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The Ability of Right- and Left-Hemisphere-Damaged Individuals to Produce and Interpret Prosodic Cues Marking Phrasal Boundaries *

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ABSTRACT

Two experiments were conducted with the purpose of investigating the ability of right- and left-hemisphere-damaged individuals to produce and perceive the acoustic correlates to phrase boundaries. In the production experiment, the utterance *pink and black and green* was elicited in three different conditions corresponding to different arrangements of colored squares. Acoustic analyses revealed that both left- and right-hemisphere-damaged patients exhibited fewer of the expected acoustic patterns in their productions than did normal control subjects. The reduction in acoustic cues to phrase boundaries in the utterances of both patient groups was perceptually salient to three trained listeners. The perception experiment demonstrated a significant impairment in the ability of both left-hemisphere-damaged and right-hemisphere-damaged individuals to perceive phrasal groupings. Results are discussed in relation to current hypotheses concerning the cerebral lateralization of speech prosody.

INTRODUCTION

It has by now been well-established that impairments in the production and perception of speech prosody may emerge subsequent to both right and left hemisphere damage. The precise nature of such deficits, however, remains obscure (see Baum & Pell, in press, for review). Several hypotheses have been advanced concerning the neural bases of prosodic processing, including right hemisphere dominance for all aspects of prosody (Weintraub, Mesulam, & Kramer, 1981), subcortical control of prosody (Cancelliere & Kertesz, 1990), and right hemisphere specialization for emotional prosody but left hemisphere specialization for linguistic prosody — the so-called functional load hypothesis (Van Lancker, 1980). The majority of studies to date have supported some version of the functional load hypothesis.

In particular, investigations of various aspects of linguistic prosody have demonstrated that, subsequent to left hemisphere damage (LHD), the production and perception of

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sentence intonation, lexical and emphatic stress, and phonemic tone are compromised (Baum, Kelsch Daniloff, Daniloff, & Lewis, 1982; Danly, Cooper, & Shapiro, 1983; Danly & Shapiro, 1982; Emmorey, 1987; Gandour, Ponglorpisit, Khunadorn, Dechongkit, Boongrid, and Boonklam, 1992a; Ouellette & Baum, 1993; Pell & Baum, 1997), whereas right hemisphere damage (RHD) is less detrimental to the processing of linguistic prosody (Behrens, 1988; Emmorey, 1987; Gandour, Dechongkit, Ponglorpisit, Khunadorn, & Boongird, 1993; Gandour, Larsen, Dechongkit, Ponglorpisit, & Khunadorn, 1995; Gandour, Ponglorpisit, Khunadorn, Dechongkit, Boongrid, Boonklam, & Potisuk, 1992b; Ryalls, Joanette, & Feldman, 1987; but compare Behrens, 1989; Blumstein & Cooper, 1974; Brådvik, Dravins, Holtås, Rosén, Ryding, & Ingvar, 1991; Bryan, 1989; Shapiro & Danly, 1985; Weintraub et al., 1981). Although a number of aspects of sentential intonation have been studied, most experiments have concentrated on the contrast between declarative and interrogative sentences (e.g., Pell & Baum, 1997) or overall patterns of declination (Danly et al., 1983; Danly & Shapiro, 1982). Little data has been gathered on brain-damaged patients' ability to utilize prosodic cues to disambiguate syntactically ambiguous sentences (but cf. Grosjean & Hirt, 1996; Perkins, Baran, & Gandour, 1996 for related issues).

Perhaps the simplest type of syntactic disambiguation is the identification of phrase boundaries in multiply conjoined strings, such as in bracketed algebraic expressions like $(1+2)\times 3$ versus $1+(2\times 3)$ (Streeter, 1978). In normal speech production, such phrase boundaries are signaled by an increase in the duration of the word preceding the boundary (Klatt, 1975; Lehiste, 1973; Lehiste, Olive, & Streeter, 1976; Price, Ostendorf, Shattuck-Hufnagel, & Fong, 1991; Scott, 1982; Wightman, Shattuck-Hufnagel, Ostendorf, & Price, 1992), an increase in pause duration following the boundary (Cooper, Paccia, & Lapointe, 1978; Price et al., 1991; Scott, 1982; Streeter, 1978), a rise in peak F0 following the boundary due to partial declination reset (e.g., Ladd, 1988) and a steeper fall in F0 and increased F0 fluctuation on the preboundary word (Cooper & Sorensen, 1981; Price et al., 1991; 't Hart & Cohen, 1973). Numerous investigations have shown that these acoustic cues are perceptually salient to normal listeners in rendering phrase boundary judgments (Lehiste et al., 1976; Price et al., 1991; Scott, 1982; Streeter, 1978). In contrast, preliminary data on brain-injured listeners indicate that LHD patients (but not RHD patients) display subnormal capacity to use intonational cues in resolving syntactic ambiguities, as demonstrated, for example, for utterances containing parenthetical clauses or tag elements (Perkins et al., 1996). Again, these findings support the larger body of evidence pointing to a major left hemisphere role in the perception of linguistic prosody, as predicted by functional load hypotheses (Baum et al., 1982; Behrens, 1985; Emmorey, 1987; Gandour & Dardarananda, 1983; Heilman, Bowers, Speedie, & Coslett, 1984; Pell & Baum, 1997; Perkins et al., 1996).

The ability of right- or left-hemisphere-damaged individuals to produce the appropriate acoustic correlates to phrase boundaries is also of interest. As noted earlier, acoustic analyses of prosodic parameters have shown that LHD patients exhibit deficits in the production of stress cues and sentence intonation, most notably affecting temporal properties of speech. For example, Cooper, Soares, Nicol, Michelow, and Goloskie (1984) reported abnormal timing patterns, as well as deviant F0 patterns, in sentence production in LHD patients (see also Danly et al., 1983; Danly & Shapiro, 1982; Ryalls, 1982). Similarly, Emmorey (1987) found that LHD speakers failed to manipulate duration and F0 appropriately to signal lexical stress, with greater impairments in the temporal parameters (see also Ouellette & Baum, 1993). Patients with RHD were better able to differentiate these stress contrasts via prosodic cues (Emmorey, 1987; Ouellette & Baum, 1993; see also Behrens, 1988). In certain studies, RHD has also been found to affect the production of linguistic prosody (Behrens, 1989; Blonder, Pickering, Heath, Smith, & Butler, 1995; Shapiro & Danly, 1985), but results are inconsistent (Baum & Pell, 1997; Ryalls et al., 1987). The inconsistent findings have been viewed as providing some support, albeit limited (Baum & Pell, 1997; Ouellette & Baum, 1993), for the proposal (based on perceptual data) that individual acoustic parameters may be differentially lateralized, with duration processed by the left hemisphere and F0 processed by the right hemisphere (i.e., the differential cue lateralization hypothesis; Van Lancker & Sidtis, 1992).

To further assess the neural substrate underlying the processing of utterance-level prosody, the present investigation evaluates the ability of left- and right-hemisphere-damaged individuals to utilize prosody to mark and identify phrase boundaries. Following Katz, Beach, Jenouri, and Verma (1996), a production subtest was designed to elicit descriptions of different arrangements of colored squares using the utterance *pink and black and green*. As described earlier, normal speakers are expected to increase the duration of words when produced in preboundary positions compared to nonboundary positions. In addition, longer pauses at phrase boundaries than within phrases are anticipated. Finally, a higher peak F0 may be expected on postboundary accented syllables due to partial declination reset at phrase boundaries (e.g., Ladd, 1988). This pattern would obviously not be evident for *pink* because it is always clause-initial. In addition, a steeper fall in F0 and increased F0 fluctuation may be expected on preboundary words, which would be most evident for the word *black* due to its medial position in the utterance (see Katz et al., 1996). A perception subtest was also designed (following Beach, Katz, & Skowronski, 1996) to examine listeners' ability to identify different groupings of the same colored squares, as signaled by prosodic cues, in the utterance *pink and black and green.*

Based on the available data, the following predictions may be made regarding the performance of LHD and RHD patients on such tasks. If the functional load hypothesis is correct (Van Lancker, 1980), we would expect LHD patients to perform poorly on both production and perception tasks assessing linguistic phrase boundary marking, but we would expect RHD patients to perform like normals. If, moreover, LHD patients' control of temporal parameters in speech production is particularly vulnerable (Baum & Pell, 1997; Ouellette & Baum, 1993), we would anticipate a breakdown in the use of duration to signal phrase boundaries, with better control of F0 in this population. Alternatively, if the differential cue lateralization hypothesis is assumed (Van Lancker & Sidtis, 1992), we might predict an impairment in the RHD subjects' ability to modulate F0 in marking phrase boundaries, with relatively intact temporal control. Subjective evaluation of the production data may help further qualify the success of brain-damaged and non-brain-damaged speakers in encoding the acoustic cues to phrase boundaries.

METHODS

Subjects

Three groups of subjects participated in the experiments: Ten left-hemisphere-damaged patients (LHD), 10 right-hemisphere-damaged patients (RHD) and 10 normal controls (NC;

mean age=66 years) with no history or current evidence of neurological dysfunction, alcohol abuse, or speech-language deficits. The brain-damaged patients had all suffered a single, unilateral cerebrovascular accident (CVA) at least four months prior to testing and all subjects were native speakers of English whose hearing was screened to be within normal limits. The patient groups underwent a battery of screening tests. The LHD patients were given parts of the *Psycholinguistic Assessment of Language* (PAL; Caplan, 1992) and the *Boston Diagnostic Aphasia Exam* (BDAE; Goodglass & Kaplan, 1983) to assess the nature of their deficits and ensure sufficient comprehension and production skills for the tasks. The RHD patients were given tests of emotional prosody perception, comprehension of figurative language and inferencing (subtests adapted from the *Test of Language Competence—Expanded Edition* (Wiig & Secord, 1987)), as well as the Bells Test for visual neglect (Gauthier, Dehaut, & Joanette, 1989) and some of the PAL subtests. Characteristics of the individual subjects are presented in Appendix 1.[1]

Stimuli and procedures—production experiment

The stimulus phrase *pink and black and green* was elicited in three different conditions, corresponding to each of three pictures of colored squares in particular groupings. In one arrangement, the pink, black, and green squares were equidistantly spaced (PBG); in a second arrangement, the pink and black squares were close together, and the green one was apart (PB_G). The third arrangement displayed the pink square separated from the black and green ones, which were close together (P_BG). Each picture was presented six times, along with the phrase in orthographic form; the eighteen presentations were in random order. Subjects were instructed to describe the grouping of the squares using only the phrase *pink and black and green*, in such a way that someone hearing them on tape (i.e., someone who could not see the arrangement) would know how the squares were arranged.

Productions were recorded on digital audio tape using a Sony DAT recorder and a high-quality directional microphone placed approximately 8 inches (20 cm) from the speaker's mouth.

Acoustic analyses

Utterances were digitized at a sampling rate of 20 kHz with a 9 kHz low-pass filter and 12-bit quantization using the BLISS speech analysis system (Mertus, 1989). Following the procedures of Katz et al. (1996), word and pause durations were computed, and the F0 contour was extracted from key positions in each utterance. The duration of the word *pink* was calculated from the burst of the [p] through the offset of the aspiration associated with the final [k]. Similarly, the duration of *black* was measured from the burst of the [b] through the offset of the [k]; *green* was measured from the burst of the [g] through the end of regular periodicity associated with the [n]. To compute the duration of *and*, cursors were placed at the onset of periodicity corresponding to the [æ] and at the end of the burst

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[1] As may be noted from the table in the Appendix, both fluent and nonfluent aphasic patients were included within the LHD group. We chose to group them together in order to compare the effects of LH damage with RH damage, irrespective of lesion site (and associated aphasia syndrome). Some validation of this grouping is seen in the Results section, where no clear differences in performance within the LHD group associated with type of aphasia emerged.

of [d] for those with released final stops or the end of noticeable periodicity for unreleased (or omitted) [d]s. Pauses between words were calculated from the offset of one word to the onset of the next. Four potential pause sites were measured.

Fundamental frequency (F0) was extracted using an autocorrelation algorithm and the peak F0 was identified; this was then verified by measuring the peak F0 (inverse of the period) of the waveform during the relevant vocalic segment in the keywords *black* and *green* to examine potential F0 resetting when these words followed a phrase boundary as compared to when they appeared within a phrase (e.g., Ladd, 1988).

Stimuli and procedures—perception experiment

The phrase *pink and black and green* was produced by an adult male speaker in response to picture stimuli illustrating the same three groupings of colored squares used in the production experiment. The utterances were recorded on digital audio tape using a Sony DAT recorder and high-quality directional microphone. These recordings were digitized at a rate of 10k samples/s with a 4.5kHz low-pass filter and 12-bit quantization, using the BLISS speech analysis system (Mertus, 1989). Three listeners confirmed that the intended grouping was indeed conveyed, and the stimuli were analyzed acoustically, as described above. Results of the acoustic analyses were largely in keeping with expected patterns. That is, keywords were longer in preboundary position and pauses were longer at boundaries than elsewhere. In addition, peak F0 was somewhat higher in postboundary position relative to within phrase boundaries.

The stimuli were recorded onto tape in random order with a 4s interstimulus interval, and presented over headphones via a Sony cassette player a total of six times each. The experimental stimuli were preceded by five practice trials to accustom subjects to the task. Subjects were presented with a card displaying the same three alternative groupings of colored squares as used in the production task: (1) pink, black, and green equidistantly spaced, (2) pink and black together, green apart, (3) pink apart, black and green together. Subjects were instructed to listen to the stimuli and indicate, by a pointing response, which grouping matched the auditory stimulus. Responses were recorded by the examiner and no feedback was provided.

RESULTS

Production experiment—duration analyses

As the overall length of utterances elicited from brain-damaged and non-brain-damaged speakers varied considerably both within and between groups, word and pause duration values (in ms) were converted to proportions of total utterance durations in order to control for interspeaker differences in speaking rate. The mean duration proportions for each of the three target groupings are presented in Figures 1 through 3 (for the NC, RHD, & LHD groups respectively) to illustrate the temporal patterns for all segments of the utterances.

Statistical analyses focused on mean duration proportions for each subject for the keywords *pink*, *black*, and *green* and for the pauses following *pink* (P1) and *black* (P3). Separate 3×3 mixed-design analyses of variance (ANOVAs) were conducted for each keyword and pause position; for each ANOVA, the between-subjects factor was Group (NC,

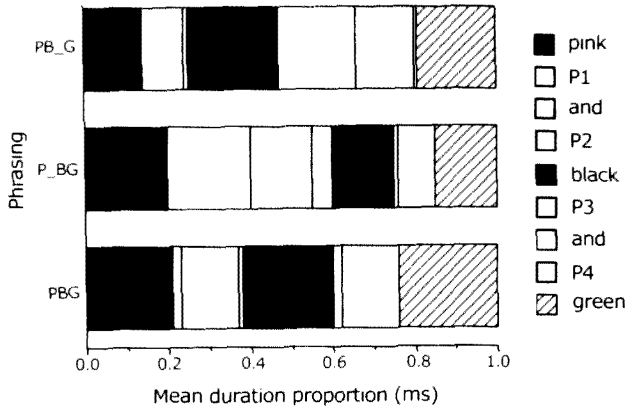

Figure 1

Mean word and pause duration proportions produced by NC subjects for the three phrasal groupings.

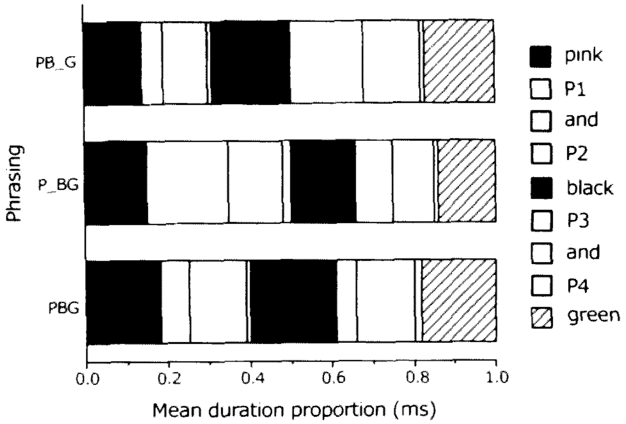

Figure 2

Mean word and pause duration proportions produced by RHD subjects for the three phrasal groupings.

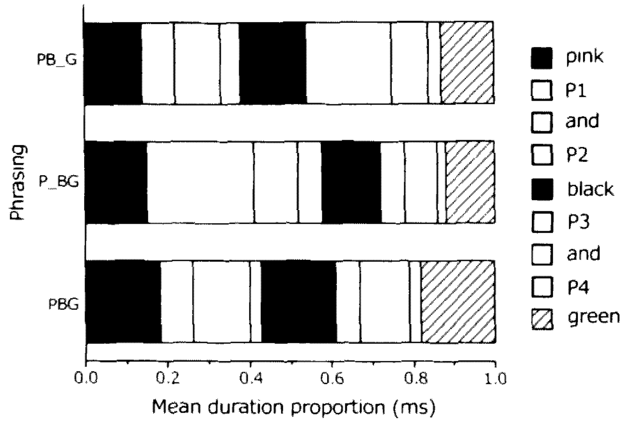

Figure 3

Mean word and pause duration proportions produced by LHD subjects for the three phrasal groupings.

RHD, LHD) and the within-subjects factor was Phrasing (PBG, P_BG, PB_G). Post hoc pairwise comparisons were completed using the Newman-Keuls procedure ($p=.05$).

Keyword pink. Figure 4 displays the mean duration proportions for the keyword *pink* in the different phrasal groupings for each subject group. The ANOVA revealed a main effect of Phrasing, $F(2,54)=45.52$, $p<.001$, with the duration of *pink* in the nonboundary position (PB_G=.136) shorter than in both preboundary (P_BG=.168) and equidistant positions (PBG=.192). Durations were clearly longest in the equidistantly-spaced condition (PBG) across groups. The ANOVA also revealed a Group×Phrasing interaction, $F(4,54)=3.46$, $p<.05$. Post hoc analyses demonstrated that within the NC group, duration of the word

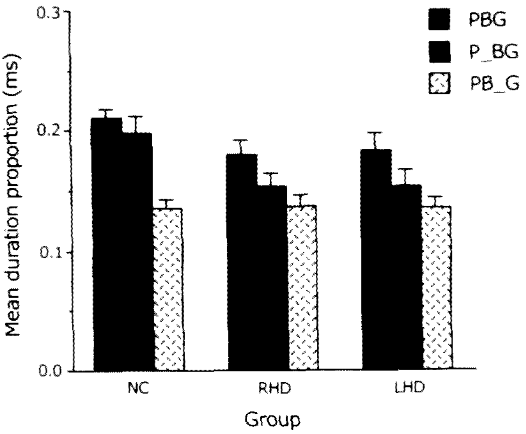

Figure 4

Mean duration proportions for the keyword *pink* for each group.

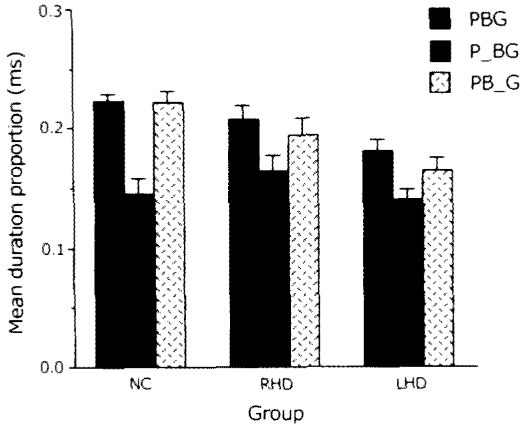

Figure 5

Mean duration proportions for the keyword *black* for each group.

pink was significantly shorter in the PB_G condition (.136) relative to the PBG (.211) and P_BG (.198) conditions, which did not differ significantly. In the LHD group, *pink* was longer in the PBG condition (.184) relative to both the P_BG (.154) and PB_G (.136) conditions, but, unlike the NCs, the difference between the latter two conditions was not significant. Within the RHD group, although a similar overall pattern emerged (PBG=.180, P_BG=.153, PB_G=.137), none of the differences reached significance.

Keyword 'black. Mean duration proportions for the keyword *black* are illustrated in Figure 5. Statistical analysis of the data revealed main effects of Group, $F(2,27)=3.71$, $p<.05$, and Phrasing, $F(2,54)=45.92$, $p<.001$, and a Group × Phrasing interaction, $F(4,54)=4.28$, $p<.01$. Analysis of the interaction demonstrated that, for the NCs, *black* was shorter in the P_BG (.145) condition relative to the other two conditions (PBG=.223, PB_G=.222), as expected. The LHD subjects showed a similar pattern, but only the difference between P_BG (.141) and PBG (.181) reached significance. Like the NCs, the RHD subjects produced *black* with shorter durations in the P_BG (.164) condition relative to the other two conditions (PBG=.208, PB_G=.194).

Keyword 'green. The mean duration proportions for the keyword *green* are depicted in Figure 6. Statistical analyses revealed a significant main effect of Group, $F(2,27)=3.75$, $p<.05$, due to shorter durations produced by the LHD subjects (.142) relative to the NCs

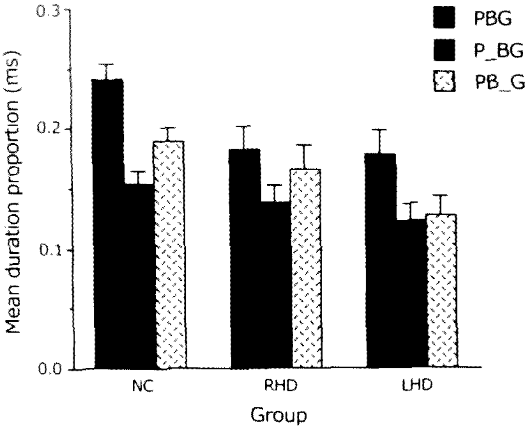

Figure 6

Mean duration proportions for the keyword *green* for each group.

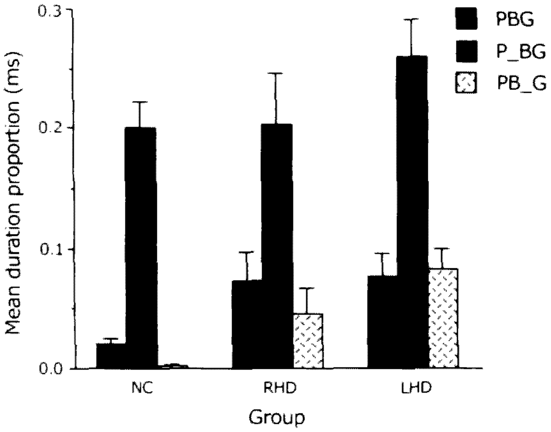

Figure 7

Mean duration proportions for pause P1 for each group.

(.195); the RHD subjects (.162) did not significantly differ from either group. The ANOVA also yielded a significant main effect of Phrasing, $F(2,54)=33.06$, $p<.001$. Pairwise comparisons indicated that the duration of *green* in the P_BG condition (.138) was significantly shorter than in the PB_G condition (.161), which was in turn significantly shorter than in the PBG condition (.201). No significant interaction emerged.

Pause P1. Mean duration proportions for the first pause (i.e., following *pink*) are presented in Figure 7. The ANOVA on P1 revealed main effects of Group, $F(2,27)=3.69$, $p<.05$, and Phrasing, $F(2,54)=74.69$, $p<.001$, but no significant interaction. The effect of Group was due to shorter P1 durations for the NCs (.074) relative to the LHD subjects (.140); the P1 durations of the RHD subjects did not differ significantly from either other group (.108). Post hoc comparisons focusing on the effect of Phrasing showed that the duration of P1 in the P_BG condition (.221) was, not surprisingly, significantly longer than in both the PB_G condition (.044) and the PBG condition (.057), which did not differ significantly from one another.

Pause P3. Mean duration proportions for the pause following *black* for each group are illustrated in Figure 8. Statistical analysis of P3 yielded only a main effect of Phrasing, $F(2,54)=48.19$, $p<.001$. Pairwise comparisons indicated that, as expected, the duration of P3 was longer in the PB_G condition (.194) relative to both the PBG (.042) and P_BG (.054) conditions, which did not significantly differ from one another. No other significant effects emerged.

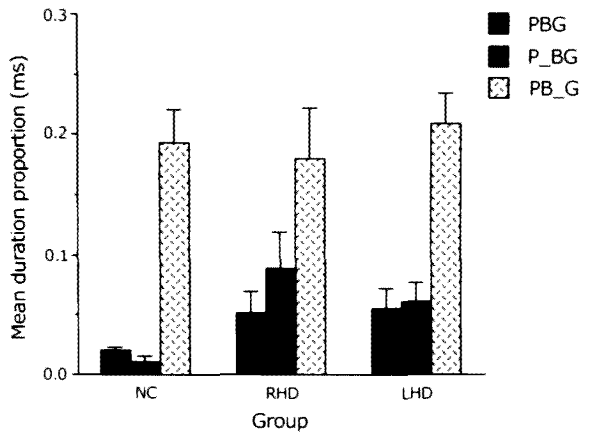

Figure 8

Mean duration proportions for pause P3 for each group.

Production experiment—F0 analyses

Separate Group × Phrasing ANOVAs were computed on the peak F0 values for the keywords *black* and *green*. In the ANOVA for *black*, a main effect of Phrasing emerged, $F(2,54)=3.484$, $p<.05$. Post hoc analysis using the Newman-Keuls procedure ($p<.05$) revealed that mean peak F0 of *black* was significantly higher in the PB_G condition (163 Hz) relative to the PBG condition (155 Hz). Contrary to expectations, mean peak F0 in the (postboundary) P_BG condition (158 Hz) fell between the other two conditions and did not differ significantly from either one. No other significant effects emerged in the analysis. Inspection of the data for individual subjects within each group revealed that, while only one speaker in each of the NC and LHD groups demonstrated the expected pattern, five of the 10 RHD subjects did.

The ANOVA for *green* yielded no significant main effects or interactions. Again in contrast to expectations, the mean peak F0 was slightly (but not significantly) lower in postboundary (PB_G: 141 Hz) relative to within-phrase conditions (P_BG: 146 Hz; PBG: 147 Hz). Although none of the differences reached significance, it is interesting to note that within the NC group, six of the 10 subjects exhibited the expected pattern, as did two of the 10 LHD subjects and five of the 10 RHD subjects.[2]

Production experiment—perceptual ratings

To determine whether the intended groupings were perceptible as produced by each speaker, three trained listeners, blind to the clinical status of the speaker, judged the intended arrangement from the tape recordings. Productions were blocked by speaker, but randomized within each speaker; blocks were also presented in random order. Mean perception scores for the three listeners were computed and are presented in Table 1.

As illustrated in the Table, mean perception scores were lower for both patient groups

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[2] As a secondary analysis, measures of F0 slope and SE_e were computed by fitting a regression line to the F0 contour. The SE_e served as a measure of F0 fluctuation (Katz et al., 1996). These analyses focused on the medial word *black* because previous studies indicate that little F0 change due to phrasing differences emerges in phrase-initial and phrase-final words (Katz et al., 1996). Separate Group × Phrasing ANOVAs using F0 slopes and SE_e values computed for the word *black* were conducted. No significant main effects or interactions emerged in either analysis.

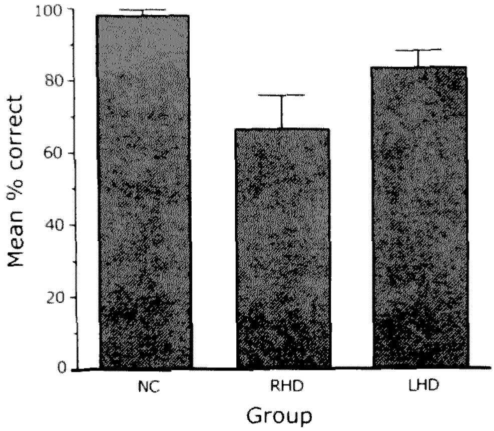

Figure 9

Mean percent correct phrase identification for each group.

(LHD mean=73%; RHD mean=72%) relative to the NC subjects (mean=96%), consistent with the acoustic analyses which demonstrated fewer significant differences across phrase types for the brain-damaged patient groups. In fact, the lowest mean perception rating for the NC group was 89% correct, whereas six subjects in the LHD group and five subjects in the RHD group were rated with 70% or less accuracy.[3] Moreover, inspection of individual acoustic measures revealed that the occurrence of expected acoustic patterns corresponded quite well with the perceptibility measures.

Perception experiment

Mean percent correct identification scores for each group are displayed in Figure 9. A one-way between-groups ANOVA on arcsin-transformed scores revealed a main effect of Group, $F(2,29)=7.518$, $p<.01$. Post hoc analysis using the Newman-Keuls procedure demonstrated that the NC subjects (98%) performed significantly better than the RHD subjects (66%) and the LHD subjects (83%), who did not differ significantly from one another. Scores for individual subjects are provided in Table 2. It should be noted that one individual in the LHD group (LHD2) identified the phrasal groupings with only 50% accuracy and that four individuals in the RHD group (RHD3, RHD5, RHD9, RHD10) achieved less than 50% accuracy (range: 22–44%). However, not all of these patients were necessarily impaired in the production experiment, as determined by the perceptual ratings discussed above. It is also noteworthy that three subjects in the LHD group (LHD1, LHD3, LHD6) and three subjects in the RHD group (RHD2, RHD4, RHD7) performed at ceiling. Interestingly, two of these LHD subjects and all three of the RHD subjects were those whose utterances were most accurately judged by the trained listeners, as shown in Table 1. This pattern suggests that a small subset of subjects within both clinical groups was identifiable by relatively normal performance on both production and perception subtests for prosody, as measured in the present study. To determine to what degree performance on the production and perception subtests were related, a Pearson correlation coefficient was computed comparing all subjects' perception scores with perceptual ratings of the speakers' productions (as a measure reflecting production of the appropriate acoustic

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[3] It should be noted that, within the LHD group, performance of the fluent and nonfluent aphasics did not differ appreciably.

TABLE 1

Mean perceptual ratings (% correct) of each speaker's productions of the phrasal groupings

Subject	*% correct*	*Subject*	*% correct*	*Subject*	*% correct*
NC1	89	LHD1	92	RHD1	51
NC2	98	LHD2	55	RHD2	96
NC3	94	LHD3	91	RHD3	83
NC4	98	LHD4	79	RHD4	100
NC5	100	LHD5	69	RHD5	37
NC6	100	LHD6	57	RHD6	71
NC7	91	LHD7	52	RHD7	96
NC8	96	LHD8	67	RHD8	69
NC9	100	LHD9	98	RHD9	65
NC10	92	LHD10	70	RHD10	48
MEAN	**96**	**MEAN**	**73**	**MEAN**	**72**

TABLE 2

Mean scores on the perception experiment for individual subjects in each group

Subject	*% correct*	*Subject*	*% correct*	*Subject*	*% correct*
NC1	100	LHD1	100	RHD1	72
NC2	100	LHD2	50	RHD2	100
NC3	94	LHD3	100	RHD3	39
NC4	100	LHD4	89	RHD4	100
NC5	100	LHD5	83	RHD5	22
NC6	83	LHD6	100	RHD6	56
NC7	100	LHD7	89	RHD7	100
NC8	100	LHD8	72	RHD8	89
NC9	100	LHD9	72	RHD9	39
NC10	100	LHD10	72	RHD10	44
MEAN	**98**	**MEAN**	**83**	**MEAN**	**66**

correlates to phrase boundaries). The correlation which emerged was moderate, at .678. Since a comparison of individual scores reveals several discrepancies between production and perception scores among the brain-damaged subjects, it is likely that much of the correlation reflects a ceiling effect for the NCs on both measures.

DISCUSSION

The goal of the present investigation was to assess the ability of individuals who had suffered left or right hemisphere damage to produce and perceive phrase boundaries signaled by suprasegmental parameters of speech. Let us focus first on the production findings for the utterance *pink and black and green.* It will be recalled that in normal speech production, word durations in preboundary positions and pauses at phrase boundaries are lengthened. In the current study, NC speakers produced all preboundary words with the expected durational pattern, consistent with the results reported by Katz et al. (1996) for a similar phrase. That is, durations for the word *pink* were longer when produced in the P_BG grouping relative to the PB_G grouping; similarly, durations for the word *black* were longer in the PB_G grouping as compared to the P_BG grouping.

For the utterance-final word *green,* durations were shortest when the word occurred within a phrase (i.e., P_BG) relative to when it occurred isolated from the rest of the utterance (in PBG and PB_G). This latter pattern was found for all three subject groups. Of particular note with regard to the data for the word *green,* word durations were significantly shorter for the LHD speakers than for the NCs. At first glance, this finding may appear surprising, given the lengthening of syllable and word durations commonly reported in LHD speakers relative to normals (see e.g., Blumstein, 1991 for a review). However, upon further consideration, the shorter utterance-final durations for the LHD subjects may reflect an absence of phrase-final lengthening in the speech of these individuals — a pattern which has been reported previously (Baum, 1992; Gandour et al., 1993).

Interestingly, although both patient groups showed the normal tendency toward preboundary lengthening for both *pink* and *black,* the duration increases did not reach significance for the LHD patients for the word *black* or for either patient group for the word *pink.* The failure of the brain-damaged subjects (particularly the LHD patients) to adequately lengthen these two keywords may have diminished important acoustic distinctions among the three syntactic groupings at points in the utterance where such cues are most essential (i.e., on words preceding potential phrase boundaries). This reduction in acoustic distinctiveness of the three target renditions, when produced by the LHD and RHD patients, appears to have culminated in increased confusability of their intended groupings when evaluated perceptually. Indeed, the association that was observed for individual LHD or RHD speakers between poor perceptual ratings and failure to prolong *pink* or *black* to a relatively normal extent underscores the importance of these cues in signaling phrase boundaries, as well as the difficulty of many brain-damaged patients in manipulating these parameters in their speech.

With respect to pause duration values, at both P1 (subsequent to *pink*) and P3 (subsequent to *black*), all speaker groups displayed longer pauses between words crossing phrase boundaries as compared to within phrases, as expected (Katz et al., 1996). For the first pause (P1), LHD patients exhibited significantly longer pauses than the NC speakers, in keeping with previous investigations that have reported lengthened pauses and slower speaking rate in certain LHD aphasic patients (e.g., Baum, 1992; Baum, 1993; Baum & Ryan, 1993; Gandour et al., 1993; Kent & Rosenbek, 1983; McNeil, Liss, Tseng, & Kent, 1990). However, the increased pause length for LHD speakers did not reach significance for P3 measures.

Data on normal speech production led to the prediction of a higher peak F0 in postboundary accented syllables relative to words occurring within phrase boundaries (e.g., Ladd, 1988). In addition, a steeper fall in F0 as well as an increase in F0 fluctuation on preboundary words relative to words occurring within phrase boundaries was expected (Cooper & Sorensen, 1981; Price et al., 1991; 't Hart & Cohen, 1973). Somewhat surprisingly, the present findings revealed no such patterns. The absence of the expected F0 patterns may be due to the very short length and linguistic simplicity of the stimuli elicited, as well as the particular phonetic composition of certain of the keywords (e.g., the short vowel and following voiceless stop in *black*). Thus, although changes in temporal properties of an utterance would appear to be sufficient when marking simple associations among a short list of items (as suggested by the present data and those reported by Katz et al. (1996)), it is possible that F0 cues gain greater importance in demarcating phrase boundaries when more complex verbal stimuli are examined (Cooper & Sorensen, 1981; Ladd, 1988; Price et al., 1991).

Taken together, the acoustic data collected in the production experiment indicate a mild deficit in temporal control in the LHD patients, reflected in the absence of significant preboundary lengthening effects, the absence of phrase-final lengthening effects, and the longer than normal pauses at phrase boundaries (especially P1). It is important to emphasize that these deficits translate perceptually into impaired demarcation of phrasal boundaries, as evidenced by the perceptual ratings of subjects' productions. Such a deficit is consistent with impairments in speech timing that frequently have been described for LHD aphasic patients (e.g., Blumstein & Baum, 1987 for review). Most previous investigations have reported durational aberrations mainly in the speech of nonfluent aphasic patients with anterior lesions (Baum, 1992; Baum, 1993; Baum, Blumstein, Naeser, & Palumbo, 1990; Baum & Ryan, 1993; Gandour et al., 1993; Kent & Rosenbek, 1983; McNeil et al., 1990)—the type of patient that comprised the majority of the LHD patients in the present study. It is important to point out, however, that subtle deficits in temporal control have also been reported for fluent aphasic patients (Baum et al., 1990; Gandour et al., 1994; McNeil et al., 1990).

An impairment in the control of temporal properties of speech subsequent to LHD may be interpreted as consistent with the differential cue lateralization hypothesis of prosodic processing. Recall that this hypothesis suggests that the LH is specialized for the processing of duration, whereas the RH is specialized for the processing of spectral attributes of speech (e.g., Van Lancker & Sidtis, 1992). Nonetheless, it must be noted that the RHD patients did not exhibit a completely normal pattern of durational cues in their productions (see Dykstra, Gandour, & Stark, 1995; Pell, 1997 for additional data), indicating that a complete left hemisphere lateralization of temporal cues is probably too strong a claim. The lack of group differences in the ability to manipulate F0 features of the stimuli in the current investigation further inhibits a strict interpretation of the differential cue hypothesis for the production data. However, it must be borne in mind that even NC subjects did not display the anticipated patterns of F0; thus, interpretation of the patients' data must be made with extreme caution.

With regard to the perception experiment, the RHD patients (somewhat unexpectedly) and the LHD patients performed significantly worse than the NC subjects in the identification of phrasal groupings. This finding is perhaps surprising in light of numerous studies which have reported impairments in the processing of linguistic prosody by LHD, but not RHD, subjects (e.g., Baum et al., 1982; Emmorey, 1987). It is interesting to note that performance on the perception subtest was variable within both the left- and right-brain-damaged groups. More specifically, three individuals within the LHD group — two of whom exhibited very mild deficits at the time of testing — performed at ceiling on this task. If the scores of these patients are excluded, the LHD group mean falls to 75% from 83%, suggesting a greater degree of impairment in the more moderately impaired subjects following dominant hemisphere lesions. Within the RHD group, three individual subjects also performed close to ceiling level, yet the group mean was quite low at 66% correct (52% correct if the scores of those three patients are excluded). These findings demonstrate clearly that both the RHD and LHD patients were impaired in the perception of phrase boundaries in the current investigation, despite the variable performance of some subjects within each clinical sample.

Although inconsistent with the functional lateralization hypothesis of prosodic processing (Van Lancker, 1980), a deficit in perceiving linguistic prosody subsequent to RHD is in keeping with other data on intonation perception (e.g., Blumstein & Cooper, 1974; Brådvik et al., 1991; Bryan, 1989; Pell & Baum, 1997; Weintraub et al., 1981). For example, in a dichotic listening task designed to assess perception of prosodically cued sentence-type contrasts, Blumstein and Cooper (1974) reported a left ear/right hemisphere advantage in normal subjects' identification of declarative, interrogative, imperative, and conditional sentences. Similarly, investigators (Brådvik et al., 1991; Bryan, 1989; Weintraub et al., 1981) have found impairments in RHD patients' ability to identify stress contrasts (but cf. Behrens, 1985; Emmorey, 1987) and to identify linguistic-prosodic meanings (e.g., Pell & Baum, 1997). It has been suggested by certain investigators that the size of the utterance or the domain over which prosody is signaled may play a role in its lateralization (Behrens, 1989; Gandour, Dechongkit, Ponglorpisit, & Khunadorn, 1994). If, as hypothesized, the RH is more involved in prosodic processing over sentence-length utterances (Behrens, 1989; Gandour et al., 1994), it is not surprising that the RHD patients demonstrated a deficit in the present perceptual experiment. As suggested recently (Pell, 1997), the increased importance of *continuous* (rather than categorical) prosodic information in phrase-level intonation and timing patterns may demonstrate a selective advantage for right hemisphere processing mechanisms, and thus may more directly underlie the RHD patients' difficulty with these stimuli (Blonder et al., 1995; Pell, 1997).

Of general note in this investigation is the relatively limited correspondence observed between expressive and receptive prosodic deficits. Although RHD patients were uniquely impaired in *perceiving* phrase boundary cues when asked to disambiguate the three syntactic groupings, both LHD and RHD patients displayed deficits when required to *implement* the same cues on an analogous production task. In fact, as described earlier, the LHD aphasic patients demonstrated greater temporal irregularities than the RHD patients in their productions, a pattern of group findings not easily accommodated with that described for perception abilities. This lack of clear convergence of the perception and production data finds considerable precedent in the prosody literature (as well as the broader literature on language impairments subsequent to brain damage) and defies a single theoretical explanation for such deficits (see Baum & Pell, in press, for a review). Rather, the current findings provide further evidence that prosodic abnormalities, even when co-occurring in the receptive and expressive modalities, may not be tied to a unitary neurofunctional disturbance. Elucidating how aspects of prosodic structure (domain of processing, nature of cues, functional considerations) influence left- and right-hemisphere-damaged patients as a function of the channel tested (input or output) remains a considerable challenge for future investigations.

To conclude, data presented herein indicate that many (but not all) speakers with left- and right-hemisphere lesions provide fewer normal acoustic cues to phrase boundary distinctions, leading to a substantial reduction in the ability of listeners to perceive their intended meaning. Moreover, individuals with right hemisphere damage often demonstrate a defect in the ability to perceive phrase-boundary markers within an intonation contour, resulting in confusion for these patients when syntactic ambiguities arise. This pattern of results, although partially supportive of a number of current hypotheses in the literature (functional load hypothesis, cue lateralization hypothesis, domain hypothesis), awaits illumination through further inquiry into the cerebral mechanisms underlying the production and perception of prosody. How each of these mechanisms interacts with aspects of prosodic structure is also of great interest. Such research may prove indispensible in delimiting each hemisphere's role within a distributed network of functions subserving speech prosody (Gandour et al., 1995; Pell, 1997; Van Lancker & Sidtis, 1992).

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APPENDIX 1

Background information on brain-damaged patients.

Right-hemisphere-damaged patients

Subject	*Age*	*MPO**	*Lesion site*	*Diagnostic Characteristics*
RHD1	75	53	right parietal hypodensity	dysphoric mood; poor comprehension of figurative language and spatial relations
RHD2	55	63	right posterior communicating artery; temporal	flat affect; impulsivity; mild impairment in comprehension of figurative language
RHD3	66	13	right Rolandic hypodensity	flat affect; emotionally labile; poor comprehension of figurative language; impaired comprehension of emotional prosody
RHD4	87	85	N/A	poor comprehension of figurative language and inferences; mild impairment in comprehension of emotional prosody
RHD5	62	13	right external capsule	flat affect; poor comprehension of figurative language and inferences; mild impairment in comprehension of emotional prosody
RHD6	84	46	right MCA	left neglect; impaired comprehension of emotional prosody; mild impairment in comprehension of inferences
RHD7	30	15	right MCA	mild impairment in comprehension of emotional prosody
RHD8	74	8	N/A	impaired comprehension of emotional prosody
RHD9	60	44	right temporo-parietal-occipital	emotionally labile; poor inferencing; poor comprehension of figurative language
RHD10	65	16	corona radiata with intra-ventricular extension	mild impairment in comprehension of emotional prosody

* MPO=Months Post Onset

Left-hemisphere-damaged patients

Subject	*Age*	*MPO**	*Lesion site*	*Diagnostic Characteristics*
LHD1	48	100	left parietal	mild Broca's aphasia
LHD2	79	13	left fronto-parietal	moderate-severe Broca's aphasia
LHD3	63	10	left fronto-parietal	moderate nonfluent aphasia
LHD4	44	54	left fronto-parietal	severe Broca's aphasia
LHD5	64	33	left fronto-temporo-parietal	moderate-severe nonfluent aphasia
LHD6	41	113	left MCA	mild nonfluent aphasia
LHD7	68	35	left parietal	Broca's aphasia
LHD8	82	53	left parietal	mild fluent aphasia
LHD9	78	59	left MCA	mild fluent, anomic aphasia
LHD10	68	11	N/A	mild-moderate fluent aphasia

*MPO=Months Post Onset