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Perceptuo-acoustic assessment of prosodic impairment in dysarthria

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Abstract

Dysprosody was studied in four groups of male subjects: subjects with amyotrophic lateral sclerosis (ALS) and mild intelligibility impairment, subjects with ALS and a more severe intelligibility loss, subjects with cerebellar disease, and neurologically normal controls. Dysprosody was assessed with perceptual ratings and acoustic measures pertaining to the regulation of duration, f_0, and intensity within tone units of conversational samples. Intelligibility reduction and prosodic disturbance were not necessarily equally impaired in all subjects, and it is concluded that these are complementary indices of severity of dysarthria. Compared to the neurologically normal control group, the clinical groups tended to decrease the overall duration of tone units, produce fewer words in a tone unit, and use smaller variations in f_0. Recommendations are offered for the assessement of prosody in dysarthria.

Keywords: dysarthria, prosody, intelligibility.

Introduction

Dysprosody has been defined as 'a phonetic disorder whereby control of the prosodic variables (F_0, Intensity, Duration and Silence and hence Pitch, Loudness, Length, and Pause) is impaired as a result of a neuro-physiological inability to programme or implement motor gestures' (Brewster, 1989: 179). This definition hints at the difficulties that accompany attempts to describe dysprosody in individual patients. Prosody is multidimensional in its attributes and therefore not easily reduced to a small set of measures or even a small set of speaking tasks. Dysprosody is a common feature of dysarthria and often is pre-eminent in perceptual descriptions of these

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disorders (Darley, Aronson and Brown, 1969a,b; Kent and Rosenbek, 1982; Ackermann, Hertrich and Ziegler, 1991; Robin, Klouda and Hug, 1991; Duffy, 1995; Lowit-Leuschel and Docherty, 1999). However, it is also one of the most challenging facets in the analysis of dysarthric speech. The analysis of dysprosody is complicated because: (1) speech materials that are the most sensitive to prosodic abnormalities (e.g. conversation) are also the most difficult to analyse; (2) there is no clear consensus on perceptual, acoustic, physiological or linguistic systems for the analysis of dysprosody; and (3) the nature of dysprosody may vary with stimulus–response variations and with the type and severity of dysarthria (and perhaps even the emotional state of the individual being examined). These issues are examined briefly in the following.

Speech materials

Prosodic characteristics appear to differ between passage reading and conversation. In reviewing this literature, Leuschel and Docherty (1996) concluded that 'speech performance in a structured task such as reading, as measured by a range of prosodic parameters, may not be wholly representative of performance in a more naturalistic task such as conversation' (p. 164). However, the analysis of prosody in conversation is complicated by the lack of control over properties of the utterances, including length, syntactic structure, and phonetic constituents. If conversation is selected for prosodic analysis, then the measures should be amenable to diverse conversational patterns that reflect not only the immediate consequences of neurological disease (e.g. weakness, slowness, tremor or rigidity) but also compensations that the speaker makes in response to the neurological disruptions, such as short phrases and syntactic-lexical simplifications.

Analysis method

There is no commonly accepted procedure for the efficient analysis of prosody in disordered speech. Furthermore, as Lowit-Leuschel and Docherty (1999) commented, the prosodic analyses developed by linguists (see Cruttenden, 1997, for a recent review) have not been applied clinically, at least not in the recently published literature. One approach to the analysis of dysprosody is based on considerations of tone units (or prosodic phrases or breath groups) and f_0 regulation. Schlenck, Bettrich and Willmes (1993) reported that individuals with severe dysarthria had shorter tone units and higher mean f_0 than individuals with either mild dysarthria or no neurological disease. The subjects with mild dysarthria had smaller variations of f_0 than either severely dysarthric individuals or neurologically normal controls.

Leuschel and Docherty (1996) analysed dysprosody with a multidimensional approach including considerations of the following: articulation rate, mean pause duration, number of pauses, articulation/pause time ratio, mean length of utterance, mean utterance duration, mean unstressed vowel duration, percentage of unstressed vowels, intensity range, intensity envelope, f_0 mean, f_0 range, f_0 envelope, and f_0 intra-vowel variation. In comparing data for reading vs conversation they determined that the differences between individuals with dysarthria and neurologically normal control subjects were greater for conversation than for reading. The authors concluded: 'Results from both the present and the previous studies have therefore shown that it is important to investigate the performance of dysarthric speakers in different sorts of elicitation tasks, structured and unstructured, in order to arrive at a complete evaluation of individual patients' abilities' (p. 166).

A common feature of recent analyses of dysprosody is the combined use of perceptual and instrumental (especially acoustic) methods (Lowit-Leuschel and Docherty, 1999). Although perceptual and instrumental methods can be used separately, a powerful interactive benefit can result from their combined application. In particular, perceptual methods provide a useful framework (e.g. tone-unit analysis) within which acoustic or physiological analyses can be interpreted. The work by Schlenck *et al.* (1993) is a good example. Although acoustic methods are useful for quantification of prosodic variables, it is usually necessary that the unit of prosodic analysis be determined perceptually.

Interaction of dysprosody with type and severity of dysarthria

Adding to the problem of dysprosody analysis is the possibility that prosodic impairment differs with the type of dysarthria and, within type, with the severity of the speech disorder. This issue certainly needs to be investigated further. For the moment it should be noted that the assessment of severity is a subject of some controversy, and various definitions and rating methods have been proposed. It is not necessarily the case that prosody can be clearly distinguished from an accompanying segmental disorder, because disturbances at the level of the phonetic segment can alter the prosodic relief of an utterance. As noted previously, Schlenck *et al.* (1993) observed an interaction between severity of dysarthria and the nature of f_0 regulation within tone units. Such an interaction indicates that any conclusions regarding dysprosody in patients with dysarthria must be accompanied by a description of severity. The variation of prosodic characteristics with severity can strongly constrain the selection of acoustic or physiological measures. Because severely dysarthric individuals tend to produce shorter tone units than do mildly impaired individuals, prosodic features may differ between severe and mild dysarthrias simply because of the different lengths of tone unit. Furthermore, it is likely that reductions in the size of tone unit have implications for syntactic organization of utterances—for example, a simplification of syntactic structure.

Rationale for current study

The work by Schlenck *et al.* (1993) and Leuschel and Docherty (1996) is instructive concerning the development of efficient and informative approaches to the study of dysprosody. The present study extends the work of Schlenck *et al.* in the following ways.

First, Schlenck *et al.* studied a mixed group of dysarthric patients, with the group being dominated by spastic, mixed and non-classifiable types of dysarthria. Can their results be generalized to other types of dysarthria, such as ataxic and the mixed spastic–flaccid type seen in amyotrophic lateral sclerosis? It is important to know if distinct profiles of dysprosody can be established for patients classified with respect to neurological lesion, type of dysarthria, severity of involvement, or some combination of these. Published studies do not permit a confident analysis of prosodic disturbances for major categories of neurological disorder.

Second, Schlenck *et al.* studied only tone-unit length and f_0 statistics determined within tone units. A more complete picture of dysprosody might be obtained with additional measures of relative intensity and the temporal duration of tone units. With these additional features dysprosody can be described in terms of f_0 and intensity variations within tone units that are expressed in words/second (or syllables/second) and/or duration.

Third, Schlenck *et al.* classified dysarthric subjects as either mild or severe, depending on judged intelligibility. Because their severity classification was useful in describing features of dysprosody, it seems appropriate to use a similar classification in further investigations. However, one caveat should be noted. Although intelligibility is one index of severity, it is likely that intelligibility reflects primarily the segmental aspects of speech, that is, precision of vowel and consonant articulation. Some individuals with a relatively severe dysprosody may, in fact, be reasonably intelligible if their articulatory skills are preserved. Indeed, the term *aprosodia* as used by Ross and colleagues (Ross and Mesulam, 1979; Ross 1981a,b; Ross, Harney, deLacoste-Utamising and Purdy, 1981) often applies to individuals who did not have severely compromised intelligibility but have difficulties in the emotional–melodic aspects of speech. The temporal pattern of abnormalities also may determine the perceived degree of severity. Seikel, Wilcox and Davis (1990) concluded that clinicians' judgements of severity are based more on the slowly varying components of the temporal pattern of speech rather than the rapidly varying temporal features such as stop bursts and voice-onset times. It seems appropriate, therefore, to consider at least two dimensions of severity, one indexed by measures of intelligibility and another by ratings of prosody. This objective must be approached with the recognition that measures of intelligibility may interact with prosodic aspects.

Procedures

Subjects

Data were obtained for four groups of male speakers: (1) five speakers who had no history of neurological disease (NG); (2) 10 speakers diagnosed with amytrophic lateral sclerosis (ALS) divided into two groups of high intelligibility (ALS1) and moderate intelligibility (ALS2); and (3) five speakers diagnosed with acquired cerebellar disease (CD). All subjects were recruited as part of a larger study of dysarthria related to various neurological aetiologies. Subject information (age, diagnosis, duration of disease, intelligibility score, and relevant neurological data) is summarized in table 1. The intelligibility score was derived from a multiple-choice word-identification test developed specifically for dysarthric speakers (Kent, Weismer, Kent and Rosenbek, 1989). The primary interest in subject selection was that the patients had a speech disorder charactarized by dysarthria. The neurologically normal controls were older males, selected to match the general ages of the clinical subjects but also to control the ageing effects on speech and voice. The ALS subjects were divided into two subgroups based on their scores on the intelligibility test. Speakers with intelligibility scores of 85% or higher were classified as having high intelligibility, and speakers with scores ranging between 60% and 83% were classified as moderately intelligible. It was discovered in preliminary work that speakers with very low intelligibility scores presented difficulties in prosodic analysis using conversational samples. Therefore, subjects with at least moderate levels of intelligibility were selected.

Table 1. *Subject characteristics: identification number, age (years), duration of disease (years), intelligibility score (percentage of words correctly identified by a panel of 10 listeners), and neurological findings*

Subject	Age	Duration	Intelligibility	Neurological findings
NG-1	68	NA	98.5	
NG-2	74	NA	98.1	
NG-3	69	NA	97.5	
NG-4	77	NA	94.5	
NG-5	68	NA	94.3	
ALS1-1	51	2	99.1	
ALS1-2	67	3	95.2	
ALS1-3	29	2	93.8	
ALS1-4	55	1	92.7	
ALS1-5	40	0.5	85.0	
ALS2-1	62	1	83.4	
ALS2-2	63	1	83.0	
ALS2-3	41	2	78.5	
ALS2-4	75	2	64.9	
ALS2-5	31	3.5	62.9	
CD-1	37	16	96.0	Spinocerebellar degeneration; atrophy of cerebellum, especially the vermis
CD-2	38	8	95.0	Posterior fossa tumour, medulloblastoma resection
CD-3	65	0.25	92.0	Olivopontocerebellar degeneration
CD-4	57	28	90.0	Spinocerebellar degeneration
CD-5	71	Unknown	86.0	Bilateral strokes, ischaemic areas in left inferior cerebellum

NG = neurologically normal control group; ALSI = subjects with ALS and good intelligibility; ALS2 = subjects with ALS and poor intelligibility; CD = subjects with cerebellar disease.

Analysis methods

The procedures for prosodic analyses were based largely on those described by Schlenck *et al.* (1993). These are numbered 1–4 in the following list. Extended data analyses (not used by Schlenck *et al.*) are included in numbers 5 and 6.

(1) Obtain intelligibility estimates (intelligibility %) using a word-identification test for the subjects to be studied.
(2) Select samples from recordings of spontaneous speech (at least 3 min of conversation).
(3) Determine the lengths of tone units in the samples (TU words). For the clinical groups the tone unit was typically the same as the breath group, i.e. the intonation pattern was bounded by the breath group. Words, rather than syllables, were used as the analysis unit because (a) the word is an informational unit in conversational analysis, and (b) telescoping and irregular articulatory breakdowns complicate the use of a syllable-based measure in some dysarthrias (especially ataxia dysarthria). This is not to say that words are always the preferred unit in intonational analysis, but simply that words are preferred in this study as a first look into the prosodic aspects of conversation for this particular group of subjects.
(4) Measure the following for each tone unit using Cspeech (a computer program for acoustic analysis of speech; Milenkovic 1992):

(a) f_0 mean, mean fundamental frequency (f_0) in Hz:
(b) f_0 SD, standard deviation of fundamental frequency in Hz; and
(c) f_0 variation, highest and lowest values of fundamental frequency in each sample.

These values (c) were used to calculate the f_0 range for the utterance (f_0 variation in Hz).

(5) Measure also with CSpeech:

(a) duration of tone unit in seconds (TU duration); and
(b) variation in relative peak intensity of syllables in a tone unit (intensity range).

Note: CSpeech computes and displays contours for fundamental frequency and intensity. Numerical values for either variable can be read off the screen at cursor-selected positions along the time axis. The algorithm for fundamental frequency extraction is robust and worked satisfactorily for the subjects in this study.

(6) Obtain ratings of dysprosody on a five-point scale (dysprosody rating).

The intelligibility test is described eleswhere (Kent *et al.* 1989) and has been used in several studies of dysarthric speech. The utterances selected for prosodic analysis were taken from a conversational sample obtained by an interviewer. Conversational topics varied widely but typically included a description of personal activities. There were no criteria for utterance inclusion, except that brief question-and-answer exchanges and interjections were excluded due to the limited production. Sets of 20 utterances were analysed for each subject, for a total of 300 utterances. The f_0 and intensity measures were made with the automatic pitch/intensity tracking algorithm (CSpeech) over the entire utterance. Contours were then manually measured to correct for implausible values (such as doubling of f_0 values).

In considering ways by which disordered prosody could be rated perceptually, we followed a prosodic categorization described by Gerken and McGregor (1998). Their approach defines prosody as referring to three general types of phenomena in language: phrasal stress, boundary cues and meter. Phrasal stress is the phenomenon of word prominence in a phrase; that is, the accentuation of one word in a group of words. Boundary cues are pauses, changes in duration, or adjustments of pitch that mark the ends of language units. Meter (or rhythm) is the patterns of stressed and unstressed syllables for words or phrases. These are interrelated phenomena in the prosodic pattern of speech. Meter essentially defines the rhythmic flow of an utterance as a sequence of alternating strong–weak syllables. This sequence is interrupted or modulated by boundary cues at the ends of linguistic units, especially phrases or sentences. Within any given phrase the speaker selects one word to receive special prominence or salience, thereby determining a phrasal stress pattern. One advantage to this classification is that it has potential for acoustic validation in so far as acoustic measures are available to document the prosodic dimensions (e.g. duration of a final word in a phrase as a boundary cue).

In accord with this system, conversational prosody was rated with a five-point equal-appearing interval scale for four dimensions: overall prosody, meter (rhythm), phrasal stress and boundary cues. Ratings were based on the entire conversational sample for each subject (minimum duration of 3 min). The value of 5 was defined as optimal prosody and 1 as greatly impaired or deviant prosody. The ratings of the dimension of overall prosody are emphasized in this report because they constitute a global measure of impairment and because ratings of the other dimensions appeared to follow the overall prosody rating quite closely (within 1 scale point in 90% of the judgements). Ratings were obtained from two judges highly familiar with dysarthric speech (K.B. and R.D.K.). Their agreement was considered acceptable, with 55% of their values being in exact agreement, 40% within 1 scale point, and 5% within 2 scale points. A mean of the two ratings was used as a general score of prosodic disorder.

Results

Summary data for the four groups are compiled in table 2. As expected, the NG subjects had the highest intelligibility (but tied with the ALS1 subjects) and the best overall prosody ratings. The ALS1 group was only slightly impaired in prosody relative to the NG subjects. The CD subjects had slightly lower intelligibility scores than the NG subjects but had a poorer prosody rating. The ALS2 subjects were the most severely involved, with poor intelligibility scores and a low prosody rating. The results for the CD and ALS2 subjects underscore the point that dysprosody and intelligibility deficit are somewhat independent dimensions. Figure 1 shows the individual associations between dysprosody ratings and intelligibility scores. Although there is a very general relationship between the two values across the total group of subjects, some subjects (especially in the CD group) with relatively intact intelligibility were judged to have poor prosody. The ALS2 group had impairments of both intelligibility and prosody.

Table 2 also shows that the major differences between the control and clinical groups are that the control speakers had a longer tone unit duration, a larger number of words in a tone unit, a smaller average duration of a word in a tone unit, and a greater range of f_0. That is, the clinical groups tended to decrease the overall duration of tone units, produce fewer words in a tone unit, and use smaller variations in f_0. Variations in mean f_0 are not clearly related to group characteristics, especially because of large inter-subject variability within groups.

The box plots in figures 2–4 depict the major differences in prosody between the control group and the clinical groups. The tone-unit ratio (the average tone-unit duration divided by the average number of words in a tone unit) was larger in all of the clinical groups than in the NG control group (figure 2), even though the ALS1 and CD groups had levels of intelligibility close to that of the NG group. But within the relatively shorter units and words they produced, the NG subjects

Table 2. *Group statistics for prosodic measurements*

	ALS1	ALS2	CD	NG
Intelligibility (%)	96 (3)	74 (10)	92 (4)	96 (3)
Dysprosody rating	4.2 (1.0)	2.4 (0.4)	3.0 (0.9)	4.4 (0.4)
TU (words)	7.7 (3)	4.6 (2)	5.7 (1)	9.3 (3)
TU duration (s)	2.4 (0.19)	2.1 (0.67)	2.1 (0.57)	2.6 (0.95)
TU ratio (ms/word)	317	464	367	283
f_0 mean	110 (6)	119 (28)	126 (11)	113 (27)
f_0 variation (Hz)	49 (8)	72 (41)	46 (6)	143 (46)
Intensity range	0.75 (0.3)	0.54 (0.3)	0.70 (0.6)	0.61 (0.3)

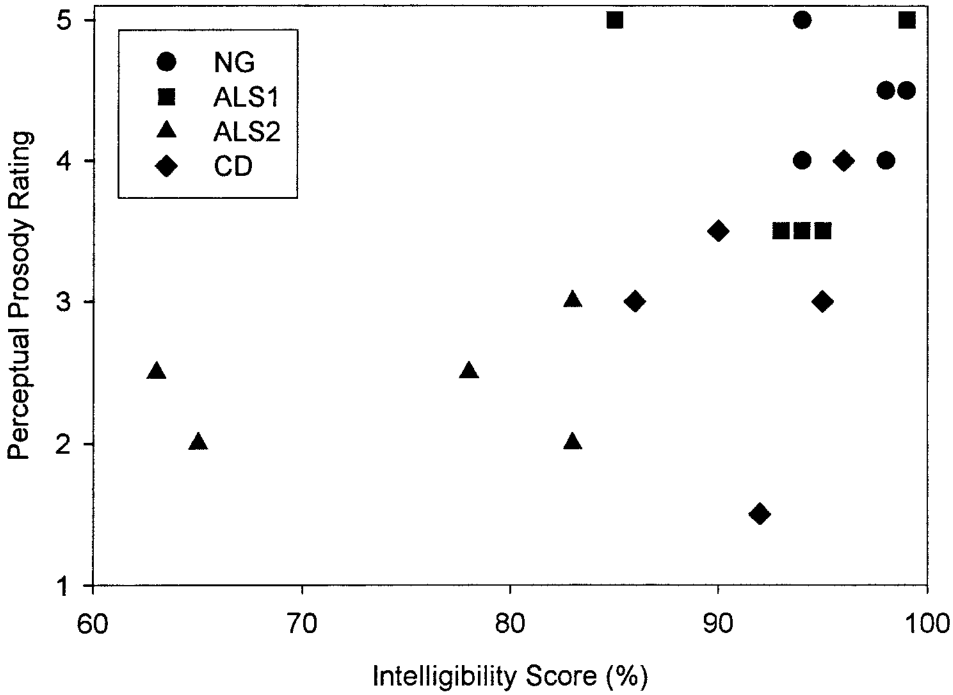

Figure 1. *Scattergram showing the relationship between word intelligibility scores and prosody rating for individual subjects.*

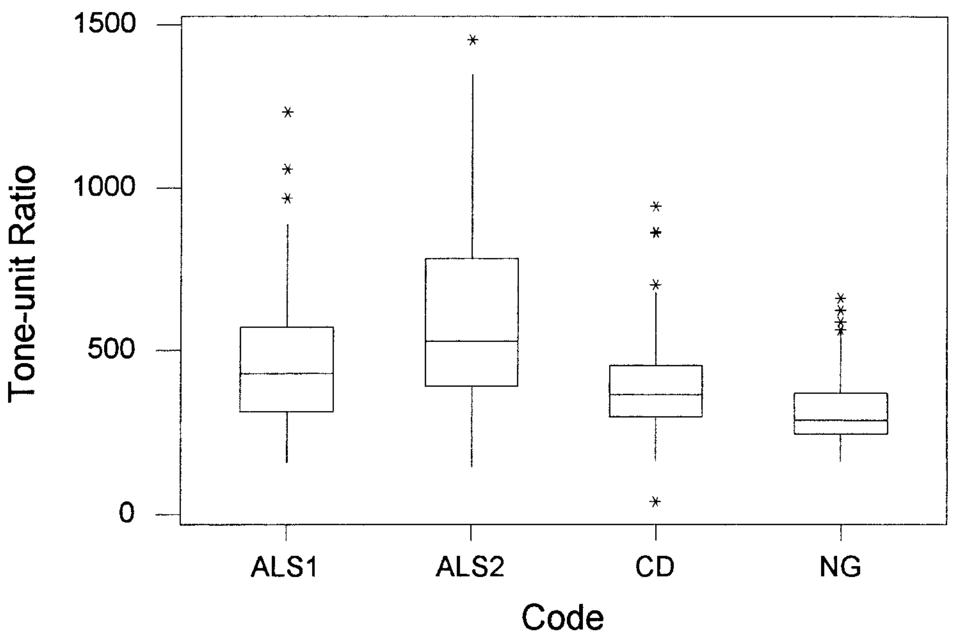

Figure 2. *Box plot for tone-unit ratio (the average tone-unit duration divided by the average number of words in a tone unit) for the four subject groups. The data reflect 20 tone units analysed per subject.*

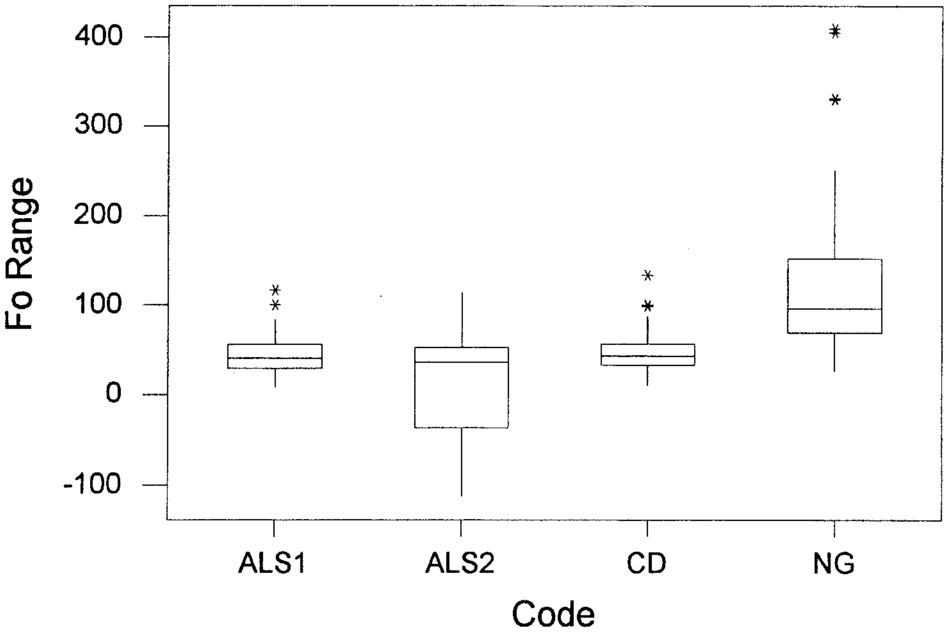

Figure 3. *Box plot for range of* f_0 *for the four subject groups.*

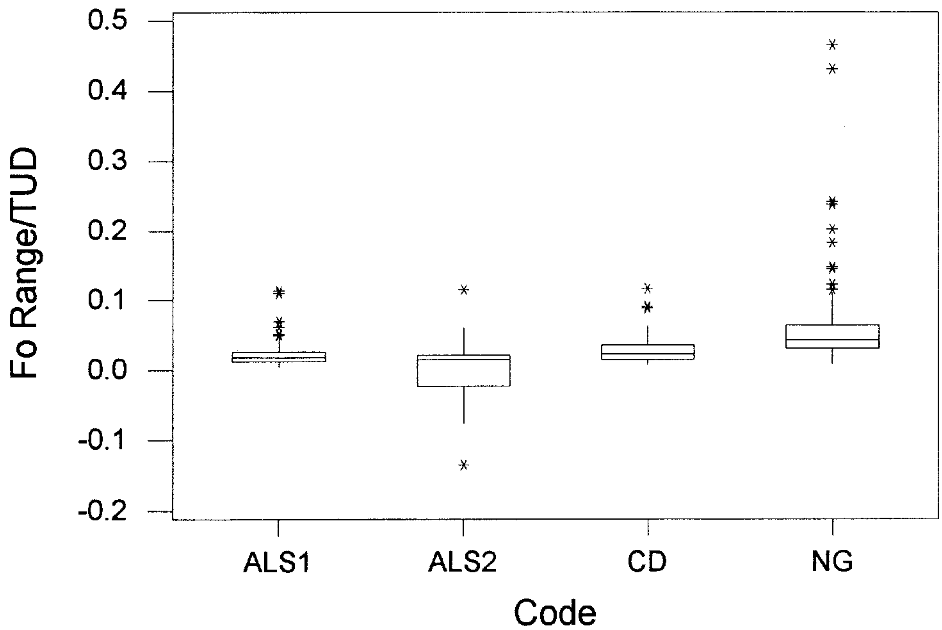

Figure 4. *Box plot for the ratio of the average* f_0 *range divided by the average tone-unit duration (an index of* f_0 *temporal regulation) for the four subject groups.*

manifested a greater range of f_0 than the three clinical groups (figure 3). A measure of the dynamic regulation of f_0, expressed as a ratio of the average f_0 range divided by the average tone-unit duration, shows that although mean values are comparable across subject groups, the variability for the clinical groups is clearly reduced (figure 4).

Discussion

Analysis of dysprosody within tone units was both feasible and useful descriptively for the study of conversational samples produced by the dysarthric subjects studied in this report. Tone units permit a structured analysis that can be interpreted relative to physiological factors (such as breath-group management), acoustic parameters (especially the intonation contour and durational adjustments for phenomena such as phrase-final lengthening) and language formulation (including considerations as to the length and complexity of syntactic structures). Some aspects of prosody can be affected even in patients who have only a mild impairment of intelligibility. For example, although the ALS1 and NG groups had clearly identical mean intelligibility scores, they differed with respect to the number of words in a tone unit, the duration of tone units, the duration of words in a tone (tone unit ratio in table 2), and variation in f_0. The subjects in the CD group also had relatively good intelligibility (mean of 92%) but impaired prosody (mean rating of 3.0).

Dysprosody presumably is a manifestation of dysarthria, but the relationship probably varies with type of dysarthria. It is likely that, in some adjustments, intelligibility and prosody tend to be affected in parallel. However, in other dysarthrias, disturbances of intelligibility and prosody may be different in degree and perhaps in their progression. If the pattern of results observed in figure 1 can be generalized to other dysarthrias, it could be concluded that wide variations of prosody occur for subjects with slight to moderate levels of intelligibility impairment. This would underscore the importance of obtaining measures of both intelligibility and prosodic disturbance in gauging the severity of a speech disorder. Ultimately, severity perhaps should be understood in terms of at least reduced intelligibility, impaired prosody and disordered voice quality. These three dimensions would appear to account for the primary deficits that can be assessed perceptually and through instrumental measures.

It is also clear that detection of prosodic disturbance is highly task-sensitive. As noted by Leuschel and Docherty (1996), conversation may be the speaking task that is most sensitive to the various dimensions of dysprosody. A task such as single-word production, often used to derive segment-based measures of intelligibility, is probably only weakly sensitive to dysprosody. The proper examination of the co-dependency between intelligibility reduction and prosodic disturbance will probably require careful and extensive analysis of conversational samples. One approach is to use a transcriptional analysis for intelligibility assessment, in which case intelligibility is scored as a percentage of words correctly recognized. This procedure generally works well enough with speakers who have mild or moderate speech impairments, but in our experience the analysis can become highly uncertain with speakers who have a severe dysarthria. Unfortunately, the analysis of conversational samples produced by persons with dysarthria is highly under-represented in the literature. Deviant prosodic patterns in dysarthria may contribute to reduced intelligibility, especially if prosody contributes to spoken word recognition (Cutler and Butterfield, 1992; Cutler, Dahan and Van Donselaar, 1997; Grosjean and Gee, 1987). At least with respect to the hypokinetic dysarthria in Parkinson's disease, it appears that reduced syllabic contrastivity (a form of dysprosody) contributes to reduced intelligibility, especially when articulatory precision is compromised (Liss, Spitzer, Cavinnes, Adler and Edwards, 1998). Liss *et al.* concluded that stressed syllables and the rhythmic pattern of speech are important in the listener's segmentation of speech into words. If the normal salience of stressed syllables is weakened, the listener's task is made more difficult.

Prosodic disturbance may be rooted in factors other than a frank motor dysregulation of the respiratory, laryngeal and supralaryngeal systems. For example, it has been suggested that prosodic disorder in Parkinson's disease results from a failure to process emotion (Scott, Caird and Williams, 1984). However, other studies have not confirmed this interpretation (Darkins, Fromkin and Benson, 1988; Caekebeke, Jennekens, Van der Linden and Buruma, 1991). Because very few studies have compared expressive and receptive aspects of prosody in dysarthric patients the degree of association is unclear. A full understanding will require an analysis of dysarthric speech samples in terms of both prosodic and paralinguistic patterns.

This study is but one step towards the design of an efficient and informative analysis of dysprosody. It is recommended that future work should obtain data for (1) additional types of dysarthria (classified by dysarthria type, medical diagnosis, or both); (2) more than one measure of severity (including at least an intelligibility score and a prosody score). Although it is premature to exclude any potential acoustic measures, it appears that data on duration and f_0 analysed within and across tone units are especially valuable. It may prove fruitful to analyse dysprosody according to the three categories of phrasal stress, boundary cues, and meter (Gerken and McGregor, 1998). These categories may be the means to coordinating instrumental data with perceptual and linguistic descriptions of prosodic structure. Finally, progress will await the collection of data for large numbers of subjects with various types of dysarthria. The present investigation is viewed as a feasibility study to help determine the kinds of perceptual and acoustic measures that should be obtained for a satisfactory analysis of dysprosody.

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