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Prosodic Boundaries, Comma Rules, and Brain Responses: The Closure Positive Shift in ERPs as a Universal Marker for Prosodic Phrasing in Listeners and Readers

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Just as the false comma in this sentence, shows punctuation can influence sentence processing considerably. Pauses and other prosodic cues in spoken language serve the same function of structuring the sentence in smaller phrases. However, surprisingly little effort has been spent on the question as to whether both phenomena rest on the same mechanism and whether they are equally efficient in guiding parsing decisions. In a recent study, we showed that auditory speech boundaries evoke a specific positive shift in the listeners' event-related brain potentials (ERPs) that indicates the sentence segmentation and resulting changes in the understanding of the utterance (Steinhauer et al., *1999a). Here, we present three ERP reading experiments demonstrating that the human brain processes commas in a similar manner and that comma perception depends crucially on the reader's individual punctuation habits. Main results of the study are: (1) Commas can determine initial parsing as efficiently as speech boundaries because they trigger the same prosodic phrasing covertly, although phonological representations seem to be activated to a lesser extent. (2) Independent of the input modality, this phrasing is reflected online by the same ERP component, namely the Closure Positive Shift (CPS). (3) Both behavioral and ERP data suggest that comma processing varies with the readers' idiosyncratic punctuation habits. (4) A combined auditory and visual ERP experiment shows that the CPS is also elicited both by delexicalized prosody and while subjects replicate prosodic boundaries during silent reading. (5) A comma-induced reversed garden path turned out to be much more difficult than the classical garden path. Implications for psycholinguistic models and future ERP research are discussed.*

KEY WORDS: punctuation; comma processing; covert prosody; event-related brain potentials; ERP; closure positive shift; CPS; P600; reversed garden path.

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INTRODUCTION

Punctuation has not received much attention within psycholinguistic research, with respect to both experimental studies and theories of sentence comprehension (cf. Mitchell, 1987). One likely reason is that the language specific punctuation rules are normally neither very strict nor very well known even by native speakers of the respective language (Bruthiaux, 1993; Chafe, 1988). Thus, often it strongly depends on the writer's preferences or intuition, whether and where a comma is inserted. Psycholinguistic experimenters often omit punctuation completely (e.g., Ferreira & Henderson, 1991). Nevertheless, punctuation seems to have considerable influence on the reader's sentence analysis. It is not unlikely that many syntactic ambiguities simply would not occur if commas were inserted. A prominent example is the Early versus Late Closure (EC/LC) ambiguity in sentences (a) and (b) below:

(a) *Since Jay always jogs* <u>*a mile and a half*</u> *this seems like a short distance to him.*
(b) *Since Jay always jogs* <u>*a mile and a half*</u> *seems like a very short distance to him.*

As Frazier and Rayner (1982) report, readers have a strong preference to initially interpret the ambiguous noun phrase "*a mile and a half*" as the direct object of the preceding verb "*jogs*" (LC). Initial misunderstandings and increased reading times result when the noun phrase turns out to be the subject of the subsequent verb "*seems*" as in sentence (b) (EC). According to one of the rare studies on punctuation by Mitchell and Holmes (1985; see also Mitchell, 1987), however, comma insertion after the verb "*jogs*" would prevent readers from being led up this garden path. Conversely, after comma insertion one would predict a reverse garden path for the normally easy-to-process sentence (a). What the comma study did not consider was interindividual differences across subjects. As it is well established that writers differ with respect to their punctuation habits (Baldwin & Coady, 1978; Bruthiaux, 1993; Chafe, 1988), readers may differ similarly in comma perception. Moreover, there may be a direct intraindividual correspondence between punctuation habits and comma perception during reading.

A related issue is that it has been long debated whether punctuation rules are, or should be, predominantly motivated by syntax or prosody (Baldwin & Coady, 1978; Bergien, 1994; Böhme, 1995; Chafe, 1988; Van Petten & Bloom, 1999). As prosody is at least partly determined by syntactic requirements (Cooper & Paccia-Cooper, 1980; Selkirk, 1984), the simplified hypothesized processing order in writers may be

$$\text{Syntax} \Rightarrow \text{(subvocal) Prosody} \Rightarrow \text{Punctuation}$$

and the reverse order may apply to readers. The assumed correspondence between visual input and phonological representations is not a new idea. It is widely accepted that, at least in healthy individuals, reading activates phonological word representations of the phylo- and ontogenetically older auditory language system (Bradley & Bryant, 1978; Patterson & Coltheart, 1987; Perfetti, 1994). This phenomenon is often referred to as phonological (re)coding (e.g., Share, 1999), or, more figurative, as "internal voice" (Chafe, 1988). However, research beyond the word level is rare. Bader (1994, 1998) was one of the pioneers who discovered the covert activation of suprasegmental phonology in silent reading. He found that a syntactic ambiguity in German led to strong garden path effects only if focus particles were present that added a *prosodic* ambiguity. Bader concluded that garden path effects might be generally enhanced if prosodic representations are also affected. Continuous psycholinguistic research on punctuation during the past years was conducted by Hill and Murray (1997, 1998; Hill, 1996). With a variety of experimental techniques, they showed that punctuation slows down reading locally but that readers profit later in a sentence; that commas are processed differently than additional spaces; and that punctuation displays an extraordinary potential in disambiguating garden path sentences. Hill and Murray also described cases of redundant punctuation where commas simply confirmed initial parsing preferences. With respect to the relationship between punctuation and prosody, Hill (1996) rejects Chafe's (1988) proposal of a direct correspondence. However, the empirical data he offers rule out only the equivalence of commas and *pauses*; and both Streeter's (1978) and our own data (Steinhauer *et al.,* 1998, 1999a) show that prosodic boundaries can be perceived in complete absence of pauses if other acoustic markers, such as boundary tones or constituent lengthening, are present. The interplay of different acoustic parameters in establishing a prosodic effect, such as a boundary or an accentuation pattern, has been called *cue trading* (e.g., Streeter, 1978; Beach, 1991). Findings of this kind appear to confirm recent work by several authors who suggest introducing a separate (ToBI-like)[4] level of phonological representations in psycholinguistic models, as well as a prosodic parsing device, possibly with direct impact on the syntactic parser (Beckman, 1996; Schafer, 1997). (As will be outlined below, there is strong empirical evidence for this view.)

In summary, the relationship between punctuation and prosody appears to be a still unresolved question. If punctuation is actually mediated by (covert or subvocal) prosody, then its processing should resemble that of

[4] ToBI, tonal and break indices (Silverman *et al.,* 1992)

overt prosody. Interestingly, similar effects as in Mitchell's work on commas have repeatedly been reported for the auditory modality. In speech perception, prosodic cues, such as speech boundaries, were demonstrated to influence initial parsing preferences in a comparable manner as the commas in the Mitchell and Holmes (1985) reading study (Marslen-Wilson *et al.,* 1992; Speer *et al.,* 1996; Warren *et al.,* 1995). However, there were also contradictory findings that challenged the view that prosody can immediately influence parsing decisions (Pynte & Prieur, 1996; Watt & Murray, 1996). One study even claimed that speakers do not provide reliable prosodic cues (Allbritton *et al.,* 1996; for counter-evidence, see Alter *et al.,* 1998 and Schafer *et al.,* 2000). Apart from the complex interplay of acoustic parameters, one important reason for the mixed data, and a major drawback in this field, was the much regretted lack of an appropriate online method. For data collection, even the sophisticated cross-modal naming task required the unnatural interruption of the prosodic processing, a switch from auditory to visual stimulus presentation, and a switch from perception to production. It was Paul Warren (1999) who suggested that new methods, such as event-related brain potentials, might be needed to shed new light on prosodic processing.

In fact, similar to other psycholinguistic domains, event-related potentials proved as a promising approach to the study of prosody. The first ERP study on prosody and parsing (Steinhauer *et al.,* 1999a) showed for spoken German sentences, such as (1a) and (1b), that prosodic cues determined whether the NP "*Anna*" was initially parsed as the object of the first verb (as required in 1a) or the second verb (as required in 1b).

(1a) *Peter verspricht Anna zu arbeiten* . . . *und das Büro zu putzen*
Peter promises Anna to work . . . and to clean the office
(1b) *Peter verspricht Anna zu entlasten* . . . *und das Büro zu putzen*
Peter promises to support Anna . . . and to clean the office

Due to the German verb-final word order, the syntactically different sentences are identical until they are lexically disambiguated by the second verb that either requires "*Anna*" as its direct object ("*entlasten*/support" in 1b) or not ("*arbeiten*/work" in 1a). It was demonstrated that a speech boundary after the first verb "*verspricht*" shifts the listeners initial sentence analysis almost entirely from (1a) toward (1b). With this boundary, the normally easy-to-process sentence (1a) is then misunderstood as *"*Peter promises to work Anna,*"[5] i.e., causing an ungrammatical verb argument structure violation, whereas the more difficult sentence (1b) becomes easy. The resulting

[5] Note: In contrast to its English translation, the original German sentence *"*Peter verspricht/Anna zu arbeiten*" does not carry any slang interpretation with potential sexual connotations and is rather completely ungrammatical.

severe processing difficulties in sentence (1a) can be viewed as a prosody-induced "reversed garden path effect" as sentence (1a) should be usually preferred over (1b) according to both the Late Closure and the Minimal Attachment principles of the garden path model (Frazier, 1978, 1987).[6]

Moreover, it was the first time that prosodic processing could be monitored online without interruptions. Apart from behavioral evidence, and in accordance with previous ERP results on verb argument structure violations (Friederici & Frisch, 2000; Osterhout & Holcomb, 1992), an online reflection of the garden path effect was observed in the event-related brain potentials (ERP). A consistent N400-P600 pattern of ERP components was found for the incompatible intransitive verb "*arbeiten*". These two ERP components are known as correlates of different levels in language processing. The P600 component (or "syntactic positive shift"), a centro–posterior positivity around 600 ms, is elicited by words that are difficult to integrate syntactically into the sentence structure (Friederici *et al.*, 1998; Osterhout & Holcomb, 1992). By contrast, difficulties in lexical and semantic processing are reflected by the N400 component, a negativity with a latency around 400 ms (Chwilla *et al.*, 1995; Friederici *et al.*, 1999; Kutas and Hillyard, 1980). Both components have been replicated in several languages with both written and spoken presentation. In the current example, the N400 appears to reflect lexical reaccess of the verb argument structure (Hopf *et al.*, 1998), while the P600 reflects the required reanalysis. As this reanalysis necessarily implies changes of both the syntactic and the prosodic structure, we assume that each of these two levels might contribute to the P600 effect (cf. Steinhauer *et al.*, 1999a). This interpretation can be taken as an extension of Bader's (1994, 1998) suggestion that phonological processing contributes to garden path effects.

Most importantly, with respect to the present work, the Steinhauer *et al.* (1999a) study with spoken sentences reported a novel electrophysiological correlate for the closure of prosodic phrases, termed the Closure Positive Shift (CPS). This positive-going waveform in the ERP was present whenever the listeners perceived an intonational boundary and could, therefore, be used to predict the garden path effect later in the sentence in condition (1a). In the meantime, the prosody-related CPS component was replicated cross-linguistically in a Dutch study by Brown and Hagoort (2000). Thus, at least in the auditory domain, ERPs allow one to monitor the phrasing of language input and its influence on syntactic parsing decisions online.

In addition, the discovery of the CPS opens a new approach in studying punctuation. If commas can, in fact, be described as visual cues triggering phonological phrasing (or covert prosody of the "inward voice," cf. Chafe,

[6] We thank Lyn Frazier, Janet Fodor, and Atsu Inoue for fruitful discussions on this issue.

1988), then they should also elicit a CPS similar to that observed for prosodic boundaries in spoken language. However, this logic may be too simple, as it does not take the hypothesized interindividual differences across readers into account. That is, commas may be more effective in individuals used to strict punctuation rules. A more complete experimental design should, therefore, control also for the readers' idiosyncratic punctuation habits. This was attempted in the first experiment.

EXPERIMENT 1

The first experiment addresses three questions. First, are commas and prosodic boundaries equivalent in guiding initial parsing decisions? Second, do commas also elicit positive shifts in the ERP (i.e., the CPS), possibly reflecting the closure of subvocally activated prosodic units? Third, does the respective impact of commas depend on the reader's own habits in the use of commas? In order to allow a direct comparison, the same sentence material and similar tasks as in the previous auditory experiments were used. Both sentence types were visually presented word-by-word either without a comma (as in 1a and 1b) or with a comma after "*verspricht*" (conditions 1a′ and 1b′). The comma was intended to mimic the prosodic boundaries of spoken sentences.

(1a′) **Peter verspricht, Anna zu arbeiten . . .*
(1b′) *Peter verspricht, Anna zu entlasten . . .*

Old and New Punctuation Rules in German

It is worth mentioning that traditional German punctuation rules used to be stricter than those in other languages, such as English. Very recently, however, a more liberal amendment passed legislation. As a consequence, this new framework covers almost the whole range of preferences displayed by the participants of this study. Nevertheless, many of the students still preferred to insert commas according to the former rule system, which they had acquired in school long before the bill came into force in August 1998. Relevant changes will be illustrated with sentence (1c).

(1c) *Peter verspricht [1] Anna [2] zu verb2 [3] und das Büro zu putzen*

As a rule of thumb, the old system required insertion of a comma after "*verspricht*" in (1b) (position [1] in example 1c) whereas no comma had to be inserted in (1a). In certain cases, a comma could be inserted in (1a), however, only after "*Anna*" (position [2]) and never after "*verspricht*". In both (1a) and (1b), no comma should be inserted preceding the conjunction "*und*" (position [3]) (Dudenredaktion, 1973). According to this convention, sentence (1a) should be preferred over (1a′), and sentence (1b′) over (1b). In contrast, the new rule system permits to leave out the comma after "*verspricht*" in (1b) and to insert the comma after "*Anna*" in (1a), according to one's own preferences. A comma before the conjunction "*und*" in position [3] seems to be allowed in order to emphasize the sentence structure (Dudenredaktion, 1996).

Methods

Twenty-four right-handed (Oldfield, 1975) university students read 48 instances of both sentence types either with a comma after "*verspricht*" (1a′, 1b′) or without this comma (1a, 1b). In best approximation to the tasks in the auditory study, participants were asked to judge whether a sentence was easy to read or not, and had to answer comprehension questions (e.g., *Does Anna promise to clean the office?*) in 20% of the trials. The 192 experimental and 144 filler sentences were pseudorandomly intermixed and presented word-by-word on a computer screen, critical commas being attached to the preceding word ("*verspricht*," vs. "*verspricht*"). Presentation times were derived from average word durations of the speech signals in the auditory experiment and were held constant across conditions. During reading, the subjects' brain potentials (EEG) were recorded continuously from 17 cap-mounted electrodes with a sampling rate of 250 Hz. After artefact rejection, ERPs were computed in representative time epochs and analyzed separately for midline and lateral electrodes. As the original ERPs were dominated by very large (but irrelevant) word onset P200 components (> 9 μV), signals were 1- or 5-Hz low-pass filtered for illustrative purposes only (allowing a better resolution of the critical effects). However, all statistical analyses were performed for the unfiltered data. (For further methodological details see Results section and Steinhauer *et al.*, 1999a.)

At the end of the second experimental session, all subjects were given a list of written sentences similar to those of the study, in which they had to insert commas according to their usual preferences ("*as in a letter to a friend*"). This additional test should shed some light on the relationship between individual preferences in punctuation and comma perception.

Results

Punctuation Strategies

The results of the comma insertion test are summarized in Table I. The 24 participating students were grouped according to their strategies (see below). Differences among the groups and within-group effects were tested by ANOVAs with factors *Sentence type (2)* × *Comma position (3)* × *Group (3).*

Table I. Data of the Punctuation Test in Experiment 1[a]

Sentence type	Comma position	Expected pattern	Group I ($N = 11$)	Deviant punctuation: Group IIa ($N = 5$)	Deviant punctuation: Group IIb ($N = 8$)
1a	1	—	—	—	4.1
	2	—	13.6	—	27.1
	3	—	1.5	80.0	—
1b	1	100	100.0	10.0	71.9
	2	—	—	—	3.1
	3	—	—	70.0	—

[a] Frequencies [%] of comma insertions at each of the three positions in sentence types (1a) and (1b) per group. The "expected pattern" in column 3 is based on the traditional German punctuation rules.

The first group comprises 11 subjects with a uniform tendency to insert commas strictly according to the traditional German rule system. In sentences, such as (1a), they hardly inserted any commas and, if so, these were almost completely restricted to position [2]. In all sentences of type (1b), by contrast, this group consistently inserted a comma at position [1] [*Sentence type* $\times$ *Comma position:* $F(2,20) = 157.55$; $p < .0001$]. As this pattern reflects the former rules gained in school, it is not very surprising that these participants represent the largest homogeneous group. The other subjects displayed a large variety of deviant patterns, but all of them repeatedly either inserted or omitted commas where the former German rule system would not have allowed it. Interestingly, a subgroup of five participants showed an obvious tendency not to insert commas at the proper disambiguating positions [1] and [2], respectively. They rather preferred to insert commas at position [3] in both (1a) and (1b) ($N = 4$), or omitted commas, in general ($N = 1$). These participants are represented by Group IIa that differs significantly from Group I in every respect. Within Group IIa, only a *Comma position* main effect reaches significance [$F(1,4) = 13.19$; $p < .03$]. As illustrated in Table I, the remaining eight students in Group IIb seemed to have similar preferences as the subjects in Group I. Again, most commas were inserted at position [1] in sentence (1b). The most important difference between the groups was that comma insertion in Group IIb was less restricted to sentence type (1b) as compared to Group I (*Sentence type* $\times$ *Group:* $F(1,17) = 9.52$; $p < .01$).

Judgment Data

The "easy/difficult-to-read" judgments collected during the ERP experiment may provide first evidence of whether comma perception corresponded to the individual comma insertion preferences just described. The respective data are summarized in Fig. 1. Statistical analyses were performed with ANOVAs employing factors *Sentence type (2)* $\times$ *Comma presence (2)* $\times$ *Group (3).*

Judgments in Group I were very similar to the prosodic judgment data of the previous auditory study (Steinhauer *et al.*, 1999a), which are also included in Fig. 1 (upper left panel). The two sentence types that met the traditional punctuation rules (i.e., 1a without the comma and 1b′ with the compatible

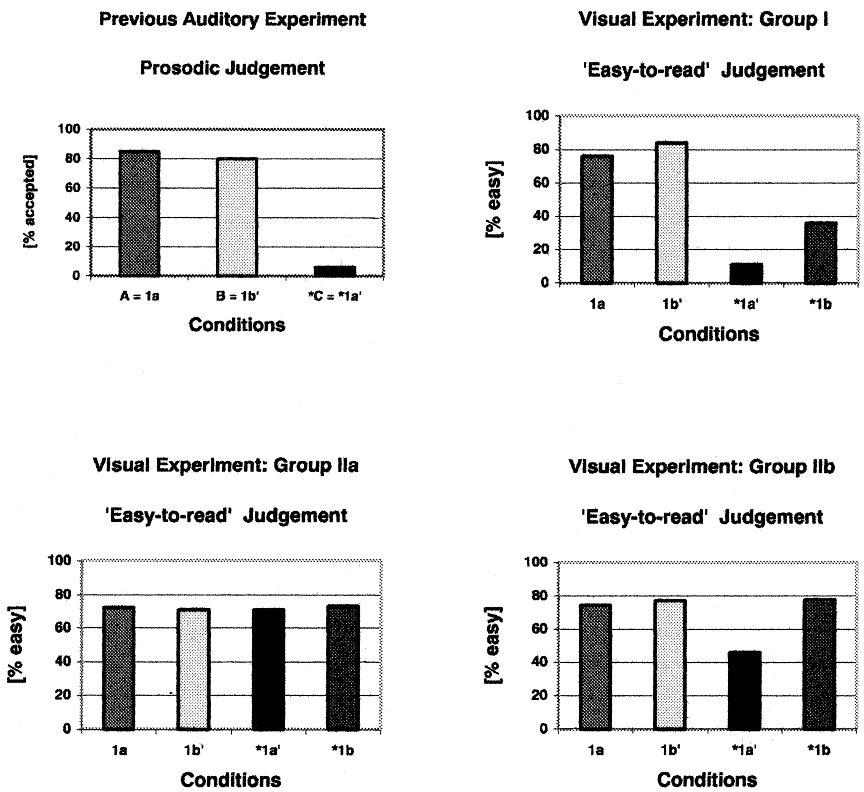

Fig. 1. "Easy-to-read" judgment data of the three subgroups compared to the prosodic acceptability data of the auditory study. Judgment data of subjects with strict punctuation habits (Group I, upper right panel) replicated those of the auditory study (upper left panel). Conditions (1a) and (1b′) were rated as acceptable in roughly 80% and the difficult reverse garden path was only exceptionally accepted (11%). The classical garden path condition (1b) (not used in the auditory experiment) displayed reduced acceptability of 36%. Participants in Group IIa (lower left panel), who almost never disambiguated sentences (1a) and (1b) in the punctuation test, were not influenced by commas in sentence perception either, i.e., all conditions were equally accepted. As in the punctuation test, Group IIb (lower right panel) displayed an intermediate pattern with moderate reductions in the ratings of the severe reversed garden path condition (1a′) only.

disambiguating comma) were judged as easy to read in about 80% of the trials and did not differ from each other ($F < 1$). The classical garden path condition (1b) (without the comma) was rated as easy in less than 40% of the trials. The reversed garden path condition (1a′) with the superfluous comma was accepted in only 11.4% of the trials, indicating an even more severe garden path effect. This pattern is reflected by a highly significant interaction *Sentence type* × *Comma presence* [$F(1,10) = 92.41$; $p < .0001$].

A completely different pattern was observed in Group IIa. These students who had hardly ever inserted commas at disambiguating positions in the punctuation test, seemed not to pay great attention to commas during reading either. Irrespective of the presence or absence of a comma in both (1a) and (1b), all sentences were equally judged as easy to read in about 70% of the trials (Fs < 1).

Surprisingly, although Group IIb had displayed a similar pattern as Group I in the punctuation test, their reading judgments resembled those of Group IIa rather than of Group I. While three conditions were judged as easy in approximately 75% of the trials, only the reverse garden path sentence (1a′) displayed a somewhat reduced acceptability of 46% [*Sentence type* × *Comma presence:* $F(1,7) = 5.33$; $p < .1$). Statistically, only Group I was clearly influenced by commas and thus differed from both Group IIa (*Sentence type* × *Comma presence* × *Group:* $F(1,14) = 40.51$; $p < .0001$] and Group IIb ($F(1,17) = 24.97$; $p < .0001$) which, on the other hand, did not differ from each other ($p > .1$).

As a whole, the behavioral data revealed that only the 11 students in Group I, who were accustomed to a strict punctuation, were as strongly influenced by commas as the subjects in the auditory experiment were influenced by prosodic boundaries.

Sentence Comprehension Data

As with the judgment data, the results of the comprehension test revealed that Group I differed from both Group IIa and Group IIb which, on the other hand, clustered together. That is, the participants with strict comma rules in Group I made significantly less errors than both other groups (main effect *Group:* $p < .0002$).

ERP Data

Due to their behavioral similarities and in order to secure a sufficient signal-to-noise ratio, subgroups IIa and IIb were analyzed jointly with respect to ERP data and will hereafter be referred to as Group II.

Comma Effects

Most importantly, the comma processing underlying the behavioral data was monitored online with ERPs (Fig. 2). In Group 1, both comma conditions (1a′) and (1b′) elicited a biphasic pattern of ERP components as compared to conditions (1a) and (1b) without the comma. A relatively small but significant positive going waveform between 550 and 650 ms post verb1 onset [midline: $F(2,20) = 5.92$; $p < .03$; lateral: $p < .02$) with a centro–parietal scalp distribution similar to that of the auditory CPS was followed by a large negative slow wave between 1000 and 2500 ms (midline: $p < 0.007$; lateral: $p < .005$) with a maximum at central recording sites and in the right hemisphere (CNV in Fig. 2a). Both comma-related components were significantly smaller in Group II (Fig. 2b) in which only the negative slow-wave effect reached significance (midline: $p < .05$).

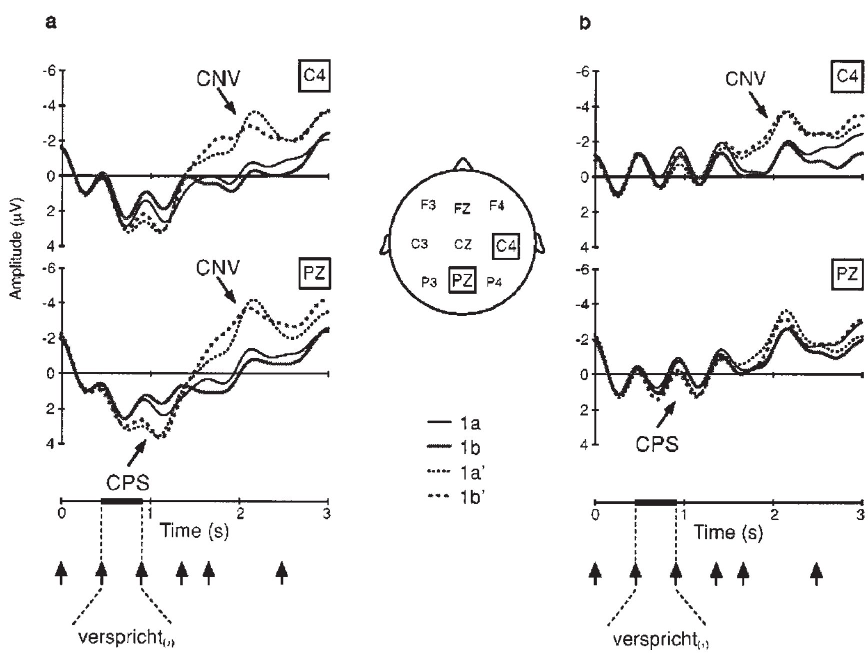

Fig. 2. Grand average ERPs for the four sentence conditions in Experiment 1. Shown are 1-Hz filtered ERPs from sentence beginning until offset of verb2 at two representative electrode sites (C4, PZ). Negative amplitudes are plotted upward. The critical verb 1 ("*verspricht*/promises") carrying the comma in (1a′) and (1b′) was presented from 450 to 900 ms (indicated by a black bar; other word onsets are marked by arrows). (a) In participants with strict punctuation habits (Group I, $N = 11$), the comma in conditions (1a′) and (1b′) (dotted lines) elicited a closure positive shift (CPS) followed by a negative slow wave (CNV). (b) In participants with less strict comma rules (Group II, $N = 13$), both comma-related ERP components were considerably smaller.

Garden Path Effects

As in the auditory study, the ERP analysis of the reversed garden path condition (1a′) again revealed effects at the incompatible intransitive verb *arbeiten.* However, only the N400 effect reached significance between 450 and 650 ms post verb2 onset [midline: $F(2,20) = 6.19$; $p < .03$; lateral: $F(2,20) = 6.61$; $p < .03$], whereas a subsequent small P600-like positivity did not. (Note: ERP garden path effects are not illustrated.) Moreover, significant effects were observed in Group I only. This finding corresponds to the behavioral data, which also indicated the strongest garden path effect to be present in Group I. For the less severe classical garden path condition (1b) (without the comma) an unexpected frontal positivity between 350 and 650 ms post verb2 onset was observed in Group I (midline: $p < .05$; lateral: $p < .03$). In Group II, a similar frontal effect occurred at midline electrodes between 650 and 850 ms ($p < .01$).

Discussion

First, the judgment data of Group I suggest that commas and prosodic cues in spoken language can be equally efficient in driving and even reversing initial parsing decisions. Thus the influence of nonlexical information on syntactic sentence processing deserves more attention in future research. Second, the reverse garden path (1a′) requiring the mental deletion of a comma turned out to be much harder than the classical garden path (1b) where a comma was omitted. Third, the group differences revealed that readers accustomed to strict punctuation habits are also more susceptible to commas during sentence reading. This finding suggests an intraindividual relationship between punctuation habits and comma perception. Fourth, the ERPs elicited by commas (small CPS-like positivity and large negative slow wave) appeared to be at least partly different from those elicited by prosodic boundaries (large CPS) in natural speech (Brown & Hagoort, 2000; Steinhauer *et al.,* 1999a).

Two interpretations would account for these differences. (1) It is conceivable that commas and prosodic boundaries, although serving the same function of structuring sentence input, are processed by different brain structures operating on modality specific input only (Steinhauer *et al.,* 1999b). (2) The small positivity elicited by commas is, in fact, equivalent to the auditory CPS. That is, commas trigger subvocal prosodic sentence phrasing but phonological representations are activated to a lesser extent, resulting in a decrease of the CPS amplitude (and of the garden path P600 in sentence 1a′). From this perspective, the subsequent negative slow wave would reflect additional, and possibly not even comma-specific, processes.

Given the negativity's time course and topographical profile, a likely candidate in terms of ERP components is the so-called contingent negative variation (CNV; Tecce & Cattanach, 1987) reflecting the expectation of response-relevant events. In the present experiment, the comma may have triggered a CNV because only subsequent to a comma, the second verb could lexically disambiguate toward the most difficult sentence structure (1a′), which required mental repair of a superfluous comma. If this second interpretation holds, the negativity was not related to the comma per se but rather an artefact of the experimental design, reflecting the expectation of the disambiguating second verb ("*arbeiten*" or "*entlasten*").

EXPERIMENT 2

In order to test this hypothesis, a second experiment was conducted in which the critical sentences appeared only with correct punctuation, i.e., excluding garden path conditions (1a′) and (1b). Incompatible commas were introduced into filler sentences containing enumerations (i.e., coordinative structures) instead (cf. sentence 2a′ with a comma after "*das Mädchen*/the girl"). This design also allowed replicating comma effects in a different sentence type.

(2a/2a′) *Der Mann sah den Jungen, das Mädchen*$_{(,)}$ *sah den Grossvater und* . . .

The man saw the boy, <u>the girl</u>$_{(,)}$ saw the grandfather, and . . .

(2b/2b′) *Der Mann sah den Jungen, das Mädchen*$_{(,)}$ und den Grossvater, während . . .

The man saw the boy, <u>the girl</u>$_{(,)}$ and the grandfather, while . . .

Note that German, unlike English, does not permit a comma after "*das Mädchen*/the girl" in either sentence (2a) or (2b). That is, even sentence (2b′) violates a German punctuation rule and subjects were aware of this rule. Although only in (2a′) does the comma also clearly violate the required phonological phrasing. Thus, it would be interesting whether a comma rule violation as such leads to processing difficulties (in both 2a′ and 2b′), or whether only the mismatch between comma-induced and required prosodic phrasing (in 2a′) causes garden path effects. This second experiment provides a rigorous test of the effects obtained in Experiment 1 as the hypothesized processing equivalence leads to a number of strong predictions: First, if the negative slow wave was in fact due to the expectation of a disambiguating verb, the lack of the difficult condition (1a′) in Experiment 2 should prevent such expectations, and hence eliminate the CNV. Second, if the positive component was equivalent to the CPS and reflected comma processing proper, it should still be apparent. Third, commas in the filler sentences (2a′) and (2b′) should then also elicit a CPS. Fourth, because the disambiguating element in the filler sentences directly follows the comma, again no expectation-related CNV can be predicted. Fifth, the incompatible verb "*sah*/saw" in the filler condition (2a′) should elicit a P600 component reflecting syntactic and prosodic processes of sentence repair, whereas the conjunction "*und*/and" in sentence (2b′) should not.

Methods

Ten right-handed students participated in Experiment 2. They read 96 sentences in conditions (1a) and (1b′) and 144 filler sentences in conditions (2a), (2a′), (2b), and (2b′). The procedure resembled that in the first experiment.

Results

As illustrated in Fig. 3, all of the predictions were confirmed by the ERP data. Commas generally elicited CPS-like positive components whereas the negative slow wave (CNV) of Experiment 1 had completely disappeared. Moreover, a P600 garden path effect was observed only in condition (2a′) but not condition (2b′).

Sentence Types 1a and 1b

The statistical comparison between conditions (1a) and (1b) (Fig.3a) revealed a significant *Comma* main effect for the time interval of the positive waveform between 550 and 750 ms post verb onset at lateral electrodes ($p < .04$) and an interaction *Comma presence* × *Electrode* at midline electrodes ($p < .04$) indicating a maximum at the parietal PZ electrode ($p <$ .03). Unlike Experiment 1, no significant differences were found in the late time range of the former negative slow wave after 1000 ms.

Filler Sentences 2a, 2a′, 2b, and 2b′

As predicted, commas in the coordinative structures (2a′) and (2b′) (Fig. 3b) also elicited positive shifts relative to the control conditions (2a) and (2b) ($p < .02$). This main effect was significant between 650 and 900 ms, i.e., somewhat later than in sentence (1b′), possibly due to differences in word length or sentence position. No indications for a negative slow wave could be found. Between 650 and 1050 ms after onset of the verb "*sah*/saw," comma condition (2a′) displays the expected P600 effect rela-

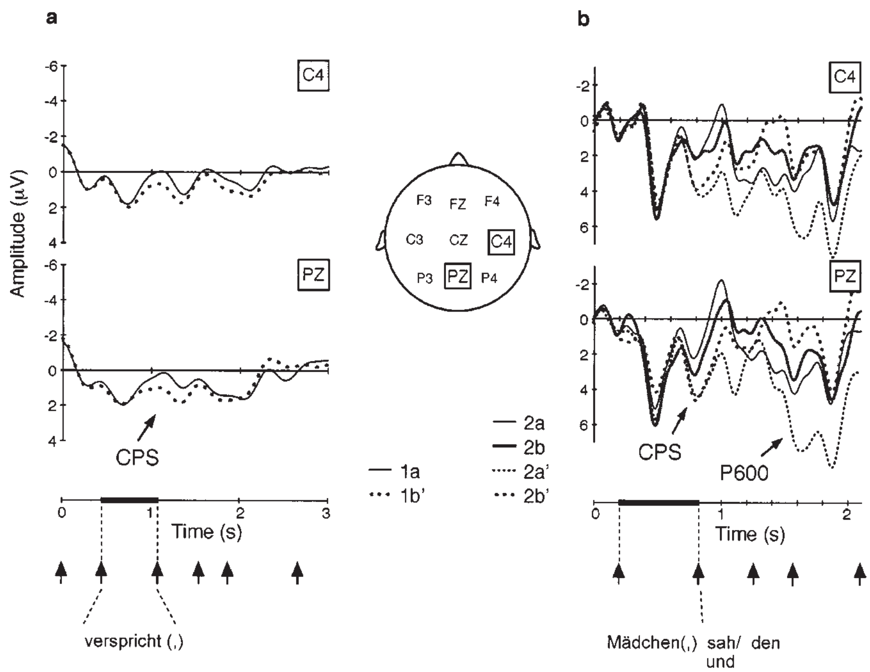

Fig. 3. ERPs in Experiment 2. (a) As condition (1a′) was removed from the design, participants did not need to prepare for a difficult-to-repair structure when encountering the comma in (1b′). Thus, in contrast to Experiment 1, the expectancy-related CNV was eliminated, whereas the CPS reflecting subvocal sentence phrasing was still elicited. (b) ERPs in sentences (2a) and (2b). Commas attached to the critical third noun "*Mädchen*/girl" (black bar) also elicited CPS but no CNV components in both conditions (2a′) and (2b′) (dotted lines; $p < 0.02$). The following verb "*sah*/saw" in condition (2a′) was incompatible with this sentence segmentation, resulting in a large P600 component ($p < 0.02$). (Note that the ERP amplitudes in Fig. 2b are generally larger than in the other figures due to a different filtering procedure; see Methods).

tive to the comma-less condition (2a) ($p < .02$). A corresponding difference was not found for the comparison between (2b′) and (2b), suggesting that a pure comma rule violation was not sufficient to explain this effect.

Discussion

The second experiment confirmed all of the hypotheses. A CPS-like positive shift occurred at all comma positions in both sentence types indicating that this component was directly linked to comma processing proper. By contrast, after removing the garden path sentences (1a′) and (1b) from the design, the remaining correct comma condition (1b′) did not elicit a negative slow wave subsequent to the positive deflection. This expected finding strongly supports the notion that the slow wave in Experiment 1 was, in fact, an expectancy-related CNV component and thus an artefact of the design. After removal of the garden path conditions, subjects did not need to prepare for the most difficult garden path (1a′). As a consequence, no expectations concerning the disambiguating second verb were developed, and hence no CNV. As the filler sentences (2a′) and (2b′) were lexically disambiguated by the first word after comma presentation, subjects had no time for building up expectations and, again, no CNV was observed. Thus, similar to the processing of prosodic speech boundaries, the only reliable ERP correlate for comma processing was the centro–parietal positive shift that we interpret as the physiological correlate of phonological phrasing. This observation suggests that both commas and prosodic cues not only share the potential of preventing or causing garden path effects, but they basically rest on the same mechanism. That is, commas seem to be visual triggers for covert prosodic phrasing. However, the smaller amplitude and shorter duration of the comma-induced as compared to the speech-induced CPS might point to a reduced activation of supra–segmental phonology during reading.

Finally, the garden path P600 found for sentence (2a′) but not for (2b′) contributes an additional piece of evidence to our understanding of how the brain processes commas. The absence of the P600 component in sentence (2b′) suggests that not the violation of a comma rule in itself but rather the recovery from the violation of the required phonological phrasing is responsible for eliciting the component. This data point can be taken as further evidence for the P600 effect being partly due to phonological processes.

Although the data of the second experiment were in complete agreement with the hypothesized phonological processing triggered by punctuation, they still allow for alternative interpretations. Most importantly, we know already from the behavioral data that, at least for this kind of ambiguity, both commas and prosodic boundaries can influence the syntactic parsing in the same way. Thus, in principle, the CPS could be viewed as the correlate of this secondary *syntactic* processing, comparable to the P600. This question was addressed in the third experiment, employing a somewhat unconventional experimental design.

EXPERIMENT 3

The rationale behind this experiment was twofold. On the one hand, it was desirable to separate prosodic from syntactic processing. On the other hand, it was necessary to find a way to control whether subjects actually activate prosodic patterns when encountering a comma. That is, we wanted to ensure that what happened during silent reading was, in fact, the subvocal prosodic phrasing. To this goal, we decided to separate prosodic and lexical information.

Methods

Sixteen right-handed students participated in this experiment. In the first phase of each trial, subjects listened to a pure prosodic "sentence melody" that was stripped of any lexical information. These "sentence melodies" were derived from the original speech signals used in our auditory study (Steinhauer *et al.,* 1999a) by applying a special filter procedure developed for this purpose (PURR; cf. Sonntag & Portele, 1998). Sentence melodies derived from sentence type B ([*Peter verspricht*] # [*Anna zu entlasten*] . . .) contained the prosodic boundary (#) after the first verb *verspricht,* whereas those derived from sentence type A ([*Peter verspricht Anna zu arbeiten*] . . .) did not. After a pause of 2000 ms, in the reading phase, subjects were visually presented with sentences in the same way as in the comma experiments 1 and 2, however this time *without any punctuation.* Instead, the subjects' task was to replicate the previously heard sentence melody during silent reading. Thus, the information as to whether they had to insert a phrase boundary after the first verb was not provided by a comma, but by the prosodic pattern they had just listened to. Similar to Experiment 1, one-half of the written sentences were structurally compatible with the prosodic pattern (e.g., prosody B followed by sentence B) and one-half were incompatible (e.g., prosody B followed by sentence A). Again, subjects were asked to judge whether reading was easy or difficult. In all trials, the number of syllables and metrical stress patterns were matched between sentence melody and the written sentence in order to rule out phonological mismatches on these basic levels. Figure 4 illustrates the schema of trial presentation. Forty-eight trials were presented in each main condition while EEG was recorded. In order to allow subjects to become accustomed to the unusual task, they performed several practice blocks of 20 trials each before the actual experiment. During the first block, they had to read the sentences aloud, so that problems in replicating the sentence melody could be taken care of by further instruction.

Hypotheses

The predictions for this experiment were straightforward. First, if the CPS reflected prosodic and not syntactic phrasing, then a CPS should already be elicited at speech boundaries while subjects listened to the pure

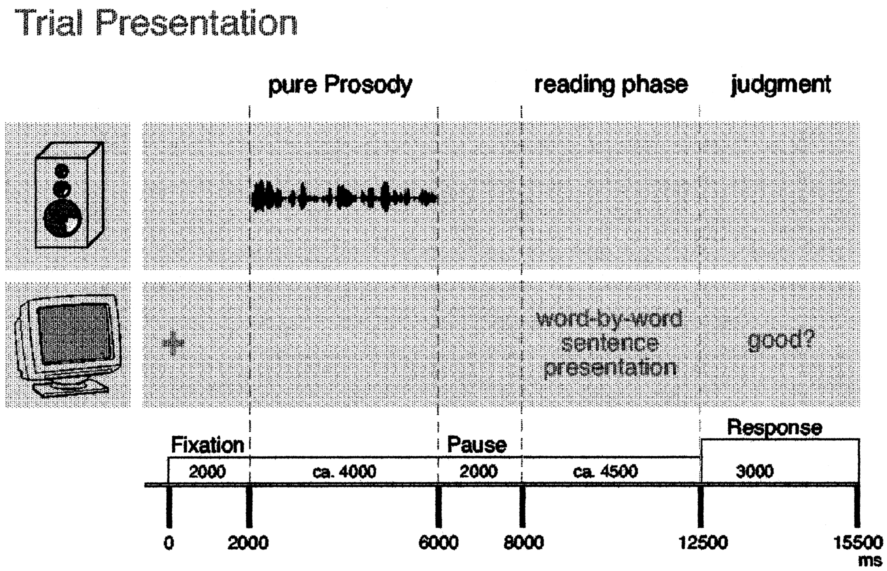

Fig. 4. Trial presentation in Experiment 3. Subjects first listened to a delexicalized sentence melody (pure prosody) and then had to replicate this prosodic pattern while silently reading a sentence. Finally they had to judge whether the sentence was easy to read ("good?") or not.

prosody of sentence type B as compared to A. If, however, the CPS were linked to syntactic processing, no such pattern was expected because syntactic parsing crucially depends on lexical information. Second, if the comma-related positive shift were in fact a correlate of subvocal phonological phrasing, then one would expect exactly the same ERP effect for the reading phase whenever subjects replicated the speech boundary of prosody B. That is, during reading, the first verb *verspricht* should elicit a positive shift only after subjects had listened to the melody of sentence type B but not A. Finally, garden path effects at the disambiguating second verb were predicted for trials, in which the prosodic pattern and syntactic requirements of the written sentence did not match (i.e., A–B and B–A).

Results

Figure 5 shows the grand average ERPs for the first phase while subjects listened to pure prosody. As predicted, the speech melody of sentence type B elicited a significant centro–parietal CPS at the phrase boundary, i.e., between 1000 and 2000 ms post onset of the stimulus [$F(1,15) = 4.86$; $p < .04$].

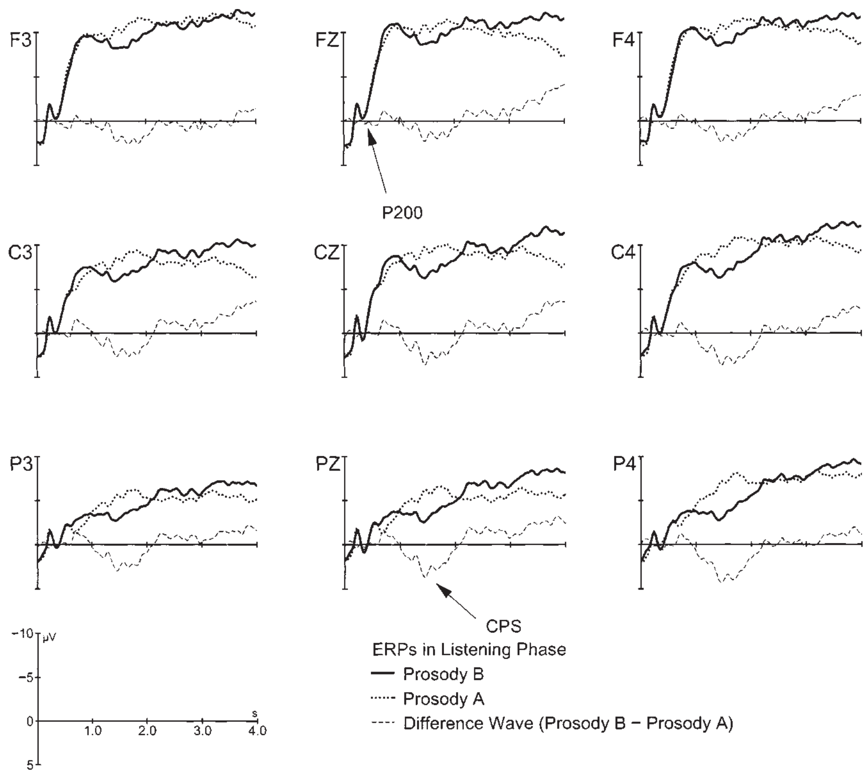

Fig. 5. Grand average ERPs in Experiment 3 while subjects were listening to the sentence melodies. The plot shows a positive shift at the additional boundary in (B), also illustrated in the difference wave (B–A).

ERPs for the reading phase are displayed in Fig. 6. Verb 1 elicits a centro–parietal positive shift (CPS) in conditions B→A and B→B, i.e., when subjects replicated the speech boundary of prosody B during silent reading [main effect *Prosody*: $F(1,15) = 7.12$; $p < .02$]. Finally, in both mismatch conditions B→A and A→B, a P600 effect can be observed at the disambiguating verb 2 ($p < .03$). This effect is most prominent in the more difficult reversed garden path condition B→A ($p < .01$).

Discussion

The data in Experiment 3 confirmed the hypothesized prosodic nature of the processes underlying the CPS component. First of all, even in delexicalized sentence melodies, prosodic boundaries elicited this component.

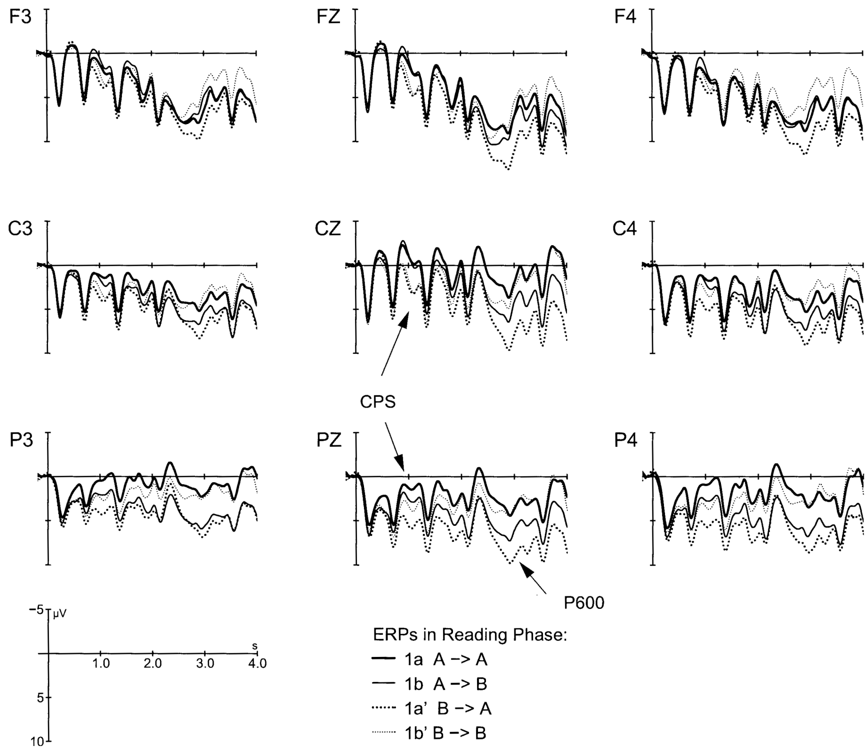

Fig. 6. ERPs for the reading phase in Experiment 3. All four conditions are superimposed. While subjects replicated the boundary during silent reading, a CPS was elicited. Later in the sentence, mismatching conditions (AB and BA) evoked a P600 component.

This effect can be attributed to syntactic processing only if one assumes that the subjects activated word information while listening to the prosody. However, on being asked they did not confirm this assumption. Thus the data strongly favor the prosodic rather than the syntactic CPS account. Second, while subjects replicated the prosodic boundary during silent reading, a positive shift was again found. This time, it resembled the one observed in the comma experiments, although its onset latency was shorter and its amplitude was somewhat larger. The resemblance between the present effect and the comma-induced shift suggests that comma processing does, in fact, induce a very similar cognitive operation, namely, subvocal phonological sentence phrasing. The latency difference is probably due to the fact that in the comma experiments subjects had to wait for the comma information, whereas here they could anticipate the position where to replicate the boundary. The amplitude differences can be interpreted as further evidence for the CPS amplitude reflecting the extent to which prosodic representations are activated. It is more than likely that subjects activated prosodic patterns particularly strongly when explicitly asked to do so, as in the present experiment. Interestingly, this interpretation can be related to the P600 effects. Recall that even the strong reverse garden path condition (1a′) in Experiment 1 did not elicit a large P600, possibly because phonological processing was less involved than in the auditory experiment. In the present experiment, where the prosodic representations seemed to be strongly activated, the P600 effect also reached significance. Thus the data are in line with two core assumptions. First, the CPS is a universal reflection of prosodic phrasing independent of both the input modality and the type of cue triggering this processing. Second, the P600 may reflect structural reanalyses on the syntactic *and* the phonological level.

GENERAL DISCUSSION AND CONCLUSION

To summarize, comma perception during reading seems to involve processes similar to the perception of prosodic boundaries in spoken language and is possibly mediated by the same brain structures. Both auditory and visual cues can be equally efficient in determining further sentence analysis and both are reflected by the same brain response (i.e., the closure positive shift, CPS). This is exactly what one would expect if commas serve as visual triggers for subvocal phonological phrasing. Thus, the CPS appears to be a universal and reliable online reflection of phonological sentence phrasing that is relatively independent of the input modality. The previous CPS finding in speech processing confirmed recent proposals of a specific prosodic parsing mechanism with direct impact on syntactic processing (Beckman, 1996; Schafer, 1997; see also Fodor, 1998). The present results extend this hypothesis in one important respect as they suggest that the same mechanism may also be involved during silent reading. This seems to hold for both accentuation patterns (Bader, 1994, 1998) and intonational phrasing.

The observed group differences in Experiment 1 suggest that, at least during reading, phonological phrasing is determined by more than the pure presence of orthographic cues, such as commas. Idiosyncratic habits in punctuation (and, hence, the subjective relevance of this information) seem to alter comma processing considerably. Given the finding that participants with strict punctuation rules displayed extreme difficulties when encountering a false comma, the general advantage of mastering such rules appears to be in question. However, even for the extremely high percentage of sentences with false punctuation used here, participants in Group 1 proved to be superior in sentence comprehension. With respect to the ongoing discussions concerning punctuation rules in a variety of countries such as Great Britain or Germany, understanding the interrelation between rule knowledge, salience, and processing mechanisms in punctuation in more detail may help to establish more empirically based punctuation rules. When applied to the auditory domain, the observed correlation between comma "production" (i.e., punctuation habits) and comma perception raises the question of whether listeners may be particularly susceptible to those prosodic cues that they would employ themselves as a speaker. A further issue is how the individual processing of overt prosody in speech and of covert prosody in written language are related to one another. The present data, together with those of the previous auditory study, suggest that ERP online measures such as the CPS are a promising approach to answer these questions. In contrast to previous purely behavioral measures such as the cross-modal naming task, ERPs do not require unnatural interruptions in order to collect data. Moreover, they allow continuous data recording beyond the presentation of isolated sentences, the processing of which may not resemble that of more complex utterances or dialogs.

Psycholinguistic Modeling

The strong and immediate influence of both prosodic cues in speech and punctuation in written language challenges most current models of language processing. Many classical garden path effects may be observable exclusively in written sentences and only if these are not punctuated. Interactive parsing approaches, such as constraint satisfaction models (e.g., MacDonald, 1994), are generally compatible with the early prosodic impact on syntax processing. However, they have to specify more clearly, when and why other information types, such as semantics, do *not* have this influence (e.g., Mecklinger *et al.,* 1995). Thus far, only prosodic information seems to completely reverse initial parsing decisions. Modular syntax first models (Frazier, 1978, 1987; Friederici, 1995), on the other hand, will have to adjust their architecture and integrate the phonological processing explicitly. As both punctuation and prosody appear to rest on the same basic mechanism, adjustments may be less difficult. The most important change seems to affect the unique status of word category information that several models treat as the very first information available to the parser. The present data as well as recent auditory studies (Kjelgaard and Speer 1999; Speer *et al.,* 1996; Steinhauer *et al.,* 1999a; Warren *et al.,* 1995), underscore that phonological information may influence the parser equally fast. However, given that the relevant prosodic information (as well as punctuation) can be viewed as "syntactically driven" already during production (i.e., in the speaker or writer), the core assumption of modular models is not affected. That is, the syntax parser could still be assumed to operate exclusively on syntactic information. Future research has to provide evidence whether the successful integration of prosodic processing requires establishing an independent prosodic parsing device (Beckman, 1996; Schafer, 1997). Bader's (1994, 1998) findings as well as recent ERP research (Hruska *et al.*, 2000) demonstrate that immediate prosodic influences on sentence comprehension hold also for accentuation patterns.

Furthermore, the differences between the rather weak classical and the much stronger reversed garden path as revealed by both behavioral and physiological data require further research. It remains an open question, whether the differences can be explained on a purely structural basis or whether they require taking (subvocal) prosodic parsing into account more generally. As reversed garden path effects are not considered in Frazier's model, it is difficult to account for them within this framework. However, there have been numerous proposals in order to explain different strengths of garden path effects (Bader, 1998; Fodor & Inoue, 1994; MacDonald, 1994; Meng & Bader, in press). Gorrell (1995) suggested that a garden path should be easy if reanalysis required *structural addition* (of nodes) only, as opposed to difficult garden paths requiring *structure alterations,* i.e., changes in the current hierarchy of nodes (in terms of dominance and precedence, respectively). With respect to the present data, the classical garden path (1b) does, in fact, require structure addition only. That is, after successful revision, the NP *Anna* is still dominated by the VP node of the first verb (*verspricht*), now as part of the sentential complement (*Anna zu entlasten*). By contrast, in the case of the reversed garden path (1a′), the parser has already predicted and projected an additional VP/IP node dominating *Anna.* This dominance relation must then be revised once NP *Anna* turns out to be dominated by the preceding verb *verspricht,* causing the observed severe garden path effect. Interestingly, Gorrell's model would correctly predict a severe garden path for sentences in which *Anna* is initially parsed as object of the first verb (as in 1a), but then turns out to be the subject of a subsequent IP as in (3):

(3) *Peter verspricht Anna befuerchtet und John bezweifelt, dass die Steuern erhoeht werden*

Peter promises Anna fears and John doubts that the taxes will be raised

Thus the different strengths of the classical and the reversed garden path can, in principle, be accounted for in terms of purely structural considerations. However, alternative explanations can be based on prosodic processing. For example, it may well be that readers generally avoid assuming pauses/boundaries until they encounter counterevidence such as a comma.

Moreover, the mental deletion of a previously assumed pause/comma/boundary may be more costly than the postponed insertion of an initially omitted pause/comma/boundary. That would explain the larger difficulty in the reversed garden path condition and also account for other Early Closure and nonminimal attachment garden path phenomena. Probably structural accounts (e.g., Gorrell, 1995) and prosodic accounts are not independent of each other. In order to achieve a more universal parsing model that does not primarily account for unpunctuated written sentences, it would be extremely fruitful to understand these interrelations.

Implications for Psycholinguistic ERP Research

Finally, we would like to highlight some important aspects concerning the observed ERP components. First, extending Bader's (1994, 1998) proposal, we suggest that the P600 component possibly reflects both syntactic and prosodic reanalyses/repairs. This assumption would not only explain the current data (e.g., the variations in the P600 amplitude across experiments) most completely. Rather it would also be compatible with previous P600 findings as (1) most employed garden path structures were confounded with prosodic ambiguities, and as (2) outright violations are generally very likely to result in narrow correction focus on the violating word, thereby changing the accentuation pattern (Bader, 1994, 1998). Interestingly, garden path sentences that did *not* involve prosodic changes (German subject/object ambiguous relative clauses) resulted in earlier and smaller positive ERP components than prosodically differing structures (Bader & Meng, 1999; Friederici & Mecklinger, 1996; Friederici *et al.,* 2001).

Second, the closure positive shift (CPS) seems to reflect prosodic phrasing independent of the input modality. The robustness of this component during auditory presentation suggests its potential clinical application in diagnosing prosodic processing impairments (so-called *aprosodias;* Baum & Pell, 1994; Ross, 1997).[7] Moreover, patient studies and localizations of the neural CPS generator may shed new light on the still unknown brain systems underlying prosodic processing (Baum & Pell, 1999; Gandour, 2000). Third, a repeatedly raised question concerns the relationship between the CPS and other ERP components, such as the working memory-related P300 (Donchin & Coles, 1988) or the P600. As the P300 can be elicited by almost any "rare and relevant" stimulus, the characterization of the very specific CPS as a P300 appears to be a trivialization of

[7] A simplified version of the auditory experiment (Steinhauer *et al.,* 1999a) was already successfully tested with a right hemispheric patient (Steinhauer, Kotz, & von Cramon, 1999, unpublished data).

this component. Moreover, neither the P300 nor the CPS should be viewed as monolithic, but are very likely to consist of multiple subcomponents reflecting multiple subprocesses (e.g., Johnson, 1993). As with the P300/P600 debate (Coulson *et al.*, 1998; Friederici *et al.*, 2001; Gunter *et al.*, 1997; Osterhout & Hagoort, 1999; Steinhauer *et al.*, 1997), the only relevant question seems to be which of the *sub*components may be shared. To the extent to which the P600 is viewed as a "syntactic positive shift" (Hagoort *et al.*, 1993), CPS findings in both correct sentences and delexicalized sentence melodies (cf. Experiment 3) clearly contradict a strong correspondence. However, as we believe the P600 may be influenced by prosody itself (see also Patel *et al.*, 1998), the two components may still share common subprocesses. The same also holds for sentence final positive going waveforms (e.g., van Petten & Kutas, 1991) usually attributed to sentence wrap-up effects. As terminal words usually close intonational phrases, these components may also be partly due to overt or covert phonological phrasing. As the "prosodic" CPS can overlap temporally with other language-related components such as the "semantic" N400 and the "syntactic" P600, future ERP studies investigating sentence comprehension should take into account nonlexical language processing, such as phonological phrasing even in (silent) reading experiments.

Finally, unlike the CPS, the large negative slow wave elicited by commas in Experiment 1 turned out to be an expectancy related artefact (CNV) due to the task relevance of the second verb. However, the profile of this ERP component provided valuable information about the underlying processes. With behavioral data alone, it would have been much more difficult to identify the real nature of this additional effect. We are optimistic that the ERP approach will continue in proving as an important tool in the examination of language processing and of prosody, in particular.

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