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Using prosody to resolve temporary syntactic ambiguities in speech production: acoustic data on brain-damaged speakers

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Abstract

Left hemisphere brain lesions resulting in aphasia frequently produce impairments in speech production, including the ability to appropriately transmit linguistic distinctions through sentence prosody. The present investigation gathered preliminary data on how focal brain lesions influence one important aspect of prosody that has been largely ignored in the literature—the production of sentence-level syntactic distinctions that rely on prosodic alterations to disambiguate alternate meanings of a sentence. Utterances characterizing three distinct types of syntactic ambiguities (scope, prepositional phrase attachment, and noun phrase/sentential complement attachment) were elicited from individuals with unilateral left hemisphere damage (LHD), right hemisphere damage (RHD), and adults without brain pathology (NC). A written vignette preceding each ambiguous sentence target biased how the utterance was interpreted and produced. Recorded productions were analysed acoustically to examine parameters of duration (word length, pause) and fundamental frequency (F_0) for key constituents specific to each of the ambiguity conditions. Results of the duration analyses demonstrated a preservation of many of the temporal cues to syntactic boundaries in both LHD and RHD patients. The two interpretations of sentences containing 'scope' and 'prepositional phrase attachment' ambiguities were differentiated by all speakers (including LHD and RHD patients) through the production of at least one critical temporal parameter that was consistent across the three groups. Temporal markers of sentences containing 'noun phrase/sentential complement attachment' ambiguities were not found to be encoded consistently within any speaker group

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and may be less amenable to experimental manipulation in this manner. Results of F_0 analyses were far less revealing in characterizing different syntactic assignments of the stimuli, and coupled with other findings in the literature, may carry less weight than temporal parameters in this process. Together, results indicate that the ability to disambiguate sentences using prosodic variables is relatively spared subsequent to both LHD and RHD, although it is noteworthy that LHD patients did exhibit deficits regulating other temporal properties of the utterances, consistent with left hemisphere control of speech timing.

Keywords: Speech production, prosody, syntactic ambiguity, brain damage, acoustic analysis.

Introduction

It has long been established that deficits in speech production are common sequelae of left hemisphere (LH) brain lesions resulting in aphasia (see Blumstein, 1998: 157–185 for a review). Such impairments have been found to affect multiple levels within the production process, from aspects of speech segment (i.e., phonetic) production to sentence production and prosody. Subsequent to right hemisphere (RH) damage, speech production deficits tied to these various levels of linguistic structure are much less common, mainly affecting the production of phrase or sentence-level prosodic parameters (see Baum and Pell, 1999 for a review). Studies that have investigated the production of linguistic prosody at the sentence level have focused on both temporal parameters of these forms and the control of fundamental frequency (F_0) during their execution. For temporal parameters, most investigators have reported deficits in speech timing in left-hemisphere-damaged (LHD) aphasic patients (Danly and Shapiro, 1982; Danly, Cooper and Shapiro, 1983; Gandour, Dechongkit, Ponglorpisit, Khunadorn and Boongird, 1993; Gandour, Dechongkit, Ponglorpisit and Khunadorn, 1994; Strand and McNeil, 1996; Baum and Boyczuk, 1999; Gandour, Ponglorpisit, Khunadorn, Dechongkit, Boongird and Satthamnuwong, 2000) but relatively normal temporal control in RHD individuals (Gandour *et al.*, 1994; 2000; Baum and Boyczuk, 1999; cf. Pell, 1999a). With respect to F_0, results have been mixed, with some investigators reporting impairments in LHD patients (e.g., Ryalls, 1982; Danly and Shapiro, 1982; Danly *et al.*, 1983; Cooper, Soares, Nicol, Michelow and Goloskie, 1984), and some reporting deficits subsequent to RHD (e.g., Weintraub, Mesulam and Kramer, 1981; Shapiro and Danly, 1985; Behrens, 1989; Bryan, 1989; Bradvik, Dravins, Holtas, Rosen, Ryding and Ingvar, 1991; Baum and Pell, 1997; Pell, 1999b).

While investigations of linguistic prosody have explored sentences of differing length and complexity, they have all but ignored sentence-level (syntactic) distinctions that—in the absence of context—rely largely on prosodic alterations for appropriate interpretation. Only a very small number of studies has focused on the ability of brain-damaged patients to produce the prosodic cues to syntactic disambiguation (e.g., Baum, Pell, Leonard and Gordon, 1997; see Perkins, Baran and Gandour, 1996, for findings concerning perception). For example, Baum *et al.* (1997) examined the ability of LHD and RHD patients to produce and interpret prosodic cues marking simple phrasal groupings in the multiply-conjoined string ‘pink and black and green’. In normal speech production, such phrase boundaries are marked by increased duration of the pre-boundary word and increased pause duration at the boundary (Lehiste, 1973; Klatt, 1975; Lehiste, Olive and Streeter, 1976; Cooper, Paccia and Lapointe, 1978; Streeter, 1978; Scott, 1982; Price, Ostendorf, Shattuck-Hufnagel and Fong, 1991; Wightman, Shattuck-Hufnagel, Ostendorf and Price, 1992; Katz, Beach, Jenouri and Verma, 1996), as well as changes in F_0 around the boundary (‘t Hart and Cohen, 1973; Cooper and Sorenson, 1981; Ladd, 1988; Price *et al.*, 1991; Katz *et al.*, 1996). Baum *et al.* (1997) found that both LHD and RHD patients displayed relatively normal patterns of pre-boundary lengthening and increased pause durations at phrase boundaries, although the increases in duration did not consistently reach significance in the patient groups. Perceptual ratings of the individual speakers’ productions demonstrated that the cues signalling phrasal groupings were less salient in the utterances produced by the brain-damaged patients, particularly the LHD individuals. The LHD patients also failed to exhibit the normal pattern of phrase-final lengthening (see also Baum, 1992; Gandour *et al.*, 1993; Baum and Boyczuk, 1999), so ubiquitous in normal speech production (Lehiste, 1973; Klatt, 1976). Analyses of the F_0 patterns revealed few of the expected patterns that serve to signal phrasal groupings, even in the normal speakers’ utterances, underscoring the heterogeneity in cue implementation in normal production (see also Allbritton, McKoon and Ratcliff, 1996). The findings for the brain-damaged patients were interpreted in keeping with a mild impairment in the control of speech timing in the LHD patients, consistent with many previous results (e.g., Kent and Rosenbek, 1983; Baum, Blumstein, Naeser and Palumbo, 1990; McNeil, Liss, Tseng and Kent, 1990; Baum, 1992; 1993; Baum and Ryan, 1993; Gandour *et al.*, 1993).

Clearly, the preliminary findings on the implementation of prosodic phrase markers reported by Baum *et al.* (1997) are limited in scope, as the study only focused on a single (and quite simple) type of syntactic disambiguation. In the normal literature, it has been established that prosody serves to disambiguate various syntactic structures, including attachment ambiguities faced by the parser. Of particular relevance to the present investigation, studies have shown that speakers reliably manipulate duration and F_0 to signal different interpretations of syntactically ambiguous (or temporarily ambiguous) word strings (e.g., Lehiste, 1973; Wales and Toner, 1979; Cooper and Paccia-Cooper, 1980; Warren, 1985; Beach, 1988; Shapiro and Nagel, 1995; but cf. Allbritton *et al.*, 1996). A great deal of data also indicates that listeners make use of prosodic information in the comprehension of these sentence structures (e.g., Lehiste *et al.*, 1976; Streeter, 1978; Scott, 1982; Beach, 1991; Marslen-Wilson, Tyler, Warren, Grenier and Lee, 1992; Nagel, Shapiro and Nawy, 1994; Shapiro and Nagel, 1995; Blasko and Hall, 1998). It is important to determine whether individuals with damage to the left or right hemisphere retain the ability to signal these subtle but highly important distinctions in their speech. Examining the production patterns of both LHD and RHD patients will permit us to address theories concerning the hemispheric lateralization of speech prosody (see Baum and Pell, 1999), as well as the extent and nature of prosodic impairments in brain-damaged speakers. To this end, several frequently-occurring types of ambiguities which require prosodic disambiguation were chosen for investigation: adjectival scope ambiguities (following Lehiste, 1973), prepositional phrase (PP) attachment ambiguities (following Lehiste *et al.*, 1976), and noun phrase (NP) versus sentential complement (S′) attachment ambiguities (following Warren, 1985; Beach, 1988; 1991; Shapiro and Nagel, 1995; Stirling and Wales, 1996). We were particularly interested in the degree to which LHD and RHD individuals would naturally alter duration and F_0 characteristics of elicited utterances to signal a specific meaning cued by a preceding context scenario.

Methods

Subjects

Three groups of individuals participated in the experiment: ten LHD aphasic patients, ten RHD patients, and 12 age-matched non-brain-damaged control subjects. All participants were native English speakers and passed audiometric screening for thresholds <35 dB HL at the speech frequencies (0.5, 1, and 2 kHz) in the better ear. Brain-damaged patients had all suffered a single unilateral lesion due to cerebrovascular accident (CVA) at least 4 months prior to testing, as documented by CT or MRI. The brain-damaged individuals also underwent a battery of screening and diagnostic tests which differed (in part) across the groups. 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). None of the patients exhibited any significant dysarthria affecting the speech musculature. A summary of background information on the participants is provided in table 1.

Stimuli and procedure

Three sets of ten ambiguous sentences were created (some adapted from Beach, 1991): adjectival scope ambiguities (scope condition), prepositional phrase attachment ambiguities (PP attachment condition), and noun phrase/sentential complement attachment ambiguities (referred to herein as the minimal attachment condition). For each sentence in all conditions, a contextual scenario was designed to bias each of the two interpretations of the ambiguous sentence. Examples of each sentence type along with biasing contexts are presented in table 2. Each context was printed in large font on $8.5 \times 11''$ paper, with the target ambiguous sentence highlighted in a frame below. Participants were instructed to read the biasing context silently, at their own pace, and to then produce the target sentence in keeping with the context.

To ensure that the subjects could adequately comprehend the written contexts and thus intuit the correct meaning, a pre-test was conducted as follows. A randomly-selected subset of the contexts (only one version for any given target sentence) was presented to the subjects, followed by two interpretive choices. Participants were asked to choose the interpretation cued by the context. A minimum of 75% accuracy was required for the subject to continue in the production experiment.

In the actual experiment, the total set of 60 contexts and target sentences (three conditions $\times$ two interpretations $\times$ ten items) was presented in random order. Productions were recorded onto DAT tape using a Sony TCD-D100 recorder and head-mounted directional microphone (AKG Acoustics C420) to ensure a constant mic-to-mouth distance. If the speaker made an error (i.e., omitted or repeated a word), (s)he was asked to repeat the sentence in its entirety. No feedback was provided concerning any other aspect of the utterances. The digital recordings were transferred directly onto disk for acoustic analyses using CSL (Kay Elemetrics). Temporal and F_0 analyses were conducted on critical constituents of each utterance for each sentence type, as described in detail in the Results section below; in all cases, demarcation of utterances was completed using standard landmarks in the

Table 1. *Background information on brain-damaged patients*

LHD patients

Patient	Age (years)	Education[a] (years)	Sex	Lesion site	MPO[b]	Speech production characteristics
1	41	15	F	Left fronto-parietal	114	Non-fluent
2	68	12	F	Left parietal	35	Non-fluent
3	48	14	M	Left parietal	102	Non-fluent
4	64	11	F	Left fronto-parietal	13	Non-fluent
5	44	15	F	Left fronto-parietal	60	Non-fluent
6	76	9	F	Left frontal	13	Mild non-fluent
7	78	12	F	Left MCA	60	Mild fluent (anomic)
8	81	11	F	Left paraventricular, deep parietal region	43	Mild fluent (anomic)
9	68	8	M	N/A[d]	12	Mild-moderate fluent (anomic)
10	84	6	F	Left MCA[c]	30	Moderate fluent (anomic)
Mean	65	11				

RHD Patients

Patient	Age (years)	Education[a] (years)	Sex	Lesion site	MPO[b]
1	55	11	F	Right posterior communicating artery	77
2	84	5	F	Right MCA[c]	47
3	87	11	F	N/A[d]	87
4	62	12	F	N/A[d]	15
5	30	13	F	Right MCA[c]	15
6	75	11	M	Right parietal	56
7	74	12	M	N/A[d]	8
8	60	12	M	Right temporo-parieto-occipital	45
9	65	8	F	Right posterior basal ganglia and corona radiata with intra-ventricular extension	16
10	69	21	F	Right posterior limb of internal capsule and corona radiata	11
Mean	66	12			

[a] Best estimated conversion into years, based on information from subject (e.g., 2 years college, high school).
[b] Months post onset.
[c] Middle cerebral artery.
[d] Information not available.

waveform display, coupled with auditory perception. All F_0 values were determined at the peak of stressed vowels within critical constituents; as will be clear in the description of results, F_0 ratios were subsequently computed as a means of normalizing for absolute differences in F_0 for male and female speakers. Potential errors in the pitch extraction algorithm were identified and corrected by adjusting analysis

Table 2. *Examples of three stimulus types: target sentences with their biasing contexts*

Adjectival scope ambiguities	
Context a:	It was dangerous there. The police wanted all the females and the elderly males to leave.
Target:	*The old men and women came home.*
Context b:	It was dangerous there for the elderly. The police wanted them all to leave.
PP attachment ambiguities	
Context a:	The policeman pulled out his gun and his nightstick. A witness saw how the man was killed.
Target:	*The cop shot the man with the gun.*
Context b:	The policeman chased two criminals into an alley. One of them had a gun and one had a knife.
Minimal attachment ambiguities	
Context a:	The man posing as a doctor had fooled everyone including the police.
Target:	*The detective didn't suspect the doctor...was a fraud.* *...from Ottawa.*
Context b:	Two doctors were arrested for questioning—one in Ottawa and one in Hull.

parameters. A second experimenter verified the peak F_0 values for keywords in a subset of two randomly-selected sentences (both versions) of each stimulus type for each speaker. The vast majority of values fell within 10 Hz of the original calculation; in the small number of instances for which the re-measurement differed from the original by more than 10 Hz, the peak F_0 value was determined by consensus of two senior experimenters. Because such adjustments occurred only rarely, there was no need to reanalyse the remaining productions.

Results

Temporal analyses

For each utterance of each sentence type, several duration measures were computed. First, overall utterance duration was calculated and used as a control for speaking rate differences across speakers, as described below.

Scope stimuli

For the Scope stimuli (e.g., 'The old men and women came home'), the durations of seven constituents were measured: initial adjective (Adj), pause (P1), initial noun (N1), pause (P2), and+pause, second noun (N2), pause (P3). Each duration measure was then adjusted for speaking rate by computing a proportional duration of constituent length over utterance length. Mean proportional durations for each participant group are displayed in figure 1. Because we were not specifically interested in comparisons of different constituent durations within each utterance, but rather across the versions and across groups (and due to the expected large variability in constituent durations for, e.g., pauses versus content words), separate group (NC, LHD, RHD) $\times$sentence version (narrow scope, wide scope) analyses of variance (ANOVAs) were conducted for each constituent. For the initial adjective, the ANOVA revealed a main effect of version (F (1, 27)=5.822, $p<0.05$), with the

Figure 1. *Mean proportional durations for each group in the production of (a) narrow and (b) wide adjectival scope ambiguities.*

narrow scope adjectives shorter than the wide scope adjectives, as expected. No interaction with group emerged. The ANOVA for P1 yielded a main effect for group only ($F(2, 27) = 4.573$, $p < 0.02$). Post hoc analyses using the Newman-Keuls procedure demonstrated that P1 measures were significantly longer when produced by the LHD than the RHD subjects. No other comparisons differed. The ANOVA for P2 revealed a main effect of version ($F(1, 27) = 10.253$, $p < 0.005$), with the pause after the first noun in the narrow scope version significantly longer than in the wide scope version, as predicted. The second noun (N2) was significantly longer in the wide scope relative to the narrow scope version, as shown in an ANOVA ($F(1, 27) = 15.401$, $p < 0.001$), which also revealed a main effect of group ($F(2, 27) = 11.484$, $p < 0.001$). Post hoc analysis of the group effect demonstrated that N2 durations were longer in the normal speakers' utterances relative to the LHD speakers' productions only. The ANOVAs conducted on the first noun (N1), and+ pause, and third pause (P3) yielded no main effects or interactions.

PP attachment stimuli

For the PP attachment stimuli (e.g., 'The cop shot the man with the gun'), durations of five constituents were measured: phrase 1 (from the sentence onset through the verb), pause (P1), phrase 2 (either NP or PP), pause (P2) and phrase 3 (PP). Mean proportional durations (constituent/utterance) for each group are displayed in figure 2. Individual ANOVAs on each constituent were computed, revealing two main effects for group (for phrase 1 ($F(2, 27) = 7.610$, $p < 0.002$; for phrase 3 ($F(2, 27) = 4.579$, $p < 0.02$), as well as a trend toward a group effect for P2 ($F(2, 27) = 3.092$, $p = 0.062$). The only other significant effect emerged in the ANOVA for P2, where the preferred PP attachment version (i.e., attaching the PP directly to the VP, modifying the verb) was produced with a longer pause prior to the PP than the non-preferred attachment version (i.e., creating an additional NP node and attaching the PP within it, modifying the noun), as expected ($F(1, 27) = 6.684$, $p < 0.02$). Post hoc analyses of the group main effects using the Newman-Keuls procedures revealed that the LHD patients' productions of phrase 1 were significantly longer than those of both other groups, whose durations did not differ ($p < 0.05$). For phrase 3, the productions of the LHD patients were significantly shorter than those of both other groups, whose duration values did not differ. There were no group $\times$ version interactions in any of the analyses.

Minimal attachment stimuli

For the minimal attachment stimuli (e.g., 'The detective didn't suspect the doctor ... was a fraud/from Ottawa'), durations of four constituents were computed: the initial verb (V), pause (P1), the noun phrase (NP), and pause (P2). Mean proportional durations for each group are displayed in figure 3. Separate ANOVAs on each constituent yielded a significant main effect for group for each pause (P1: $F(2, 27) = 9.542$, $p < 0.001$; P2: $F(2, 27) = 5.281$, $p < 0.02$). Post hoc analyses showed that in both instances, pauses produced by the LHD patients were significantly longer than those produced by the other two groups, whose duration values did not differ. No other significant main effects or interactions emerged in any analysis.

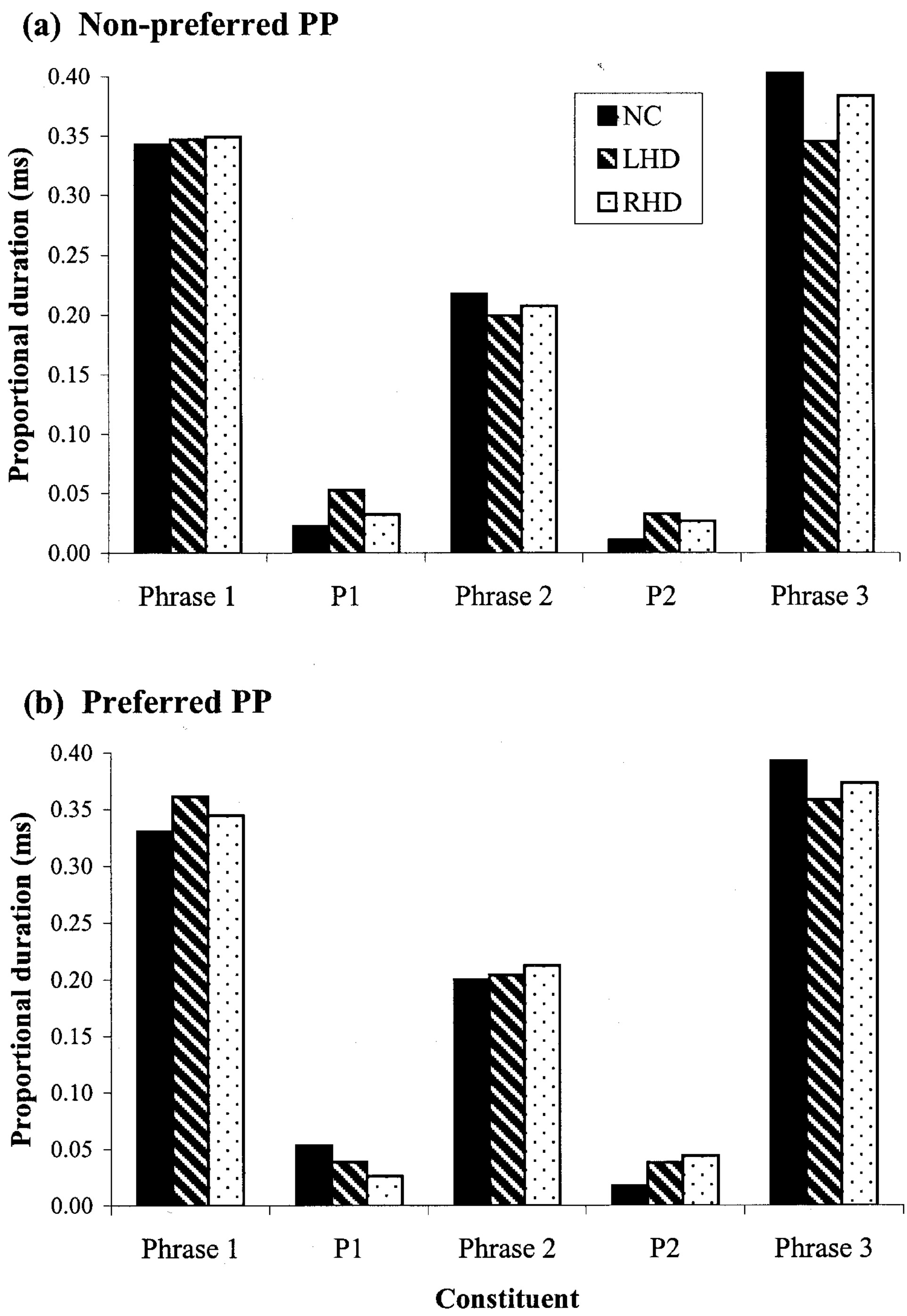

Figure 2. *Mean proportional durations for each group in the production of (a) non-preferred and (b) preferred prepositional phrase (PP) ambiguities.*

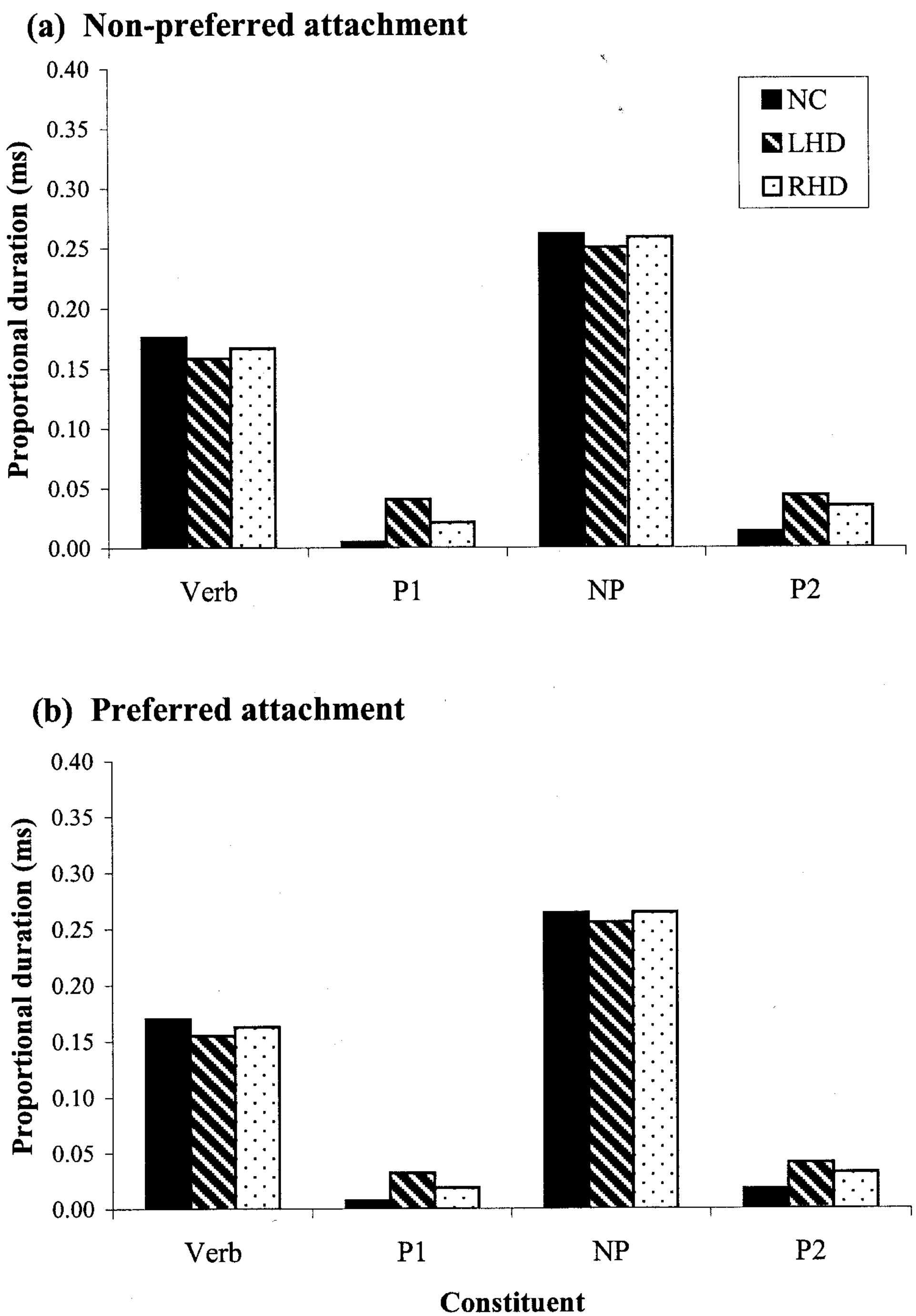

Figure 3. *Mean proportional durations for each group in the production of (a) non-preferred and (b) preferred minimal attachment ambiguities.*

F_0 analyses

Peak F_0 values within stressed syllables of critical content word constituents were extracted and ratios of neighbouring constituents were calculated and submitted to group × constituent × sentence version ANOVAs.

Scope stimuli

For the Scope stimuli, the mean F_0 ratios of the initial adjective to N1 and N1 to N2 for each group are displayed in table 3. The ANOVA revealed only a main effect of constituent ($F(1, 27) = 13.823$, $p < 0.001$), with ratios for adjective/N1 larger than for N1/N2 across versions and groups, perhaps as a function of F_0 declination.

PP attachment stimuli

For the PP attachment stimuli, mean F_0 ratios of phrase 1 to phrase 2 and phrase 2 to phrase 3 for each group are again supplied in table 3. The ANOVA yielded a main effect for constituent ($F(1, 27) = 102.687$, $p < 0.001$) and interactions of group × constituent ($F(2, 27) = 9.554$, $p < 0.001$) and group × version ($F(2, 27) = 5.217$, $p < 0.02$). Post hoc analysis of the group × constituent interaction using the Newman-Keuls procedure showed that within each group, F_0 ratios were larger for the phrase 1 to phrase 2 comparison. Further analysis of the group × version interaction revealed that F_0 ratios for the preferred PP attachment version were significantly smaller ($p < 0.01$) than for the non-preferred attachment interpretation for the RHD patients, contrary to expectations. No differences were found for the other two groups.

Minimal attachment stimuli

For the minimal attachment stimuli, a single F_0 ratio of peak F_0 pre- versus post-boundary was computed (review table 3). A group × sentence version ANOVA

Table 3. *Mean F_0 ratios for each speaker group in the three syntactic conditions*

(a) Scope condition						
	NC		*LHD*		*RHD*	
Ratio	Narrow	Wide	Narrow	Wide	Narrow	Wide
Adj/N1	1.12	1.18	1.15	1.14	1.18	1.18
N1/N2	1.12	1.03	1.09	1.10	1.09	1.10
(b) PP condition						
	NC		*LHD*		*RHD*	
Ratio	Non-preferred	Preferred	Non-preferred	Preferred	Non-preferred	Preferred
Phrase1/Phrase2	1.20	1.23	1.15	1.15	1.18	1.14
Phrase2/Phrase3	0.96	0.98	1.05	1.05	1.05	1.02
(c) Minimal attachment condition						
	NC		*LHD*		*RHD*	
Ratio	Non-preferred	Preferred	Non-preferred	Preferred	Non-preferred	Preferred
Pre/post boundary1.08	1.08	1.10	1.02	1.03	1.07	1.04

yielded no main effects or interactions, indicating that these comparisons did not reflect F_0 cues to type of attachment.

Discussion

The acoustic analyses conducted in the present investigation revealed several noteworthy findings. In particular, the duration measures demonstrated a remarkable preservation of many of the temporal cues to syntactic boundaries in both LHD and RHD patients. The stimuli utilized in the current experiment reflected relatively subtle syntactic distinctions, including scope and attachment ambiguities that can only be disambiguated (out of context) by prosodic cues. As noted earlier, studies of normal speech production have indicated that both duration changes (including pauses) and alterations in F_0 patterns (e.g., F_0 resetting) serve to distinguish such syntactic ambiguities (e.g., Warren, 1985; Beach, 1991; Price *et al.*, 1991; Blasko and Hall, 1998; but cf. Allbritton *et al.*, 1996; Stirling and Wales, 1996). In the present investigation, for two of the three sentence types examined (i.e., scope ambiguities and PP attachment ambiguities), all speaker groups produced the two sentence versions (i.e., narrow and wide scope; preferred and non-preferred PP attachment) with at least one critical temporal parameter which differentiated the stimuli. Specifically, for the scope stimuli, durations of the initial adjective, the pause following the first noun, and the second noun were all manipulated to signal narrow or wide adjectival scope. This pattern held across all speaker groups, with the only significant differences among the groups emerging for overall duration measures unrelated to disambiguating the sentence versions. That is, not surprisingly, the LHD speakers tended to produce longer pauses than the normal speakers and tended not to exhibit evidence of phrase-final lengthening (see also Danly and Shapiro, 1982; Kent and Rosenbek, 1982; 1983; Baum *et al.*, 1997; Baum and Boyczuk, 1999).

For the PP attachment stimuli, the primary temporal cue to disambiguating the two sentence versions was the pause before the PP, which was longer in the preferred (i.e., VP) attachment version, as expected. Here, again, all speaker groups displayed the same temporal patterns, with the LHD speakers producing longer phrase durations overall for phrases 1 and 2. In contrast, for the final phrase, the durations produced by the LHD speakers were significantly shorter than for the healthy control subjects, indicating again that these individuals failed to produce normal phrase-final lengthening effects.

Finally, for the minimal attachment stimuli, no durational differences disambiguating the sentence versions emerged for any speaker group (see also Allbritton *et al.*, 1996), and the LHD patients again produced longer pauses overall than did the other speaker groups. The absence of temporal differences signalling attachment is contrary to expectations and therefore, at first glance, surprising. However, although several investigations have reported such durational cues to attachment (e.g., Warren, 1985; Beach, 1991), a recent study by Allbritton *et al.* (1996) has shown that prosodic cues to attachment are fragile at best, and emerge only for conditions under which speakers' attention is specifically drawn to the contrast. Thus, in the present investigation, where such conditions did not hold, one might have expected reduced differentiation of the sentence versions (which was, indeed, found). A second notable finding for the minimal attachment stimuli was the longer pauses produced by the LHD speakers relative to both other groups, as was also observed in the production of the scope stimuli.

With regard to the F_0 measures, the findings were not very revealing. Essentially, no differences emerged to disambiguate the sentence versions in the F_0 ratios that were calculated. It is possible that the specific measures computed were not reflective of changes in F_0 that actually were implemented. However, the measures were based on those reported in previous literature as providing cues to syntactic disambiguation (e.g., Cooper and Sorenson, 1977; Warren, 1985; Ladd, 1988; Beach, 1991; Blasko and Hall, 1998). Moreover, other investigators have failed to find consistent evidence of F_0 alterations signalling parsing assignments (e.g., Allbritton *et al.*, 1996; Stirling and Wales, 1996). Several investigations of normal speech production have also suggested that temporal parameters (including pre-boundary lengthening and pause duration) may serve as sufficient, perhaps primary, cues to syntactic boundaries and parsing decisions (e.g., Lehiste *et al.*, 1976; Scott, 1982). For example, in an investigation of the on-line use of prosody in processing attachment ambiguities, Shapiro and Nagel (1995) synthesized stimuli with flat F_0 contours, retaining only durational cues to attachment disambiguation. Their findings indicated that the temporal cues alone influenced processing of the syntactically ambiguous sentences (Shapiro and Nagel, 1995). It has also been shown that individual speakers differ in the degree to which specific acoustic parameters are used to signal syntactic structure (Streeter, 1978), as well as other prosodic variables such as lexical and emphatic stress (Lieberman, 1960; Behrens, 1988).

Taken together, the results suggest that the ability to disambiguate sentences using prosodic variables is relatively spared subsequent to both LHD and RHD (see also Gandour *et al.*, 1994; Baum and Boyczuk, 1999). It should be noted, however, that due to the nature of the task, the patients who participated were, perforce, relatively mildly impaired; thus, the retained ability to implement prosodic parameters may not reflect the capacities of more severely affected individuals. Further, it is conceivable that the written stimuli may have provided support that is normally absent in spontaneous speech, and therefore performance may have been artificially inflated relative to what it would be under more natural circumstances. Despite these caveats, the findings are consistent with the hypothesis that impairments in temporal control are not pervasive in LHD (particularly non-fluent aphasic) patients (Baum *et al.*, 1990; Blumstein, 1998) and that linguistic level or level of speech production plays an important role in the emergence of timing deficits. With respect to RHD patients, a number of earlier investigations that included such groups in speech production analyses reported sparing of temporal control in these individuals at phoneme and syllable levels (e.g., Gandour *et al.*, 1994; Baum and Boyczuk, 1999; but cf. Blonder, Pickering, Heath, Smith and Butler, 1995; Dykstra, Gandour and Stark, 1995; Pell, 1999a). The present findings extend these results to the phrasal and sentence levels, with specific reference to cueing syntactic boundaries (see also Baum and Pell, 1997; Baum *et al.*, 1997).

Despite the preserved ability to use durational parameters to signal syntactic structure, the LHD patients, in particular, did exhibit some deficits in speech timing. In particular, in keeping with earlier investigations of sentence-level production (e.g., Danly and Shapiro, 1982; Kent and Rosenbek, 1982; 1983), the LHD patients tended to produce longer than normal pauses, even in terms of proportional durations which adjust for overall speaking rate differences. In addition, the LHD patients displayed an absence (or reduction) of phrase-final lengthening (Danly and Shapiro, 1982; Baum *et al.*, 1997; Baum and Boyczuk, 1999), suggesting either a limited domain of planning (Danly *et al.*, 1983; Cooper *et al.*, 1984; Gandour *et al.*, 1993; 1994; Strand and McNeil, 1996) or an impairment in planning of intonational phrases (Baum and Boyczuk, 1999), possibly related to deficits in marking syntactic boundaries (but cf. Ferreira, 1993, regarding the independence of syntax and prosody). These data are in keeping with LH control of speech timing—a claim which has a long history in the literature (e.g., Efron, 1963; Tallal and Newcombe, 1978; Smith, 1980). To briefly extend the implications of these results to theories concerning the hemispheric lateralization of prosody, the durational findings are partially supportive of the differential lateralization of temporal (LH) and spectral or F_0 (RH) parameters in the brain (e.g., Van Lancker and Sidtis, 1992; cf. Pell and Baum, 1997; Pell, 1999a; b). However, because even the normal speakers did not show the anticipated patterns of F_0 signalling syntactic disambiguation, little may be said concerning the neural control of F_0.

In sum, the findings add to the growing body of research indicating very specific and constrained impairments in the implementation of temporal parameters of speech subsequent to LHD (e.g., Blumstein, 1998: 157–185). The results also suggest that the potential prosodic cues to syntactic disambiguation in normal speech production have yet to be adequately specified.

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