Aphasiology

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/paph20

Production of affective and linguistic prosody by brain-damaged patients

Shari R. Baum a b & Marc D. Pell a
a McGill University, Montreal, Quebec, Canada
b School of Communication Sciences and Disorders, McGill University, 1266, Pine Avenue West, Montreal, Quebec, H3G 1A8, Canada

Available online: 29 May 2007

To cite this article: Shari R. Baum & Marc D. Pell (1997): Production of affective and linguistic prosody by brain-damaged patients, Aphasiology, 11:2, 177-198

To link to this article: http://dx.doi.org/10.1080/02687039708248463

PLEASE SCROLL DOWN FOR ARTICLE

Full terms and conditions of use: http://www.tandfonline.com/page/terms-and-conditions

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing, systematic supply, or distribution in any form to anyone is expressly forbidden.

The publisher does not give any warranty express or implied or make any representation that the contents will be complete or accurate or up to date. The accuracy of any instructions, formulae, and drug doses should be independently verified with primary sources. The publisher shall not be liable for any loss, actions, claims, proceedings, demand, or costs or damages whatsoever or howsoever caused arising directly or indirectly in connection with or arising out of the use of this material.
Production of affective and linguistic prosody by brain-damaged patients

SHARI R. BAUM and MARC D. PELL
McGill University, Montreal, Quebec, Canada

(Received 15 February 1996; accepted 15 April 1996)

Abstract
To test a number of hypotheses concerning the functional lateralization of speech prosody, the ability of unilaterally right-hemisphere-damaged (RHD), unilaterally left-hemisphere-damaged (LHD), and age-matched control subjects (NC) to produce linguistic and affective prosodic contrasts at the sentence level was assessed via acoustic analysis. Multiple aspects of suprasegmental processing were explored, including a manipulation of the type of elicitation task employed (repetition vs reading) and the amount of linguistic structure provided in experimental stimuli (stimuli were either speech-filtered, nonsensical, or semantically well formed). In general, the results demonstrated that both RHD and LHD patients were able to appropriately utilize the acoustic parameters examined (duration, fundamental frequency ($F_0$), amplitude) to differentiate both linguistic and affective sentence types in a manner comparable to NC speakers. Some irregularities in the global modulation of $F_0$ and amplitude by RHD speakers were noted, however. Overall, the present findings do not provide support for previous claims that the right hemisphere is specifically engaged in the production of affective prosody. Alternative models of prosodic processing are noted.

Introduction
A relatively large database has begun to accumulate on the neural substrates of speech prosody. Investigators have explored the ability of left- and right-hemisphere-damaged individuals to process both the affective and linguistic functions of prosody. To date, however, results have not led to a consistent view of the functional lateralization of prosody (see e.g. Ryalls and Behrens 1988 for a review). Many studies of perception or comprehension have indicated deficits in RHD patients’ ability to identify emotional tone (e.g. Blonder et al. 1991, Bowers et al. 1987, Heilman et al. 1984, Tompkins and Flowers 1985). However, additional studies have demonstrated that LHD patients are equally impaired in the identification of affective prosodic cues and/or that RHD and LHD patients both exhibit deficits in the processing of both linguistic and affective prosody (e.g. Cancelliere and Kertesz 1990, Heilman et al. 1984, Schlanger et al. 1976, Van Lancker and Sidtis 1992). Results of production studies are equally inconclusive, with data variably supporting a RH control for all types of prosody (e.g. Shapiro and Danly 1985, Weintraub et al. 1981), a RH dominance for affective prosody but...
a LH dominance for linguistic prosody (e.g. Colsher et al. 1987, Cooper et al. 1984, Gandour et al. 1995, Hughes et al. 1983, Ryalls et al. 1987), differential patterns of lateralization depending on the size of the utterance or the task demands (e.g. Behrens 1988, 1989, Gandour et al. 1989), or differential lateralization for specific acoustic cues (e.g. Danly and Shapiro 1982, Gandour et al. 1989, Van Lancker and Sildis 1992). Below we will describe some of the production experiments in greater detail, focusing on examinations of sentence-level linguistic and affective prosody.

The acoustic cues to both affective and linguistic prosody include (but are not limited to) variations in fundamental frequency (F0), duration, and amplitude (Lehiste 1970). In normal speech production, declarative sentences typically exhibit a terminal fall in F0, in contrast to yes–no interrogatives which exhibit a terminal rise. These distinctions lead to a higher mean F0 in questions relative to statements (Behrens 1989, Lieberman 1960, Shapiro and Danly 1985). Although the precise acoustic characterization of different emotions is as yet unsettled, the differences between happy, sad, and angry utterances include changes in mean F0 and amplitude, and longer durations in sad sentences relative to happy and angry utterances (e.g. Fairbanks and Hoaglin 1941, Scherer 1986, Scherer and Oshinsky 1977, Williams and Stevens 1972).

Shapiro and Danly (1985) were among the first to utilize acoustic analyses to examine linguistic and affective prosody in RHD patients. They elicited target sentences from reading paragraphs that were biased to require a declarative or interrogative sentence or a sentence produced in a happy or sad emotional tone. A variety of measures of F0 were derived from the speech of 11 RHD patients (three with anterior damage, three with central damage, and five with posterior damage), five LHD patients with posterior lesions, and five normal control subjects. Results revealed low mean F0 and restricted F0 range in the right anterior and central patients; in contrast, patients with right posterior lesions exhibited higher than normal mean F0 and increased range. LHD patients performed similarly to normals, as expected. Importantly, the deficits shown by the RHD subjects held across both linguistic and affective conditions, suggesting a RH role in the production of both types of prosody. However, the analyses conducted by Shapiro and Danly (1985) have been criticized for failing to account for mean F0 when examining variability (Colsher et al. 1987). Increases in F0 are generally accompanied by increased variability; therefore, variability measures should be normalized with respect to mean fundamental frequency (Colsher et al. 1987). Colsher and colleagues (1987) reported lower than normal variability in two RHD patients clinically diagnosed as hypermelodic once the data were normalized.

In addition, in a recent study, Gandour et al. (1995) examined the production of affective prosody in a group of Thai-speaking RHD subjects following the methodology of Shapiro and Danly (1985). The speech of these subjects had been previously determined to include accurate cues to linguistic prosody (Gandour et al. 1992a, b, 1994). Results revealed that the RHD patients were significantly impaired relative to normal controls in their ability to produce perceptually distinct emotional tones. Acoustic analyses of ‘on-target’ utterances yielded few differences between the groups. Off-target productions of ‘happy’ sentences differed from on-target utterances in terms of duration, F0, and amplitude for both subject groups. Based on these findings, coupled with their previous results, Gandour and colleagues (1995) concluded that the RHD patients exhibited deficits in the production of affective prosody only. They suggest that, at least in tone languages,
linguistic and affective prosody appear to be differentially lateralized (Gandour et al. 1995).

Two additional studies of sentence-level intonation are particularly relevant. In one investigation that focused only on affective prosody, Ross et al. (1988) found impairments in \( F_0 \) characteristics in patients undergoing right-sided Wada tests. Pre- and post-Wada test recordings revealed normal acoustic cues for the differentiation of various emotions. These data provide further evidence of the role of the RH in the production of affective prosody, but do not address linguistic prosody at all. The second experiment examined linguistic prosody only. RHD patients were found to exhibit deficits relative to normal controls in the production of sentence-level intonation (Behrens 1989). These same patients were able to produce appropriate cues to phonemic and emphatic stress (Behrens 1988). Behrens (1989) concluded that the RH may be implicated in the control of global sentence-level intonation, but may play little or no role in prosodic production at a more local, lexical level.

Subsequent to LH damage, investigations have revealed that aspects of linguistic prosody may be implicated. Dysprosody in anterior LHD aphasis patients has been most often attributed to impaired temporal control, with a relative sparing of \( F_0 \) parameters except over long units of production (Danly and Shapiro 1982, Gandour et al. 1989). However, these findings are not without controversy (e.g. Ryalls et al. 1987, Ryalls 1982) and questions concerning the functional lateralization of prosody remain.

As may be seen, findings have supported a functional load theory of prosodic processing (Behrens 1988, 1989, Van Lancker 1980), a differential cue lateralization theory (Gandour et al. 1995, Van Lancker and Sistis 1992), and a theory purporting RH control of all prosodic processing (Shapiro and Danly 1985, Weintraub et al. 1981). The disparate patterns of results may in part be accounted for by differences in the types of stimuli examined, the task demands required (e.g. reading vs repetition or spontaneous speech), and the absence of an appropriate brain-damaged control group in many studies. It is important to explore multiple aspects of suprasegmental processing within the same patients in order to determine what neural substrates may underlie the production (and comprehension) of prosodic parameters of speech.

To that end, in the present investigation we compared the abilities of RHD patients, LHD patients, and normal controls to produce several of the acoustic cues to both linguistic and affective prosody. We included both reading and repetition tasks to determine whether the results found would be task-specific. It is possible that brain-damaged subjects would be better able to imitate prosody than to produce it spontaneously (or on demand), indicating that they remain capable of instantiating the prosodic cues. Alternatively, performance in the repetition task may be equally if not more difficult than in the reading task, due to potential misperceptions of the model. In addition, we manipulated the amount of linguistic structure provided in the stimuli in order to assess the functional load hypothesis of prosodic processing and to explore whether a low-level, across-the-board impairment in prosodic cue production would emerge in either of the brain-damaged patient groups. As described in greater detail below, we examined subjects' ability to differentiate declarative, interrogative, and imperative sentences (linguistic prosody) and happy, angry, and sad utterances (affective prosody) when stimuli had: (1) no phonetic content (filtered speech), (2) phonetic but no syntactic
or semantic content (nonsense utterances), and (3) semantically and syntactically well-formed content. According to the functional load hypothesis, we would predict that LHD subjects would break down as the linguistic content in the stimuli increased. In contrast, RHD patients may benefit from the support of the semantic and syntactic structure in the well-formed stimuli.

Methods

Subjects

A total of 21 subjects participated in the experiment: four LHD aphasic patients, seven RHD nonaphasic patients, and 10 age-matched non-neurological controls. Due to the nature of the task, the LHD group was necessarily limited to relatively mild, non-fluent aphasic patients. Even with this constraint it proved difficult to find a critical number of LHD patients who could perform the tasks. The data from the LHD group are included, but must be interpreted with caution due to the small number of subjects. The brain-damaged patients (all of whom were greater than 3 months post-onset at the time of testing) underwent a battery of screening tests to ensure adequate reading skills and auditory comprehension (including sections of the PAL (Caplan and Bub 1990) and the BDAE (Goodglass and Kaplan 1983)); patients were also screened for visual neglect and hearing loss (PTA < 30 dB HL in the better ear). Only those patients with single, unilateral lesions who passed all screening tests were included in the groups. Three additional tests were administered to RHD patients to assess functions typically associated with the RH. Two of the tests focused on the interpretation of figurative language and inferences. The third test, composed of three subtests, examined the perception of affective prosody. Part 1 was a same/different discrimination task using 30 filtered emotionally intoned sentences. Part 2 tested identification of emotions from emotionally intoned nonsense utterances and Part 3 examined identification of emotions from semantically biased emotionally intoned stimuli. Subjects who displayed impairments in at least one of the RH communication skills were included in the investigation. Table 1 provides additional data on individual subjects, including areas of deficit in communication skills.

Stimuli

The stimuli were those used by Pell and Baum (1996) in an investigation of the comprehension of affective and linguistic prosody. Three sets of stimuli were devised which varied in the amount of linguistic structure each set provided: semantically well-formed sentences, nonsense sentences, and filtered sentences. Thirty semantically well-formed sentences formed the basis for all of the stimuli in the linguistic tasks. Ten sentences were declaratives, 10 interrogatives, and 10 imperatives. Each sentence utilized the prototypical syntactic structure associated with the specific sentence type (e.g., subject–verb–object, for declaratives or verb-initial for imperatives). An additional 30 semantically well-formed sentences formed the basis for the affective stimuli. Ten sentences were constructed to signal happiness (via both prosodic cues and the inclusion of specific lexical items), 10 to signal sadness, and 10 to convey anger. All sentences were eight or nine syllables in length.
Table 1. Background information on RHD and LHD subjects

<table>
<thead>
<tr>
<th>Subject number</th>
<th>Age</th>
<th>Sex</th>
<th>Site of lesion</th>
<th>Clinical characteristics</th>
<th>Months post-onset</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>52</td>
<td>F</td>
<td>Right temporoparietal haematoma</td>
<td>Emotional lability, impaired identification of affective prosody</td>
<td>36</td>
</tr>
<tr>
<td>R2</td>
<td>53</td>
<td>F</td>
<td>Right posterior communicating artery (subarachnoid haemorrhage); small temporal haematoma</td>
<td>Flat affect, impulsivity, mild impairment in comprehension of figurative language</td>
<td>45</td>
</tr>
<tr>
<td>R3</td>
<td>72</td>
<td>M</td>
<td>Right parietal (2 cm)</td>
<td>Dysphoric mood, significant impairment in comprehension of figurative language, spatial relations</td>
<td>24</td>
</tr>
<tr>
<td>R4</td>
<td>57</td>
<td>M</td>
<td>Right internal carotid artery aneurysm, lucency in deep temporal (periventricular)</td>
<td>Impaired identification of affective prosody</td>
<td>26</td>
</tr>
<tr>
<td>R5</td>
<td>70</td>
<td>M</td>
<td>Right deep parietal haematoma, deep to angular gyrus and superior parietal lobe</td>
<td>Impaired identification of affective prosody</td>
<td>21</td>
</tr>
<tr>
<td>R6</td>
<td>85</td>
<td>F</td>
<td>Right CVA, N/A</td>
<td>N/A</td>
<td>57</td>
</tr>
<tr>
<td>R7</td>
<td>58</td>
<td>M</td>
<td>Right temporoparietal–occipital haemorrhage</td>
<td>Emotional lability, impairment in comprehension of figurative language, impaired inferencing skills</td>
<td>16</td>
</tr>
<tr>
<td>L1</td>
<td>46</td>
<td>M</td>
<td>Left parietal</td>
<td>Broca’s aphasia, mild–moderate apraxia</td>
<td>76</td>
</tr>
<tr>
<td>L2</td>
<td>78</td>
<td>M</td>
<td>Left CVA, N/A</td>
<td>Mild Broca’s aphasia</td>
<td>9</td>
</tr>
<tr>
<td>L3</td>
<td>43</td>
<td>F</td>
<td>Left frontoparietal infarct with subcortical extension</td>
<td>Severe Broca’s aphasia, verbal and oral apraxia, right hemiparesis</td>
<td>36</td>
</tr>
<tr>
<td>L4</td>
<td>78</td>
<td>F</td>
<td>Left CVA, N/A</td>
<td>Broca’s aphasia, apraxia</td>
<td>58</td>
</tr>
</tbody>
</table>

CVA = Cerebrovascular accident; N/A = not applicable.

For the second set of stimuli, 10 sentences composed of nonsense words were created, matched to the well-formed sentences in terms of syllable length. These sentences provided phonetic and prosodic structure, but no additional syntactic or semantic cues. Each nonsense utterance was produced in six different versions, matched to each of the well-formed sentence types (i.e. declarative, interrogative, imperative, happy, angry, sad). Finally, for the third stimulus set, the semantically well-formed sentences were low-pass filtered at 350 Hz to leave only prosodic cues audible. In Pell and Baum (1996) the stimuli had been filtered at 500 Hz, which could have retained minimal phonetic cues (but see Pell and Baum (1996). Therefore, in the present investigation, a lower cut-off frequency was utilized. Precise details of recording techniques are provided in Pell and Baum (1996).
Procedure

Two main sets of production tasks were utilized: repetition and reading. Their order of presentation was counterbalanced across subjects. For the repetition tasks all of the stimuli described above were recorded onto cassette tape for presentation to subjects. Stimuli were blocked by stimulus type (well-formed, nonsense, filtered) and by linguistic vs affective sets. There were two distinct randomizations of the stimuli within each block; the filtered condition was always presented first to avoid cueing via the phonological and semantic information in the other conditions. Stimuli were presented in free field and subjects were asked to mimic the stimuli as closely as possible. For the filtered stimuli, subjects were instructed to use the vowel [a] as a ‘carrier’ for the prosodic contour.

For the reading tasks, by necessity only the nonsense and well-formed stimulus types were used. (There was no visual analogue to the filtered stimuli.) Sentences were presented orthographically in large print. Below each sentence, the appropriate linguistic or affective tone was indicated (e.g. happy, interrogative); this was obviously critical for production of the nonsense stimuli as no other cues were provided. Subjects were allowed to read the nonsense utterances silently several times prior to their production, in order to ensure that they were comfortable articulating the non-words. As with the repetition tasks, two random orders were utilized and order of presentation of the stimulus blocks was counterbalanced across subjects.

All productions were recorded onto cassette tape using a Sony Professional Walkman WMD6C and a high-quality directional microphone placed approximately 8 inches from the speaker’s mouth. Recordings were then digitized with 12-bit quantization at a rate of 10k samples/s with a 4.5 kHz low-pass filter using the BLISS speech analysis system (Mertus 1989).

Acoustic analyses

For each utterance the following measures were computed: sentence duration, mean $F_0$ extracted via an autocorrelation algorithm, $F_0$ range within each sentence (max–min $F_0$), mean $F_0$ for the sentence terminal (approximately the final 150 ms) and its direction, and a measure of relative amplitude (in RMS units) defined as the mean energy level across the sentence minus the energy averaged over the five highest amplitude pitch periods (determined by visual estimate). Following $F_0$ extraction, an automated routine checked for doubling errors and removed all jumps of greater than 100 Hz from one frame to the next (every 20 ms) before computing the mean, minimum, and maximum $F_0$ values. Values for the terminal segment were calculated by averaging all non-zero $F_0$ values beginning with the last non-zero value and moving back seven frames.

Results

For all findings, the performance of all three groups of subjects is reported. However, given the very small number of subjects in the LHD group ($n = 4$), the data from these patients were not included in any of the statistical analyses described below. Four separate ANOVAs were conducted for each acoustic measure—one for each task (repetition and reading) and prosody type (linguistic
Figure 1. Normalized sentence durations (in ms) in the repetition task for linguistic (a) and affective (b) stimuli.
and affective). When appropriate, post-hoc Newman–Keuls analyses ($p < 0.05$) were used to investigate significant effects.

**Sentence duration**

**Repetition task**

Prior to statistical analysis, sentence durations for each individual speaker were normalized for differences in speaking rate by dividing the mean sentence duration by the maximum sentence duration for that speaker (Gandour et al. 1995). These values were used in subsequent analyses. Mean (normalized) sentence durations in the repetition task varied as a function of stimulus set condition (filtered, nonsense, semantic—henceforth, condition) and sentence type both in the linguistic and affective stimuli. Figure 1 displays these data for linguistic (a) and affective (b) prosody for all three groups. The ANOVA conducted on the linguistic stimuli revealed a main effect for group ($F(1,15) = 19.498$, $p < 0.001$), with longer sentence durations for the normal control speakers relative to the RHD subjects. Average durations for four of the RHD speakers (R1, R2, R4, R5) were shorter than those for any normal subject. A main effect of condition also emerged ($F(2, 30) = 39.428$, $p < 0.001$), as did an effect of sentence type ($F(2, 30) = 4.188$, $p < 0.05$). No interactions of group with any other variable were found. Post-hoc Newman–Keuls analyses revealed that repetitions of filtered sentences were shorter than the nonsense and semantic sentences, which did not differ from one another. In addition, declarative sentences were longer than interrogatives and imperatives. The LHD subjects displayed a similar pattern overall, but interrogatives were shorter than both declaratives and imperatives. Within the affective stimuli, a condition $\times$ sentence type interaction emerged ($F(4, 60) = 5.297$, $p < 0.001$). Post-hoc analyses indicated that angry sentences were shorter than happy and sad in all but the nonsense condition. As in the linguistic stimuli, filtered sentences were shorter than nonsense and semantic sentences. Although no main effect for group emerged, the productions of the RHD group tended to be shorter than those of the normal controls, as in the linguistic stimuli; however, mean durations for only two of the RHD subjects (R2, R4) were outside the range of the normal speakers. In contrast to the other two groups, the LHD did not exhibit shorter durations for angry sentences relative to happy and sad; they did, however, produce shorter sentences in the filtered condition than in the other two conditions.

**Reading task**

In the reading task, as may be seen in Figure 2, nonsense stimuli tended to be longer than semantic stimuli in both linguistic (a) and affective (b) sentences (linguistic: condition main effect $F(1, 15) = 218.216$, $p < 0.001$; affective: condition $\times$ type interaction $F(2, 30) = 20.632$, $p < 0.001$). As in the repetition task, interrogatives were shorter than declaratives, but imperatives were approximately as long as declaratives (linguistic: type main effect ($F(2, 30) = 7.276$, $p < 0.005$). Within the nonsense stimuli, sad sentences were longer than happy and angry; in the semantic condition, angry sentences were again the shortest, but sad and happy sentences did not differ (see condition $\times$ type interaction above). Although not visible in the figure, due to the normalization, the durations for the LHD group in the reading task were extremely lengthy due to their difficulties with reading in general.
Figure 2. Normalized sentence durations (in ms) in the reading task for linguistic (a) and affective (b) stimuli.

Fundamental frequency

Repetition task

Average fundamental frequencies (untransformed, see below) for each sentence type in the repetition task are presented in Figure 3. As illustrated in Figure 3a, all three groups of subjects displayed similar patterns of mean $F_0$. In general,
declaratives had lower mean $F_0$ compared to imperatives and interrogatives, as expected; $F_0$ values in the semantic condition tended to be slightly higher than in the nonsense and filtered conditions. One subject in the RHD group and one subject in the normal control group did not display the group pattern across sentence types. Mean $F_0$ values for three RHD subjects (R1, R4, R6) did not fall within the normal range in at least one condition. There is no evident reason (e.g.
Figure 4. Mean $F_0$ (in Hz) in the reading task for the linguistic (a) and affective (b) stimuli.

Lesion site, clinical traits) for these particular subjects to have differed from the rest of the group. To normalize for differences in overall $F_0$ across speakers, the $F_0$ values were transformed to $z$-scores for statistical comparisons according to the formula outlined in Gandour et al. (1995); $F_{0\text{norm}} = (F_{0i} - F_{0\text{mean}})/s$. The patterns noted were confirmed in a group $\times$ condition $\times$ type ANOVA which yielded a main effect for type ($F(2, 30) = 32.098, p < 0.001$) and a significant
condition x type interaction ($F(4, 60) = 11.632, p < 0.001$). Post-hoc analyses demonstrated that, in the filtered condition, interrogatives had higher mean $F_0$ than declaratives and imperatives, which did not differ. In the nonsense and semantic conditions, both interrogatives and imperatives had higher mean $F_0$ than declaratives. For interrogatives, nonsense stimuli had lower $F_0$ than filtered and semantic; for the imperative sentences, the lowest $F_0$ was found in the filtered condition, followed by the nonsense and then the semantic. No differences in mean $F_0$ across conditions were found for the declarative sentences.

Figure 3b displays the average $F_0$ data for the affective task. In this task, for all groups, sad sentences resulted in the lowest $F_0$; the RHD patients appear to have a lower $F_0$ on average for the affective stimuli. All but one of the RHD subjects (R2) demonstrated average $F_0$ values outside the range of those found for normal subjects on the sad sentences. An ANOVA on these data revealed main effects of group ($F(1, 15) = 6.056, p < 0.05$), condition ($F(2, 30) = 4.456, p < 0.02$) and type ($F(2, 30) = 49.763, p < 0.001$), as well as a condition x type interaction ($F(4, 60) = 4.059, p < 0.01$). Post-hoc tests indicated that, in all conditions, sad stimuli had significantly lower $F_0$ than happy and angry; in addition, for both happy and angry stimuli, mean $F_0$ in the semantic condition was significantly higher than in the filtered and nonsense conditions. For the LHD speakers, average $F_0$ did not differ substantially across sentence types in the nonsense condition.

**Reading task**

The mean $F_0$ measures for the reading task are presented in Figure 4. Analyses revealed that imperative and interrogative sentences had higher average $F_0$ than declaratives (type main effect: $F(2, 30) = 13.605, p < 0.001$) and sentences in the nonsense condition had higher $F_0$ than in the semantic condition within the linguistic stimuli (condition main effect: $F(1, 15) = 9.562, p < 0.01$). For the affective stimuli (shown in Figure 4b) a main effect for type emerged ($F(2, 30) = 30.559, p < 0.001$), with sad sentences displaying lower mean $F_0$ relative to happy and angry, consistent with expectations. No group differences emerged in the reading task.

**Repetition task**

In addition to the average $F_0$ across the sentences, $F_0$ values for the terminal segment, as well as range measures, were analysed. The data for the sentence terminals matched those for the average $F_0$ and will not be reported in detail. Range values were normalized for mean $F_0$ prior to being submitted to ANOVA, in order to ensure that changes in range associated with changes in mean $F_0$ did not influence the findings. $F_0$ range values (untransformed) are provided in Figures 5 and 6 for the repetition and reading tasks respectively. (The figures present the untransformed data for the sake of simplicity and clarity of exposition.) It is clear from Figure 5 that, for both linguistic and affective stimuli, the $F_0$ range for the RHD patients is restricted relative to the normal controls (and the LHD subjects) in the repetition task (linguistic: group main effect $F(1, 15) = 5.332, p < 0.05$; affective: group main effect trend $F(1, 15) = 4.333, p = 0.055$). Across sentence types, all but one RHD patient (R6) exhibited range values in the linguistic condition outside the normal range; in the affective condition, subjects R2 and R6 were the only patients whose range values fell within the normal limits. LHD
Affective and linguistic prosody after brain damage

In the repetition task (Figure 5), subjects' range fell between that of the normal controls and the RHD group. In the reading task (Figure 6), no such group difference is apparent (but LHD subjects appeared to have absolute higher $F_0$ ranges). Despite the overall group differences in the repetition task, the pattern of performance across the groups was similar, with a narrower range in declaratives and imperatives relative to interrogatives (type main effect: $F(2, 30) = 4.033, p < 0.05$); similarly, there was a narrower $F_0$...
Figure 6. \( F_0 \) range (in Hz) in the reading task for the linguistic (a) and affective (b) stimuli.

range in sad sentences relative to happy and angry (type main effect: \( F(2, 30) = 11.738, p < 0.001 \)).

Reading task

In the \( F_0 \) range analyses, no significant effects emerged for either the affective or the linguistic stimuli in the reading task.
Affective and linguistic prosody after brain damage

Relative amplitude

Repetition task

Relative amplitude measures were also compared in each task and each condition, with the means displayed in Figures 7 and 8. For the linguistic stimuli in the repetition task (Figure 7a), the ANOVA revealed significant interactions of
Figure 8. Relative amplitude (RMS energy) in the reading task for the linguistic (a) and affective (b) stimuli.

condition × type ($F(4, 60) = 3.021, p < 0.05$) and group × type ($F(2, 30) = 3.525, p < 0.05$). *Post-hoc* analyses of the former interaction showed that, in the filtered condition, interrogatives had higher amplitude than declaratives; in the nonsense and semantic conditions, both imperatives and interrogatives had higher amplitude than declaratives. Analysis of the group × type interaction revealed higher
amplitude for interogatives relative to imperatives and declaratives for normals; in contrast, both interrogatives and imperatives had higher amplitude than declaratives in the RHD patients' productions. The LHD patients did not show a consistent pattern with respect to amplitude measures for the linguistic stimuli, but displayed higher amplitude overall. Consistent with expectations, as shown in Figure 7b, sad sentences were produced with lower amplitude than happy and angry sentences (type main effect: \( F(2,30) = 9.510, p < 0.001 \)). Here again, no consistent pattern of amplitude values was found for the LHD subjects.

Reading task

In the reading task, the ANOVA for the linguistic stimuli yielded main effects for group \( (F(1,15) = 6.046, p < 0.05) \), condition \( (F(1,15) = 58.134, p < 0.001) \), and type \( (F(2,30) = 4.446, p < 0.02) \). As may be seen in Figure 8a, the RHD subjects (and again, the LHD subjects) produced sentences with higher relative amplitude values overall; for both RHD and normal control groups, sentences in the nonsense condition were higher in amplitude compared to the semantic condition, and interrogatives and imperatives were higher in amplitude than declaratives (like the RHD in the repetition task). The ANOVA on the affective stimuli revealed main effects for group, condition, and type and a three-way interaction \( (F(2,30) = 4.597, p < 0.02) \). Post-hoc analysis of the interaction showed a similar pattern in the semantic condition for both subject groups, with sad stimuli lower in amplitude than happy and angry. Normal control speakers showed a comparable pattern in the nonsense condition; however, for the RHD subjects, no differences across sentence types were found in the nonsense condition. Perhaps somewhat surprisingly (unlike the findings for \( F_o \)), the LHD subjects' data were in keeping with those of the normal control subjects in the nonsense condition, as well as the semantic condition.

Discussion

The goals of the present investigation were to test a number of hypotheses concerning the functional lateralization of prosody. Specifically, we assessed the claim that the RH is specialized for the production of affective prosody (Gandour et al. 1995, Hughes et al. 1983, Ross et al. 1988, Weintraub et al. 1981). We also tested one version of the hypothesis that the RH controls spectral attributes of prosody (e.g. \( F_o \)), whereas the LH is dominant for temporal parameters (Danly and Shapiro 1982, Gandour et al. 1989, Robin et al. 1990, Van Lancker and Sidtis 1992). It is important to point out that the original hypothesis concerning differential lateralization for spectral and temporal cues was formulated based largely on psychoacoustic data testing temporal contrasts of a different nature than that measured in the present investigation. However, in speech production studies with LHD aphasic patients, impairments in temporal control have been revealed at both the segmental level and the utterance or sentence level, indicating that speech timing at all levels may be a function of the LH, thereby justifying the extension of the original differential cue lateralization hypothesis to broader temporal parameters. The major findings of the acoustic analyses conducted do not provide compelling support for either hypothesis in its strong form. In general, both RHD and LHD patients were able to differentiate both linguistic and affective prosodic
attributes associated with specific sentence types in a manner comparable to normal control speakers, raising questions about the role of the RH in the control of prosodic cues at that level.

However, there was some evidence that the RH may be involved in the global control of certain prosodic parameters. In particular, in the repetition task, the average $F_0$ of the RHD subjects was lower than that of the normal controls (and the LHD subjects) for the affective stimuli, consistent with previous studies (Colsher et al. 1987, Shapiro and Danly 1985). In addition, $F_0$ range was narrower for the RHD subjects relative to the normal controls for both affective and linguistic stimulus sets (Colsher et al. 1987, Ross et al. 1988, Shapiro and Danly 1985). The restriction in $F_0$ range coupled with the reduction in average $F_0$ may contribute to the clinical perception of flattened affect in these patients. Although no formal assessment of speech quality was performed, at least four of the seven RHD patients were reported to have impaired affect in clinical reports. The findings point to a possible low-level implementation deficit in the gross control of $F_0$ via laryngeal mechanisms; the ability to modulate $F_0$ to signal both linguistic and affective prosodic distinctions appears unaffected. Interestingly, such group differences did not emerge in the reading task, which may indicate that the RHD subjects may have had difficulty perceiving the $F_0$ pattern as required for accurate repetition, but not for reading (but cf. Pell and Baum 1996). Alternatively, performance in the reading task may not be representative of spontaneous speech (where breakdowns presumably occur), which may be more closely approximated by the repetition task.

A second difference among the groups emerged in the examination of relative amplitude data in the reading task. Within the linguistic stimuli, the amplitude values computed for the RHD speakers were higher than for the normal speakers; however, no differences in patterns across sentence types or conditions emerged. In contrast, within the affective stimuli, although the normal subjects consistently produced sad sentences with lower amplitude than happy and angry sentences in both nonsense and semantic conditions, the RHD speakers only exhibited amplitude differences across emotion types in the semantic condition. Without the benefit of full semantic cues, the RHD subjects did not display a normal pattern of amplitude changes in sad relative to happy and angry sentences. These findings (weakly) suggest that the RHD patients may be impaired in the production of affective prosody in the absence of semantic supports. However, this claim must be considered highly speculative because the so-called impairment was apparent in only one acoustic parameter and in the reading task alone.

Although the data for the LHD subjects were based on only four speakers, the same general patterns in acoustic cue use were noted for these individuals as for the normal speakers (Shapiro and Danly 1985). Sentence durations were, not surprisingly, longer than for normal controls, particularly in the reading task. Further, a number of sentence type effects did not emerge in the nonsense conditions for the LHD speakers. This is probably due to the overall difficulty that the subjects experienced in producing the nonsense stimuli. On the whole, like the RHD group, the LHD subjects were capable of appropriately manipulating all of the acoustic parameters examined, indicating no effect of the LH brain damage on the ability to distinguish sentences via prosodic cues. Nonetheless, it should be recalled that the group included only those patients who could perform the rather complex tasks, thereby possibly limiting the generalizability of the findings. It
should also be noted that subjects in both patient groups were tested in a presumably stable, chronic phase of their disorders (> 3 months post-onset); it is conceivable that prosodic deficits may have existed in the acute stage and have resolved prior to testing. However, most studies of neurologically impaired populations (including previous experiments in this area) test patients at least 3–6 months post-onset, to avoid the confounding effects of oedema and spontaneous recovery. Theories of lateralization emerging from cognitive neuropsychological studies have generally been based on patients with such chronic deficits.

The results of the acoustic analyses for both the repetition and reading tasks were quite comparable in a general sense. With respect to linguistic prosody, declarative sentences were reliably longer than interrogatives across conditions and groups. Declaratives were also produced with lower mean $F_0$ relative to the interrogatives and imperatives, and with a narrower $F_0$ range (Behrens 1989, Lieberman 1967, Shapiro and Danly 1985). Much of this difference in $F_0$ may be due to the terminal rise present in interrogatives (and possibly a higher starting $F_0$ and/or higher stress peaks in imperatives). Finally, declaratives also were produced with lower amplitude than interrogatives and imperatives. A higher relative amplitude in imperatives relative to declaratives is not surprising; however, there is no obvious explanation for the higher amplitude in the interrogative stimuli.

Consistent with previous findings, subjects in the present investigation produced sad sentences with lower amplitude than happy and angry sentences. Sad sentences also were produced with a lower mean $F_0$, as well as a narrower range of $F_0$ when compared to happy and angry utterances (Scherer 1986, Scherer and Oshinsky 1977, Williams and Stevens 1972). These patterns held across conditions, across tasks, and across subject groups. An additional consistent finding was shorter durations for the angry stimuli relative to the other emotion types. Previous investigations have reported a tendency for shorter durations in happy sentences as well, as noted in the introduction (Scherer 1986, Scherer and Oshinsky 1977). The contradictory results may reflect differences in the overall length and complexity of the specific utterances under analysis. Further, the acoustic attributes that characterize different emotions are not yet fully understood, and differences in duration may not be consistently produced.

For the most part, the manipulation of stimulus set condition did not differentially affect the subject groups. Interestingly, few two-way (group $\times$ condition) or three-way (group $\times$ condition $\times$ type) interactions emerged (but see earlier discussions of relative amplitude), and the condition main effects that did prove significant were not surprising. For example, durations of nonsense stimuli were longer than well-formed stimuli because of the difficulty subjects encountered in producing the unfamiliar strings. Across groups, the well-formed stimuli yielded results most consistent with expectations.

In sum, in contrast to a number of recent studies (e.g. Gandour et al. 1995, Hughes et al. 1983, Ross et al. 1988), but not all (Cooper et al. 1984, Ryalls et al. 1987), the RHD patients in the current investigation were capable of controlling $F_0$, duration, and amplitude to differentiate emotions and linguistic sentence types regardless of task demands, despite small deviations in the gross control of overall $F_0$. These data are in keeping with the findings reported by Pell and Baum (1996) for receptive affective prosody using the same stimuli. In that earlier study it was suggested that specifics related to patient characteristics and variability in lesion sites might have contributed to the unexpectedly normal performance of the RHD.
subjects on the affective tasks. These potential explanations are also applicable in
the present investigation. The results of the acoustic analyses described herein lead
us to seek out other than the standard theories of prosodic lateralization (e.g. Van
Lancker 1980, Van Lancker and Sidtis 1992). For example, the production of both
linguistic and affective prosody may be under the control of subcortical structures
not implicated in most of the lesions of the participants in the present study (e.g.
only very limited data were available, from a review of individual patient
performance there was no clear pattern associating degree of impairment with
particular lesion sites. Nor was there an apparent relationship between clinical
evidence of prosodic processing deficits and the ability to produce the acoustic
parameters examined.

It is interesting to note, as highlighted by Gandour et al. (1995), that impairments
in the production of affective prosody have been more consistently reported for
speakers of tone languages than non-tone languages (Gandour et al. 1995, Hughes
et al. 1983, Ross et al. 1992). It is thus possible that the strength of laterality effects
may depend in part on phonological structure. Future cross-linguistic studies
should help resolve this issue.

It is essential that the concept of dysprosody be clearly defined across
investigations. For instance, in the current study it should be reiterated that the
RHD patients did exhibit several global differences from the normal speakers
consistent with flat affect. Mean $F_0$ and $F_0$ range were reduced in the RHD
population relative to both LHD subjects and normal controls. Despite these
prosodic deviations the patients were still capable of differentiating the linguistic
and affective stimuli. Taken together, the findings support a role for the RH in the
global (perhaps motor-level) control of $F_0$; a breakdown in the production of
affective and linguistic prosodic cues, however, does not necessarily result from
RHD. It would be interesting, in future investigations, to determine whether the
aesthetic parameters manipulated by the brain-damaged speakers yield utterances
which are as perceptually distinct (in terms of prosodic cues) as those of normal
speakers. Continued research that attempts to correlate particular neural regions
with prosodic production and comprehension across languages is clearly needed.

Acknowledgements

This work was supported by grants from the Medical Research Council of Canada
and the Fonds de la Recherche en Santé du Québec. The comments of the reviewers
are also acknowledged.

References

Behrens, S. (1988) The role of the right hemisphere in the production of linguistic stress. Brain and
Language, 33, 104–127.


emotional communication. Brain, 114, 1115–1127.


prehension of emotional prosody following unilateral hemispheric lesions: processing defect
Affective and linguistic prosody after brain damage 197


