykey*; "Tigger-Dat" in Table 1) mandatorily requires to be the object of the matrix verb, the initially preferred interpretation of *Robin* turns out to be wrong and needs to be revised, causing a garden path effect. As will be explained below, an implicit prosodic boundary after the long subject NP (*Little Piglet*) can be expected to weaken this garden path effect, because it separates *Robin* from the matrix clause and pushes it closer to the RC (*that Pooh picked*). Given that the expected implicit prosodic pattern is best predicted by overt prosody in a reading-aloud study, we will first show how both syntactic structure and the length manipulation of the subject NP can determine where speakers produce *overt* prosodic breaks in these sentences (Hwang & Schafer, 2009).

In the first part of Hwang and Schafer's production experiment, participants read aloud visually presented sentences *without prior skimming*. This type of "first-pass reading" paradigm was used to mimic the perspective of a silent reader, who generally does not know the meaning or syntactic form of the sentence in advance. The first-pass production results showed that 88% of ambiguous utterances with *short subject* NPs were produced with a single boundary after the first dative NP (Robin-Dat), such that both the matrix subject NP and this dative NP occurred in the same intonation phrase. This pattern in *short subject* conditions is consistent with the strong initial bias for matrix clause attachment of the dative NP discussed above (Kiaer, 2007). In sharp contrast, 95% of *long subject* utterances were produced with an intonation phrase boundary immediately after the subject NP (Piglet-NOM). Among these, 69% displayed intonation phrases for both the matrix subject NP and the dative NP, whereas in the remaining 26% only the subject NP corresponded to an intonation phrase. In other words, in "first-pass reading," subject-length determined the prosodic phrasing: *Long-subject* conditions either changed the initial preference or, more often, constituted a rather neutral prosody (with *two* boundaries after Piglet-Nom and Robin-Dat), consistent with either attachment of the dative NP.

In the second part of this study *with prior skimming*, participants were informed of the sentence ambiguity and were asked to provide a disambiguating production for each of the two interpretations. This "second-pass reading" measure mimics the perspective of a spontaneous speaker (who knows what to say in advance) rather than a silent reader. Here, the known *syntactic structure*

Table 1. Examples of the Four Experimental Conditions

	Sentence							
	***Long** Matrix Subject NP vs. **Short** Matrix Subject NP*		*Ambiguous 1st Dative NP*	*Relative Clause Subject*	*Relative Clause Verb*	*Accusative NP*	***2nd** Dative NP **(Disambiguation)** vs. Adverb*	*Matrix Clause Verb*
Condition	*P1–P3*	*P4*	*P5*	*P6*	*P7*	*P8*	*P9*	*P10*
a. Short subject, ambiguous		Phigules-i	Lopin-eykey	Phwuwu-ka	ttacwu-n	pelcip-ul	unkunsulccek	phalapelyessta
		Piglet-Nom	Robin-Dat	Pooh-Nom	pick- Rel	honeycomb-Acc	stealthily	sold
	*Piglet stealthily **sold** the honeycomb [that Pooh picked]] **to Robin**.* or							
	*Piglet stealthily sold [the honeycomb [that Pooh **picked for Robin**]].*							
b. Short subject, disambiguated (RA)		Phigules-i	Lopin-eykey	Phwuwu-ka	ttacwu-n	pelcip-ul	Thige-eykey Tigger-Dat	phalapelyessta
		Piglet-Nom	Robin-Dat	Pooh-Nom	pick- Rel	honeycomb-Acc		sold
	*Piglet sold Tigger [the honeycomb [that Pooh **picked for Robin**]].*							
c. Long subject, ambiguous	Akitwayci	Phigules-i	Lopin-eykey	Phwuwu-ka	ttacwu-n	pelcip-ul	unkunsulccek	phalapelyessta
	Little	Piglet-Nom	Robin-Dat	Pooh-Nom	pick- Rel	honeycomb-Acc	stealthily	sold
	*Little Piglet stealthily **sold** [the honeycomb [that Pooh picked]] **to Robin**.* or							
	*Little Piglet stealthily sold [the honeycomb [that Pooh **picked for Robin**]].*							
d. Long subject, disambiguated (RA)	Akitwayci	Phigules-i	Lopin-eykey	Phwuwu-ka	ttacwu-n	pelcip-ul	Thige-eykey Tigger-Dat	phalapelyessta
	Little	Piglet-Nom	Robin-Dat	Pooh-Nom	pick- Rel	honeycomb-Acc		sold
	*Little Piglet sold Tigger [the honeycomb [that Pooh **picked for Robin**]].*							

For alignment of comparable lexical contents across conditions, sentences are right-aligned and position numbers (P1–P10) decrease from right to left across sentences. In the short and long *disambiguated* conditions (b and d), attachment of the first dative NP (in Position P5) is locally ambiguous and then disambiguated toward RC attachment by the second dative NP located in the matrix clause (in Position P9). Each word position, as indicated by numbers, was presented separately. The identical portion of the long matrix subject NP and the short matrix subject NP is in Position P4 (although this portion in the short subject condition always occurred sentence initially). The unmatched portion in the long proper name is assigned to Positions P1–P3, depending on its constituency. English translations are provided in *italics*.

RA = RC attachment, Nom = Nominative case, Dat = Dative case, Acc = Accusative case, Rel = RC marker.

determined the position of prosodic breaks whereas subject-NP length played only a secondary role. Sentences that disambiguated the dative NP toward RC attachment typically showed one single prosodic boundary after the matrix subject NP, whereas productions with matrix clause attachments of the dative NP had a single boundary following that dative NP. Importantly, together the two parts of the study demonstrated that length manipulations of the matrix subject NP in first-pass reading affected the same boundary positions used to signal syntactically motivated boundaries in second-pass reading, such that *long subject NPs should facilitate RC attachment* of the ambiguous dative NP in silent reading. This was confirmed by the following comprehension data.

As expected, the overt prosodic patterns of the "first-pass reading" study were closely mirrored in self-paced reading patterns that crossed matrix subject length with ambiguity (ambiguous vs. disambiguated sentences). Disambiguated sentences contained a second dative NP (e.g., *Thige-eykey*, "Tigger-Dat") in the matrix clause that forced the normally less preferred relative attachment of the first dative NP. This disambiguating second dative NP was processed significantly faster in the long (as compared with the short) subject NP condition, suggesting that length-induced prosodic boundaries supported RC attachment. In addition to these length effects, the long *disambiguated* condition also displayed a significant (but weaker) garden path effect, as compared with its long *ambiguous* counterpart. Thus, the length-driven boundary did not seem to completely override the initial preference; otherwise, no garden path effect should have resulted at all. Hwang and Schafer (2009) interpreted these results as indicating that the covert prosodic boundary associated with the long NP conditions facilitated the normally dispreferred RC attachment of the dative NP but predominantly during reanalysis. Hwang and Schafer's data are also in line with self-paced reading time data from Japanese (Hirose, 2003), which demonstrated the on-line effect of matrix subject length on the resolution of the ambiguous attachment of a subsequent accusative NP. Although very consistent across studies, these off-line findings provide rather indirect support for the implicit prosody hypothesis, as effects of phrase length on prosodic phrasing early in the sentence were reflected only by prosody–syntax mismatch effects further downstream in the sentence. The present study builds on Hwang and Schafer and adopts their experimental design in an ERP study. Unlike the behavioral data, ERPs were expected to offer more direct clarification of prosody-based length effects.

Electrophysiological Correlates of Prosodic Sentence Processing

Because of their high temporal resolution in assessing cognitive process, ERPs provide a valuable on-line means to investigate the time course of prosodic processing and the interaction of prosody with syntax. Also, unlike the limited data points in behavioral studies, multidimensional ERP measures are continuously available across the full sentence length and can distinguish different levels of linguistic processes in terms of the distinct language-related ERP components. Here, we briefly review the components directly relevant to the current study.

The best-studied language-related ERP component is the N400 (Kutas & Hillyard, 1980), a negative deflection peaking around 400 msec postonset, which primarily reflects difficulties in lexical processing and semantic integration. It is also associated with word frequency, lexical class, and semantic context in sentences (e.g., Kutas & Federmeier, 2009). This negativity exhibits a slightly right-lateralized centro-parietal distribution, especially in reading. In contrast, the P600 component occurs between 500 and 1000 msec postonset in response to syntactic processing difficulties due to grammatical violations, garden path effects, and syntactic complexity (Kaan & Swaab, 2003; Friederici, 2002; Hagoort, Brown, & Groothusen, 1993; Osterhout & Holcomb, 1992). This late positive-going waveform is regarded as a reflection of syntactic repair, structural reanalysis, or syntactic integration; it is typically most prominent at centro-parietal sites, but a frontal distribution of the P600 effect has also been observed for garden path sentences (Friederici, Hahne, & Saddy, 2002; Hagoort, Brown, & Osterhout, 1999; see our Discussion section below).

The processing of prosodic phrasing is reflected by a positive shift at boundary positions—CPS (Steinhauer, Alter, & Friederici, 1999). Steinhauer et al. (1999) contrasted speech materials with and without a prosodic boundary and observed the CPS with a duration of about 500 msec in the boundary condition relative to the no-boundary condition. The component was most prominent at centro-parietal sites in this study, but more recent studies have reported variability in its scalp distribution (e.g., a fronto-central CPS in Pauker, Itzhak, Baum, & Steinhauer, 2011; Itzhak, Pauker, Drury, Baum, & Steinhauer, 2010; Pannekamp, Toepel, Alter, Hahne, & Friederici, 2005). Pauker et al. (2011) and Steinhauer et al. demonstrated that the prosodic boundary can prevent garden path effects when prosody cooperates with syntax or, conversely, can mislead listeners when prosody conflicts with syntax. In auditory processing, the CPS has been reported cross-linguistically for prosodic boundaries: in German (Steinhauer, 2003; Steinhauer et al., 1999), in Dutch (Bögels, Schriefers, Vonk, Chwilla, & Kerkhofs, 2010; Kerkhofs et al., 2008; Kerkhofs, Vonk, Schriefers, & Chwilla, 2007), in Japanese (Wolff, Schlesewsky, Hirotani, & Bornkessel-Schlesewsky, 2008), in Mandarin Chinese (Li & Yang, 2009), and in English (Pauker et al., 2011; Itzhak et al., 2010). Importantly, Steinhauer et al. showed that the CPS does not depend on a pause and, thus, may be triggered by any acoustic cues signaling a prosodic boundary (e.g., phrase-final syllable lengthening and boundary tones). This component was also elicited by boundaries in hummed and pseudoword sentences deprived of any semantic or syntactic content

(Pannekamp et al., 2005). These results strongly suggest the CPS is a specific and reliable marker for the processing of prosodic boundaries. However, CPS effects have also been shown to be modulated by nonprosodic information, that is, by the expectation of contrastive focus that builds a focus (prosody) domain (Toepel, Pannekamp, & Alter, 2007), by contextually induced syntactic expectations that do or do not support a prosodic boundary (Kerkhofs et al., 2007), or by lexically predicted boundary positions (transitivity bias; Itzhak et al., 2010).

Turning to implicit prosody, Steinhauer and Friederici (2001) examined whether comma processing during silent reading is similar to prosodic boundary perception in spoken language and, thus, whether commas trigger the CPS effect. They observed a small but significant CPS at comma positions only for native German speakers with strict punctuation habits, suggesting that commas may reliably generate subvocal prosodic boundaries during silent reading if readers are used to rely on punctuation. More compelling evidence for the (implicit) prosodic nature of the CPS in silent reading was obtained by these authors as follows. In Experiment 3, they first presented delexicalized (filtered) sentence melodies, which contained only the prosodic information of spoken sentences including boundaries, but no segmental information. Following the listening phase in each trial, participants were instructed to replicate the prosodic contour while silently reading a visually presented sentence without any punctuation. At boundary positions, the authors found a positive shift that strongly resembled the one observed in the comma experiment. Taken together, these findings provided evidence for the CPS as a universal reflection of prosodic phrasing, both in listening and reading; the smaller CPS amplitude in the visual modality (~2 μV) compared with its auditory counterpart (>3 μV) was attributed to the smaller degree of activation of phonological representations (Steinhauer, 2003; Steinhauer & Friederici, 2001). On the other hand, Kerkhofs et al. (2008) failed to replicate the CPS at comma positions in Dutch sentences, although the commas were shown to influence parsing decisions. The authors tentatively concluded that the lack of CPS effects might be because of language differences in punctuation rules. More recently, Liu et al. (2010) reported a comma-induced CPS in Chinese, suggesting that ERP effects of implicit prosody are not specific to the rather strict punctuation rules in German. One important finding across behavioral and ERP comma studies was that punctuation (likely mediated by implicit prosody) can immediately disambiguate a syntactic structure and prevent garden path effects, just as prosodic boundaries in speech (e.g., Steinhauer, 2003).

The Current Study

Here, we used ERPs (a) to test Hwang and Schafer's (2009) hypothesis that phrase length effects in Korean are mediated by implicit prosody and (b) to examine how implicit prosody and syntax interact in the resolution of a garden path ambiguity that has not been previously explored with ERPs. Our predictions were as follows: First, in line with the IPH, the RSH, and with Hwang and Schafer's robust finding of an early boundary in 95% of the long sentences, we predicted that increasing the length of sentence-initial subject NPs should trigger an implicit prosodic boundary and yield a CPS for long—but not short—subject NPs. Second, on the basis of Hwang and Schafer's "first-pass reading data," we also expected a prosodic boundary at the end of the first dative NP for both the long and the short condition, however, for different reasons. In the long condition, the first dative NP alone was too short to force a length-based intonation phrase boundary, but a prosodic boundary is syntactically motivated (especially if the parser still pursues a matrix verb attachment preference of the first dative NP). By contrast, in the *short* condition, the short matrix NPs and the following first dative NP group into one intonation phrase, such that the boundary is motivated by both syntax and phrase length. Because the syntactic motivation for a boundary relies largely on the visibility of the upcoming second NP-Nom (the subject NP of the RC), a CPS right after the dative NP was more likely for the short condition (where the boundary could be postulated based on already available length information alone).[3] Third, with respect to garden path effects, the specific predictions depended on the respective theoretical framework. According to the RSH, the length of the matrix subject NP should not affect the readers' initial preference for matrix verb attachment of the first dative NP. Thus, both short and long conditions should show a similar garden path P600 on the disambiguating second dative NP. In contrast, the implicit prosody hypothesis predicts that the length-driven prosodic boundary after the matrix subject NP should facilitate the required RC attachment of the first dative NP in the long condition. This implicit prosodic boundary could be used immediately to change the initial parsing preference toward RC attachment and prevent a garden path effect in the long condition altogether (i.e., similar to comma effects; Steinhauer & Friederici, 2001). Alternatively, in line with Hwang and Schafer's behavioral data, the length-driven boundary may primarily facilitate the revision process such that the garden path effect (P600) should be present but weaker in the long compared with the short disambiguated condition.

In summary, CPS effects would be expected by *both* the IPH and the RSH, whereas significant differences between the short and long conditions in the strength of garden path effects (at the disambiguating dative NP, reflected by P600s) would be predicted by the IPH only.

METHODS

Pretest

As ERP reading studies generally use rapid serial visual presentation (RSVP), it was important to learn about possible effects of the invariant timing of this paradigm, which crucially differs from the self-paced reading paradigm (Hwang & Schafer, 2009) and may already provide boundary clues by the way words are chunked (or separated; see also Footnote 3 above). Moreover, it was necessary to confirm that the intended presentation time of 600 msec per word (which was derived from the Korean self-paced reading time data) would be appropriate to replicate the length effects, as no published psycholinguistic ERP studies using the Korean writing system with RSVP were available. Therefore, we first examined phrase length effects in a behavioral pretest using RSVP.

In this behavioral pretest, 24 sets of Hwang and Schafer (2009)'s experimental sentences, in four versions each ([Long vs. short matrix subject] × [Ambiguous vs. disambiguated]) were counterbalanced across four lists in a Latin square design, and combined with 48 fillers (24 unambiguous and 24 ungrammatical sentences). Fifty-six Korean speakers silently read sentences presented one word at a time (600 msec per word). Thus, long subject NPs (either two or three words long in this 24 set) were presented in two to three frames, depending on the number of words involved, whereas short subject NPs were presented as one frame. Participants judged whether a sentence was easy to understand or not.

Figure 1 shows these difficulty ratings and corresponding response times in four conditions. The observed pattern of response times replicated Hwang and Schafer's (2009) self-paced reading results, despite the invariant timing of the RSVP presentation. A 2 × 2 repeated measures ANOVA detected main effects of matrix subject length ($F(1, 55) = 4.275$, $p < .05$) and ambiguity ($F(1, 55) = 6.734$, $p < .02$), and their interaction was also significant ($F(1, 55) = 6.728$, $p < .02$). As predicted, the short subject disambiguated condition was processed significantly more slowly than the long subject disambiguated condition, whereas the two ambiguous conditions did not differ from each other. Difficulty rating data found main effects of matrix subject length ($F(1, 55) = 9.846$, $p < .004$) and ambiguity ($F(1, 55) = 67.699$, $p < .001$). Two disambiguated conditions were significantly more difficult to understand than the two ambiguous conditions that allowed either interpretation (Van Gompel, Pickering, Pearson, & Liversedge, 2005). Finally, fillers were accurately judged (82.5% correct response). Overall, the results confirmed the validity of using RSVP with a time interval of 600 msec for stimulus presentation.

Participants (EEG Study)

Thirty-two right-handed native Korean speakers from the Montreal area (17 women; age range, 18–33 years) were recruited by advertisement and compensated for their time. All subjects had normal or corrected-to-normal vision, reported no history of hearing impairment or brain injury, and gave written informed consent before their participation. Ten subjects (two women) were later excluded from analyses because of excessive EEG artifacts ($n = 8$) and below-chance performance across conditions in the behavioral task ($n = 2$).

Materials

The experimental materials were 144 four-tuple following the same logic as the Hwang and Schafer's (2009) materials discussed above (Table 1). Two levels of *sentence ambiguity* (ambiguous vs. disambiguated) were crossed with two levels of *length for the matrix subject NP* (long vs. short). Short subject NPs used one word version (mean = 3.8 syllables) of relatively well-known cartoon characters' names to naturally group with the ambiguously attached subsequent dative NP into one intonation phrase (Jun, 2000, 2003; Selkirk, 2000).[4] In contrast, long NPs had the long version of the name (mean = 8.32 syllables), which consisted of either two words (78.5%), three words (20.1%), or four words (1.4%); they were long enough to correspond to an intonation phrase by themselves (Jun, 2003; Selkirk, 2000).

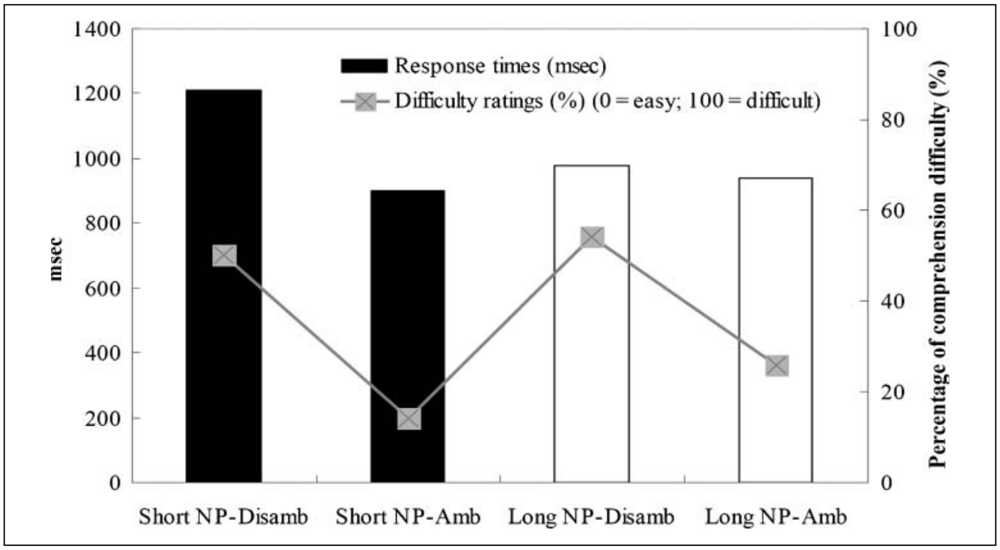


Figure 1. Length effects in the RSVP paradigm, a pretest. Converted mean percentage of difficulty ratings (with lines) and corresponding response times (with bars) per condition. Short NP-Disamb = the short matrix subject-disambiguated condition, Short NP-Amb = the short matrix subject-ambiguous condition, Long NP-Disamb = the long matrix subject-disambiguated condition, Long NP-Amb = the long matrix subject-ambiguous condition.

The ambiguous first dative NPs were always four syllables long. The disambiguating second dative NP and the adverb were matched on the number of syllables within each item set.

Experimental items ($n = 576$) were distributed and counterbalanced across four lists, such that only one member of each matched four-tuple was presented to each participant to avoid repetition effects. Each list contained 144 additional filler sentences, which were created with the same sets of cartoon characters as the experimental ones. Filler sentences were composed of three different types of syntactic structure with two lengths of matrix subject NP. These six conditions were rotated through 144 filler sentences (i.e., in six conditions of 24 sentences each), such that the same sets of cartoon characters were repeated only once in each list—one with an experimental sentence and one with a filler sentence. As all of the disambiguated experimental sentences forced RC attachment of the ambiguous dative NP, one third of the filler sentences forced the dative NP to attach to matrix clause by the presence of the second dative NP located in the RC (e.g., (Little) Piglet-Nom Robin-Dat [[Pooh-Nom *Tigger-Dat* pick- Rel] honeycomb-Acc] sold.—"(Little) Piglet sold Robin the honeycomb that Pooh picked for Tigger."). As a consequence, materials were relatively well balanced, with a slight bias for RC (56%) compared with matrix clause (44%) attachment interpretations (assuming a 50:50 distribution in fully ambiguous sentences). However, if we take the actual parsing preferences observed in Hwang and Schafer (2009) into account, a slight overall bias toward matrix clause attachment would result for the materials. The rest of filler sentences did not involve any (local) syntactic ambiguity at all.

To ensure participants were attending to the meaning of the sentences, comprehension probes were prepared for 33% of the experimental and filler sentences with the matched cartoon characters. Of 48 comprehension probes for the experimental sentences, half paraphrased the matrix clause attachment of the ambiguous dative NP (e.g., Piglet sold Robin the honeycomb) and the other half paraphrased the RC attachment of the NP (e.g., Pooh picked the honeycomb for Robin). Forty-eight probes for the filler sentences did not ask for the interpretation of dative NPs to divert attention from the experiment purpose. Given the low accuracy level (about 66%) observed in responses to the exact same comprehension probes in Hwang and Schafer (2009), we did not expect high performance on paraphrases. Nevertheless, this kind of comprehension question may be better compatible with normal sentence processing than metalinguistic grammatical judgment tasks and, thus, enhances the ecological validity of our ERP data. Otherwise, such a behavioral task was not necessary, as previous behavioral studies have extensively tested similar sentence construction and all predicted processing effects were examined on-line with ERPs.

Finally, two sublists were created based on each of the four major lists, resulting in eight presentation lists in total. The two sublists differed in terms of whether a probe from the same set of cartoon characters occurred with either an experimental or a filler sentence. Thus, each of the eight presentation lists included 48 probes counterbalanced between experimental and filler items and was used for 4 of the 32 participants. In each list, the 144 experimental and 144 filler sentences were pseudorandomly intermixed to avoid consecutive presentation of similar sentence types and evenly divided into six blocks of items.

Procedure (EEG Study)

Participants were tested in a dimly lit shielded chamber. They were instructed to read the sentences carefully and avoid eye movement and blinking while the sentences were presented. They silently read the 288 sentences presented in the center of a computer monitor. Sentences were displayed word-by-word (using RSVP) at a rate of 600 msec per word (duration = 400 msec; ISI = 200 msec). Each trial began with the presentation of a picture displaying cartoon characters along with their names for 2000 msec, followed by a fixation cross presented for 500 msec. Then, each word was presented and directly followed by the next word. After the last word of the sentence, the screen remained blank for 1000 msec. Periodically, a comprehension probe (48 probes, in total) appeared and stayed on the screen until participants made an acceptability judgment between "correct" and "incorrect" with a mouse click. Before the next trial began, a prompt ("!!!") appeared on the monitor for 2000 msec to indicate the time interval in which participants were allowed to blink their eyes. Testing sessions lasted for 3 hr, on average, including electrode placement and cleanup.

EEG Recording and Data Analysis

EEG was continuously recorded (250 Hz/32 bit sampling rate; impedances $< 5\ \text{k}\Omega$; Neuroscan Synamps2 amplifier) from 19 cap-mounted Ag/AgCl electrodes (Electro-Cap International, Eaton, OH), referenced to the right mastoid and placed according to the standard International 10–20 System. Vertical and horizontal EOG was recorded bipolarly to monitor eye movement artifacts.

EEG data were analyzed using the EEProbe software package (ANT, Enschode, the Netherlands) and filtered off-line with a bandpass of 0.5–30 Hz. Trials contaminated with blinks or other artifacts (30 μV threshold) were rejected from averaging; the number of trials that survived this procedure differed slightly between long (94%) and short conditions (91%) for the CPS analysis ($p < .02$), whereas those for the P600 (and N400, see below) analysis did not differ across conditions (82%, on average). For each condition, single subject waveforms were averaged over 1300 msec epochs following target words, with a 150-msec poststimulus onset baseline (unless stated otherwise below).

On the basis of visual inspection of the data, representative time windows to quantify ERP components were identified and subjected to repeated-measures ANOVAs with the mean amplitude as the dependent measure. Global ANOVAs for repeated measures were run separately for three midline (Fz, Cz, and Pz) and 12 lateral electrodes (F7, F3, F4, F8, T3, C3, C4, T4, T5, P3, P4, and T6). Both midline and lateral analyses included the topographical factor Anterior–posterior (AntPost: frontal vs. central vs. posterior); lateral analyses additionally included factors Hemisphere (right vs. left) and Laterality (medial vs. lateral). The ANOVAs for the CPS included one condition factor, Matrix subject length (long vs. short), and were carried out collapsing across ambiguous and disambiguated conditions. The ANOVAs for the P600 (and N400, see below) included two condition factors, Ambiguity (ambiguous vs. disambiguated) as well as Matrix subject length. All significant interactions were followed up with additional ANOVAs. The Greenhouse–Geisser correction for violations of sphericity was applied where applicable.

RESULTS

Behavioral Data

Although collection of behavioral off-line data in our ERP study was not expected to reveal any new insights, given the wealth of on-line data from previous studies examining the same sentences, we still included comprehension probes in 16.7% of the trials to ensure attentive and ecologically valid processing across the entire session. As expected, these data replicated the findings of Hwang and Schafer (2009). That is, participants found it hard to judge a given paraphrase but still correctly interpreted a reasonable number of sentences across conditions (mean accuracy is 60.4% as compared with 66% in Hwang & Schafer, 2009). Importantly, the short disambiguated garden path condition without prosodic support caused more misinterpretations than the long disambiguated condition that was predicted to profit from the length-driven implicit boundary. However, these numerical differences did not reach statistical significance, perhaps, because of the small number of paraphrases in each condition ($n = 6$).

Overall, the behavioral data were not very conclusive, likely because this off-line measurement was not sensitive enough to detect more subtle effects compared with the on-line self-paced reading task or the RSVP tasks (described above). Alternatively, this might result from the level of task difficulty, as accepting/rejecting paraphrases might be more difficult than making easy/difficult or grammaticality judgments (Hwang & Schafer, 2009). The online ERP data were expected to shed more light on the real-time processing.

ERP Data

The effects of phrase length on sentence processing across the entire sentence was monitored on-line with ERPs. The predicted CPS and P600 components were confirmed. We will first present the early CPS effects and then two late effects—the garden path P600 effects and an N400 word class effect.

Early Effects: CPS

The grand average ERP waves (at nine representative electrodes) and a voltage map of difference waves are illustrated in Figure 2. These ERP waves are time-locked to the onset of target nouns that are identical in the short and long NP conditions (*Phigules-i*, "Piglet-Nom"). Between 300 and 600 msec, a frontal positive shift near the midline is visible for the long NP condition: the predicted CPS. Instead of a standard prestimulus baseline, we selected a baseline interval into the word (0–150 msec relative to word onset), because the two length conditions differed systematically before onset of the target word: in the short NP condition, the target word occurred sentence initially, whereas in the long condition it was preceded by the first part of the character's name (corresponding to, e.g., *Pooh* vs. *Winnie the Pooh*). As shown in Figure 2, with this baseline, the prestimulus differences were confined to the prestimulus interval (see large differences between −100 and 0 msec), whereas the onset N100 and P200 components of the target word were largely matched across conditions. However, during the first 300 msec, the long subject condition tends to be somewhat more negative at frontocentral sites (e.g., the P200 is smaller; midline: $ps < .02$ at both Fz and Cz; lateral: $ps < .02$ at frontal and central sites) compared with the short condition. These differences are because of larger P200s at sentence onset and, importantly, are not problematic for the subsequent CPS effect of interest. That is, compensating for them (e.g., by using an even later baseline interval of 160–260 msec) would increase (rather than decrease) the CPS (as illustrated in the included plot at Fz and a corresponding voltage map).[5]

Table 2 summarizes the CPS analyses for the 300–600 msec time window. The long condition (Long subject-ambiguous + Long subject-disambiguated) evoked the expected CPS between 300 and 600 msec postmatrix subject NP onset as compared with the short condition (Short subject-ambiguous + Short-disambiguated). The global ANOVA revealed a main effect of matrix subject length (midline: $p < .02$; lateral: $p < .03$). This CPS was largest near the midline at frontal electrodes and slightly right-lateralized, as demonstrated by further interactions with Laterality ($p < .005$), AntPost (midline: $p < .08$; lateral: $p < .05$), and Laterality × AntPost × Hemisphere ($p < .02$). The follow-up analyses for all lateral electrodes found the most prominent CPS effects at medial regions ($p < .02$) of the anterior site ($p < .02$) over the right hemisphere ($p < .03$). The frontal distribution of the CPS was also confirmed by the follow-up analyses for the midline electrodes (Fz: $p < .02$) as well as the amplitude differences between conditions, which was largest at Fz. The

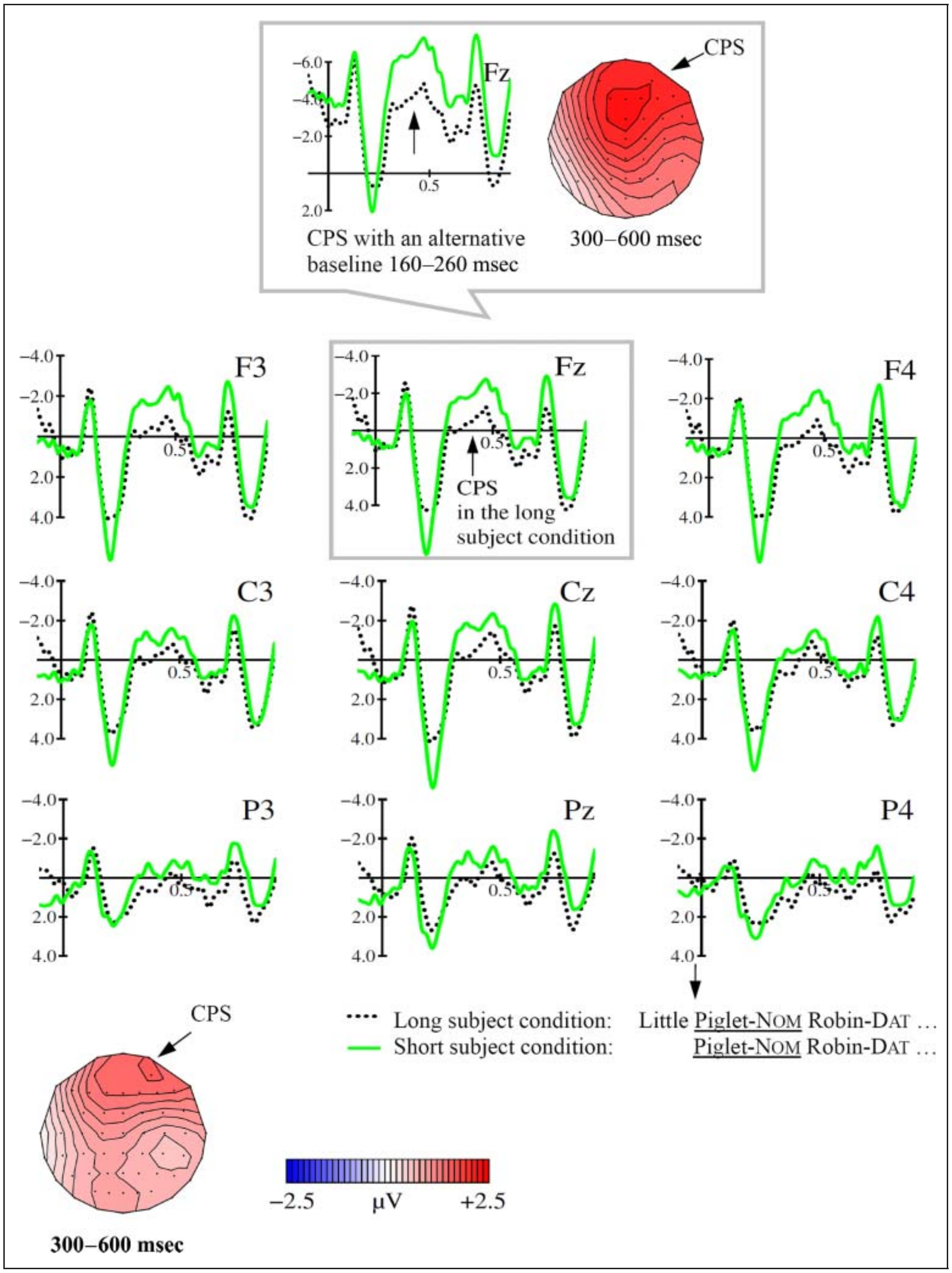


Figure 2. Grand average waveforms and voltage maps for the long subject conditions (black dotted: Long subject-ambiguous + Long subject-disambiguated) and the short subject condition (green solid: Short subject-ambiguous + Short subject-disambiguated). Waveforms are time-locked to the onset of the short version of the matrix subject NP (vertical lines at 0 msec), using a baseline of 0–150 msec. The voltage map shows differences between the two conditions. The top displays grand average waveforms at Fz using a baseline of 160–260 msec and a corresponding voltage map. The long subject condition elicited a CPS at the end of the subject NP between 300 and 600 msec.

frontal distribution is in line with a number of previous CPS findings (Pauker et al., 2011; Itzhak et al., 2010; Pannekamp et al., 2005).

However, to justify the interpretation of the positive-going shift in the long condition in terms of the CPS effect, it is important that the CPS be distinguished from N400 semantic priming effects that are due to words before the target word for the long condition relative to the short one. For example, "Winnie the" in the long version of the proper name "Winnie the Pooh" could prime "Pooh," whereas such priming effects would be absent in the short proper name. Similarly, the different word positions (sentence initial position for short NPs, either second, third or fourth position for long NPs) may also have contributed to a smaller N400 for the target word in long NPs, as N400s tend to decrease in amplitude across word positions (e.g., Van Petten & Kutas, 1991).

Although both name priming and word position effects in reading studies have consistently been shown to display posterior distributions (e.g., Kutas & Federmeier, 2009; Schweinberger, Ramsay, & Kaufmann, 2006; Van Petten & Kutas, 1991), interindividual variability may have led to a more frontal N400 in our subjects. Therefore, we examined whether N400 differences between words in different positions of our study showed any overlap with the observed CPS-like effect or not. Two types of analyses across word positions were conducted in the 300–600 msec time window: (a) one including only the four words following the target word (i.e., Positions P5–P8 in Table 1, before the disambiguating Region 9 where we expected to see garden path effects) and (b) another one that additionally included the target word (i.e., Positions P4–P8 in Table 1). The corresponding ANOVAs included factors Position and Length. If the frontal CPS finding was in fact distinct from the expected posterior position effects, we predicted that Analysis (a) would reveal posterior N400 in absence of any Length or Position × Length effects, whereas Analysis (b) would reveal additional Length and Length × Position effects that would further interact with topographical factors reflecting the distinct distribution of length and

Table 2. Analysis of Variance for ERP Amplitudes of the Subject NP (300–600 msec), Reflecting the CPS in the Long NP Condition

1. Global ANOVA

Source	*df*	*F*	*p*
Lateral Electrodes			
Length	1	5.79	.0254
Length × Laterality	1	10.27	.0043
Length × AntPost	2	4.26	.0453
Length × Laterality × Hemisphere	1	14.26	.0011
Length × Laterality × AntPost × Hemisphere	2	5.61	.0136
Midline Electrodes			
Length	1	6.59	.0180

2. Follow-up Analyses

Lateral Electrodes

Source	*df*	*F*	*p*		*df*	*F*	*p*
	Lateral				*Lateral: Right Hemisphere*		
				Length	1	5.26	.0322
Length × AntPost	2	4.22	.0479	Length × AntPost	2	4.12	.0480
					Lateral: Left Hemisphere		
				Length × AntPost	2	4.16	*.0458*
	Medial				*Medial: Right Hemisphere*		
Length	1	7.43	.0127	Length	1	6.23	.0210
					Medial: Left Hemisphere		
				Length	1	7.81	.0108

		Frontal		*Central*		*Posterior*	
Source	*df*	*F*	*p*	*F*	*p*	*F*	*p*
Lateral Electrodes							
Length	1	7.79	.0109			5.10	.0348
Length × Laterality	1	10.97	.0033	15.88	.0007		
Length × Laterality × Hemisphere	1	6.33	.0201	32.84	.0001		
Midline Electrodes							
Length	1	7.98	.0101	4.72	.0414	5.02	.0360

position effects. All of these predictions were confirmed. Analysis (a) revealed highly significant Position × AntPost interactions at both lateral ($p < .0001$) and midline electrodes ($p < .0001$), pointing to a centro-parietal N400 (frontal: *ns*; central: $p < .02$ at midline electrodes, $p < .07$ at lateral; parietal: $p < .0001$ at both midline and lateral electrodes), whereas no effects involving factor length were found. This interaction effect disappeared after around 600 msec. Analysis (b), in contrast, revealed additional length main effects (lateral: $p < .03$; midline: $p < .07$) and a Length × Position effect (lateral and midline: $ps < .04$), which further interacted with AntPost (lateral: $p < .04$; midline: $p < .067$) and laterally with laterality and hemisphere ($p < .001$). Unlike the posterior position effect, the length main effect was significant only at frontal sites (lateral: $p < .02$; midline: $p < .05$). Viewed together, these analyses strongly suggest that the frontal CPS effect was distinct and independent of the N400 effects in our study (i.e., word category and sentence position effects).

As expected and consistent with Hwang and Schafer's (2009) read-aloud data, the CPS patterns at the first dative NP were less clear than those reported above for the lengthening of the matrix subject NP. Recall that the CPS was expected to reflect primarily length-driven on-line effects but not the delayed insertion of syntactically motivated boundaries at this position (cf. Footnote 3). We did not find significant differences between long and short conditions at the first dative NP ($ps > .6$). As this could point to either the presence or the absence of a CPS in both conditions, we needed an additional approach to clarify the ERP pattern at this position. One possibility is to compare the first dative NP with the sentence-initial matrix subject NP in the *short* condition, just as we have done above for the long subject NP.[6] Indeed, the dative NP in the *short* condition (vs. the matrix subject NP) showed a slightly right-lateralized frontal CPS between 300 and 600 msec (see Figure 3A). There was a significant interaction of position with laterality, hemisphere, and AntPost ($p < .04$). Follow-up analyses detected significant interactions of Position with Laterality (frontal sites: $p < .02$; central sites: $p < .04$) and with laterality and hemisphere (frontal: $p < .04$; central: $p < .02$) at fronto-central sites. In summary, these analyses suggest a CPS-like positivity at the first dative NP in the short condition, whose scalp distribution was very similar to that of the CPS found at the matrix subject NP in the *long* condition (in Figure 2). However, because both of these CPS effects were quantified in contrasts against the sentence-initial matrix subject NP of the short condition, a potential concern is that these effects may be driven by a relative frontal negativity in this control condition. To address this concern, we also compared the RC subject (Pooh-Nom) to the same control, but did not find any evidence for differences (all *F*s < 1; see Figure 3B), thus ruling out this alternative account. Moreover, the same comparisons (dative NP vs. sentence-initial word) were made for the long subject condition but did not show a CPS effect at the dative NP. Overall, these results provide evidence for the CPS at the end of the first

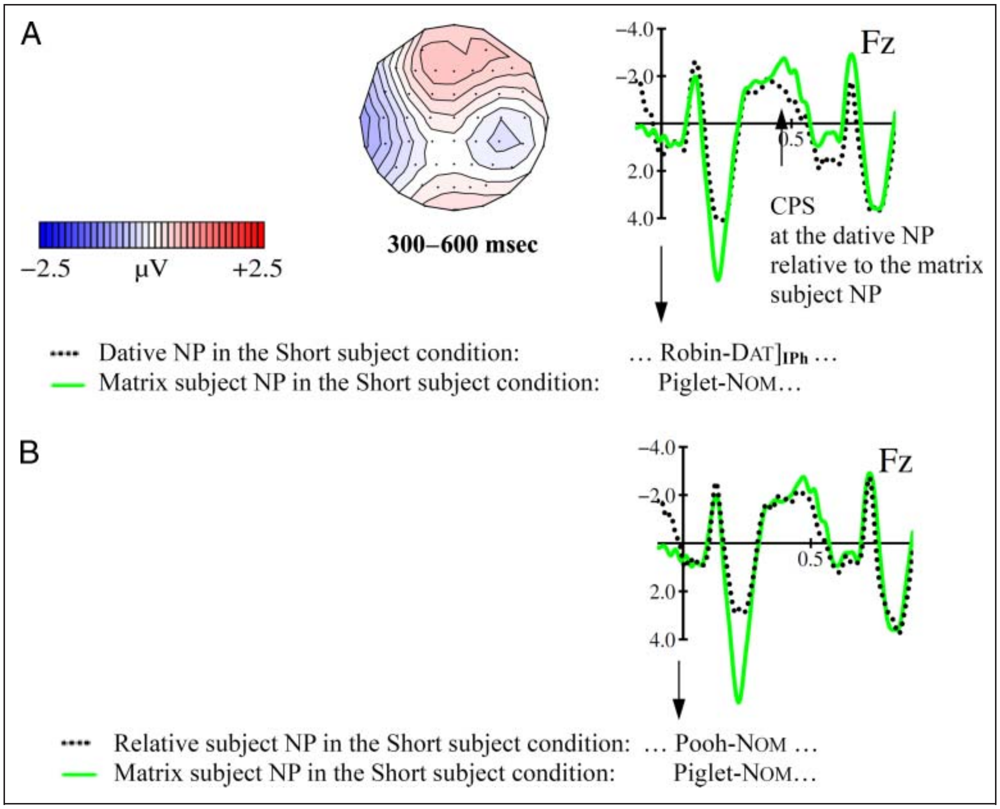


Figure 3. Grand average waves at Fz and voltage maps for (A) the matrix clause short subject NP (green solid) and the following dative NP (black dotted) in the short condition. Grand average waves for (B) the matrix clause short subject NP (green solid) and the RC subject NP (black dotted) in the short condition. IPh = intonation phrase boundary.

dative NP for the short condition; however, the effects remained ambiguous for the long condition.

Late Effects

If the CPS effects reflect the expected subvocal generation of a prosodic boundary, the distinct patterns in long versus short conditions may have affected the garden path effects at the disambiguating region, as predicted by the implicit prosody hypothesis. However, ERP patterns revealed that conditions differed in this region even before the typical P600 time window; specifically, there were effects of word class differences. We will discuss these before we turn to the P600.

Word Class Effects

In Figure 4A, grand average waveforms in all four conditions are presented, time-locked to the onset of the disambiguating dative NP (*Thige-eykey*, "Tigger-Dat") for the disambiguated conditions or the adverb (*unkunsulccek*, "stealthily") for the ambiguous conditions (Position P9 in Table 1). Figure 4B shows voltage maps of the N400 differences between 300 and 550 msec as well as the P600 differences across conditions during the 550–800 msec time window.

The word category difference between ambiguous and disambiguated conditions at this word position had an effect on the N400 between 300 and 550 msec. The N400 effect appeared more posterior and slightly right lateralized over the medial sites in the two ambiguous conditions (i.e., for adverbs) as compared with the two disambiguated conditions (NPs). Significant interactions of Ambiguity with AntPost (midline: $p < .0003$; lateral: $p < .0001$) confirmed a typical centro-parietal distribution of the N400 (a main effect of Ambiguity at Pz ($p < .003$) as well as at the posterior sites for lateral sites [$p < .02$] and only a marginal ambiguity effect at Cz [$p < .0885$]). This posterior distribution is similar to N400 profiles previously reported for semantic violations in Korean (Kwon, 2008) and Japanese (Nakagome et al., 2001). Although the right hemisphere dominance and main distribution over the medial regions was indicated by significant interactions of Ambiguity × Hemisphere ($p < .05$) as well as Ambiguity × Laterality ($p < .0007$) and their marginal three-way interaction ($p < .0578$), there were no significant effects on the follow-up analyses conducted for lateral/medial and right/left electrodes separately except a marginal Ambiguity effect at the medial site of the right hemisphere ($F(1, 21) = 4.01$, $p < .0583$). Results of N400 analyses along with P600 (below) are shown in Table 3.

Garden Path Effects

Turning to the P600, Figure 4A and B shows the expected positive deflection following the N400 for both disambiguated garden path sentences between 550 and 800 msec. In addition, this positivity is considerably larger in the short than the long disambiguated condition, especially at right fronto-central sites, whereas the short and long ambiguous control conditions do not seem to differ from each other. Upon first inspection, the shared effect across disambiguated (vs. ambiguous) conditions may appear like an ongoing N400 word class effect (see above); it was reflected at both midline and lateral electrodes by Ambiguity_AntPost interactions ($ps < .02$), a highly significant Ambiguity_Hemisphere effect ($p < .003$), and a Ambiguity_Laterality_Hemisphere interaction ($p < .04$). This pattern points not only to a parietal maximum (similar to that of the N400) but also to a strong right lateralization of the P600 that was not observed for the preceding N400. When directly contrasting the ERPs in the N400 and in the P600 time window, the distinct scalp distributions of these two components were further reflected by a four-way interaction of Time window_Matrix subject length_Ambiguity_Laterality ($F(1, 21) = 5.71, p < .03$).

Most importantly, the larger P600 garden path effect for short as compared with long matrix subjects was confirmed by Length × Ambiguity × AntPost interactions (midline: $p < .01$; lateral: $p < .07$) in the global ANOVA that led to a Length × Ambiguity interaction only at frontal electrodes both at the midline ($p < .04$) and at lateral sites ($p < .05$). Follow-up analyses revealed significant main effects of Matrix subject NP length only for disambiguated sentences (midline: Fz: $p < .03$, Cz: $p < .04$; Pz: *ns*; at lateral electrodes: frontal: $p < .05$; central: $p < .05$; parietal: *ns*), whereas no single effect involving factor length was found for ambiguous sentences.

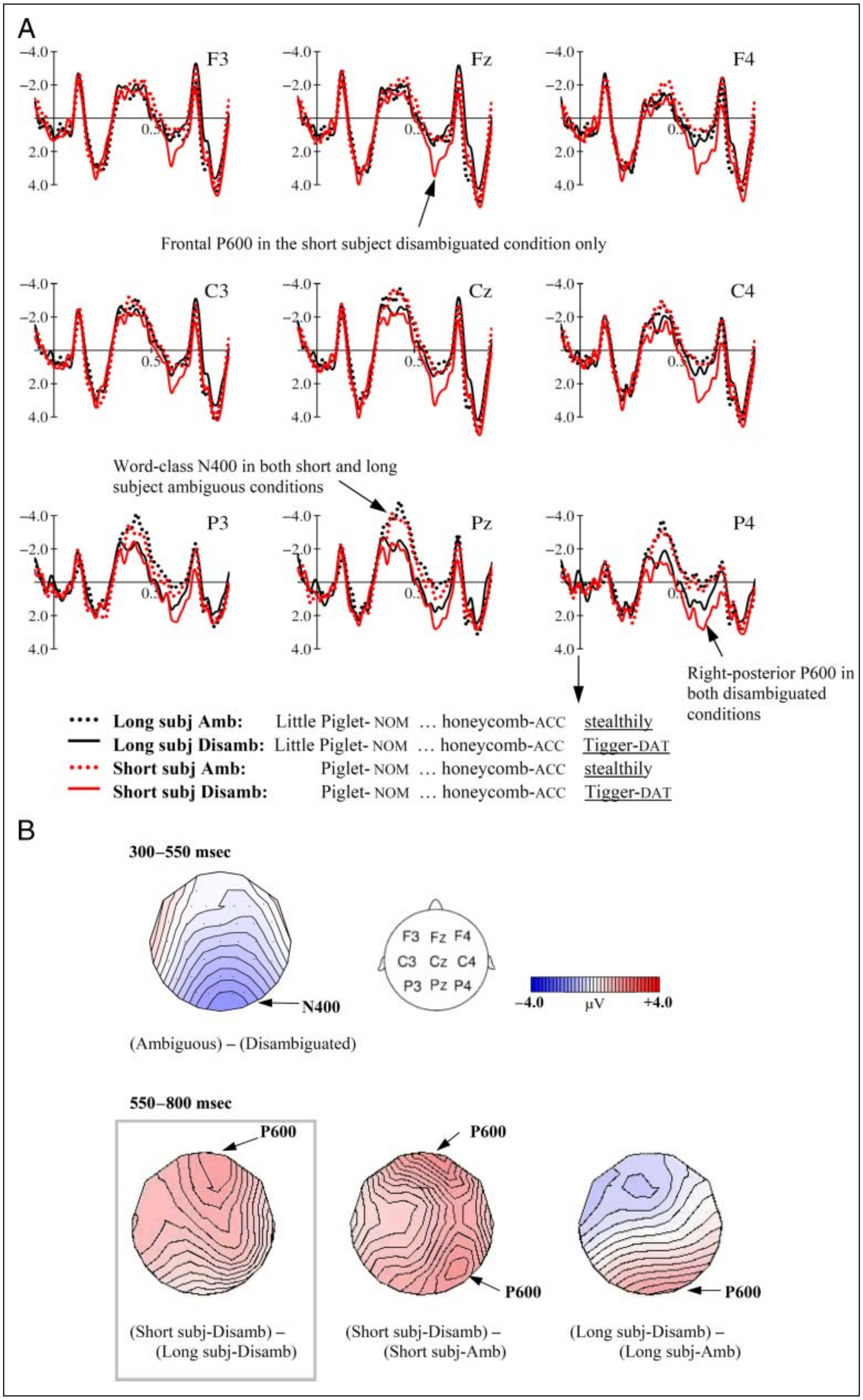
DISCUSSION

The present ERP study investigated (a) the effect of phrase length on implicit prosody and (b) how this implicit prosodic pattern affected the processing of a syntactic garden path ambiguity in Korean. In line with previous reports, we also replicated N400 word class and sentence position effects with a centro-parietal distribution. Our discussion focuses on the predicted CPS and P600 findings.

CPS

The on-line processing of phrase length during silent reading involved the processing of prosody, as reflected by electrophysiological patterns. Recall that in RSVP reading studies, the CPS can be expected to reliably reflect prosodic phrasing on the basis of previously available information (commas, lexical biases, and phrase length) but not delayed boundary insertion based on syntactic constraints. As predicted by both the RSH and the IPH, the long subject condition displayed a CPS at the end of the long matrix subject NP, suggesting that long (but not short) subject sentences were read with a subvocal intonation phrase boundary during silent reading. Also, a small CPS was observed at first dative NPs in the short condition, whereas a

Figure 4. (A) Grand average ERPs of all four conditions time-locked to the onset of the disambiguating dative NP for the disambiguated conditions or the adverb for the ambiguous conditions, using a baseline of 0–150 msec. Both disambiguated conditions evoked P600 components between 550 and 800 msec, reflecting different extent of the prosody–syntax mismatch effect. The two ambiguous conditions elicited N400 word class effects between 300 and 550 msec. Long subj-Amb (black dotted) = the long subject-ambiguous condition, Long subj-Disamb (black solid) = the long subject-disambiguated condition, Short subj-Amb (red dotted) = the short subject-ambiguous condition, Short subj-Disamb (red solid) = the short subject-disambiguated condition. (B) Voltage maps of the difference waves illustrate the scalp distribution of both N400 and P600 components. Ambiguous = the ambiguous condition, Disambiguated = the disambiguated condition, Long subj-Amb = the long subject-ambiguous condition, Long subj-Disamb = the long subject-disambiguated condition, Short subj-Amb = the short subject-ambiguous condition, Short subj-Disamb = the short subject-disambiguated condition.



CPS in the long condition was inconclusive. Our present results extend previous ERP findings on punctuation and instructed prosodic phrasing in silent reading in several ways (Steinhauer, 2003; Steinhauer & Friederici, 2001). First, phrase length in written language was shown to be an equally efficient visual trigger for subvocal prosodic boundaries as punctuation. Thus, at least in Korean, length information seems to induce effects similar to overt speech boundaries. This hypothesis was previously suggested based on behavioral work (Hwang & Schafer, 2009; Hirose,

Table 3. N400 Effect in Ambiguous Condition (300–550 msec) and P600 Effect in Disambiguated Conditions (550–800 msec)

		N400 (300–550 msec)		*P600 (550–800 msec)*	
Source	*df*	*F*	*p*	*F*	*p*
1. Global ANOVA					
Lateral electrodes					
Ambiguity × Laterality	1	15.86	.0007		
Length × AntPost	2	6.31	.0168		
Ambiguity × AntPost	2	17.74	.0001	5.82	.0174
Ambiguity × Hemisphere	1	4.43	.0476	11.60	.0027
Length × Ambiguity × AntPost	2			3.70	.0623
Ambiguity × Laterality × Hemisphere	1			5.21	.0330
Length × Ambiguity × AntPost × Hemisphere	2	4.57	.0240		
Midline electrodes					
Ambiguity × AntPost	2	13.73	.0003	5.89	.0143
Length × Ambiguity × AntPost	2			6.69	.0097
2. Follow-up Analyses					
Lateral electrodes					
For frontal sites					
Length × Ambiguity	1			4.44	.0473
Ambiguity × Hemisphere	1			7.23	.0138
Ambiguity × Laterality	1	13.57	.0014		
Length × Ambiguity × Laterality × Hemisphere	1	4.75	.0408		
For central sites					
Ambiguity × Laterality	1	14.71	.0010		
Ambiguity × Hemisphere	1			11.60	.0027
For posterior sites					
Ambiguity	1	7.26	.0136	4.59	.0440
Ambiguity × Laterality	1	11.15	.0031		
Ambiguity × Hemisphere	1			7.36	.0130
Ambiguity × Laterality × Hemisphere	1	5.99	.0233	7.66	.0115
Length × Ambiguity × Laterality × Hemisphere	1	4.38	.0486		
For frontal in disambiguated					
Length	1			4.42	.0477
For central in disambiguated					
Length	1			4.78	.0402
Midline electrodes					
For Fz					
Length × Ambiguity	1			5.27	.0322
For Pz					
Ambiguity	1	11.73	.0025		
For Fz in disambiguated					
Length	1			5.80	.0253
For Cz in disambiguated					
Length	1			4.82	.0394

1999, 2003; Fodor, 2002), but only the present CPS data were able to reveal that phrase length in silent reading has the same on-line effect on subvocal prosody as it has on overt prosodic phrasing when Korean speakers read these sentences aloud. Second, the CPS at the dative NP for short sentences suggests that similar boundary findings in first-pass reading data (Hwang & Schafer, 2009) were not exclusively driven by syntactic constraints but, at least partly, also by the length of the prosodic phrase. Third, the profile of the length-driven CPS in our current study replicates that of previous CPS findings during silent reading (Steinhauer & Friederici, 2001). That is, the CPS in the visual modality seems generally smaller in amplitude and shorter in duration than the CPS in speech (Steinhauer, 2003; Steinhauer & Friederici, 2001).

The somewhat more frontal distribution of the present effect compared with previous CPS findings in silent reading (centro-parietal in Steinhauer, 2003; central in Liu et al., 2010) seems to suggest a similar variability in scalp topography as in auditory CPS studies (Itzhak et al., 2010; Pannekamp et al., 2005; Steinhauer et al., 1999).[7] Although all CPS components reported to date have been found near the midline, their variability along the AntPost axis needs further systematic investigation. Only two previous studies have identified relevant factors. Pannekamp et al. (2005) showed (within-subjects) that boundaries in hummed sentences elicited more anterior CPS components than those in natural speech. Using speech stimuli in English, Steinhauer, Abada, Pauker, Itzhak, and Baum (2010) demonstrated more posterior CPS effects in older people compared with young adults. Whether either length-driven boundaries or implicit prosodic boundaries in Korean generally elicit frontally distributed CPS components needs to be clarified by future research.

Given this variability in CPS scalp distribution, it is important to carefully examine apparent CPS findings to rule out alternative accounts in terms of other ERP components (Steinhauer, 2003). Above, we demonstrated that CPS differences between long and short conditions could not be caused by lexical differences or word position effects. Specifically, as the positive deflection following long subject NPs was yielded for the exact same words in the long and the short condition, the differences between the conditions could have alternatively reflected (a) that words preceding the long subject primed the target word and thereby reduced the N400 or (b) that differences in word position reduced the N400 for long subject NPs. However, these possibilities were successfully ruled out by discriminating the CPS from any N400 effects in terms of scalp distribution. Moreover, to our knowledge all ERP studies on proper name priming or name processing have also consistently reported posterior effects (e.g., Schweinberger et al., 2006), as did N400 studies on sentence position effects (Van Petten & Kutas, 1991).

Alternatively, the current frontal CPS profile may be viewed as resembling left anterior negativities.[8] In the absence of any syntactic anomaly (e.g., Friederici, 2002) or NP scrambling (Kwon, 2008; Hagiwara, Soshi, Ishihara, & Imanaka, 2007; Ueno & Kluender, 2003), the only left anterior negativity effect conceivable at this early position would be because of an enhanced working memory load for the more complex NP in the long condition. However, as this would predict a negative rather than a positive going shift in the long NP condition, we are confident that the actual pattern is best accounted for by the predicted CPS component reflecting prosodic phrasing.

A related point of concern for the CPS in the literature is a distinction between CPS and P600 because of many shared characteristics such as polarity and scalp distribution (Kerkhofs et al., 2007; Steinhauer, 2003), especially in the auditory domain. P600s are known to be sensitive to sentence and discourse complexity (Dwivedi et al., 2010; Friederici, 2002). For example, increasing the number of NPs (the number of discourse referents) can elicit frontal P600 effects (Kaan & Swaab, 2003). By contrast, in the present study, which sought to avoid such confounding effects, the long subject NP did not increase the number of discourse referents. Therefore, discourse complexity in the long and short matrix subjects should not differ from each other, and thus, the positive shift is unlikely to reflect processing difficulties due to complex structures. In addition, the latency of the present CPS (300–600 msec) does not fit the standard P600 latency in reading studies (500–700 msec; Osterhout & Holcomb, 1992). Finally, the predicted and observed garden path P600 difference between long and short conditions later in these sentences (see below) in the present study also points to the mediation of length effects by means of prosodic phrasing, as already suggested by behavioral work using the same sentences (Hwang & Schafer, 2009), and by the pretest reported in this article. This will be discussed next.

Garden Path Effects

As predicted by the implicit prosody hypothesis, phrase length of the subject NP—mediated by implicit prosody—had also on-line effects on syntactic ambiguity processing. This suggests that silent prosodic boundaries induced by length information, like auditory boundaries, are sufficient to influence the attachment of the ambiguous dative NP (Hwang & Schafer, 2009; Hirose, 1999, 2003; Steinhauer, 2003; Fodor, 1998, 2002; Steinhauer & Friederici, 2001). The prosody–syntax mismatch effects were most clearly reflected by a significant frontal positivity (550–800 msec) at the disambiguating second dative NP in the short (but not the long) disambiguated condition. This component was tentatively interpreted as a P600 known to reflect processes of structural revision in garden path sentences (Friederici et al., 2002; Hagoort et al., 1999). More specifically, intonation phrase boundaries projected after the long subject NP established prosodic patterns that supported the correct analysis and, thus, attenuated garden path effects, as reflected by the reduced P600 amplitude in the long disambiguated condition. This contrasts with the short disambiguated condition where readers were "led down the garden path" because of the absence of such boundaries. Without support from implicit prosody, one may have expected a larger garden path effect in the *long* subject-disambiguated condition because reanalysis should be more difficult in long sentences than short ones (Kaan & Swaab, 2003).

Recall that even the long disambiguated condition showed a posterior P600, which however should be interpreted with some caution. Inspection of the ERP effects between 300 and 800 msec in Figure 4A suggests that the word class N400 (larger for the long ambiguous condition at more posterior sites) and the garden path P600 (larger for the long disambiguated condition at more posterior sites) may be difficult to disentangle, although the boundary seems to be around 550 msec. Thus, a first question to address is whether the ERP difference between 300 and 800 msec can be better explained in terms of either one single effect (prolonged N400) or rather two effects (N400 plus P600). In the visual domain, N400 effects that last beyond 600 msec are extremely rare in adult native speakers (Kutas & Federmeier, 2009), although a prolonged N400 might be due to the Korean-specific writing system. Kwon (2008) also found an N400 between 300 and 600 msec for semantic incongruities in Korean. Nakagome et al. (2001) reported N400 durations until 700 msec for selectional restriction violations in Japanese when using the ideographic script (*kanji*), which however is different from Korean in many respects. In the present study, similar to Kwon (2008), word position N400 effects were significant just for the 300–600 msec time window, and therefore, an atypical Korean-specific word class N400 lasting for 500 msec (300–800 msec) seems very unlikely. This means that the effect in the later time window (550–800 msec) is best accounted for in terms of P600s in the long disambiguated condition as compared with its ambiguous counterpart, despite the similarity in scalp distribution for N400 and P600. The most compelling empirical support for this interpretation was offered by a highly significant Ambiguity × Hemisphere interaction that was more evident in the P600 than the N400 time window, thus suggesting distinct topographies of the N400 and P600. In global ANOVAs (cf. Table 3), this effect was less robust in the early ($p < .05$) than the late time window ($p < .003$). Follow-up analyses revealed that a main effect of ambiguity was significant only over the right hemisphere and only in the late time window ($F(1, 21) = 5.37$; $p < .04$). This pattern is unlikely to be driven just by the short disambiguated condition because in this case there should be a strong Ambiguity × Length × Hemisphere interaction, but there is not. Thus, the significant Ambiguity × Hemisphere interaction in absence of an Ambiguity × Length × Hemisphere interaction points to shared right-lateralized garden path P600 across both long and short disambiguated conditions, replicating garden path patterns in Hwang and Schafer (2009).[9]

Functional Significance of P600 Components

Given our discussion above, we end up with two distinct P600 effects: (i) a parietal P600 that is shared between both disambiguated conditions and (ii) a frontal P600 for the short disambiguated condition only. Following Hwang and Schafer (2009), the additional P600 for the short (vs. long) disambiguated condition could in principle reflect that the syntactic revision was more difficult for the short than the long condition. This raises the question of how syntactic revisions in the long disambiguated condition could be facilitated. Compared with the biasing prosodic pattern for the matrix verb attachment of the first dative NP in the short condition, the first-pass prosodic pattern generated in the long condition could have either speeded up syntactic reanalyses or enhanced the proportion of sentences that were successfully reanalyzed. For this account to be supported, P600 effects in the long and short disambiguated conditions would have been expected to be qualitatively similar (e.g., in terms of scalp distribution), although quantitatively differing from each other in terms of amplitude and/or latency. What we found instead was a comparable posterior P600 in both conditions and a distinct frontal P600 in the short condition only.

Alternatively, their distinct scalp distributions may suggest qualitatively different underlying processes. What kind of cognitive processes may be reflected by each of these components? Given what we know about implicit prosody and its role in garden path resolution (Hirose, 2003; Bader, 1998; Kondo & Mazuka, 1996), it is not unreasonable to assume that the final outcome of a revision process has to provide an adequate and coherent representation of the target sentence at all levels, that is, lexically, syntactically, and prosodically. For both short and long disambiguated garden path sentences, the revision clearly involved a syntactic reanalysis changing the attachment site of the first dative NP *Robin-Dat* (i.e., the initially preferred matrix clause attachment must be given up and replaced by a RC attachment). This syntactic revision must be reflected by the posterior P600 found in both conditions. Moreover, irrespective of subject-NP length, the resulting sentence structure (after successful syntactic revision) was shown by Hwang and Schafer (2009) to correspond to a very characteristic prosodic phrasing pattern with one single boundary after the matrix subject NP, and no boundary after the dative NP.[10] Thus, to reach a coherent representation of the revised sentence at all levels, the syntactic revision is likely to co-occur with a prosodic revision, that is, (a) the mental deletion of the inappropriate boundary after the first dative NP and/or (b) the insertion of the appropriate boundary after the subject NP. As the former prosodic revision (a) is also equally required in long and short disambiguated sentences (Hwang & Schafer, 2009), the posterior P600 found in both conditions may reflect this process as well. This notion is completely in line with previous posterior P600 findings for garden path sentences that required syntactic reanalyses as well as prosodic boundary deletion, both in the auditory domain (Pauker et al., 2011; Steinhauer et al., 1999) and for implicit prosody in silent reading (Steinhauer, 2003; Steinhauer & Friederici, 2001).

Now let us turn to the frontal P600. The short disambiguated condition (which elicited this P600 effect) differed from the long condition (which did not show this effect) primarily in terms of the early implicit boundary. That is, only the long subject condition already elicited a boundary right after the subject-NP (as reflected by the CPS in Figure 2). By contrast, this boundary still needed to be "created" in the short disambiguated condition to meet the criterion of coherent representation at all levels. We, therefore, suggest that the frontal P600 found only in the short condition may, at least in part, reflect the mental insertion of this prosodic boundary (i.e., a prosodic revision). This hypothesis may be linked to yet another interesting observation related to the scalp distribution of these ERP components. As demonstrated in various ERP studies (Itzhak et al., 2010; Steinhauer & Friederici, 2001), on-line insertion of prosodic boundaries is usually reflected by a CPS. In the present study, the CPS after the long subject NP had a rather frontal and slightly right-lateralized scalp distribution (cf. Figure 2). Intriguingly, the frontal P600 in the short subject condition displayed a very similar scalp topography (see voltage maps in Figures 2 and 4B, bottom left). When directly contrasting the scalp distribution of these two frontal effects, we found significant shared main effects (*p*s < .02) and interactions with AntPost (*p*s < .04), but no single difference in scalp distribution at either midline or medial electrodes. Therefore, if we are right and the frontal "P600" actually reflects boundary insertion, it may—in this particular case—potentially also be viewed as a delayed "CPS" component. This tentative interpretation is in line with our auditory study replicating both types of frontal effects (Hwang & Steinhauer, in preparation) but clearly needs to be tested in future studies. If confirmed, it may explain some variability in the scalp distribution of P600 components more generally.

There are a number of alternative accounts for the frontal P600 that need to be considered. Previous studies reporting frontal P600 effects linked the anterior scalp distribution to (a) syntactic reanalysis in general (e.g., Friederici et al., 2002), (b) the processing costs related to the noncanonical ordering of NPs in a sentence (so-called scrambling; Hagiwara et al., 2007), and (c) discourse processing including logical contradictions (Dwivedi et al., 2010). Unlike the latter, both (a) and (b) played a role in our materials, however, to the same extent in both short and long sentence conditions. They would, therefore, be expected to influence the shared posterior P600 effects rather than the frontal P600 that was found for the short condition only. Consequently, we believe that the prosodic account of the frontal P600 (insertion of a boundary) is more consistent with our data.

Length-driven Implicit Prosody and Its Role in Sentence Processing

The present data highlight the cognitive process underlying the CPS that immediately uses phrase length information to structure incoming sentence input without delay.[11] Consistent with the predictions of the implicit prosody hypothesis (Fodor, 1998, 2002) and the RSH (Clifton et al., 2006), the CPS in the long subject conditions showed immediate on-line effects of phrase length on implicit prosodic phrasing during silent reading.

What needs to be further discussed is (a) how the length-driven implicit prosodic boundary in the long disambiguated condition made it easier to build the normally less preferred RC attachment analysis and (b) whether each alternative account fits either the IPH or the RSH. Three scenarios are conceivable. First, as predicted by the IPH, the prosodic boundary at the end of the long subject NPs could have changed the initial parsing preference, especially in absence of an additional boundary after the first dative NP (Hwang & Schafer, 2009). But this scenario is not supported by the actual ERP garden path effects (the posterior P600 in the long disambiguated [vs. ambiguous] condition), in line with Hwang and Schafer's behavioral findings. Second, the length-motivated boundary may have facilitated syntactic revision, as suggested by Hwang and Schafer (2009) and by the IPH as well. However, as discussed above, qualitative differences in P600 scalp distribution did not provide strong evidence for a purely syntactic reanalysis account either.

The third possibility is that the neutral prosody in the long condition did not primarily help the syntactic reanalysis but rather facilitated the prosodic revision, compared with the short condition. An additional prosodic revision step was needed only for the short condition, because implicit prosodic boundaries already assigned after the *long* subject NPs during the initial parse were likely "recycled" (Hirose, 2003), and thus, an additional implicit prosodic boundary did not need to be inserted at the position in the long condition to match the revised syntactic structure. At present, this third account is best compatible with the current ERP data. It leads to a slight reinterpretation of Hwang and Schafer's (2009) data, which could not distinguish between effects of prosodic vs. syntactic revisions to account for the additional costs in short (vs. long) disambiguated sentences. At first sight, this last prosodic account appears to be also in line with the RSH, as it makes explicit claims about the unavailability of length-driven boundaries for syntactic decisions and revisions only. However, the frontal CPS-like P600 in the short (but not long) condition still poses a problem for the RSH. Unlike the IPH, the RSH strictly distinguishes length-induced boundaries from syntactically licensed ones such that these must be represented separately. In other words, this framework does not allow for any "recycling" of length-driven boundaries for syntactic purposes, and the delayed insertion of a syntactically licensed prosodic boundary should have been required in the long disambiguated condition, as well.

Conclusion

The present study demonstrated that phrase length affected the readers' choice of prosodic phrasing during silent reading, which in turn was used in their on-line comprehension of sentences involving syntactic ambiguity. Implicit prosodic boundaries triggered by the long subject phrases elicited a CPS and facilitated reanalysis in the corresponding garden path condition. In the absence of such a length-driven boundary, the processing difficulties in the "short subject disambiguated" condition (requiring delayed insertion of a boundary) were reflected by an additional frontal P600. Its resemblance of the CPS profile suggests that some P600 effects may reflect prosodic rather than syntactic revision processes. Although these findings seem to be largely in line with the Implicit Prosody Hypothesis, they cannot be completely accounted for by either the IPH or the RSH.

Length-driven implicit prosody effects, which closely mirror explicit prosody, seem to hold across self-paced reading, RSVP, and ERP paradigms. The effects differ from those elicited by punctuation in that they do not generally affect initial parsing decisions. The current ERP data replicate the CPS component for the first time in Korean sentences and add cross-linguistic validity to the notion of a common mechanism in implicit and explicit prosody (Steinhauer, 2003; Fodor, 2002; Steinhauer & Friederici, 2001; Bader, 1998).

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Notes

1. To divide the sentence in two equal parts, longer RCs (e.g., *who was on the balcony*) tend to attract a prosodic boundary at #2, whereas short RCs (*who cried*) tend to produce a boundary at #1. These distinctive prosodic patterns can alter attachment preferences: Longer RCs with a boundary at #2 attach higher (to *the servant*) than short RCs with a boundary at #1.
2. This matrix clause attachment is the simpler analysis because the relative clause needs not be assumed until the relative clause subject NP *Phwuwu-ka* ("Pooh-Nom") is encountered.
3. The reason is as follows: The syntactic motivation for this boundary depends on the presence of a RC, which is first indicated by the RC subject NP (Pooh-Nom). Hwang and Schafer's first-pass reading-aloud study (reporting such boundaries in both short and long conditions) presented the entire sentence at once, such that parafoveal preview allowed readers to see this RC subject NP while reading aloud the dative NP and, thus, to produce a boundary right away. In contrast, in ERP reading studies using word-by-word (RSVP) presentation, this preview is not possible and the syntactically motivated prosodic boundary after the dative NP can be postulated only later in the sentence (likely while the RC subject NP was presented). Hwang and Schafer (2009) showed that such a delayed insertion of prosodic boundaries is in fact supported by self-paced reading data. Given that ERPs reflect processes in real time, no CPS at the dative NP would be expected for delayed boundary insertion. Thus, a CPS right after the dative NP in the long conditions may be absent. In contrast, as the boundary after the dative NP in the short conditions is at least partly length-driven (both matrix subject NP and dative NP are available at this point), a CPS *can* be expected. However, given that Hwang and Schafer found such a boundary in only 88% even when parafoveal preview was present, a purely length-driven boundary (in absence of parafoveal preview) may occur only in a rather small proportion of trials, predicting a reduced CPS amplitude compared with the CPS at the subject NP in the long condition.
4. To insure that the 144 cartoons are relatively well known in Korea, their familiarity was assessed by 15 participants making yes/no judgments on the cartoons and their characters. Although relative familiarity of the cartoons varied somewhat, none of them were unanimously judged unfamiliar (mean = 62%, range = 13%–100%).
5. Additional statistical analyses were run both with this 160–260 msec baseline as well as with a poststimulus baseline in the time range of the onset components of the next word (i.e., 800-1000 msec). Independent of the baseline, we always replicated the main finding of a significant frontal (and somewhat right lateralized) CPS near the midline for long subject NPs. Importantly, all of these effects had a different scalp distribution compared with N400 effects but were similar to the CPS distribution reported in Pauker et al. (2011) and Itzhak et al. (2010).
6. We would like to thank an anonymous reviewer for suggesting these analyses, including the contrasts in both Figure 3A and B.
7. We found a similar frontal CPS for comma processing in English sentences (Hwang, Baum, Drury, Valeriote, & Steinhauer, 2011).
8. We would like to thank an anonymous reviewer for drawing our attention to this fact.
9. If we reinterpreted the N400/P600 effects between 300 and 800 msec as one single effect, that is, a prolonged N400, this would have an interesting implication for the phrase length effect on syntactic analysis. Then, the absence of any P600 in the long condition would suggest that the prosodic boundary at the end of the long subject NP entirely prevented garden path effects and immediately altered the initial parsing preference.
10. As discussed above, this prosodic pattern with an early boundary (i.e., Piglet-Nom # Robin-Dat…) was consistently produced by speakers who knew the entire sentence in advance ("second-pass reading" data). Importantly, in contrast to implicit prosody during "first-pass reading," the early boundary was *independent* of the length of the matrix subject-NP and was produced whenever the first dative NP was attached to the relative clause. Thus, this should be the prosodic pattern to be expected after successful revision.
11. Our data show on-line effects of length on implicit prosody and parsing decisions, which supports the principle of incremental comprehension. However, the generality of these results may be restricted to cases where length manipulation occurs sentence initially, that is, before the critical regions (the ambiguously parsed phrase or its potential attachment sites). When phrase length varies *after* potential attachment points, the implicit prosody hypothesis can work in a counterintuitive way, challenging the incremental nature of sentence processing (thanks to an anonymous reviewer for pointing out this issue). For example, in a sentence like *The colonel shot the daughter of* {*the diplomat vs. the diplomat with a silly hat*} *on the balcony*, the last prepositional phrase (PP) *on the balcony* can modify either *the*

daughter or *the diplomat*. When the first PP *of the diplomat* becomes longer, a prosodic break tends to occur after *daughter* (Fodor, 1998, 2002), which makes the long PP more likely to be modified by the following PP *on the balcony*. The attachment decision can be made at *of*. Here, the question is how readers can know at this early attachment point about the length of the PP. Pynte (2006) argues that "the optimal phrasing for a particular syntactic combination of words is globally determined. An assignment of implicit prosody on-line must , therefore, either tolerate a less-than-optimal phrasing or else adjust it retroactively as later constituents are processed" (p. 263). If prosodic cues induced by phrase length become available only after the whole prosodic phrase has been processed, implicit prosody on the basis of constituent length must be delayed (i.e., cannot be incremental). For these cases, our current findings would predict a frontal positivity (P600/CPS) at the end of the PP, reflecting the delayed insertion of a boundary. A more detailed discussion of this issue is beyond the scope of the present article.

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