



## Sensitivity to prosodic structure in left- and right-hemisphere-damaged individuals

Shari R. Baum\* and Veena D. Dwivedi

*McGill University, Montreal, Que., Canada*

Accepted 8 April 2003

### Abstract

An experiment was conducted in order to determine whether left- (LHD) and right-hemisphere-damaged (RHD) patients exhibit sensitivity to prosodic information that is used in syntactic disambiguation. Following the work of Marslen-Wilson, Tyler, Warren, Grenier, and Lee (1992), a cross-modal lexical decision task was performed by LHD and RHD subjects, as well as by adults without brain pathology (NC). Subjects listened to sentences with attachment ambiguities with either congruent or incongruent prosody, while performing a visual lexical decision task. Results showed that each of the unilaterally damaged populations differed from each other, as well as from the NCs in terms of sensitivity regarding prosodic cues. Specifically, the RHD group was insensitive to sentence prosody as a whole. This was in contrast to the LHD patients, who responded to the prosodic manipulation, but in the unexpected direction. Results are discussed in terms of current hypotheses regarding the hemispheric lateralization of prosodic cues.

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*Keywords:* Brain damage; Prosody; Syntactic structure

### 1. Introduction

The neural substrates for the processing of prosodic information in the speech signal remain undetermined. Numerous hypotheses concerning the hemispheric lateralization of prosodic processing have been espoused, with varying degrees of supportive evidence. The two principal classes of hypotheses in current favour have been referred to as “task-dependent” and “cue-dependent” (Gandour et al., 2003). A prime example of a task-dependent hypothesis is the functional lateralization hypothesis (Van Lancker, 1980) which attributes linguistically relevant prosodic processing to left hemisphere mechanisms and affectively relevant prosodic processing to right hemisphere mechanisms. Whereas a good deal of data from both patient studies and neuroimaging studies supports the proposal that linguistic significance plays a role in the

lateralization of prosodic processing, a parallel set of findings on both speech and non-speech processing tasks supports the contention that the two cerebral hemispheres are specialized for the processing of specific acoustic parameters, with temporal properties being preferentially processed by the left hemisphere and spectral properties by the right hemisphere—a cue-dependent lateralization theory (e.g., Robin, Tranel, & Damasio, 1990; Van Lancker & Sidtis, 1992; Zatorre, 1997; Zatorre, Evans, Meyer, & Gjedde, 1992).

One means of assessing the contrasting hypotheses is to employ a task that draws on strongly linguistic (or strongly affective) prosodic processing skills, but that requires processing of both temporal and spectral parameters. That is, in Van Lancker’s (1980) original formulation of the functional lateralization hypothesis, functional load was considered to vary along a continuum, with phonemic tone representing a highly linguistic function of prosody, sentence modality (i.e., declarative vs. interrogative, etc.) representing an intermediate step and emotional tone representing the affective end of the continuum.

\* Corresponding author. Present address: School of Communication Sciences and Disorders, McGill University, 1266 Pine Avenue West, Montreal, Que., Canada H3G 1A8.

*E-mail address:* [shari.baum@mcgill.ca](mailto:shari.baum@mcgill.ca) (S.R. Baum).

The majority of studies of the comprehension of linguistic prosody by brain-damaged patients have focused on phonemic tone contrasts, emphatic stress contrasts, or sentence modality contrasts. To summarize the literature briefly, numerous investigations of left-(LHD) and right-hemisphere-damaged (RHD) patients (e.g., Baum, 1998; Baum, Kelsch Daniloff, Daniloff, & Lewis, 1982; Brådvik et al., 1991; Bryan, 1989; Emmorey, 1987; Gandour & Dardarananda, 1983; Hughes, Chan, & Su, 1983; Pell & Baum, 1997a, 1997b; Weintraub, Mesulam, & Kramer, 1981), as well as recent neuroimaging studies (e.g., Gandour et al., 2000; Gandour et al., 2003; Hsieh, Gandour, Wong, & Hutchins, 2001; Klein, Zatorre, Milner, & Zhao, 2001) have supported a left hemisphere superiority (or preference) for the processing of linguistically significant prosody such as phonemic (or lexical) and emphatic stress, as well as sentence modality. Far fewer studies have addressed the neural bases for the processing of prosody which serves to signal syntactic boundaries or cue syntactic attachment patterns—another function of prosody that may be considered highly “linguistic” along a functional continuum. Interestingly, there has been a resurgence of interest in this issue in the normal psycholinguistic literature (see, e.g., an entire issue of *Language and Cognitive Processes*, Vol. 11, 1996). With regard to normal language processing, investigations have demonstrated that listeners make use of prosodic cues in comprehending sentences containing phrase boundary and attachment ambiguities (e.g., Beach, 1991; Blasko & Hall, 1998; Marslen-Wilson et al., 1992; Nagel, Shapiro, & Nawy, 1994; Shapiro & Nagel, 1995). Whether the prosodic influence occurs during on-line syntactic parsing, directing parsing, or whether the parsing process is autonomous, with prosody influencing the output of the parser, remains controversial (e.g., Kjelgaard & Speer, 1999; Marslen-Wilson et al., 1992; Nagel, Shapiro, Tuller, & Nawy, 1996; Schafer, Carter, Clifton, & Frazier, 1996; Speer, Kjelgaard, & Dobroth, 1996). Irrespective of the outcome of this debate, it is of interest to determine whether LHD and RHD patients are able to extract the relevant prosodic parameters and map the different patterns onto the appropriate syntactic constructions.

Three previous studies are particularly relevant in this regard. In an examination of both production and perception of prosodic cues to simple phrasal groupings, Baum, Pell, Leonard, and Gordon (1997) reported that individuals with both LHD and RHD exhibited an impaired ability to identify phrase boundaries in multiply conjoined strings. Although the emergence of a deficit for the RHD patients in this linguistic prosodic processing task was somewhat surprising (and not in keeping with the functional lateralization of prosodic processing), the authors suggested—consistent with other previous proposals (e.g., Behrens, 1989; Gandour,

Dechongkit, Ponglorpisit, & Khunadorn, 1994; Gandour et al., 2003; Pell & Baum, 1997a)—that the right hemisphere may be implicated in prosodic processing that requires integration over longer temporal domains (see also Poeppel, 2001, in press).

In a study exploring yet another type of syntactic boundary cued by prosody—e.g., the contrast between parenthetical and subordinate clauses—Perkins, Baran, and Gandour (1996) found that patients with LHD performed significantly worse than normal controls on a sentence–picture matching task in which the segmentally identical stimuli differed only in terms of prosodic pattern. RHD patients’ performance fell between that of the normal controls (whose accuracy scores were near ceiling) and those of the LHD group, but did not differ significantly from either one. The authors interpreted the findings in keeping with the functional lateralization of prosodic processing. In a recent follow-up to this investigation, Walker, Fongemie, and Daigle (2001) conducted three experiments that examined the role of prosody in syntactic disambiguation of attachment and closure ambiguities of the following type:

- (a) “While the man parked cars, bikes were waiting.”
- (b) “While the man parked, cars were waiting.” (Walker et al., 2001, p. 177).

The sentence in (a) above represents an interpretation that is in keeping with the parsing principles of minimal attachment and late closure (Frazier & Fodor, 1978), whereas the (b) version represents a non-minimal attachment/early closure construction. Without the help of the comma in the written version, the portion of the sentences that are segmentally identical (i.e., through the word “cars”) is syntactically ambiguous. More precisely, the intended attachment for the NP “cars” is ambiguous until additional material is encountered. However, as noted earlier, prosodic information may assist in disambiguating such sentences in the auditory modality (e.g., Beach, 1988; Shapiro & Nagel, 1995; Warren, 1985; but cf. Albritton, McKoon, & Ratcliff, 1996; Baum et al., 1997; Baum, Pell, Leonard, & Gordon, 2001).

Walker et al. (2001) designed three tasks to assess whether LHD and RHD patients would make use of prosodic information in disambiguating stimuli of these types. The first task was a ‘naturalness judgment’ task in which cross-spliced versions of the critical sentences were developed to create what the investigators refer to as “cooperating” and “conflicting” stimuli (i.e., those in which the prosody matched the intended attachment and those in which the sentence-initial prosody contrasted with the remainder of the sentence). Participants were asked to judge the naturalness of the presented stimuli via a binary decision. Reaction times (RTs) for the naturalness judgments constituted the primary dependent variable of interest. Results revealed that all subject groups exhibited faster RTs in the cooperating

condition relative to the conflicting condition. A second task using the same stimuli required subjects to indicate by a button press whether they understood the sentence presented. RTs again revealed that all subjects were faster in processing the cooperating relative to the conflicting stimuli (although, not surprisingly, there were group differences in overall RT). In a final experiment, an analogue of a cross-modal naming task (e.g., Marslen-Wilson et al., 1992) required participants to judge whether a visually presented target word represented a correct continuation of an auditorily presented sentence fragment. (An example of a conflicting stimulus, for which the correct response would be 'no', is: "While the man parked cars, WERE (visual target).") Analysis of RTs again revealed that all groups were sensitive to the prosodic manipulation, yielding slower RTs in the conflicting relative to the cooperating conditions. Within the latter two experiments, the accuracy rates for the brain-damaged patients (particularly for the LHD group) were lower than those of the non-brain-damaged controls.

The combined results of all three experiments were interpreted as supporting an important role for prosody in guiding syntactic parsing for all groups (Walker et al., 2001). With respect to the lateralization of prosodic processing, the authors suggested that the findings were largely in keeping with the functional lateralization hypothesis, as the LHD patients' judgment accuracy decreased with the increasing linguistic demands of the tasks. A similar decline in performance by the RHD group was attributed to associated cognitive deficits rather than an impairment in linguistic prosodic processing per se. It is of particular interest to note that, somewhat surprisingly, both the LHD and RHD patients in Walker et al.'s (2001) study were sensitive to the prosodic information contained in the stimuli as cues to syntactic parsing decisions, as reflected in response latency patterns. It is unclear whether the lower accuracy rates of the brain-damaged patient groups reflect general linguistic or cognitive processing deficits or are specifically related to the mapping of prosody to syntax. It is also important to point out that the tasks used in Walker et al.'s experiments required metalinguistic judgments and thus tapped processing in a quite explicit way. In many psycholinguistic investigations (with non-brain-damaged participants), tasks are designed to tap processing (in this case, parsing) more implicitly, not requiring goodness or naturalness judgements but relying on RT data in unrelated tasks to reflect syntactic processing skills (e.g., Marslen-Wilson et al., 1992; Nagel et al., 1994; among many others). The present study adopts the latter strategy in an effort to further elucidate the abilities of LHD and RHD patients to use prosody in syntactic disambiguation, with the larger goal of advancing our understanding of the neural bases of prosodic processing.

In particular, following Marslen-Wilson et al. (1992) and Nagel et al. (1994), a cross-modal lexical decision task was designed in which sentences with attachment ambiguities were presented in both congruent and incongruent prosody conditions to determine whether patients with LHD and RHD are sensitive to prosodic parameters in on-line sentence processing.

If prosody facilitates parsing decisions (i.e., aids in syntactic disambiguation), minimal attachment stimuli with normal (i.e., congruent) prosody should yield RTs that are faster than or equivalent to those found for normal prosody non-minimal attachment sentences. Stimuli with incongruent prosody (both minimal and non-minimal versions) should yield slower RTs than their respective normal prosody counterparts, and the non-minimal attachment stimuli with incongruent prosody should yield the longest RTs due to the non-preferred attachment (alone). If prosody is not used on-line by subjects, and their parsing decisions are driven solely by syntactic preferences in the initial instance (e.g., minimal attachment; Frazier & Fodor, 1978), then RTs to the congruent minimal attachment sentences should be faster than to the non-minimal attachment sentences and the incongruent prosody versions should not differ from the congruent versions, with one possible exception. It is conceivable that the incongruent non-minimal attachment sentences would yield slower RTs than their congruent prosody counterparts for the following reason. For these non-minimal attachment stimuli, the parser is able to quickly correct its initial misanalysis with the help of congruent prosody. In contrast, for the incongruent non-minimal attachment stimuli, the reanalysis may be slowed due to conflicting disambiguating information from the syntax and the prosody.

Ignoring, for the moment, the specific acoustic attributes of the stimuli, under the functional lateralization hypothesis (Van Lancker, 1980), the LHD patients should demonstrate less sensitivity to the prosodic manipulations, whereas the RHD patients should perform quite comparably to non-brain-damaged controls. (Recall, however, that previous data on related sentence types are equivocal.) If, however, as mentioned earlier, the domain over which prosody is signaled plays a role in its lateralization (e.g., Behrens, 1989; Gandour et al., 2003; Poeppel, in press), the RHD patients may, in fact, exhibit some deficits in the current task. This latter prediction may be interpreted as consistent with recent versions of what may be considered to be cue-dependent hypotheses, such as that proposed by Poeppel (in press) (see also Gandour et al., 2003). That is, if the RH preferentially processes spectral information integrated over longer time windows (e.g., Poeppel, in press), perception of sentence-level prosody (as in the present investigation) may be difficult for individuals with RHD.

## 2. Methods

### 2.1. Subjects

Three groups of subjects participated in the current experiment: 10 LHD nonfluent aphasic patients, 9 RHD patients, and 10 age-matched non-brain-damaged control subjects. All subjects were right-handed native speakers of English who passed an audiometric screening at <35 dB HL at the frequencies. 5, 1, and 2 kHz in the better ear. Brain-damaged patients had all suffered a single, unilateral cerebrovascular accident (CVA; confirmed by CT or MRI) at least four months prior to testing and underwent a series of screening tests that varied (in part) depending on their lesion lateralization. The LHD patients were screened for various speech and language skills using subtests of the *Psycholinguistic Assessment of Language* (Caplan, 1992); the RHD patients were screened for communication skills often impaired in this population (e.g., comprehension of inferences and figurative language). Background information on the participants appears in Table 1.

### 2.2. Stimuli

Experimental stimuli consisted of the 24 sentence pairs used by Marslen-Wilson et al. (1992). Each sentence pair began identically, but continued with either a minimal (MA) or non-minimal (NMA) attachment ending. For example, the following sentence pair is representative of all experimental stimuli (taken from Marslen-Wilson et al. (1992), p. 87):

- a. The workers considered the last offer from the management was a real insult (NMA).
- b. The workers considered the last offer from the management of the factory (MA).

Each experimental stimulus was recorded onto DAT tape by a phonetically trained female adult native speaker of English who took care to ensure the MA and NMA versions were produced with distinct prosody thought to be characteristic of the different attachment versions (see, e.g., Beach, 1988; Warren, 1985; but cf. Albritton et al., 1996). These recordings were then digitized onto computer using the BLISS speech analysis system (Mertus, 1989). Prior to any further manipulations, acoustic analyses of these stimuli were conducted to ensure that the expected prosodic cues were indeed present in the sentences. To this end, measures of overall sentence duration, duration of the initial verb (i.e., “considered” in the example above), and duration of the pause following that verb (if any) were computed. In addition, the F0 contour was extracted and examined for a fall–rise pattern in the vicinity of the verb and following noun phrase in the NMA versions, compared to a gradual and continual fall for the MA versions (see Fig. 1). The findings of these analyses are presented in

Table 2, where it is shown that the two sentence versions were, in fact, distinguished by both temporal and F0 cues.

Having established that the appropriate prosodic parameters were present in the stimuli, the point at which the two versions diverged lexically was identified in the acoustic signal (using standard cues from the waveform display, coupled with auditory perception). The endings of the MA versions were then digitally cross-spliced with the NMA sentence onsets; similarly, endings of the NMA versions were spliced onto the MA sentence onsets, creating a second set of 24 pairs of experimental stimuli with incongruent prosody (see Shapiro & Nagel, 1995).

In addition to the experimental stimuli, a set of 96 filler sentences of comparable length were created, and recorded and digitized as described above. These distractor sentences included a range of syntactic structures, *excluding* sentences of the type used in the experimental stimulus set.

Each of the experimental sentences was paired with an unrelated monosyllabic probe word of 4 or 5 letters, with frequencies ranging between 90 and 120 per million (Francis & Kucera, 1982). Within the filler sentences, 24 unrelated probe words were defined, along with 72 non-word probes, all obeying the phonotactic and orthographic constraints of the language. Probe words were displayed visually in the centre of a CRT at random points at the offset of a word within the filler sentences (excluding the first three word positions). For the experimental stimuli, the offset of the word which served to disambiguate the sentence structure was identified with a cursor which triggered visual display of the probe word.

### 2.3. Procedure

In order to reduce repetition, two experimental lists were generated, each containing half of the experimental stimuli, half of the filler stimuli that had been paired with real word probes, and half of the filler stimuli paired with non-word probes. If the congruent prosody MA version of a stimulus was included in one list, its corresponding incongruent prosody version appeared in the second list. Thus, each experimental list consisted of 24 congruent (i.e., normal) prosody experimental sentences (CMA, CNMA), 24 incongruent prosody experimental sentences (IMA, INMA), 12 fillers with real word probes, and 36 fillers with non-word probes, presented to listeners in random order over closed headphones at a comfortable listening level. Participants were seated directly in front of a CRT which displayed the visual target for lexical decision and were instructed to indicate their response to the probe word by pressing a ‘yes’ or ‘no’ button on a response board, also in front of them, using their currently dominant hand. ‘Yes’ and

Table 1  
Background information on participants

Subject	Sex	Age (years)	Education <sup>a</sup> (years)	MPO <sup>b</sup>	Lesion site	Diagnostic characteristics
<i>Left-hemisphere-damaged patients</i>						
1	F	58	N/A <sup>d</sup>	30	Left MCA <sup>c</sup>	Nonfluent
2	F	74	12	97	Left parietal	Nonfluent
3	M	71	16	114	Left fronto-parietal (subcortical)	Moderate nonfluent
4	M	57	10	21	N/A <sup>d</sup>	Moderate-severe nonfluent
5	F	70	9	96	Left fronto-temporo-parietal	Moderate-severe nonfluent
6	M	82	9	75	Left frontal	Mild nonfluent anomic
7	F	69	11	74	Left fronto-parietal	Severe nonfluent
8	M	54	14	164	Left parietal	Mild-moderate nonfluent
9	M	60	N/A <sup>d</sup>	30	N/A <sup>d</sup>	Moderate nonfluent (anomic)
10	F	79	N/A <sup>d</sup>	9	Left MCA <sup>c</sup>	Moderate-severe nonfluent
	Mean	67	12	71		
	SD	10	3	49		
<i>Right-hemisphere-damaged patients</i>						
1	M	72	14	60	Right thalamus and/or right ventricle	Mild impairments in inferencing, figurative language, and emotional prosody
2	M	89	11	58	N/A <sup>d</sup>	Mild impairments in inferencing, figurative language, and emotional prosody
3	M	64	12	12	N/A <sup>d</sup>	Mild impairments in inferencing and figurative language
4	F	36	13	76	Right MCA <sup>c</sup>	N/A <sup>d</sup>
5	M	81	11	52	Right temporo-parietal	Mild impairments in inferencing and figurative language; moderate impairment in emotional prosody
6	F	61	13	117	Right posterior communicatory artery	N/A <sup>d</sup>
7	F	68	13	84	Right internal capsule, basal ganglia	N/A <sup>d</sup>
8	F	68	12	76	N/A <sup>d</sup>	Impairments in inferencing, figurative language, and emotional prosody
9	F	44	9	59	Right MCA <sup>c</sup>	Impairments in inferencing and figurative language. Mild impairment in emotional prosody
	Mean	65	12	66		
	SD	17	2	28		
<i>Normal controls</i>						
1	M	69	9			
2	F	67	13			
3	F	69	13			
4	F	67	16			
5	F	70	12			
6	M	73	14			
7	F	72	11			
8	F	77	18			
9	M	65	11			
10	M	69	9			
	Mean	70	13			
	SD	3	3			

<sup>a</sup> Best estimated conversion into years, based on information from subject (e.g., 2 years college, high school).

<sup>b</sup> Months post-onset.

<sup>c</sup> Middle cerebral artery.

<sup>d</sup> Information not available.

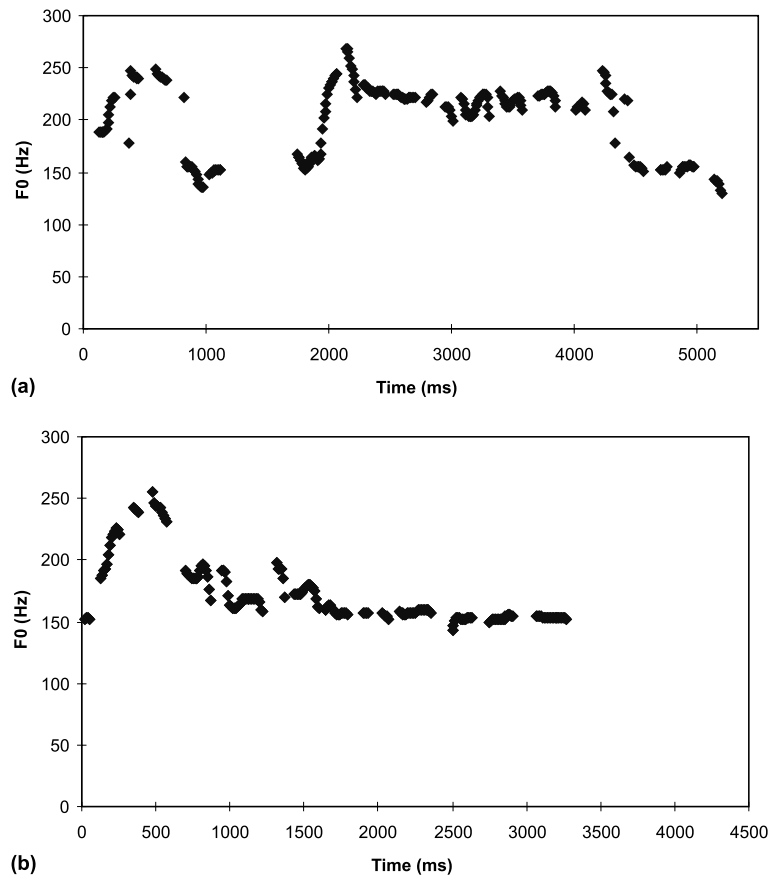


Fig. 1. Sample F0 contours for paired non-minimal (a) and minimal (b) attachment sentence versions: (a) The doctor confirmed his initial diagnosis of lung cancer was completely accurate. (b) The doctor confirmed his initial diagnosis of lung cancer with reluctance.

'no' buttons were counterbalanced across subjects within each group, as was order of presentation of the two experimental lists. At least one week intervened between presentation of the two lists. Responses and reaction times were recorded by the computer.

### 3. Results

Mean reaction times (RTs) for correct responses within each condition (excluding outliers  $>2$  standard deviations from the mean) were computed for each individual participant. These values, averaged across participants within each group are illustrated in Fig. 2. As may be seen, for the normal group, RTs to minimal attachment stimuli tended to be faster than to non-minimal attachment stimuli in both congruent and incongruent prosody conditions; however, the RT difference across attachment conditions for the incongruent prosody stimuli was substantially larger than that for the congruent prosody stimuli. For the non-minimal attachment stimuli alone, the influence of the incongruent prosody appeared to be quite dramatic; there was little difference in RT due to the prosodic mismatch for the minimal attachment stimuli.

Response latencies for the RHD group showed a similar pattern with respect to the syntactic manipulation. That is, the non-minimal attachment conditions tended to yield slower RTs than did the minimal attachment conditions. In contrast to the normal subjects, however, the presence of incongruent prosody did not affect RTs to either the minimal or non-minimal attachment stimuli. Patterns for the LHD group differed even more from those of the normal controls. In particular, within the congruent prosody stimuli, there appeared to be little difference in RT between minimal and non-minimal attachment stimuli. Further, quite unexpectedly, the stimulus conditions with incongruent prosody tended to yield faster latencies than did those with congruent prosody.

Statistical analysis of the data was conducted using repeated measures ANOVAs for each group separately.<sup>1</sup> The Prosody (congruent, incongruent)  $\times$  Attachment

<sup>1</sup> Ideally, a three-way ANOVA including group as a between-subjects factor would have been conducted. However, given the limited sample size and the heterogeneity within the brain-damaged patient groups, the anticipated and most relevant three-way interaction (among group, prosody, and attachment type) was unlikely to emerge. Thus, analyses were conducted separately for each subject group.

Table 2  
Acoustic measures of experimental stimulus sentences

	Sentence duration	Verb duration	Pause duration	Verb/sentence	Pause/sentence	Sentence F0 contour <sup>a</sup>
<i>Non-minimal attachment sentences</i>						
1	4266	671	348	0.16	0.08	F–R
2	4240	620	460	0.15	0.11	F–R
3	4084	395	485	0.10	0.12	F–R
4	4735	451	499	0.10	0.11	F–R
5	3544	454	300	0.13	0.08	F–R
6	4810	601	353	0.12	0.07	F–R
7	3964	532	379	0.13	0.10	F–R
8	5005	732	593	0.15	0.12	F–R
9	3711	624	245	0.17	0.07	F–R
10	4760	612	464	0.13	0.10	F–R
11	4830	591	637	0.12	0.13	F–R
12	3725	876	494	0.24	0.13	F–R
13	5320	671	482	0.13	0.09	F–R
14	4280	539	211	0.13	0.05	F–R
15	4189	659	329	0.16	0.08	F–R
16	4719	617	416	0.13	0.09	F–R
17	4207	588	172	0.14	0.04	F–R
18	4603	648	441	0.14	0.10	F–R
19	5080	613	530	0.12	0.10	F–R
20	5075	733	404	0.14	0.08	F–R
21	5214	437	342	0.08	0.07	F–R
22	5250	756	298	0.14	0.06	F–R
23	3844	612	295	0.16	0.08	F–R
24	4256	803	272	0.19	0.06	F–R
Means	4488	618	394	0.14	0.09	
<i>Minimal attachment sentences</i>						
1	3105	432	23	0.14	0.01	F
2	3069	466	13	0.15	0.00	F
3	3269	120	0	0.04	0.00	F
4	3174	274	6	0.09	0.00	F
5	2503	713	0	0.28	0.00	F
6	3429	255	28	0.07	0.01	F
7	2237	294	0	0.13	0.00	F
8	3019	519	5	0.17	0.00	F
9	3635	532	20	0.15	0.01	F
10	1196	458	28	0.38	0.02	F
11	3799	499	0	0.13	0.00	F
12	3219	414	0	0.13	0.00	F
13	3764	482	0	0.13	0.00	F
14	2891	383	0	0.13	0.00	F
15	3300	486	31	0.15	0.01	F
16	3571	471	66	0.13	0.02	F
17	3323	417	38	0.13	0.01	F
18	3644	477	0	0.13	0.00	F
19	3569	356	51	0.10	0.01	F
20	3705	580	11	0.16	0.00	F
21	2879	199	41	0.07	0.01	F
22	4268	629	35	0.15	0.01	F
23	3588	505	50	0.14	0.01	F
24	3315	616	0	0.19	0.00	F
Means	3228	441	19	0.14	0.01	

<sup>a</sup> F–R, fall–rise; F, gradual and continual fall.

Type (minimal, non-minimal) ANOVA for the normal subjects revealed significant main effects of Prosody ( $F(1, 9) = 6.982$ ,  $p < .05$ ) and Attachment Type

( $F(1, 9) = 16.121$ ,  $p < .003$ ), as well as a Prosody  $\times$  Attachment Type interaction ( $F(1, 9) = 16.901$ ,  $p < .002$ ). Post hoc analysis of the interaction using the Newman–

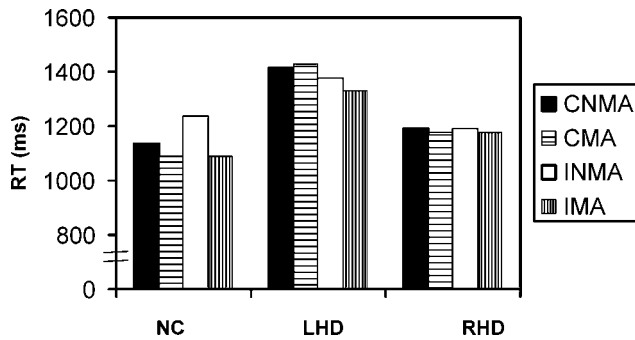


Fig. 2. Mean reaction times (RTs) for each condition for normal controls (NC), left-hemisphere-damaged (LHD) and right-hemisphere-damaged (RHD) participants.

Keuls procedure ( $p < .05$ ) revealed significant differences between the minimal and non-minimal attachment conditions for the incongruent prosody stimuli only. The small RT difference between minimal and non-minimal attachment stimuli with congruent prosody did not prove to be significant. In addition, only for the non-minimal attachment stimuli was there a significant influence of the incongruent prosody (i.e.,  $INMA > CNMA$ ).

The ANOVA for the RHD patients yielded no main effects or interactions ( $F$ 's all  $\leq 1$ ). Finally, the ANOVA for the LHD patients revealed only a main effect for Prosody ( $F(1,9) = 17.574$ ,  $p < .002$ ). As illustrated in the figure, this influence of prosody was in an unexpected direction, with stimuli with incongruent prosody yielding faster RTs than those with congruent prosody.

When dealing with brain-damaged patient groups, it is always of interest to examine individual patterns of performance to determine whether the group findings are truly representative of all of the individual participants. To this end, individual data within each group were explored to ascertain the number of participants whose RT patterns conformed to those of the group as a whole and/or to those of the normal control group.

Within the normal control group, all participants exhibited longer RTs to INMA relative to IMA conditions and all but one (NC6) produced longer RTs in the INMA relative to the CNMA condition, suggesting that the influences of both prosody and attachment type were quite robust. Similarly, 8 of the 10 normal controls demonstrated the expected RT patterns in comparisons of the CNMA and CMA conditions, as well as the IMA and CMA conditions, with latencies in the non-minimal and incongruent conditions equal to or greater than those in the CMA condition.

For the RHD subjects, because no significant effects emerged, the individual data were contrasted with those of the NC group. Of greatest interest, only two of the RHD patients' (RHD8 and RHD9) RTs demonstrated a

clear influence of incongruent prosody, with latencies in the INMA condition slower than in the CNMA condition; the majority of the patients' RTs were in the direction opposite to that expected. Moreover, only about half the group showed results paralleling those of normal controls in comparing the INMA to IMA conditions (i.e., slower latencies in the INMA than the IMA condition), indicating an inconsistent sensitivity to attachment type in this patient group.

Recall that the LHD patients, as a group, demonstrated surprisingly longer latencies in the congruent prosody conditions relative to the incongruent prosody conditions. For the non-minimal attachment stimuli, 7 of the 10 patients exhibited such a pattern; for the minimal attachment stimuli, 8 of the 10 LHD patients' RTs were consistent with the group pattern. Thus, only a very small number of LHD patients produced response latencies in keeping with those of normal controls; this group of LHD patients was therefore quite homogeneous in their insensitivity to attachment type as well as their unexpected "misuse" of prosodic information.

#### 4. Discussion

The present study set out to investigate how sentence prosody is decoded by normal and neurologically impaired adults. Two independent questions were asked; first, under normal parsing circumstances, at what point does prosodic information come into play? Second, for unilaterally brain-damaged adults, is there evidence that these individuals can perceive prosodic cues relevant for syntactic structure? If so, how would these findings bear on theories of lateralization of prosodic processing?

We turn our attention to the normal controls (NCs) first. The question posed for this group was based on previous findings by Marslen-Wilson et al. (1992) who argued that prosody influences syntactic structure (Kjelgaard & Speer, 1999; Walker et al., 2001; but see also Albritton et al., 1996; Stirling & Wales, 1996). In contrast to that work, the results of the present experiment were consistent with a 'syntax-first' (serial processor) model, where prosodic information is integrated after initial structural assignments have been made. This follows from the finding that no significant influence of prosody was found for the minimal attachment stimuli (i.e., IMA vs. CMA conditions). For the non-minimal attachment stimuli, the significant influence of incongruent prosody that emerged (i.e.,  $INMA > CNMA$ ), is unsurprising on a 'syntax-first' model. As mentioned in the introduction, in the congruent condition, the parser quickly re-assigns its initial (minimal attachment) structure to a non-minimal attachment structure with the aid of the prosodic information. But for the



incongruent non-minimal attachment stimuli (INMA), as the processor re-analyzes its original parse, conflicting prosodic cues cause confusion, resulting in longer processing times. The one finding that is not entirely consistent with predictions of a syntax-first model is the absence of a significant difference between congruent minimal and non-minimal attachment stimuli. Without the assistance of prosody, one would predict longer RTs to the non-minimal attachment stimuli due to the requirement for syntactic reanalysis. However, aided post hoc by congruent prosody, perhaps the reanalysis in the present investigation was too fast to be captured by the lexical decision measures. In sum, the findings are consistent with a model where prosodic information does not direct the *initial* analysis of a sentence, but is quickly integrated in reanalysis (Stirling & Wales, 1996; Watt & Murray, 1996).

With regard to the neurologically impaired adults, the results regarding syntactic processing were largely as expected. That is, the individuals with LHD displayed no effect of attachment type, which is unsurprising for individuals with nonfluent aphasia who likely exhibit syntactic processing impairments. On the other hand, the performance of the RHD patient group was more comparable to normal with respect to syntactic processing. Namely, minimal attachment sentences were processed somewhat faster than non-minimal ones, although this difference did not reach significance. Upon closer examination of the individual data, a large amount of individual variability emerges. Recall that, for the normal controls, RTs were slower in the INMA condition relative to the IMA condition (but not for the congruent stimulus comparisons), supporting a reanalysis interpretation. Within the RHD group, approximately half of the participants displayed a similar pattern (i.e., slower latencies in the INMA than the IMA condition), indicating an inconsistent sensitivity to attachment type in this patient group. We speculate that this variability may be attributed to working memory and/or attentional deficits commonly associated with RHD, rather than syntactic processing deficits per se. Such associated deficits may have interfered with some of the RHD patients' ability to perform the experimental task, ultimately influencing the pattern of lexical decision latencies. Recall that the task employed—cross-modal lexical decision—requires subjects to attend to auditory input, while also focusing on a secondary visual (lexical decision) task. It is possible that this exceeded the computational limits of some of the RHD patients (cf. Walker et al., 2001).

With regard to prosodic processing—the main focus of the present investigation—we were interested in addressing hypotheses concerning the hemispheric lateralization of prosodic cues. To anticipate the conclusion, our data are consistent with the hypothesis that the RH preferentially processes prosodic information that oc-

curs over a relatively long temporal domain, whereas the LH is more specialized for prosodic information that spans a relatively short temporal domain (Baum & Pell, 1997; Gandour et al., 2003; Poeppel, in press; Zatorre et al., 1992). Furthermore, we will argue that the specific formulation of this hypothesis found in Gandour et al. (2003) better captures the present results.

In contrast to the findings of Walker et al. (2001), neither patient group demonstrated normal sensitivity to the prosodic manipulations. Specifically, the performance of the RHD patients showed no effect of prosody. This is inconsistent with a functional lateralization of prosody, which would predict normal processing of linguistic prosody by RHD individuals. The results may, however, be interpreted within the context of a cue lateralization hypothesis that incorporates the concept of temporal domains, as described above. That is, the intonational cues that are purported to delimit phrasal boundaries like those used in the present investigation (cf. Beach, 1991) correspond to prosodic information which spans over 'long' domains, i.e., a phrase or a sentence. If we assume that this is precisely the kind of global domain that the RH specializes in processing (Behrens, 1989), then it is unsurprising that RHD would yield impairments in processing of just such information, as found in the current results.

The performance of the LHD patients differed from that of both the RHD patients and the normal controls. Surprisingly, the prosodic manipulation *did* yield an effect, but in the unexpected direction. That is, the incongruent conditions were unexpectedly processed faster than the congruent conditions. These results suggest that, although the LHD patients did not process the prosodic information in the expected manner, they were nevertheless *sensitive* to it, unlike the RHD individuals. That is, the prosodic information was being processed by the LHD patients, albeit in a manner not easily understood. Below, we offer some possible explanations for this pattern of results.

First, as Selkirk (1984) and Albritton et al. (1996) have noted, there is no one-to-one mapping between a prosodic contour and a syntactic structure. Thus, there are presumably other possible acoustic patterns that can be used during a parse to disambiguate a structure. It could be the case that the LHD patients were relying on a different set of prosodic 'expectations.'

Another perhaps more likely explanation is the following: it is the case that the LHD patients are processing the same cues as do normals, but they have either lost the ability to map those cues onto syntactic structures, or they are mis-assigning the cues. Under a cue-lateralization hypothesis, where the temporal domain of the prosodic cue influences lateralization, one might argue that, whereas syntactic disambiguation of the type required in the present investigation depends in

large part on phrase-length prosodic information, another major cue is pause duration—arguably of relatively short temporal domain; this may be precisely the type of cue that the LHD patients are unable to appropriately map onto syntactic structure. Despite presumably intact access to prosodic information spanning over phrases, the LHD individuals are unable to make use of that information alone for disambiguation.

An alternative description of the short vs. long temporal domains may prove useful. Gandour et al. (2003) argue that the unit of measurement that distinguishes ‘short’ vs. ‘long’ temporal processing should not be one that uses absolute time scales, in the sense of Poeppel (in press). Instead, they propose that hierarchical levels of linguistic structure determine what domain is ‘larger’ than another. Specifically, Gandour and colleagues claim that the level of the syllable should be distinguished from the phrase. Suppose Gandour et al. (2003) are correct. How would their claim bear on the present findings? It is clear that the kind of prosodic information examined here involves structures that are between the syllable and the sentence. Prior to considering the current results within hierarchical prosodic structure, a brief review of prosodic theory is required.

It is uncontroversial that the phonological representation of a sentence must contain at least the constituent of a syllable. The grammar of prosody consists of hierarchically layered structures, the lowest of which is the syllable (this is the layer below the word) and the highest is the Intonational Phrase (see Beckman & Pierrehumbert, 1986; Nespor & Vogel, 1986; Selkirk, 1984, 1995). For our purposes, we will concern ourselves with the levels of Prosodic Word, Phonological Phrase and Intonational Phrase.<sup>2</sup> A short description is given below, with an example (from Ferreira, 1993).

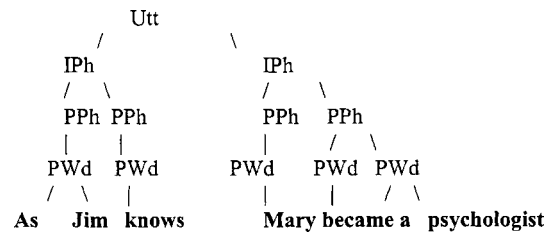
#### 4.1. Constituents of prosodic structure

*Intonational Phrase (IPh).* The unit over which F0 in a declarative sentence typically falls; tends to be followed by a pause.

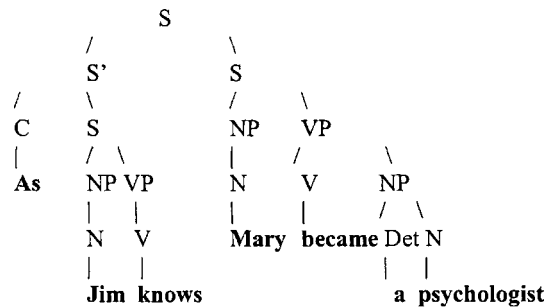
*Phonological Phrase (PPh).* All material up to a syntactic boundary constitutes a single phonological phrase.

*Prosodic Word.* Content word plus function word.  
Example 1 “As Jim knows, Mary became a psychologist.”

#### A. Prosodic structure



#### B. Syntactic structure



Ferreira (1993) and Schafer, Speer, Warren, and White (2000) have convincingly argued for the psychological reality of prosodic structures as in Example 1A. The question being posed here is whether there are any neural correlates to the phonological categories inherent in prosodic structure. So far, researchers have focused largely on the segmental and syllable levels; whether the prosodic categories depicted above can be localized is an open question (Phillips, 2001). For the sake of argument, suppose these categories do have neural correlates. Then the results for the LHD patients could be explained in the following way: whereas the LHD individuals are sensitive to prosodic information at the level of the Intonational Phrase, they do not have access to the smaller units of Phonological Phrase or Prosodic Word. In fact, the level of prosodic phrasing that is most closely associated with syntactic structure is purported to be the Phonological Phrase (Nespor & Vogel, 1986; Selkirk, 1984, 1995; see also Kjelgaard & Speer, 1999 for a psycholinguistic investigation of the Phonological Phrase). This is precisely the level to which we suggest the LHD patients have impaired access. As such, even though the ‘long’ domain of the IPh is processed by the LHDs, knowledge of syntactic boundaries is impaired due to the inability to accurately interpret the prosodic structure of the Phonological Phrase. In comparison, the inability of the RHD patients to accurately perceive and interpret the Intonational Phrase, the highest level of prosodic structure, results in their insensitivity to prosodic information as a whole.

<sup>2</sup> It should be noted that Selkirk’s (1984) construction of the Phonological Phrase differs from that of Nespor and Vogel (1986) and from that of Beckman and Pierrehumbert’s (1986) intermediate phrase (iph). For consistency, we adopt Selkirk’s terminology, and note that the theoretical distinctions in the definition of this prosodic category between the Intonation Phrase and the syllable do not concern us here.

In conclusion, the present findings suggest that the individuals with RHD were largely insensitive to prosodic cues, whereas the individuals with LHD could perceive prosody, but not in an appropriate manner. The results are in keeping with a cue lateralization theory of prosodic processing that incorporates the notion of varying temporal domains. Phrasal acoustic cues (which correspond to Intonational Phrases) are preferentially processed in the right hemisphere, which specializes in processing acoustic cues that span over a long domain. In contrast, the left hemisphere is superior in processing acoustic cues that span short domains (e.g., Phonological Phrases and Syllables, as well as segmental duration, etc.; Gandour et al., 2003). Finally, the results for the non-brain-damaged participants are consistent with a 'syntax-first' serial processing model, where prosodic cues are used for quick re-analysis.

## References

- Albritton, D. W., McKoon, G., & Ratcliff, R. (1996). Reliability of prosodic cues for resolving syntactic ambiguity. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 22, 714–735.
- Baum, S. (1998). The role of fundamental frequency and duration in the perception of linguistic stress by individuals with brain damage. *Journal of Speech, Language, and Hearing Research*, 41, 31–40.
- Baum, S., Kelsch Daniloff, J., Daniloff, R., & Lewis, J. (1982). Sentence comprehension by Broca's aphasics: Effects of some suprasegmental variables. *Brain and Language*, 17, 261–271.
- Baum, S., & Pell, M. (1997). Production of affective and linguistic prosody by brain-damaged patients. *Aphasiology*, 11, 177–198.
- Baum, S., Pell, M., Leonard, C., & Gordon, J. (1997). The ability of right- and left-hemisphere-damaged individuals to produce and interpret prosodic cues marking phrasal boundaries. *Language and Speech*, 40, 313–330.
- Baum, S., Pell, M., Leonard, C., & Gordon, J. (2001). Using prosody to resolve temporary syntactic ambiguities in speech production: Acoustic data on brain-damaged speakers. *Clinical Linguistics and Phonetics*, 15, 441–456.
- Beach, C. M. (1988). The influence of higher level linguistic information on production of duration and pitch patterns at syntactic boundaries. *Journal of Acoustical Society of America*, 75, S1.
- Beach, C. M. (1991). The interpretation of prosodic patterns at points of syntactic structure ambiguity: Evidence for cue trading relations. *Journal of Memory and Language*, 30, 644–663.
- Beckman, M., & Pierrehumbert, J. B. (1986). Intonational structure in Japanese and English. *Phonology Yearbook*, 3, 255–310.
- Behrens, S. (1989). Characterizing sentence intonation in a right hemisphere-damaged population. *Brain and Language*, 37, 181–200.
- Blasko, D. G., & Hall, M. D. (1998). Influence of prosodic boundaries on comprehension of spoken English sentences. *Perceptual and Motor Skills*, 87, 3–18.
- Brådvik, B., Dravins, C., Holtås, S., Rosén, I., Ryding, E., & Ingvar, D. (1991). Disturbances of speech prosody following right hemisphere infarcts. *Acta Neurologica Scandinavica*, 84, 114–126.
- Bryan, K. (1989). Language prosody and the right hemisphere. *Aphasiology*, 3, 285–299.
- Caplan, D. (1992). *Language: Structure, processing and disorders*. Cambridge, MA: MIT Press.
- Emmorey, K. (1987). The neurological substrates for prosodic aspects of speech. *Brain and Language*, 30, 305–320.
- Ferreira, F. (1993). Creation of prosody during sentence production. *Psychological Review*, 100, 233–253.
- Francis, W. N., & Kucera, H. (1982). *Frequency analysis of English usage*. Boston: Houghton Mifflin.
- Frazier, L., & Fodor, J. D. (1978). The sausage machine: A new two stage parsing model. *Cognition*, 6, 291–325.
- Gandour, J., & Dardarananda, R. (1983). Identification of tonal contrasts in Thai aphasic patients. *Brain and Language*, 18, 98–114.
- Gandour, J., Dechongkit, S., Ponglorpisit, S., & Khunadorn, F. (1994). Speech timing at the sentence level in Thai after unilateral brain damage. *Brain and Language*, 46, 419–438.
- Gandour, J., Dzemic, M., Wong, D., Lowe, M., Tong, Y., Hsieh, L., Sathamnuwong, N., & Lurito, J. (2003). Temporal integration of speech prosody is shaped by language experience: An fMRI study. *Brain and Language*, 84, 318–336.
- Gandour, J., Wong, D., Hsieh, L., Weinzapfel, B., Van Lancker, D., & Hutchins, G. D. (2000). A cross-linguistic PET study of tone perception. *Journal of Cognitive Neuroscience*, 12, 207–222.
- Hsieh, L., Gandour, J., Wong, D., & Hutchins, G. D. (2001). Functional heterogeneity of inferior frontal gyrus is shaped by linguistic experience. *Brain and Language*, 76, 227–252.
- Hughes, C., Chan, J.-L., & Su, M. (1983). Aprosodia in Chinese patients with right cerebral hemisphere lesions. *Archives of Neurology*, 40, 732–736.
- Kjelgaard, M. M., & Speer, S. (1999). Prosodic facilitation and interference in the resolution of temporary syntactic closure ambiguity. *Journal of Memory and Language*, 40, 153–194.
- Klein, D., Zatorre, R. J., Milner, B., & Zhao, V. (2001). A cross-linguistic PET study of tone perception in Mandarin Chinese and English speakers. *Neuroimage*, 13, 646–653.
- Marslen-Wilson, W. D., Tyler, L. K., Warren, P., Grenier, P., & Lee, C. S. (1992). Prosodic effects in minimal attachment. *Quarterly Journal of Experimental Psychology*, 45A, 73–87.
- Mertus, J. (1989). *BLISS User's Manual*. Providence: Brown University.
- Nagel, H., Shapiro, L., & Nawy, R. (1994). Prosody and the processing of filler-gap sentences. *Journal of Psycholinguistic Research*, 23, 473–485.
- Nagel, H., Shapiro, L., Tuller, B., & Nawy, R. (1996). Prosodic influences on the resolution of temporal ambiguity during on-line sentence comprehension. *Journal of Psycholinguistic Research*, 25, 319–340.
- Nespor, M., & Vogel, I. (1986). *Prosodic phonology*. Dordrecht: Foris.
- Pell, M., & Baum, S. (1997a). The ability to perceive and comprehend intonation in linguistic and affective contexts by brain damaged adults. *Brain and Language*, 57, 80–99.
- Pell, M., & Baum, S. (1997b). Unilateral brain damage, prosodic comprehension deficits, and the acoustic cues to prosody. *Brain and Language*, 57, 195–214.
- Perkins, J., Baran, J., & Gandour, J. (1996). Hemispheric specialization in processing intonation contours. *Aphasiology*, 10, 343–362.
- Phillips, C. (2001). Levels of representation in the electrophysiology of speech perception. *Cognitive Science*, 25, 711–731.
- Poeppl, D. (2001). Pure word deafness and the bilateral processing of the speech code. *Cognitive Science*, 25, 679–693.
- Poeppl, D. (in press). The analysis of speech in different temporal integration windows: Cerebral lateralization as 'asymmetric sampling in time'. *Speech Communication*.
- Robin, D. A., Tranel, D., & Damasio, H. (1990). Auditory perception of temporal and spectral events in patients with focal left and right cerebral lesions. *Brain and Language*, 39, 539–555.
- Schafer, A., Carter, J., Clifton, C., & Frazier, L. (1996). Focus in relative clause construal. *Language and Cognitive Processes*, 11, 135–163.

- Schafer, A., Speer, S., Warren, P., & White, S. D. (2000). Intonational disambiguation in sentence production and comprehension. *Journal of Psycholinguistic Research*, 29, 169–182.
- Selkirk, E. (1984). *Phonology and syntax: The relation between sound and structure*. Cambridge, MA: MIT Press.
- Selkirk, E. (1995). Sentence prosody: Intonation, stress and phrasing. In J. Goldsmith (Ed.), *Handbook of phonological theory* (pp. 550–569). Oxford: Basil Blackwell.
- Shapiro, L., & Nagel, N. (1995). Lexical properties, prosody and syntax: Implications for normal and disordered language. *Brain and Language*, 50, 240–257.
- Speer, S., Kjelgaard, M. M., & Dobroth, K. M. (1996). The influence of prosodic structure on the resolution of temporary syntactic closure ambiguities. *Journal of Psycholinguistic Research*, 25, 247–268.
- Stirling, L., & Wales, R. (1996). Does prosody support or direct sentence processing. *Language and Cognitive Processes*, 11, 193–212.
- Van Lancker, D. (1980). Cerebral lateralization of pitch cues in the linguistic signal. *International Journal of Human Communication*, 13, 227–277.
- Van Lancker, D., & Sidtis, J. J. (1992). The identification of affective-prosodic stimuli by left- and right-hemisphere-damaged subjects: All errors are not created equal. *Journal of Speech and Hearing Research*, 35, 963–970.
- Walker, J. P., Fongemie, K., & Daigle, T. (2001). Prosodic facilitation in the resolution of syntactic ambiguities in subjects with left and right hemisphere damage. *Brain and Language*, 78, 169–196.
- Warren, P. (1985). The temporal organization and perception of speech. Unpublished doctoral dissertation, University of Cambridge.
- Watt, S. M., & Murray, W. S. (1996). Prosodic form and parsing commitments. *Journal of Psycholinguistic Research*, 25, 291–318.
- Weintraub, S., Mesulam, M.-M., & Kramer, L. (1981). Disturbances in prosody: A right-hemisphere contribution to language. *Archives of Neurology*, 38, 742–744.
- Zatorre, R. J. (1997). Cerebral correlates of human auditory processing: Perception of speech and musical sounds. In J. Sykora (Ed.), *Acoustical signal processing in the central auditory processing system* (pp. 453–468). New York: Plenum Press.
- Zatorre, R. J., Evans, A., Meyer, E., & Gjedde, A. (1992). Lateralization of phonetic and pitch discrimination in speech processing. *Science*, 256, 846–849.