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Recognition of prosody following unilateral brain lesion: influence of functional and structural attributes of prosodic contours

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Abstract—The perception of prosodic distinctions by adults with unilateral right- (RHD) and left-hemisphere (LHD) damage and subjects without brain injury was assessed through six tasks that varied both functional (i.e. linguistic/emotional) and structural (i.e. acoustic) attributes of a common set of base stimuli. Three tasks explored the subjects' ability to perceive local prosodic markers associated with emphatic stress (Focus Perception condition) and three tasks examined the comprehension of emotional-prosodic meanings by the same listeners (Emotion Perception condition). Within each condition, an initial task measured the subjects' ability to recognize each "type" of prosody when all potential acoustic features (but no semantic features) signalled the target response (*Baseline*). Two additional tasks investigated the extent to which each group's performance on the Baseline task was influenced by duration (*D-Neutral*) or fundamental frequency (*F-Neutral*) parameters of the stimuli within each condition. Results revealed that both RHD and LHD patients were impaired, relative to healthy control subjects, in interpreting the emotional meaning of prosodic contours, but that only LHD patients displayed subnormal capacity to perceive linguistic (emphatic) specifications via prosodic cues. The performance of the RHD and LHD patients was also selectively disturbed when certain acoustic properties of the stimuli were manipulated, suggesting that both functional and structural attributes of prosodic patterns may be determinants of prosody lateralization. © 1998 Elsevier Science Ltd. All rights reserved.

Key Words: cerebral laterality; acquired brain injury; speech perception; emotional prosody; linguistic prosody.

Introduction

There is little debate that prosodic features, or perceived alterations in the pitch, length and loudness of the speech stream, contribute indispensably to the meaning of a verbal message. These suprasegmental parameters supply information which enhances or elaborates the propositional intent of speech, for example, highlighting the semantic value accorded to individual words within an utterance [9, 45]. Concurrently, prosody represents the primary vehicle by which internal fluctuations in a speaker's affective state are conveyed vocally, a prosodic function considered outside the domain of the speaker's linguistic competence [26, 27, 62]. Potential hemispheric differences in the processing of speech prosody as an index of these "functional" specifications (i.e. the linguistic vs emotional import of the stimulus) have been explored in numerous investigations of both normal and brain-injured adults (see [5] for a review). Regrettably, a unitary description of the neural mechanisms underlying linguistic and emotional prosody has not been forthcoming from this body of research [34, 58, 68].

Based on early studies of patients with focal right hemisphere dysfunction (RHD), the right hemisphere was ascribed a privileged role in decoding the *emotional* attributes of prosodic contours [34, 35, 55, 58, 59, 65, 66]. Such a claim fits with more recent data on RHD patients [8, 13, 21, 22, 29, 33] and converges with data on normal subjects using the Wada technique [57] and positron emission tomography [32]. However, increased attention to both right- and left-hemisphere-damaged (LHD) patients suggests that insult to *either* cerebral hemisphere often produces emotional prosody deficits of a similar magnitude [16, 51, 60, 63–65, 68]. These latter findings favour greater bilateral control over emotional prosody, although they do not infer that emotional prosody defects stem from common underlying mechanisms in RHD and LHD patients [60, 65].

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The notion that right hemisphere processing mechanisms are uniquely dedicated to emotional aspects of prosody is challenged further by reports demonstrating impaired comprehension of *linguistic* prosody following right hemisphere insult. Such deficits have been observed when RHD patients were required to identify the prosodic intent of "speech acts" (e.g. declarative vs interrogative intonation) [14, 15, 34, 51, 69], to identify emphatic stress placement within verbal stimuli [14, 15, 69] and to perceive stress features assigned phonemically within the lexicon (e.g. those cues that disambiguate **hot** dog (the food) from hot **dog** (a dog that is hot)) [69]. Again, however, a significant left-hemisphere contribution demonstrated at *each* of these levels of linguistic-prosodic processing suggests that many of the operations underlying linguistic prosody are incompletely lateralized in the brain, or constitute dominant left hemisphere functions (in the case of phonemic stress) [3, 6, 23, 28, 30, 34, 51, 53]. Certainly, conflicts in the data on prosody highlight the need to re-examine how functional attributes of prosodic stimuli are related to hemispheric differences in processing capacity.

Few investigations have explored each hemisphere's contribution to the decoding of linguistic and emotional prosody within comparable groups of left-, right- and non-brain-damaged subjects simultaneously [34, 51, 52]. Furthermore, despite evidence from normal speakers that the need to relate information at one level of prosodic structure influences the parameters that cue information at other levels of representation [41, 43, 47, 56, 62], no studies to date have considered the *interactive* influence of linguistic and emotional specifications on the perception of prosody in unilaterally brain-damaged subjects.

Such research could inform current ideas about prosody lateralization—derived largely from studies examining specific prosodic functions in isolation—in a manner more reflective of natural discourse and its demands. Controlled manipulation of the acoustic structure underlying linguistic and emotional meanings could additionally prove useful in testing hypotheses concerning the auditory capabilities of each hemisphere. Summarized briefly, it has been postulated that the right hemisphere is more adept at processing pitch attributes of prosodic stimuli, whereas the left hemisphere serves a privileged role in perceiving duration features of the same stimuli [54, 68; cf. 52]. As alterations in pitch and duration are generally considered the two primary auditory cues to *both* linguistic- and emotional-prosodic meanings [9, 46, 62], hemispheric asymmetries in the perception of these underlying cues (if indeed true) could further influence how linguistic and emotional prosody are processed in the brain. Thus, investigation of both functional and structural aspects of prosodic stimuli is called for if we are to gain insight into the neurolinguistic mechanisms underlying prosody perception.

To test the ability of RHD, LHD and normal (NC) subjects to identify the communicative import of prosodic cues under different task conditions, the current study manipulated both behavioural (linguistic, emotional) and acoustic (duration, fundamental frequency (F_0)) aspects of prosodic contours presented for perceptual recognition. Based on overall trends in the literature, it was anticipated that both RHD and LHD patients would display subnormal accuracy in labelling the emotional significance of prosody (with possibly more extensive impairment in the RHD sample), whereas linguistic prosody (emphatic stress) would be impaired to a substantially greater extent in the LHD sample tested [67]. Finally, LHD and RHD patients may display a selective disadvantage in perceiving prosody *across* behavioural conditions when a correct response is determined by duration or F_0 properties of the stimuli (respectively) following "neutralization" of the opposing cue (explained later) [54, 68]. The interactive effects of various components of prosodic structure (focus position, sentence modality, emotional tone) on the receptive performance of brain-injured patients remain unspecified.

Methods

Subjects

Thirty volunteers were recruited for the study, including subjects with single infarcts confined to the right ($n = 9$) and left ($n = 11$) hemisphere of the brain and subjects without neurological injury ($n = 10$). All participants were right-handed native English speakers who displayed acceptable hearing following a pure-tone air conduction screening of both ears (inclusion criteria: 30 dB HL at 0.5, 1 and 2 kHz, for the better ear). Exclusion criteria included a history of neurologic or psychiatric illness or substance abuse. The three diagnostic groups were matched closely for mean age (RHD = 64.7, LHD = 65.5; NC = 66.1).

For the brain-damaged subjects, CT information (obtained from patients' medical records) confirmed the presence and location of the offending lesion within the right or left hemisphere. In all cases, infarction was the result of a single vascular event of an occlusive or haemorrhagic nature. Patients were tested at least three months post-CVA to ensure medical stability and consistency in performance. All LHD patients were aphasic (7 non-fluent, 4 fluent) but displayed good auditory comprehension of language as determined by a subsection of the Psycholinguistic Assessment of Language [17] and an aphasia screening. None of the RHD patients evidenced signs of aphasic or dysarthric deficits. Contralateral visual neglect was identified in four RHD patients and one LHD patient following administration of the bells test [31]. Table 1 summarizes basic clinical and demographic characteristics of the RHD and LHD groups.

Stimuli

Base stimuli consisted of five, six-syllable sentences (e.g. *Robert read the letter*). To test the interaction of focus distribution (first, last, none), linguistic modality, (declarative, interrogative) and emotional tone (angry, sad, happy, neutral) on prosody perception, multiple renditions of each of the five stimuli were recorded by an adult female speaker onto digital audiotape in a sound-attenuated chamber. Twenty-four unique versions of each stimulus exhausted the potential combinations

Table 1. Basic demographic and clinical characteristics of the LHD and RHD subjects

	LHD Subjects				RHD Subjects			
S	Sex/age	Post-onset	Lesion site	Major clinical signs	Sex/age	Post-onset	Lesion site	Major clinical signs
1	M/48	91	parietal	(R) hemiparesis, mild-mod. non-fluent aphasia	M/74	48	parietal	(L) hemiparesis
2	F/43	48	frontoparietal with subcortical extension	(R) hemiparesis, severe non-fluent aphasia, severe verbal and oral apraxia	F/66	12	frontoparietal	(L) hemiparesis, (L) visual neglect
3	F/63	23	fronto-temporoparietal	(R) hemiparesis, mod-severe non-fluent aphasia, (R) visual neglect	F/82	40	temporal	(L) hemiplegia, (L) visual neglect
4	M/68	61	parietal	(R) hemiplegia, severe non-fluent aphasia	M/59	31	temporoparietal	(L) hemiparesis, (L) visual neglect, 'inappropriate mood'
5	F/79	9	frontoparietal	(R) hemiparesis, mod-severe non-fluent aphasia, 'flat affect'	F/29	7	MCA	(L) hemiplegia
6	F/63	6	frontoparietal	(R) hemiparesis, severe non-fluent aphasia	M/69	59	temporoparietal	(L) hemiparesis
7	F/67	29	parietal	(R) hemiparesis, non-fluent aphasia	F/54	66	posterior	(L) hemiparesis, 'flat affect'
8	F/81	46	para-ventricular deep parietal	(R) hemiparesis, mild fluent aphasia	F/62	10	external capsule	(L) hemiparesis, (L) visual neglect, 'flat affect'
9	F/79	31	MCA	(R) hemiparesis, moderate fluent aphasia	F/87	83	MCA	(L) hemiparesis
10	F/53	34	basal ganglia	(R) hemiparesis, mild fluent (anomic) aphasia				
11	F/66	56	MCA	(R) hemiparesis, mild fluent (anomic) aphasia				

Note: Age = years, post-onset = months.

of the three prosodic variables (focus, modality, emotion), culminating in 120 utterances (5×24) in total. The speaker was encouraged to produce each token several times to ensure an adequate sample from which to choose exemplars believed to be "on-target" for each of the three prosodic dimensions. Potentially good exemplars were then digitized onto disk using the BLISS speech analysis system [44] at a sampling rate of 20 kHz, with a 9 kHz low-pass filter setting and 12-bit quantization.

Perceptual rating procedure

To ensure that perceptual stimuli successfully conveyed the prescribed combinations of prosodic attributes, the 120 stimuli were rated independently by five phonetically-trained listeners using a checklist. Stimuli were presented to raters in random order over headphones; each trial was played two consecutive times to permit ample opportunity to judge each token on the three dimensions of importance: location of emphasis within the sentence (first, last, none), sentence "type" (statement, question) and emotion (happy, sad, angry, neutral). Inclusion criteria were set at four out of five correct responses for each of the three dimensions, per stimulus. Productions that did not meet these criteria upon initial presentation were re-recorded by the female speaker and judged by the same five raters on a subsequent occasion (at least one week later). Four rating sessions ensured that 117 (98%) of the stimuli projected the desired prosodic meanings for all three prosodic variables, although three (2%) stimuli met criterion for only two of the three prosodic variables. The three "problematic" stimuli did not show a bias towards failure on a specific prosodic category, however and were deemed acceptable for inclusion in the experiment.

Acoustic analyses

The 120 perceptually-validated utterances were subjected to acoustic analysis to determine some of the physical differences underlying this set of stimuli. Acoustic characterization of the stimuli was also prerequisite to manipulating specific parameters of the stimuli important in decoding linguistic and emotional prosody (outlined in Experimental tasks). To characterize both temporal and spectral changes in each prosodic contour, measures of duration and mean F_0 were extracted on the stressed vowel of each content word. Visual inspection of the speech waveform enabled the duration of the target vowel (steady state and transition) to be determined by placing cursors at zero crossings at the vowel's onset and offset. Mean F_0 was calculated from the average of five contiguous glottal pulses isolated at the centre of each vowel [7, 48]. The F_0 of the utterance terminal (measured in the final 150 ms) and the total utterance duration were further noted. An acoustic profile of the F_0 and duration distinctions underlying the perceptual stimuli is supplied in Table 2. As may be seen, these data generally conform to normal patterns of cue usage in speech production as reported in previous acoustic investigations [18, 20, 50, 70].

Experimental tasks

The perception of prosody by RHD, LHD and NC subjects was assessed in six independent tasks: three tasks explored the subjects' ability to process local prosodic markers of emphatic stress (*Focus Perception*); and three tasks examined the recognition of emotional-prosodic features by the same listeners (*Emotion Perception*). Within each perception condition, an initial task (*Baseline*) measured subjects' ability to recognize prosodic stimuli when *all* potential acoustic features (but no semantic features) contributed to the perception of these forms (i.e. the stimuli were those judged by the phonetically-trained raters on the pre-task). Two additional tasks investigated the extent to which each group's performance on the Baseline task was influenced by only duration (*D-Neutral*) or F_0 (*F-Neutral*) parameters of the stimuli within each condition. The independent contributions of duration and mean F_0 in perceiving emphasis (focus condition) and discrete emotions (emotion condition) was evaluated by "neutralizing" the effect of each parameter via acoustic manipulation of the Baseline stimuli (described in detail below) [40, 42]. Table 3 provides an outline of the stimuli employed in each of the six tasks.

1. Focus perception

(i) *Baseline*: Of the 120 base stimuli, subjects were required to judge only those utterances containing sentence-initial or sentence-final emphasis (2 focus locations × 2 sentence modalities × 4 emotions × 5 items = 80 trials). Stimuli rated as lacking emphasis ($n = 40$) were not presented on the Baseline task, but rather, were essential in implementing acoustic modifications to the stimuli presented in the D-Neutral and F-Neutral tasks (described below).

(ii) *D-Neutral*: To "neutralize" the influence of temporal changes in perceiving emphasis while preserving the effect of F_0 (and other) cues, the duration of all emphasized words presented in the Baseline task was modified to reflect the duration of *unfocussed* words in matched utterances. (Previous findings indicate that these cues are typically localized to the emphasized word in speech production, e.g. [20].) Each utterance spoken with sentence-initial and sentence-final emphasis was first paired with the same utterance spoken without emphasis, preserving all other prosodic distinctions. Following a procedure to correct for potential differences in speaking rate between stimuli (vowel durations were expressed as a proportion of the total utterance duration), the duration of emphasized vowels was then adjusted to correspond to the duration of the same vowel spoken in the sentence without emphasis. Pitch periods were either removed from the centre of the focussed vowel or (infrequently) added to it to reflect the duration of the vowel spoken in the unfocussed context. Cuts were made at zero-crossings to ensure that there was no audible evidence of the editing.

(iii) *F-Neutral*: To selectively neutralize the contribution of F_0 cues to emphasis, the F_0 of each of the 80 Baseline stimuli was extracted via an autocorrelation algorithm and the LPC spectrum for each stimulus was computed automatically. A

Table 2. Acoustic features (mean F_0 and duration) of the stimuli presented in tasks of focus and emotion perception, as a function of emotion, focus location, and sentence modality. Measures were computed on the stressed vowel (V) of each content word as well as for the utterance as a whole

		Mean F_0 (Hz)										Duration (ms)							
		V1 (R*o*bert)		V2 (r*ea*d)		V3 (l*e*t-)		Terminal (t*er*)		Utterance Mean		V1 (R*o*bert)		V2 (r*ea*d)		V3 (l*e*tter)		Utterance Total	
Emotion/focus		(.)	(?)	(.)	(?)	(.)	(?)	(.)	(?)	(.)	(?)	(.)	(?)	(.)	(?)	(.)	(?)	(.)	(?)
Neutral	None	225	229	201	221	180	187	162	320	192	239	103	106	86	69	110	125	1169	1144
	Initial	250	195	170	338	165	354	171	431	189	330	132	132	71	81	87	108	1138	1190
	Final	214	233	193	216	207	196	162	432	194	269	93	93	66	68	122	127	1110	1180
Sad	None	201	213	179	213	180	195	183	265	186	222	126	167	78	79	143	141	1311	1487
	Initial	190	196	171	271	171	269	174	297	177	258	190	170	78	90	96	114	1340	1349
	Final	218	209	189	195	182	198	172	282	190	221	118	112	81	73	148	137	1408	1349
Happy	None	439	322	187	260	409	289	194	533	307	351	99	111	83	75	124	105	1102	1157
	Initial	482	265	208	497	185	504	172	596	262	466	150	149	93	75	120	113	1258	1217
	Final	425	314	255	287	476	343	229	611	346	389	95	96	79	74	146	121	1253	1224
Angry	None	302	253	226	236	234	231	178	320	235	260	113	125	63	62	132	115	1050	1141
	Initial	309	303	202	338	193	348	176	411	220	350	165	143	75	72	111	121	1205	1235
	Final	267	284	217	257	244	284	177	488	226	328	91	92	63	56	122	124	1103	1172

Note: (.) = Declarative, (?) = Interrogative.

Table 3. Summary of the acoustic characteristics of the 120 base stimuli presented in each of the six perception tasks

	Focus perception (measures apply to focussed word only)			Emotion perception (measures apply to all content words)		
	Baseline	D-Neutral	F-Neutral	Baseline	D-Neutral	F-Neutral
Duration	present	absent	present	present	absent	present
F_0	present	present	absent	present	present	absent

vocoding software programme was then utilized to replace the F_0 contour of each emphasized word with that of its unfocussed homologue in the same keyword position (all other factors remaining equal) and the utterance was resynthesized.

2. *Emotion perception*

(i) *Baseline*: Of the 120 base stimuli, those sentences judged by the phonetically-trained listeners as conveying a sad, happy, or angry tone were presented for emotional identification on the Baseline task (3 emotions × 3 focus locations × 2 sentence modalities × 5 items = 90 trials). "Neutral" stimuli were not presented for emotional recognition, again providing a benchmark for implementing acoustic manipulations to the emotional stimuli on the D-Neutral and F-Neutral tasks (described below).

(ii) *D-Neutral*: As temporal changes *throughout* an utterance are believed to contribute to emotional distinctions in the speech signal (e.g. [62]), duration attributes of the emotional stimuli were neutralized by manipulating the vowel length of *all* content words present within the Baseline stimuli. Stimuli spoken in a sad, happy, or angry tone were first paired with the same utterance spoken in a neutral tone, maintaining all other prosodic distinctions. The duration of stressed vowels within the emotional utterances were then adjusted (where necessary) to reflect the values of the same vowels spoken in the neutral context by adding or removing pitch periods at the centre of the vowel. This process culminated in a set of 90 stimuli varying naturally in F_0 cues, but for which temporal features were no longer indicative of the target emotion.

(iii) *F-Neutral*: To render the F_0 attributes of discrete emotions unavailable for perceptual recognition, the F_0 of each of the 90 Baseline stimuli was extracted via an autocorrelation algorithm and the LPC spectrum for each utterance was computed. Emotional stimuli were then vocoded by replacing the F_0 contour of each utterance with that of its "neutral" homologue (i.e. the contour extracted from the same utterance spoken in a neutral tone, all other factors remaining constant). Utterances were then resynthesized, maintaining their temporal pattern in each case but eradicating the effect of pitch cues in projecting the speaker's affect.

Procedure

Subjects were tested individually on two separate occasions, three tasks being administered during each session. For focus perception, subjects were asked to locate the position in which they heard emphatic stress within each sentence (choices: first, last, none). For emotion perception, subjects indicated the "emotional tone" in which each sentence was produced (choices: sad, angry, happy, neutral). Focus and emotion perception tasks were presented in random order for each subject and counterbalanced within each of the three groups, with the restriction that at least one focus or emotion perception task be presented during each session. For all six tasks, auditory stimuli were presented one at a time (separated by a 5 s interval) over headphones. Order of presentation was fully randomized within each task and presented by a computer, which recorded the accuracy of each subject's responses. Decisions were indicated by pushing a button on a response board (aligned vertically). Buttons were labelled both verbally and with a corresponding pictogram (e.g. a facial expression). Five practice trials ensured that subjects were comfortable with the task demands and were oriented to the positioning of response buttons. A 5 min break was set at the half-way point of each task.

Statistical analyses

Accuracy data were examined independently for each of the six tasks using analysis of variance (ANOVA) techniques. In the focus perception condition, three 3 × 2 × 2 × 4 mixed-design ANOVAs were conducted. For these analyses, group membership (NC, RHD, LHD) served as the between-subjects factor and FOCUS (initial, final), MODALITY (declarative, interrogative) and EMOTION (angry, sad, happy, neutral) served as the repeated factors. In the emotion perception condition, three 3 × 3 × 2 × 3 mixed-design ANOVAs were performed. Again, GROUP (NC, RHD, LHD) served as the between-subjects variable in these analyses, while EMOTION (angry, sad, happy), MODALITY (declarative, interrogative) and FOCUS (initial, final, none) served as measures of within-subjects variation for these data sets. Post-hoc analyses, where appropriate, were performed using Tukey's HSD pairwise comparisons ($P < 0.05$).

Results

Statistical findings are reported independently for the focus and emotion conditions. Given the relatively large number of independent factors considered in the present design, only those effects deemed of greatest theoretical relevance are described in the text. All statistically significant effects produced by the six ANOVAs are reported in the Appendix.

1. *Focus perception*

Mean group accuracy (percentage correct) in identifying sentence-initial and sentence-final emphasis on the Baseline, D-Neutral, and F-Neutral tasks is furnished in

Table 4, as a function of sentence modality and emotion type.

The three (GROUP × FOCUS × MODALITY × EMOTION) ANOVAs performed on the focus perception data each yielded a significant main effect for GROUP [Baseline: $F(2,27) = 10.94$, $P < 0.001$; D-Neutral: $F(2,27) = 4.42$, $P < 0.05$; F-Neutral: $F(2,27) = 5.71$, $P < 0.01$]. Post-hoc inspection of these main effects (displayed concurrently in Fig. 1) indicated that the NC and RHD subjects were significantly more accurate than matched LHD patients in perceiving emphasis on two of the three tasks: when focussed words were marked by all naturally-occurring acoustic cues (Baseline); and when only the duration cues to emphasis were rendered perceptually unavailable (D-Neutral). When the F_0 correlates to emphasis were obscured (F-Neutral), RHD patients were again superior to LHD aphasic patients in detecting emphasis position within the utterance, although neither clinical group differed significantly from the control group for these stimuli. This finding would appear to reflect the relatively greater decrement in the accuracy of the NC group than the two patient groups on the F-Neutral task (Fig. 1). It is worth noting that the accuracy of the RHD and NC subjects in perceiving linguistic focus could not be distinguished statistically on any of the three tasks.

The possibility that each group's capacity to perceive emphasis was dependent on specific aspects of prosodic structure (i.e. various combinations of focus position, sentence modality and emotion) was of further interest in the current study. When "natural" stimuli containing all normally-occurring acoustic features were presented (Baseline), no interactions between the GROUP variable and the three prosodic variables were produced ($P > 0.05$ in all cases). This finding suggests that, despite overall group differences in perceiving emphasis on the Baseline task, neither the brain-damaged nor non-brain-damaged subjects was influenced by variations in the stimuli along other prosodic dimensions when performing this judgement.

However, differential group sensitivity to variations in prosodic structure was evident to some extent following manipulation of duration (D-Neutral) and F_0 (F-Neutral) properties of the focus stimuli. More specifically, analysis of the D-Neutral data yielded a significant interaction of GROUP × FOCUS × EMOTION ($F(6,81) = 3.32$, $P < 0.01$). Post-hoc comparisons considered how differences in focus placement and emotional tone affected each group's recognition of emphasis, given the absence of appropriate temporal correlates to focus. For the NC group, accuracy in perceiving emphasis was unaffected by its position within the utterance or by the emotional tone of the speaker in the face of this manipulation (consistent with the Baseline data). For both the RHD and LHD groups, however, sentence-initial emphasis was recognized more poorly when spoken in a sad tone than when spoken in a happy or angry tone in the absence of normal temporal markers to prominence. (The LHD subjects also differed for sad and neutral prosody.) The RHD patients also displayed impaired recognition of sentence-*final* emphasis when spoken in a sad tone than in an angry tone, although the LHD group's perception of sentence-final focus did not differ as a function of emotion or focus location on the D-Neutral task. Viewed generally, these findings suggest that when detecting emphasis in conjunction with particular emotional tones (i.e. sad), the need to rely on only pitch (and not duration) parameters of verbal stimuli proved inadequate for the RHD and LHD patients, although such cues proved sufficient for matched control subjects without brain injury.

Relatedly, analysis of the F-Neutral data yielded

Table 4. Percentage of correct responses (by group) in identifying sentence-initial (I) and sentence-final (F) emphasis on the Baseline D-Neutral, and F-Neutral tasks, as a function of emotion type and sentence modality

		Baseline						D-Neutral						F-Neutral					
		NC		RHD		LHD		NC		RHD		LHD		NC		RHD		LHD	
Emotion/Mod		I	F	I	F	I	F	I	F	I	F	I	F	I	F	I	F	I	F
Neutral	(.)	80	52	95	57	58	43*	86	50	71	53	55	45	70	26*	76	40*	51	20*
	(?)	66	92	78	91	51	74	68	98	64	87	51	84	12*	88	29*	73	35*	75
Sad	(.)	28*	68	58	55	18*	44*	24*	62	44*	56	24*	53	56	46	56	53	35*	36*
	(?)	58	74	72	77	31*	53	70	64	62	56	33*	40*	14*	54	40*	62	33*	44*
Happy	(.)	94	82	98	77	66	60	96	76	98	69	76	60	56	68	71	80	53	56
	(?)	88	92	93	87	52	69	80	92	93	82	71	69	62	90	69	78	56	65
Angry	(.)	76	90	87	89	69	65	76	90	84	91	89	65	78	84	84	82	73	65
	(?)	62	88	93	87	58	61	78	88	78	91	71	65	58	88	67	82	53	69
Mean		69	80	84	78	50	59	72	78	74	73	59	60	51	68	62	69	49	54
SD		21	14	14	14	17	11	21	17	18	17	22	14	24	24	19	16	14	19

Note: (.) = Declarative, (?) = Interrogative, (*) indicates performance expected at or below chance for a three alternative forced choice paradigm based on 95% confidence limits, where chance = 33% ± 11 (binomial distribution).

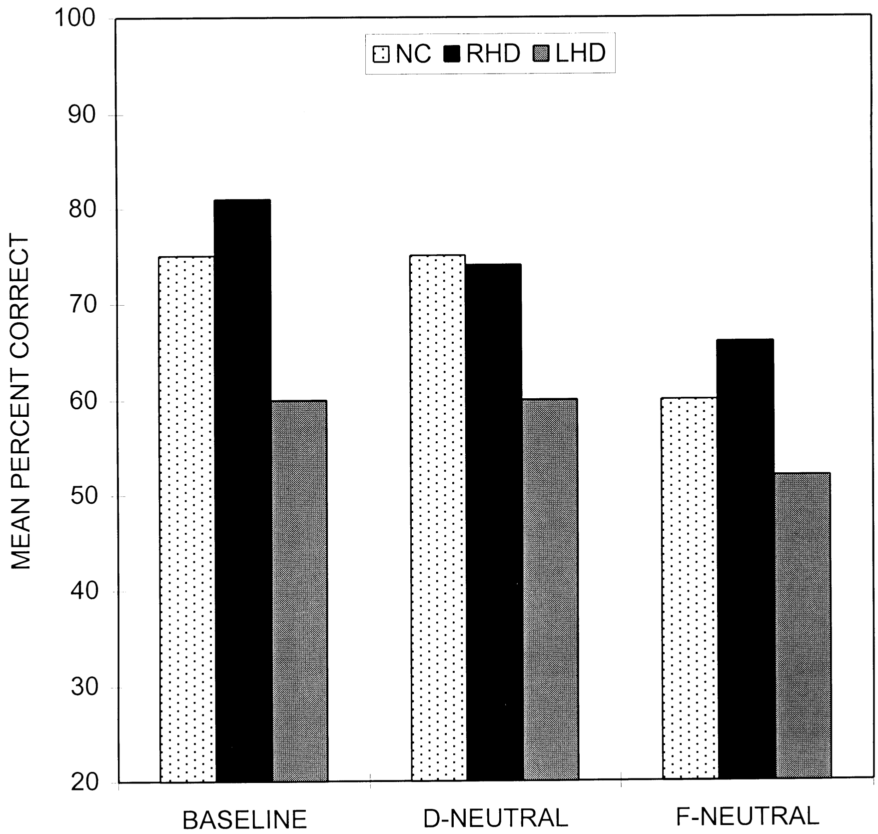

Fig. 1. Mean group accuracy on the Baseline, D-Neutral, and F-Neutral tasks of the focus perception condition.

significant interactions of GROUP × FOCUS × MODALITY [$F(2,27) = 3.39$, $P < 0.05$] and GROUP × MODALITY × EMOTION ($F(6,81) = 3.09$, $P < 0.01$). Post-hoc inspection of the first interaction revealed that when F_0 parameters were unindicative of emphasis, LHD patients demonstrated significantly more difficulties than RHD patients in identifying focussed words (both initial and final) in conjunction with declarative intonation contours. In contrast, when interrogative contours were presented in matched stimuli, group differences in perceiving emphasis were entirely lacking. Examination of the second interaction (GROUP × MODALITY × EMOTION) indicated that for declarative utterances, recognition of focus by the LHD group was significantly inferior to that of the RHD group when spoken in three of the four emotional tones (happy, sad, neutral). Again, no significant group differences were observed when focus identification took place in conjunction with interrogative intonation contours. Taken together, these interactions suggest that when the pitch correlates to emphasis were rendered unavailable, the LHD group benefited less than the other two groups from remaining duration (and other) perceptual cues to emphasis in the auditory signal. These results further imply that the perceived magnitude of pitch variation is a particularly strong determinant of emphasis in declarative intonation contours, although additional cues may assume greater perceptual weight when judging emphasis from interrogative contours.

Analysis of the focus perception data uncovered further interactions among the prosodic variables that were common to all three tasks and independent of group status. Most notably, each ANOVA yielded a significant interaction of FOCUS × MODALITY × EMOTION (Baseline: $F(3,81) = 9.61$, $P < 0.001$; D-Neutral: $F(3,81) = 27.94$, $P < 0.001$; F-Neutral: $F(3,81) = 30.44$, $P < 0.001$). Post-hoc inspection of each interaction revealed only slight differences among the three analyses; for clarity of exposition, this relationship is summarized in Fig. 2 averaged across the three tasks As depicted in Fig. 2, emphasis recognition tended to be highest for all subjects when happy and angry prosody were presented and lowest for all subjects when sad (and sometimes neutral) prosody were presented, irrespective of sentence modality or focus position. Furthermore, interrogative (but not declarative) intonation contours tended to facilitate the accuracy of all subjects in detecting emphasis in sentence-*final* rather than sentence-initial position. The consistency of these findings—observed for both brain-damaged and non-brain-damaged subjects irrespective of the acoustic attributes of the stimuli—exemplifies some of the constraints in perceiving focus as a function of different illocutionary or affective modes present in

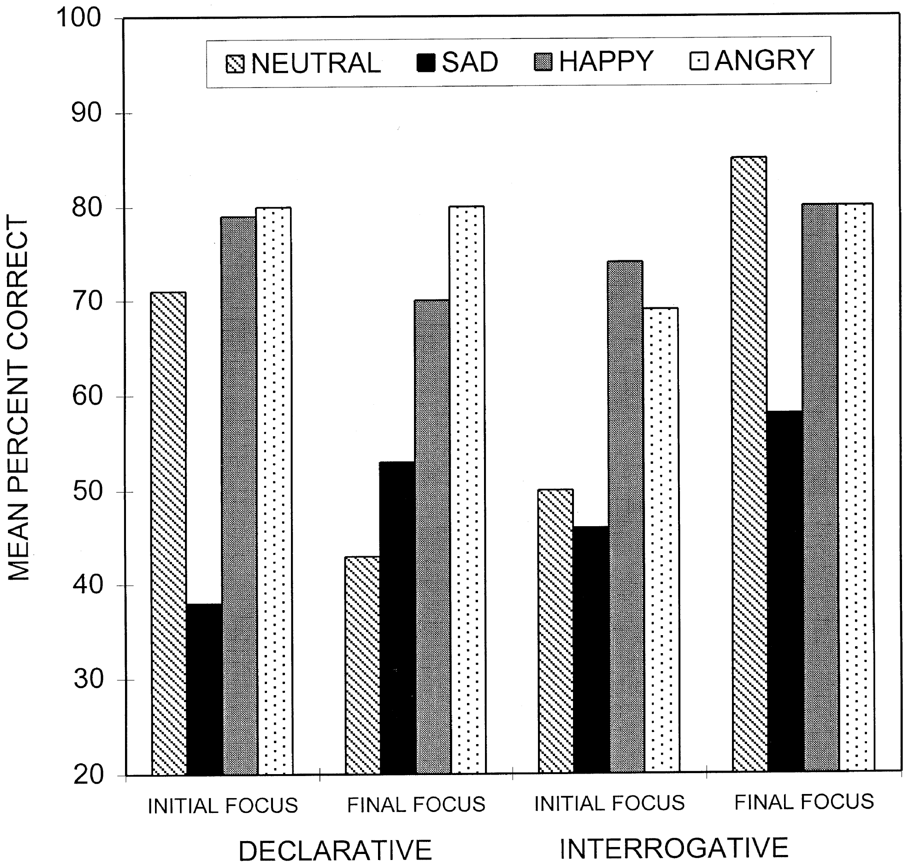

Fig. 2. Interaction of emotional tone, sentence modality, and focus position on the perception of emphatic stress (averaged across the three tasks).

speech. These data further imply that brain-injured patients remain largely sensitive to such alterations in the speech signal, despite certain irregularities in their performance described for the D-Neutral and F-Neutral tasks.

2. *Emotion perception*

Recognition of the vocal cues to *emotional* distinctions was tested in the same subject sample employing the same set of base stimuli presented in the focus perception condition. Mean group accuracy (percentage correct) in identifying sad, happy, and angry prosody on the Baseline, D-Neutral, and F-Neutral tasks may be viewed in Table 5, as a function of sentence modality and emphasis position.

The three (GROUP × EMOTION × MODALITY × FOCUS) ANOVAs performed on the emotion perception data each yielded a significant main effect for GROUP (Baseline: $F(2,27) = 7.51$, $P < 0.01$; D-Neutral: $F(2,27) = 8.25$, $P < 0.01$; F-Neutral: $F(2,27) = 4.45$, $P < 0.05$). Exploration of these main effects (presented concurrently in Fig. 3, by task) indicated that the RHD and LHD patients (who did not significantly differ) were significantly less able to identify the emotional meaning of prosodic patterns than matched control subjects for two of the three tasks: when all prosodic features were perceptually available in semantically-neutral stimuli (Baseline); and when the temporal patterns corresponding to discrete emotional states were selectively "neutralized" (D-Neutral). When the F_0 underpinnings to discrete emotions were neutralized (F-Neutral), only the LHD patients displayed a significant impairment relative to NC subjects; interestingly, emotion recognition scores for the RHD patients did not differ significantly from those of the other two diagnostic groups on the F-Neutral task. The emergence of fewer group differences on the F-Neutral task (reported earlier in describing the focus perception data) may again stem from the low accuracy of all three groups (especially the NC group) in perceiving emotional attributes when deprived of appropriate pitch modulation in the auditory signal.

Significant interactions between the GROUP factor and the independent prosodic variables (emotion type, sentence modality, emphasis location) also emerged. In contrast to the focus perception data, such interactions were not confined to those tasks involving acoustic manipulation of the experimental stimuli. The ANOVA performed on the Baseline data revealed a significant

Table 5. Percentage of correct responses (by group) in identifying sad (S), happy (H), and angry (A) stimuli on the Baseline, D-Neutral, and F-Neutral tasks, as a function of sentence modality and emphasis location

		Baseline									D-Neutral									F-Neutral								
		NC			RHD			LHD			NC			RHD			LHD			NC			RHD			LHD		
Mod/focus		S	H	A	S	H	A	S	H	A	S	H	A	S	H	A	S	H	A	S	H	A	S	H	A	S	H	A
(.)	None	78	66	92	51	64	73	38	65	53	76	70	76	47	60	62	47	62	56	60	12*	54	47	20*	49	25*	27*	44
	Initial	86	82	60	67	53	67	36	60	36	76	74	68	71	60	64	38	69	42	58	18*	40	36	29*	42	27*	20*	29*
	Final	84	88	80	49	60	62	38	71	47	82	82	76	47	58	53	27*	71	56	74	24*	72	49	29*	51	31*	29*	35
(?)	None	82	72	58	47	51	49	42	64	35	74	54	54	56	51	29*	45	38	24*	60	60	28*	42	51	27*	25*	42	18*
	Initial	76	74	40	58	44	42	35	56	35	56	60	38	49	53	31*	22*	38	38	38	34*	22*	33*	44	29*	13*	38	22*
	Final	64	72	68	49	47	60	35	56	40	46	70	64	53	47	51	31*	56	36	32*	54	66	27*	44	56	27*	51	40
Mean		78	76	66	54	53	59	37	62	41	68	68	63	54	55	48	35	56	42	54	34	47	39	36	42	25*	35	31*
SD		8	8	18	8	8	11	3	6	7	14	10	15	9	5	15	10	15	12	16	20	20	9	12	12	6	11	10

Note: (.) = Declarative, (?) = Interrogative, (*) indicates performance expected at or below chance for a four alternative forced choice paradigm based on 95% confidence limits, where chance = 25% ± 9 (binomial distribution).

GROUP × EMOTION interaction ($F(4,54) = 4.43$, $P < 0.01$]. Follow-up tests established that the LHD patients' accuracy on the Baseline task varied significantly as a function of emotion type, their recognition of happy prosody surpassing that of both angry and sad prosody. (The performance of RHD and NC subjects did not significantly differ as a function of emotion type on this or any other task.) A significant four-way interaction of GROUP × EMOTION × MODALITY × FOCUS ($F(8,108) = 2.40$, $P < 0.05$), produced by the analysis of the D-Neutral data, again reflected the LHD subjects' superior recognition of happy intonation relative to that of the other two emotional tones.* It is noteworthy that interactions between GROUP and the independent prosodic variables (including the "happy" bias demonstrated by the LHD patients) did not emerge from the analysis of the F-Neutral data, where performance tended to be relatively poor for all subjects across stimulus types.

A significant EMOTION × MODALITY × FOCUS interaction produced by each of the three analyses [Baseline: $F(4,108) = 2.80$, $P < 0.05$; D-Neutral: $F(4,108) = 3.38$, $P = 0.01$; F-Neutral: $F(4,108) = 7.15$, $P < 0.001$] indicated that for all subjects, recognition of emotional prosody was influenced to some extent by linguistic-prosodic specifications in the auditory signal. This relationship, which was again characterized by minor differences among the three analyses (including the four-way interaction with GROUP described for the D-Neutral task), is most clearly summarized when averaged across the three tasks (Fig. 4). In general, recognition of sad prosody was largely unaffected by sentence modality or emphasis position for any of the three tasks. Recognition of happy prosody, although mostly unaffected by changes in sentence modality and emphasis placement on the Baseline and D-Neutral tasks,† was significantly enhanced by the presence of interrogative (rather than declarative) intonation contours on the F-Neutral task. By contrast, recognition of angry prosody was consistently and *systematically* influenced by the linguistic-prosodic variables on the three tasks. Anger tended to be identified more reliably in declarative (rather than interrogative) utterances or when sentence-final emphasis was present (in which case modality distinctions were not a factor). Inspection of the acoustic data, coupled with comments made by experimental subjects following the testing session, suggest that the initial rising pattern displayed in certain interrogative contours (i.e. those without focus or

* The "happy" bias demonstrated by the LHD patients was less pervasive when temporal cues to emotion were impoverished. For this task, LHD patients identified happy prosody better than sad prosody (sentence-initial and sentence-final emphasis) and angry prosody (sentence-initial emphasis) for declarative utterances, but no significant emotional differences were noted for interrogative utterances, or when declarative utterances lacked sentential focus.

† Recall that on the D-Neutral task, perception of happy prosody was significantly influenced by sentence modality and emphasis position for the LHD group.

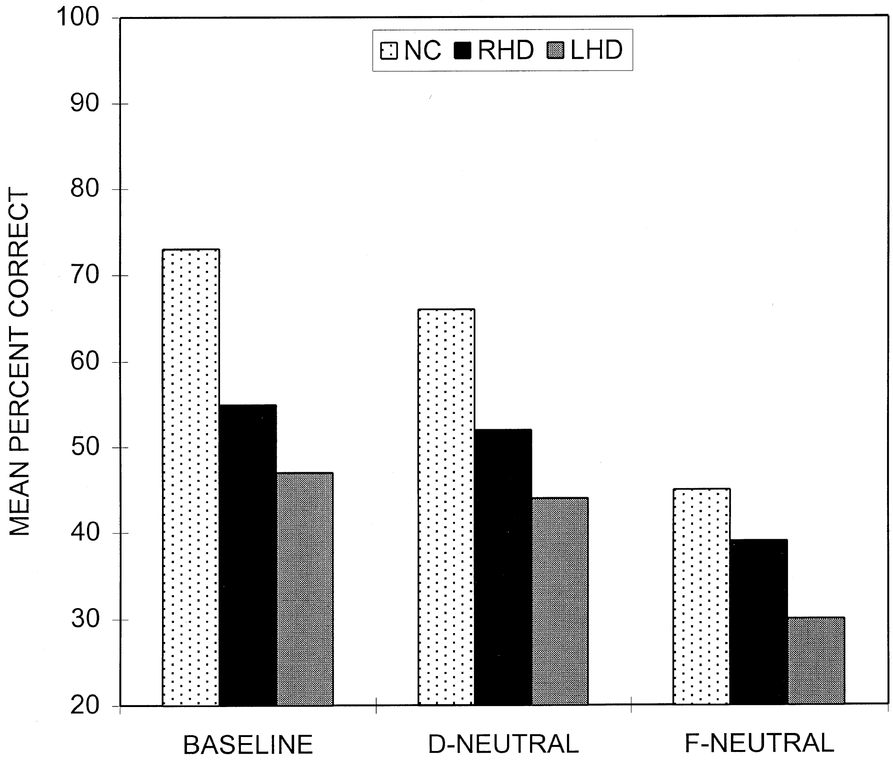

Fig. 3. Mean group accuracy on the Baseline, D-Neutral, and F-Neutral tasks of the emotion perception condition.

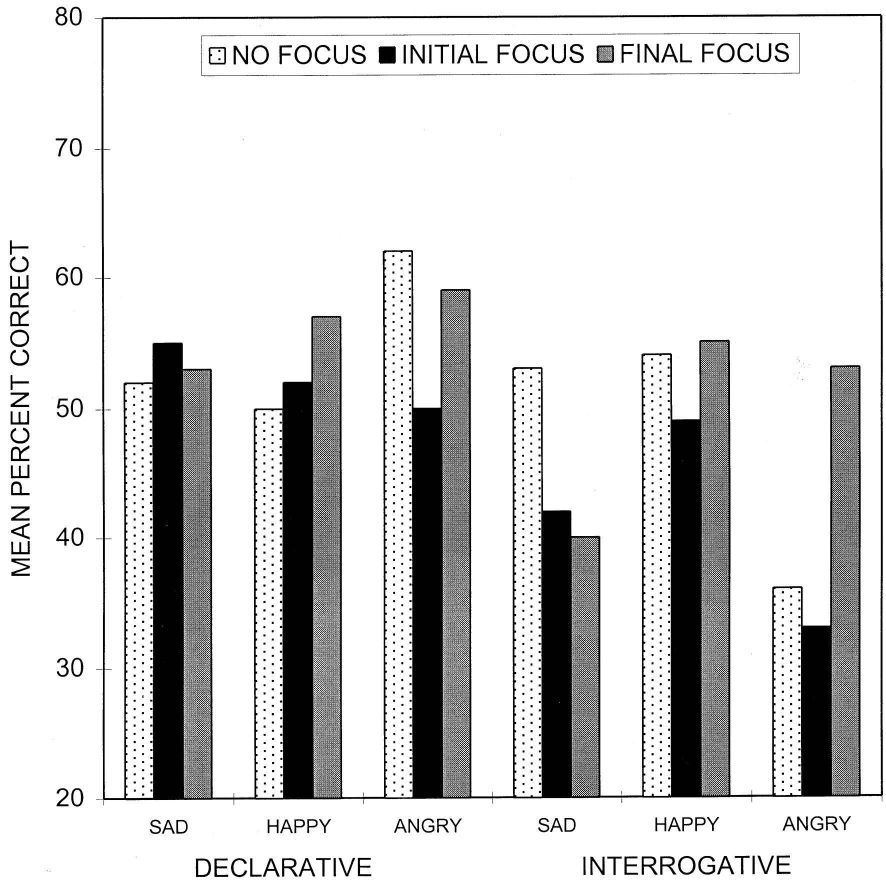

Fig. 4. Interaction of focus position, sentence modality, and emotional tone on the perception of emotional prosody (averaged across the three tasks).

with sentence-initial focus—see Table 2) may have been more typical of "surprise" than "angry" prosody, leading to less reliable performance for those stimuli.

Discussion

In a more carefully controlled manner than in most previous studies, the present investigation considered how prosodic aspects of speech are translated into affective and non-affective messages following focal left- or right-hemisphere insult. To build upon previous research, the presentation of auditory stimuli enriched with multiple prosodic cues and the manipulation of specific temporal and spectral properties of prosodic contours, were employed as novel means of assessing how unilateral brain damage effects prosodic perception under a variety of conditions. Furthermore, data emanating from this experiment illuminate some of the processes underlying the perception of linguistic and emotional prosody and the interaction of these two "types" of representations in normal listeners.

The perception of emphasis is known to be critical in deriving the propositional intent of speech, highlighting the semantic value accorded to individual constituents within an utterance. Three tasks assessed the ability of RHD, LHD and NC subjects to perceive emphatic stress in the present study. On each task, the LHD aphasic patients were significantly impaired relative to matched RHD patients, who performed at a comparable level to non-neurological control subjects in each case. The LHD patients were also impaired relative to non-neurological controls on two of the three focus perception tasks (Baseline, D-Neutral). These findings point to a disturbed capacity to perceive emphatic stress distinctions in patients with focal left hemisphere lesions and aphasia [2, 3, 37], providing the strongest evidence to date that left hemisphere mechanisms are more crucially involved in these processes.

The observation that focus perception was spared in patients with unilateral right-hemisphere insult is at odds with some previous reports in the literature [14, 15, 69]. However, methodological differences may explain the conflicting patterns noted. For example, two studies which described impaired recognition of emphatic stress in RHD patients [14, 15] based their conclusions on an extremely small (and potentially unreliable) number of items (i.e. no more than 12 trials were presented for perceptual identification in these studies, compared to 240 trials in the current experiment). Conclusions arrived at by one of these studies [69] defy direct comparison with the present results, as those authors evaluated RHD patients' success in *discriminating* paired utterances differing in emphatic stress location. Moreover, analyses conducted in that study simultaneously considered how RHD patients differentiate statement/question contrasts, a potentially independent deficit reported elsewhere in the literature [14, 34, 51]. These inconsistencies render the findings of previous investigations on emphatic stress less certain, favouring the present contention that RHD patients are largely unimpaired in the receptive processing of emphatic stress [2].

Stimuli presented for focus recognition were tested in the same subject sample for the recognition of *emotional*-prosodic attributes. Results obtained for the three emotion perception tasks indicated a distinct pattern of group performance from that reported in the focus perception condition. Namely, both the RHD and LHD patients performed at an inferior level to the control subjects on individual emotional tasks except the F-Neutral task (where all three groups performed poorly—see Results). A disruption of emotional prosody comprehension following compromise of either left or right hemisphere cortical regions is in accordance with much recently-published data [16, 19, 60, 64, 68], arguing that *both* cerebral hemispheres may be engaged to some extent in decoding emotional attributes of speech (see [60] for an alternative explanation).

The comparable performance of the RHD and LHD patients in the emotion perception condition stands in sharp contrast to the performance of these two groups in the focus perception condition, where the accuracy of the RHD patients *always* surpassed that of the LHD patients. Assessment of group performance across functional domains, therefore, implies that right hemisphere lesions were more frequently tied to a receptive disruption for emotional and not linguistic attributes of prosody [23, 67]. These data suggest an instrumental role for the right hemisphere in assessing the emotional significance of prosodic cues in speech perception [10–12]. However, as emotional-prosodic deficits emerged on a comparable scale in both RHD and LHD patients, the present data are incompatible with the notion of *exclusive* right-hemisphere control of emotional prosody [8, 13, 22, 35, 36, 58, 66]. Further inquiry may illuminate the potentially unique processing resources contributed by each hemisphere in the task of decoding emotional signals.

The emergence of distinct group patterns as a function of individual stimulus types in both perception conditions points to subtle differences in the mechanisms employed by brain-damaged and non-brain-damaged subjects when processing suprasegmental stimuli. These differences were especially noteworthy in the focus perception condition. For example, requiring subjects to judge emphasis based predominantly on pitch fluctuation (D-Neutral task) selectively disturbed both the LHD and RHD patients (relative to NC subjects), but only for those stimuli in which pitch fluctuation was relatively minimal due to emotional constraints on F_0 modulation (i.e. for sad utterances—review Table 2). This finding suggests that both RHD and LHD patients were less efficient than normal listeners in utilizing pitch change as a cue to emphasis when such excursions were relatively small in magnitude (i.e. least informative of the target response). Moreover, it implies that both clinical groups derived benefit from the temporal correlates of emphasis when presented with sad stimuli on the Baseline and F-Neutral tasks, where this selective pattern of disruption was not evident.

In a similar vein, requiring subjects to rely predominantly on temporal parameters when perceiving emphasis (F-Neutral task) selectively impaired the LHD patients relative to the RHD patients, but only when *declarative* intonation contours were presented. Inspection of the acoustic data suggests that, despite neutralizing the magnitude of pitch change associated with focussed items on the F-Neutral task, interrogative stimuli remained marked by the *direction* of pitch change occurring on focussed items (i.e. pitch accents displayed a rising contour on focussed items within interrogatives sentences but a falling contour within declarative sentences, [20, 50]). These categorical alterations in the *direction* of the pitch accent contained in interrogative contours may have proven sufficient for the LHD patients in perceiving emphasis, their deficits on this task being confined to those stimuli in which pitch markers were completely absent and only temporal cues to emphasis could be harnessed (i.e. declarative contours). This result points to a subtle defect in processing temporal parameters of linguistic-prosodic stimuli in LHD patients [4, 68], a shortcoming largely obscured when pitch markers are salient (i.e. Baseline and D-Neutral tasks). Such a defect, although not fully supportive of previous hypothetical descriptions, is consistent with the notion that each hemisphere may possess unique capabilities to process specific acoustic parameters underlying prosodic stimuli [54, 68]. More generally, the susceptibility of the brain-damaged patients to acoustic modifications of the stimuli affirms that RHD and LHD patients require both spectral *and* temporal aspects of prosody when processing emphatic stress distinctions, redundancy not typically required by the normal system on such a task.

Finally, in the emotion perception condition, the LHD group showed a bias towards recognition of happy prosody over sad and angry prosody on all tasks except the F-Neutral task. Such a bias has been noted previously using a comparable stimulus set [51] and may underscore the proficiency of aphasic patients at processing prosodic forms displaying large excursions in continuous F_0 features [39, 52]. Alternatively, in view of the emotional responses permitted in the present experiment, recognition of happy prosody may have been enhanced by a predilection for "positive" stimuli in the LHD patients [1, 61]. This latter explanation is unlikely, however, given the weight of evidence opposing the "emotional valence" hypothesis [22, 34, 51, 52], including the failure of the present data to produce the converse pattern (i.e. RHD patients demonstrating a perceptual bias for "negative" affects). The likelihood that pitch attributes of happy stimuli guided the LHD patients' performance is reinforced by the lack of an emotional bias on the F-Neutral task, where F_0 properties of the stimuli were rendered "neutral" and therefore ineffective determinants of emotional content.

More generally, results obtained herein demonstrate that for both brain-damaged and non-brain-damaged subjects, the perception of linguistic prominence and emotional prosody varies as a function of concurrent alterations in the structure of intonation contours. This interaction was particularly evident in the focus perception condition, where all subjects displayed superior recognition of emphatic stress in utterances spoken in a happy or angry tone than those spoken in a sad tone. As demonstrated by the acoustic data, the magnitude of F_0 change associated with focussed items in both sentence-initial and sentence-final position was extremely large for happy and angry stimuli, relative to that underlying sad and neutral stimuli. These highly exaggerated pitch changes may have enhanced the prosodic contrast between items with and without prominence within happy and angry contours, facilitating emphasis recognition for these stimuli when compared to utterances containing relatively small pitch accents (i.e. sad stimuli). It is unlikely that temporal differences across emotional categories facilitated emphasis perception, as focussed vowels in sentence-initial and sentence-final positions were actually longest (i.e. presumably most indicative of focus) for the sad stimuli, for which recognition of focus was *least* accurate.

The present observation that affective modes which naturally enhance or "exaggerate" distinctions in linguistic-prosodic content render emphatic items more salient to all listeners, including both fluent and non-fluent aphasics, extends previous findings in the prosody literature [38, 39, 49]. Possibly, the more "informative" nature of expanded contours renders the communicative intent of the speaker more intelligible to the listener, leading to the use of such forms in speech directed to infants or foreign language speakers [24, 25]. Although it remains highly speculative whether exaggerated or expanded intonation contours could serve to facilitate aspects of sentence comprehension in aphasic adults, this line of inquiry nonetheless presents a promising direction for future research. Through increased knowledge of how functional and structural attributes of prosody *interact* in speech production and perception, future undertakings will be better equipped to address this and other issues that speak to the question of how prosody is organized in the brain.

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Appendix: Significant ANOVA results table

Focus perception	Main effects	Interactions
Baseline	G: $F(2,27) = 10.94$, $P < 0.001$	F × M: $F(1,27) = 15.31$, $P = 0.001$
	M: $F(1,27) = 12.83$, $P = 0.001$	F × E: $F(3,81) = 10.40$, $P < 0.001$
	E: $F(3,81) = 27.10$, $P < 0.001$	M × E: $F(3,81) = 5.64$, $P = 0.001$
		F × M × E: $F(3,81) = 9.61$, $P < 0.001$
D-Neutral	G: $F(2,27) = 4.42$, $P < 0.05$	F × M: $F(1,27) = 13.02$, $P = 0.001$
	M: $F(1,27) = 7.23$, $P = 0.01$	F × E: $F(3,81) = 7.16$, $P < 0.001$
	E: $F(3,81) = 45.28$, $P < 0.001$	M × E: $F(3,81) = 7.87$, $P < 0.001$
		F × M × E: $F(3,81) = 27.94$, $P < 0.001$
		G × F × E: $F(6,81) = 3.32$, $P < 0.01$
F-Neutral	G: $F(2,27) = 5.71$, $P < 0.01$	F × M: $F(1,27) = 71.58$, $P < 0.001$
	F: $F(1,27) = 15.24$, $P = 0.001$	M × E: $F(3,81) = 6.48$, $P = 0.001$
	E: $F(3,81) = 37.38$, $P < 0.001$	F × M × E: $F(3,81) = 30.44$, $P < 0.001$
		G × F × M: $F(2,27) = 3.39$, $P < 0.05$
		G × M × E: $F(6,81) = 3.09$, $P < 0.01$
Emotion Perception		
Baseline	G: $F(2,27) = 7.51$, $P < 0.01$	G × E: $F(4,54) = 4.43$, $P < 0.01$
	E: $F(2,54) = 3.23$, $P < 0.05$	E × F: $F(4,108) = 4.62$, $P < 0.01$
	M: $F(1,27) = 29.35$, $P < 0.001$	E × F × M: $F(4,108) = 2.80$, $P < 0.05$
D-Neutral	G: $F(2,27) = 8.25$, $P < 0.01$	E × F: $F(4,108) = 3.46$, $P = 0.01$
	M: $F(1,27) = 42.37$, $P < 0.001$	E × F × M: $F(4,108) = 3.38$, $P = 0.01$
		G × E × F × M: $F(8,108) = 2.40$, $P < 0.05$
F-Neutral	G: $F(2,27) = 4.45$, $P < 0.05$	E × F: $F(4,108) = 4.21$, $P < 0.01$
	F: $F(2,54) = 12.67$, $P < 0.001$	E × M: $F(2,54) = 12.76$, $P < 0.001$
		E × F × M: $F(4,108) = 7.15$, $P < 0.001$

Note: G = Group, F = Focus, M = Modality, E = Emotion.