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Acoustic analysis of neurologically impaired speech

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ABSTRACTS

The acoustic phonetic analysis of neurogenically disordered speech permits considerable insights into the detailed nature and possible origin of such disorders. Representative results obtained with a concise speech protocol, comprising spontaneous speech, diadochokinesis, phoneme distinction, rhythm and intonation, are illustrated. Disorders at the supralaryngeal, laryngeal and durational levels are distinguished. This non-invasive technique reveals aspects of speech disorders that are difficult or impossible to perceive auditorily. This research is part of a general computer-based diagnostic approach presently under development in our laboratory.

L'analyse phonétique acoustique de la parole affectée par des perturbations neurologiques permet une compréhension de la nature et des origines de telles perturbations. Nous illustrons des observations caractéristiques, obtenues au moyen d'un protocole concis comportant la parole spontanée, la diadochocinésie, la distinction phonémique, le rythme et l'intonation. Les perturbations sont distinguées selon leur affectation aux niveaux du conduit vocal supralaryngé et laryngé et de l'organisation temporelle. La présente technique non-invasive révèle des aspects des perturbations qui sont difficiles ou impossibles à percevoir auditivement. Cette recherche fait partie d'une approche diagnostique informatisée plus large qui est actuellement sous développement dans notre laboratoire.

Die akustische phonetische Analyse von neurologischen Sprechstörungen ermöglicht ein Verständnis der detaillierten Natur und des möglichen Ursprungs solcher Störungen. Charakteristische Resultate werden wiedergegeben, die durch eine kurze Untersuchung der Spontansprache, der Diadochokinese, der Phonemunterscheidung, des Rythmus und der Intonation ermittelt wurden. Störungen auf den Ebenen des supralaryngalen und laryngalen Sprechtraktes, sowohl wie auch der temporalen Organisation des Sprechflusses, werden unterschieden. Diese nicht-invasive Technik zeigt Aspekte von Sprechstörungen, die auditorisch nur schwer oder überhaupt nicht erkennt werden können. Diese Forschung ist ein Unterteil eines komputer-basierten diagnostischen Ansatzes, der zur Zeit in unserem Labor entwickelt wird.

Key words: acoustic analysis, neurogenically disordered speech, computer-based approach.

INTRODUCTION

Over the last several years, we have studied neurologically impaired speech with two objectives: one theoretical and one clinical. Within the theoretical perspective, the speech of different patient groups has been examined to test hypotheses concerning various aspects of real-time speech motor processing (Keller, 1987a, 1987c, 1989, 1990c). Within a clinical perspective, an instrumental evaluation of the acoustic speech signal of neurologically impaired patients has been developed. This procedure involves four components: (1) a brief (20-minute) *test protocol* ('Speech Examination' or 'SE', Keller, 1990a), (2) a specially adapted computer program (Keller, 1990b), (3) an *analysis procedure* for acoustic observations in neurologically impaired speech (Keller, 1990a), (4) the *systematic and statistical evaluation* of results obtained with several patient groups.

At this point, the first three components of the procedure are essentially in place. The aim of the present document is to survey the procedure, and to present a few representative results from both a descriptive and a graphic perspective. A previous review of neurogenic speech disorders (Keller, Ladouceur, Vachon, Audet & Chartrand, 1987a, 1987b) presents some of the historical antecedents of the present discussion.

The Acoustic Analysis

A number of reasons motivate the choice of an instrumental acoustic approach over a perceptual or instrumental articulatory analysis of neurologically impaired speech. Many researchers (including the first author of this paper) have previously examined motor speech disorders by means of EMG, laryngoscopy, ultrasound, X-ray film and X-ray microbeam (e.g. Itoh, Sasanuma, Tatsumi, Murakami, Fukusako & Suzuki, 1982; Keller, 1987b, 1987d; Hunker & Abbs, 1984 and many others). Also, important efforts have been devoted to developing a clinically useful perceptual evaluation procedure for neurologically impaired speech (Darley, Aronson & Brown, 1975). It is thus legitimate to inquire why a complete evaluation procedure should be developed exclusively around instrumental acoustic analysis.

At the most fundamental level, it can be argued that the acoustic aspects of speech provide the essential communicative interface between patient and interlocutor. While underlying articulatory performance is of great diagnostic and theoretical importance, a patient's communication or rehabilitation performance is ultimately evaluated with reference to the acoustic and perceptual levels.

Also, instrumental acoustic analysis has clear advantages over purely perceptual judgements. Darley *et al.*'s studies showed that nearly all patients with dysarthria suffer from what is perceived as 'indistinct consonants', 'monopitch' and 'slow speech'. On average, patient groups differed only by a few percentage points with respect to degree of impairment on any – or any combination – of these criteria. Instrumental acoustic analysis, however, promises to provide more detailed and more distinctive details. A systematic analysis of this material may well lead to a more conclusive diagnosis of speech perturbations than was possible with purely perceptual evaluations.

Further, acoustic analysis represents the least expensive and least intrusive instrumental approach to the evaluation of dysarthria. Minimal equipment for this type of evaluation can be obtained for under £2000, and recordings are performed external to the patient's oral cavity. At the same time, this type of analysis provides surprisingly detailed information on the disordered behaviour.

Finally, systematic analyses can be executed in a relatively short time using the approach described below. An evaluation performed for clinical purposes should take no more than two and a half hours, and a research evaluation should not take more than a day and a half.

PROTOCOL OF THE SPEECH PERTURBATIONS

A number of sometimes competing objectives had to be respected in producing a reliable and clinically useful speech examination: (1) the recording time should be as short as possible (due to typical tolerance levels of neurological patients); (2) an adequate sample of the patient's speech characteristics should be tested; (3) the evaluated performance should be clinically relevant, i.e. should be related systematically to severity and/or prognosis of the speech disorder; (4) stimuli ought to present exclusively phonetic difficulties and should exclude semantic and pragmatic difficulties; (5) in bilingual and multilingual environments, largely equivalent versions in different languages should be available; (6) evaluation criteria should be unambiguous; (7) analyses should be brief to execute; and (8) the evaluation must provide statistically reliable results.

The SE (see Appendix) attempts to strike a compromise between these multiple and sometimes conflicting objectives. From a larger preceding version of the protocol, a subset of stimuli has been abstracted; clinical experience suggests a high likelihood that the retained stimuli will evoke speech difficulties in neurologically impaired adult populations. Among these stimuli, core performances are indicated that should be included in all clinical evaluations. Supplementary tasks are also identified; these should be included in a more elaborate clinical evaluation or in an evaluation performed for research purposes.

This examination is concurrently being developed for English, French, German and Finnish with the aim of facilitating comparability of results obtained in different laboratories. In each language, the patient is asked to perform tasks that are representative of the language's native phonology. Only well-established words of the given language are used and loan words involving rarely used phonemes or consonant clusters are not employed. Consequently, tasks are similar from language to language, but differ where necessitated by the patient's native phonology.

Task Presentation

The following are part of the core performances:

1. *Held (prolonged) sounds:* [i:], [ɑ:], [o:], [s:], [z:], [ʃ:], [ʒ:].
2. *Repeated syllables* at two speech rates (normal and fast): [pɑ . . .], [tɑ . . .], [kɑ . . .].
3. Stimuli incorporating a *consonant transition* with a graduated complexity: [ti tɑ tu], [sti stɑ stu], [stri strɑ stru].
4. A *rhythm* task: [pɑ́: pɑ́: pɑ́: pɑ], [pɑ́: pɑ́: pɑ pɑ], [pɑ́: pɑ pɑ pɑ] etc. where [ɑ́] is an accentuated vowel.

5. An *intonation* task: simple high and low tones and floating transitions between high and low tones, simple prosody-bearing lexemes ('mommy?', 'mommy!'), and interrogative sentences.

The supplementary tasks are:

1. *Complex repeated syllables*, starting with a voiced or voiceless plosive consonant and ending in different vowels: [pi pɑ pu], [bi bɑ bu].
2. Simple high frequency, familiar *words* that incorporate the fricative [ʃ] or a consonant transition like [st] and [kt], e.g. 'patience', 'stupid', 'actor'.
3. Simple, easily imageable *sentences* incorporating consonant transition between [ps], [kt] and [pt] in intermorpheme position: 'He came to a stop sign', 'The truck took a turn'.

Performances Examined by these Tasks

Research to be performed in the next few years will elucidate in detail which aspects of speech processing are evaluated by these tasks. A priori, however, it is estimated that the following aspects of speech performance should be brought to the fore by this stimulus material.

Core performances

The objective of the *held sounds* task is to verify the maintenance of stable articulation as well as sustained control of respiration and its coordination with laryngeal and supralaryngeal activity. Some dysarthrics show particular problems with stability in fundamental frequency, sound intensity and formant frequency. The comparison between performance on [s:, ʃ:] and on [z:, ʒ:] is expected to provide particular indications on the capacity to coordinate superior and inferior vocal tract activity, since unvoiced fricatives involve a coordination of respiratory and supralaryngeal activity, while voiced fricatives involve an additional coordination with laryngeal musculature.

The *repeated syllables* task ([pɑ], [tɑ], [kɑ]) first verifies the patient's capacity to alternate between conditions of an entirely closed [p, t, k] and an entirely opened [ɑ] vocal tract. Many patients with neurogenic speech disturbances show excessive difficulties in performing a clearly articulated alternation between the two conditions.

Secondly, the repeated syllables task examines the capacity to impose particular durations on the articulation sequence. Following the instruction to 'speak like a metronome', normal subjects show a low degree of variation on syllable durations, and they produce repetitions at rather regular intervals. By contrast, some neurologically impaired patients show a high degree of variability on syllable durations and on intersyllabic intervals.

Thirdly, the patient's performance for this task provides indications on the distinction of normal and fast speech rates. Some patients cannot maintain a fast speech rate, while others demonstrate less difference between normal and rapid rate than is found in normal subjects.

Finally, this task allows a comparison of occlusions in the anterior and the posterior superior vocal tract. Patients frequently produce well-articulated anterior plosives but inadequately formed posterior plosives.

The *consonant transition task* (consonant clusters, both intra- and intersyllabic) tests the patient's performance with difficulties found in the rapid transitions between one consonant and another. Such clusters are often broken up into component sections or slurred over by patients with neurogenic speech disorders.

The *rhythm* task tests the capacity to perceive and apply to the articulatory level different rhythms and stress patterns. Frequently, particular difficulties are seen in the application of relatively complex rhythm patterns (e.g. [pɑpɑpɑ́:pɑ]), while fewer difficulties are seen with simpler patterns (e.g. [pɑ́:pɑ]).

The *intonation* task tests the capacity to produce an interrogative or a declarative tone pattern ('melody') within a speech utterance. Some patients demonstrate excessively monotone speech and cannot manipulate such prosodic differentiations.

Supplementary performances

Additional tasks are provided to increase the number of observations on a number of tasks, to verify intra-patient observational reliability, and to examine a number of additional speech characteristics.

The word and sentence tasks allow the verification of differences between speech articulation produced with or without linguistic context. Consonant transitions in sentences are at morpheme-to-morpheme transitions (e.g. 'I'll take/ten rolls') to examine potential differences between performance on intramorphemic and intermorphemic consonant clusters.

Finally, repeated syllables with different vowels ([pi–pɑ–pu]) verify the patient's ability to distinguish different members of the vowel space. Some patients can be observed to produce vowels that are quite indistinct.

Multilingual performance

So far, English, French, German and Finnish versions of our protocol have been developed for the analysis of the performance of multilingual patients. Also, these protocols with a similar format permit comparisons of results obtained in different test sites. The protocol can easily be adapted to other languages.

COMPONENTS OF INSTRUMENTAL PHONETIC ANALYSIS

The evaluation is generally performed with a computer-based speech analysis system. Such systems minimally have the following components:

1. A microphone.
2. An anti-aliasing audio filter.
3. An analogue-to-digital converter.
4. A computer.
5. A sound signal analysis program that permits the measurement of duration, amplitude, fundamental frequency and formants at different signal zoom settings.
6. A spreadsheet program for simple statistical calculations (optional).

Illustrations shown below were obtained with a Macintosh-based program developed by the first author ('Signalyze'). However, concepts discussed here are also applicable to other analysis systems.

PHONETIC IMPAIRMENTS OF NEUROGENIC SPEECH DISORDERS

Phonetic impairments of neurogenic speech disorders can be subdivided in a number of ways. It was considered appropriate to group observations into three major categories: (1) perturbations relating to the superior vocal tract (lips, tongue, velopharyngeal opening), (2) those relating to the inferior vocal tract (larynx, respiration), and (3) impairments relating to control over timing.

IMPAIRMENTS IN THE SUPERIOR VOCAL TRACT CONTROL

In the acoustic signal, articulatory actions at the superior vocal tract level are reflected in the signal in two ways, either by a total silence (pause) or by modifications of formants 1 and 2. Of these, silences and modifications of formant 2 are the most common indicators of speech impairment.

Insufficient Occlusion

Usually, voiceless plosive consonants ([p, t, k]) cause periods of complete silence at the moment of total occlusion of the superior vocal tract. In pathological cases, an uninterrupted continuation of the sound wave is often observed in the place of silence (Figure 1).

Uneven Formant Frequency

In vowel production, the place of greatest constriction (degree of 'frontness' and 'backness') in the vocal tract can be estimated by the frequency of the energy band known as formant 2 (F_2) (Figure 2). Although the lack of an exact 1:1 correspondence between F_2 frequency and frontness/backness is well established, major variations in F_2 generally do imply substantial reconfigurations of the superior vocal tract. This has been verified in dysarthric speech (Gerratt, 1983). In normal subjects, major changes in formant frequencies tend to be associated with transitions from one phoneme to another. In neurologically impaired patients, major variations of formant frequencies, furthermore, tend to be associated with degradations of vowel quality. In addition, non-speech articulatory movements can be deduced, such as compulsive lingual movements found in tardive dyskinesia.

Illustrations showing formant 2 modulation are found in Figures 2, 6 and 8.

IMPAIRMENTS IN THE INFERIOR VOCAL TRACT

Impairments at the inferior vocal tract level manifest themselves primarily with respect to fundamental frequency and amplitude.

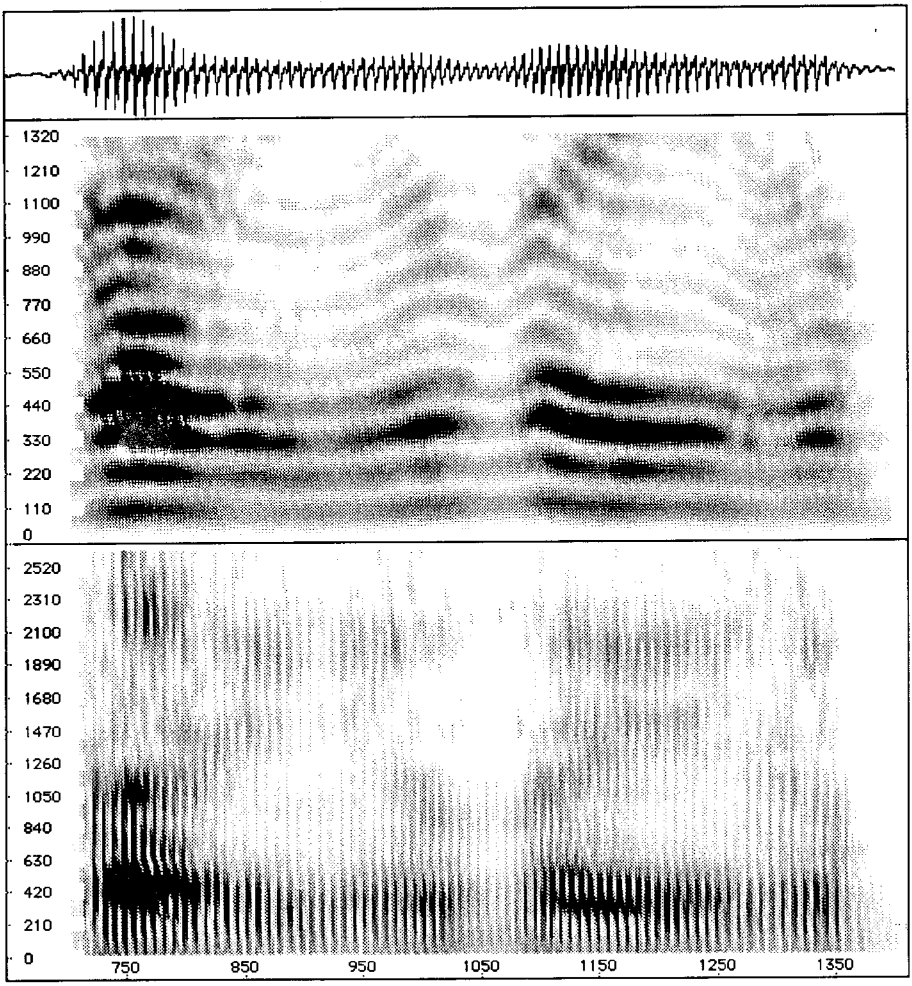

Figure 1: *Insufficient occlusion: patient with Parkinson's disease. Task: [pa pi pu] at normal speech rate, repeated twice. Upper panel: signal; middle panel: narrow band spectrogram; lower panel: wide band spectrogram. Signal and spectrograms show continued acoustic energy where silent periods for the [p] consonant should be found. Perceptually, the sequence of segments appears slurred and is characterised by a rapid and indistinct articulatory execution of the two utterances.*

Impairments of Fundamental Frequency (F_o)

The rate at which major signal oscillations repeat in the voiced segments of speech corresponds to the fundamental frequency. This frequency is directly linked to vocal cord activity. Perceptually, F_o corresponds most directly to the tone of voice, or to intonation. It must be kept in mind, however, that amplitude and duration also contribute to perceived tone. F_o can be extracted from the acoustic signal by means of a number of algorithms, including spectral analysis by FFT (Fast Fourier Transform), autoregression or temporal structure analysis. In addition, time measures of the major oscillations taken in large zooms of the speech signal can readily be converted to estimates of F_o.

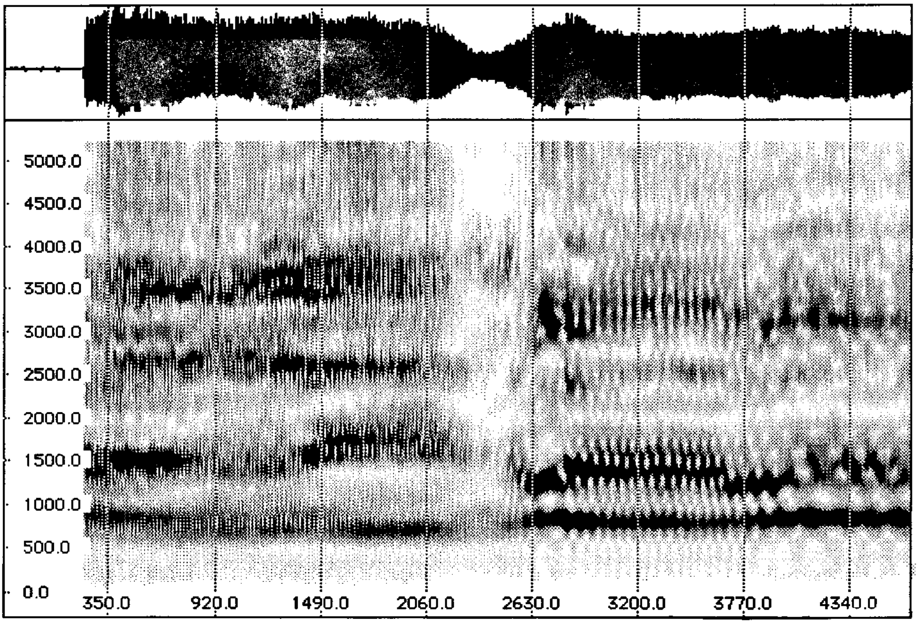

Figure 2: *Uneven formant structure: patient with Friedreich's ataxia. Task: prolonged [ɑ]. Upper panel: signal; lower panel: wide band spectrogram. As shown in the spectrogram, there is a rise of formant 2 before, and a reduction of F_2 after, a sudden loss of amplitude. This can be interpreted as an anteriorisation of the linguopalatal constriction, followed by a complete occlusion and a rapid posteriorisation of the constriction. Perceptually, it appears as if the patient executed a swallowing movement in the middle of the stimulus. This is heard as [ɑγɑ], where [γ] corresponds to a voiced posterior linguopalatal occlusion.*

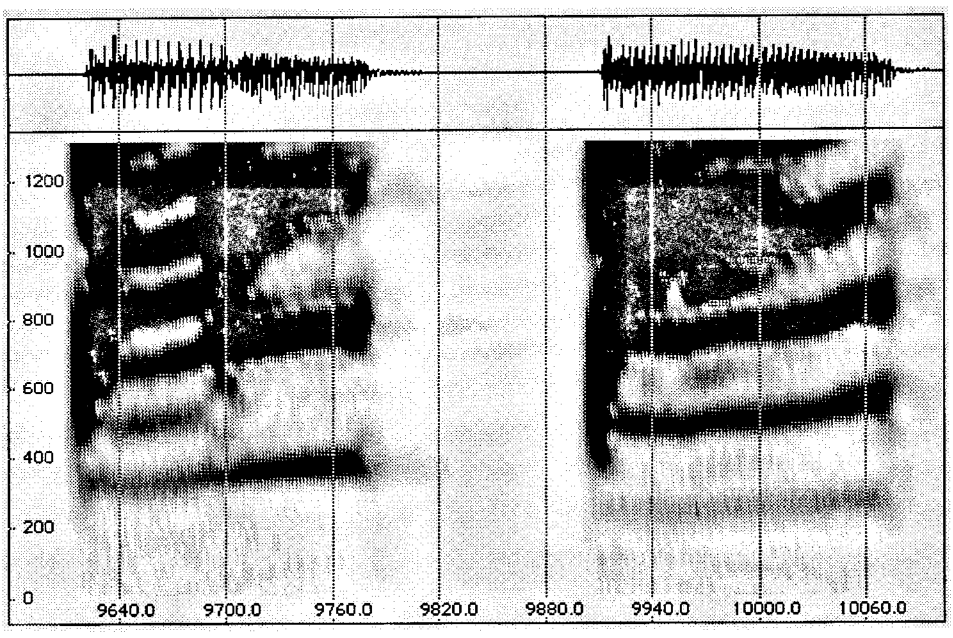

Figure 3: *Bitonal voice: female patient with cerebral palsy. Task: repeated [pɑ] at normal speech rate. Upper panel: signal; lower panel: narrow band spectrogram. The narrow band analysis shows the addition of a second set of fundamental and harmonic frequencies at 500, 1000, 1500 Hz etc., overlapping a first set at 350, 700, 1050 Hz etc. (see first half of the left-hand stimulus). Some evidence of bitonal voice is also seen in the mid-portion of the right-hand stimulus. Perceptually, only the lower set of frequencies is heard.*

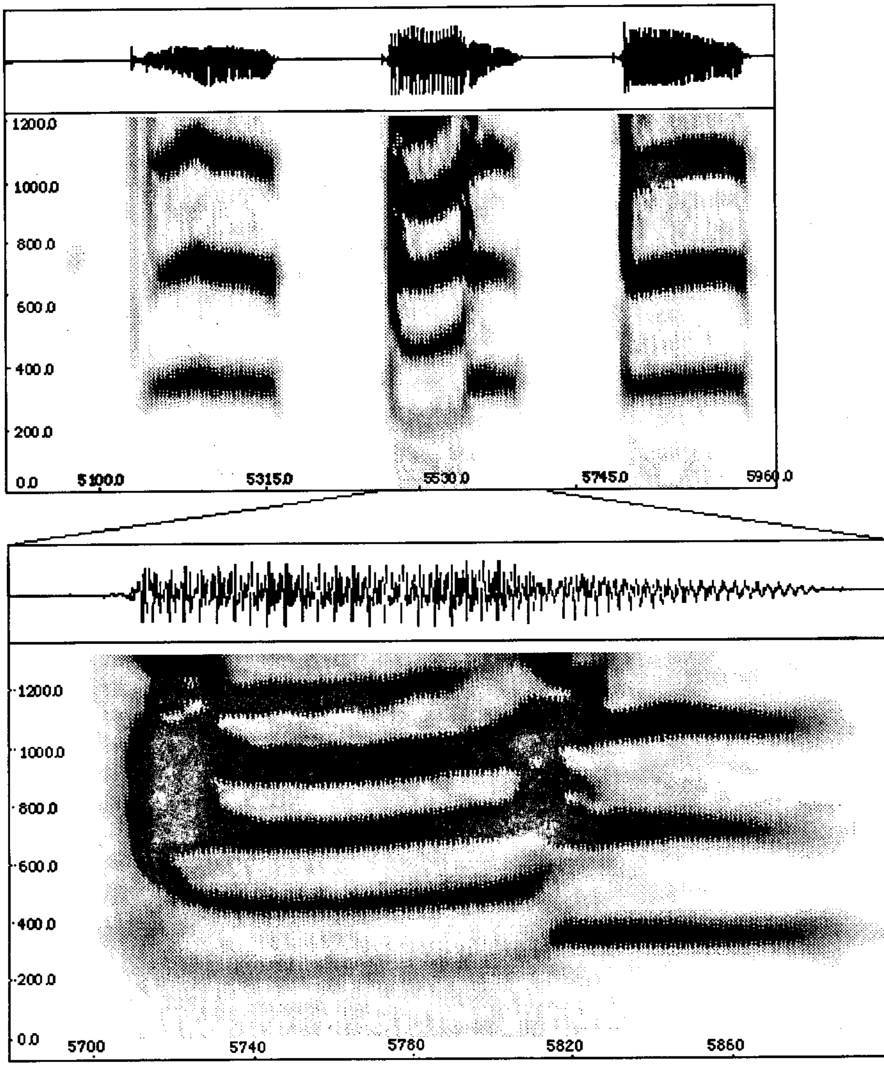

Figure 4: *Pitch break: female patient with cerebral palsy. Task: repeated [pa] at normal speech rate. Upper panel: signal and narrow band spectrogram; lower panel: zoom on the second stimulus. The zoom clearly shows the sudden F_0 shift from about 235 Hz to about 365 Hz. Perceptually, only a rise in tone is heard and the pitch break is barely audible.*

In neurologically impaired speech signals, pitch breaks, bitonal, 'strangled' and 'raspy' voice can be observed through the analysis of F_0. A pitch break is defined as a sudden shift in F_0 (Figure 4). Bitonal voice involves the adding of a second fundamental frequency to a first F_0 (Figure 3). Strangled and raspy voice are characterised respectively by particularly high and low F_0 frequencies (Figures 5 and 6). Furthermore, raspy voice is often accompanied by uneven harmonics. In addition, F_0 analysis identifies cases of insufficient on–off control over vocal fold activity (Figure 7) and circumscribed decreases in voice intensity (see Figure 12).

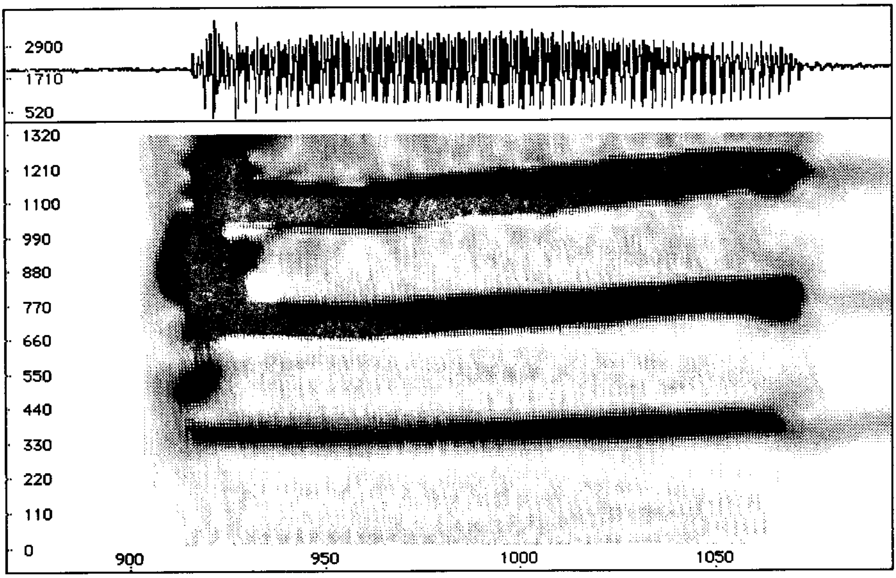

Figure 5: *Strangled voice: adult female patient with cerebral palsy. Task: repeated [pa] at normal speech rate. The fundamental frequency in this stimulus begins at about 365 Hz and rises to above 400 Hz, a frequency range more characteristic of children than of adult females. Perceptually, the impression of a child's voice is conveyed.*

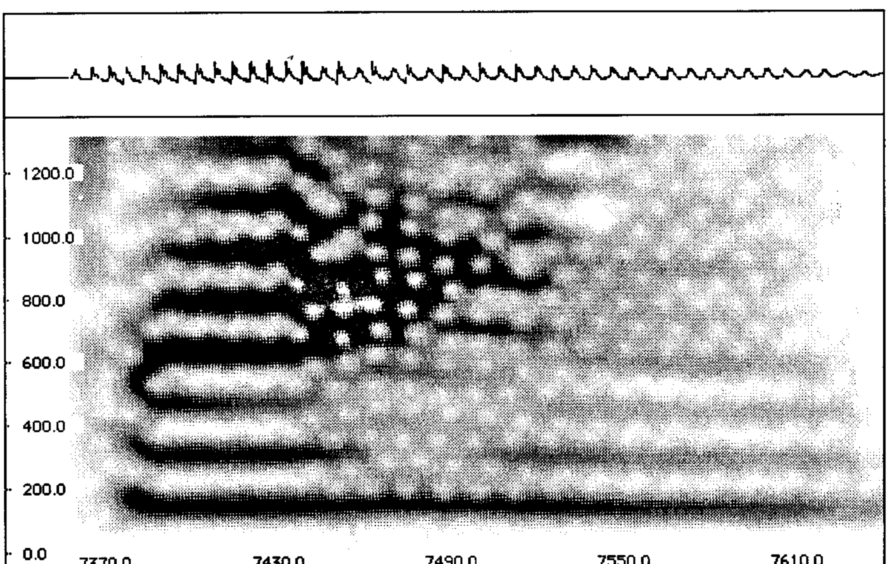

Figure 6: *Raspy voice: female patient with Friedreich's ataxia. Task:repeated [ta] at fast speech rate. Upper panel: signal; lower panel: narrow band spectrogram. The spectrogram shows an F_0 at 126 Hz, below the characteristic range for adult females. The harmonic frequencies show pronounced irregularity during the second portion of the stimulus. Perceptually, the voice appears to be affected by 'raspiness'.*

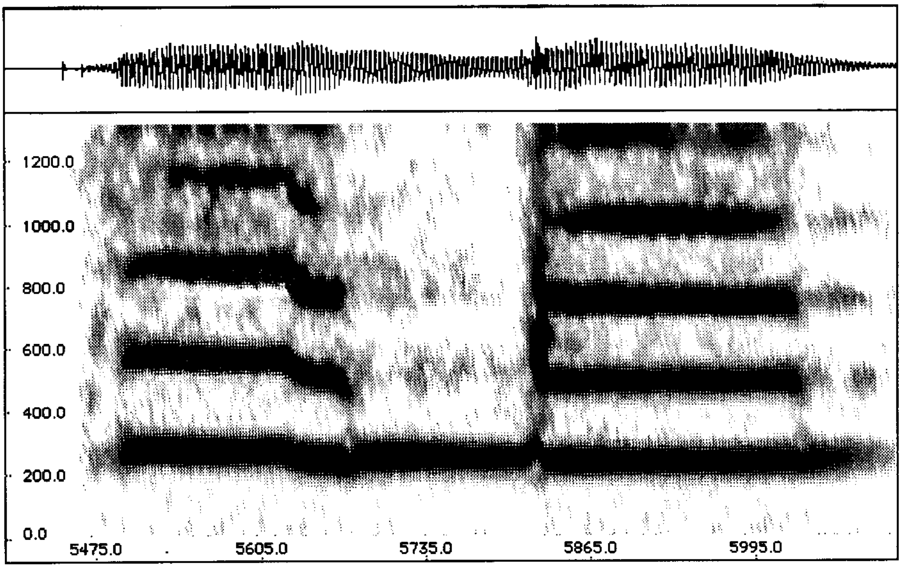

Figure 7: *Insufficient on–off control for F_0: patient with Friedreich's ataxia. Task: repeated [pɑ] at fast speech rate. Upper panel: signal; lower panel: narrow-band spectrogram. Instead of a coordinated interruption of F_0 and its harmonics during the [p] consonant, F_0 is maintained throughout the occlusion. This probably indicates continued vocal fold activity in the presence of a superior vocal tract occlusion. Perceptually, the [p] is heard as a [b] sound.*

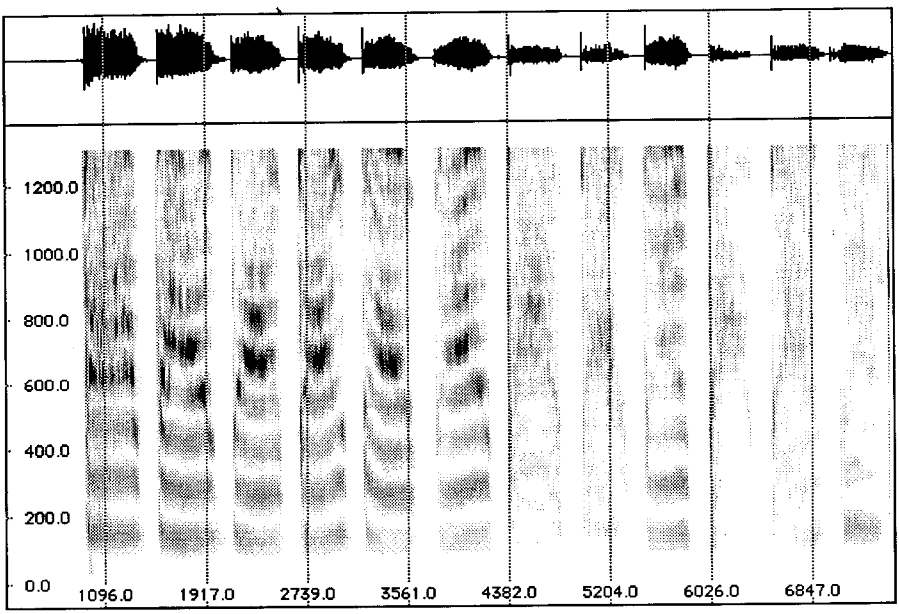

Figure 8: *Overall decrease in F_0 energy: patient with Friedreich's ataxia. Upper panel: signal; lower panel: narrow-band spectrogram. Task: repeated [pɑ] at normal speech rate. The narrow band spectrogram shows a substantial loss of energy at the fundamental and harmonic frequencies in the seventh, eighth, tenth and eleventh stimuli. Perceptually, this is heard as a concurrent diminishing of expiratory force, voice amplitude and articulatory precision.*

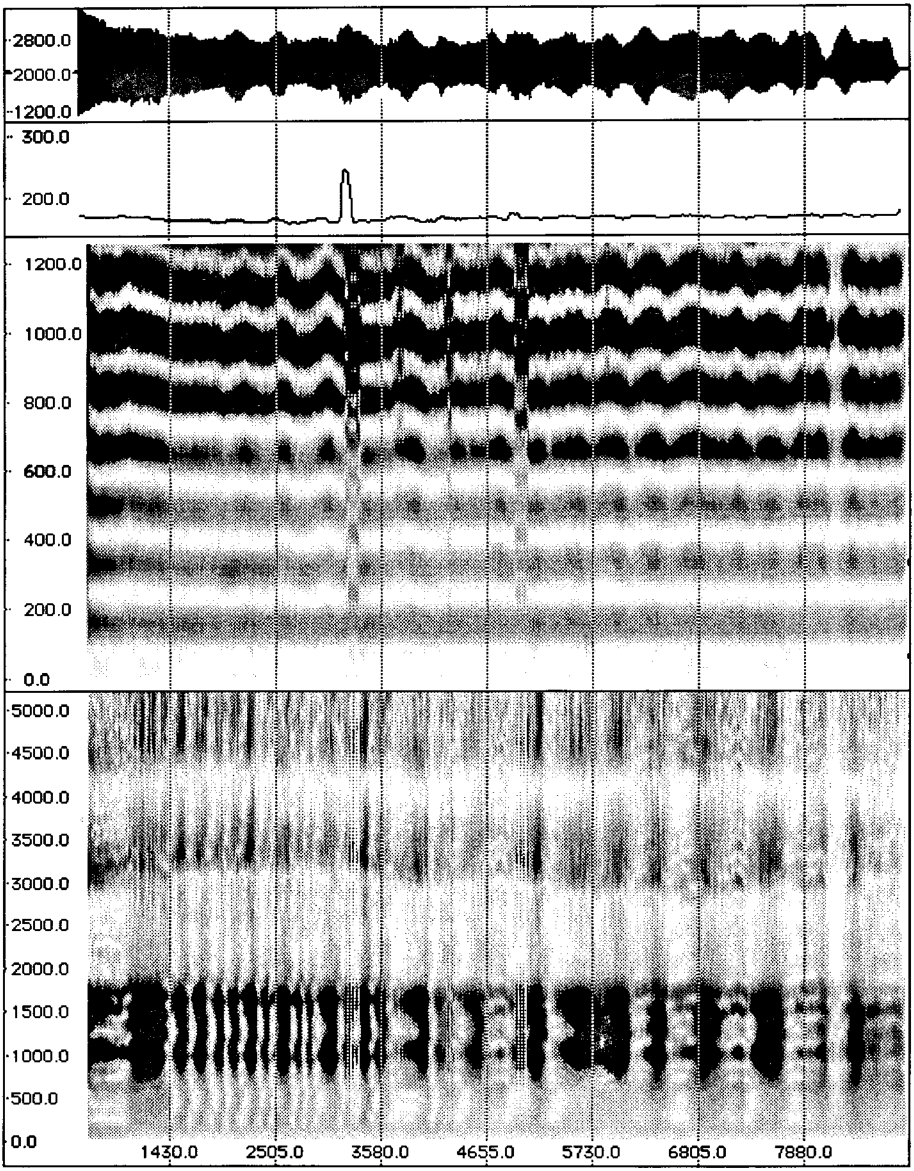

Figure 9: *Uneven amplitude: patient with Friedreich's ataxia. Task: prolonged [ɑ]. Upper panel: signal; second panel: F_o; third panel: narrow-band spectrogram; lower panel: wide-band spectrogram. The signal, F_o and its harmonics show excessive amplitude variations. At the same time, the wide-band spectrogram indicates the maintenance of relatively stable formant frequencies. This can be interpreted as unevenness in laryngeal control, in the presence of an essentially stable upper vocal tract configuration. Perceptually, the impression of uneven respiratory control is conveyed.*

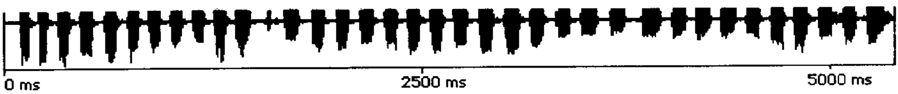

Figure 10: *Amplitude variation over utterance: patient with Friedreich's ataxia. Task: repeated [pɑ] at a fast speech rate. Considerable increases and decreases in amplitude variation can be observed. Perceptually, the amplitude variations are barely audible, but changes in vocalic quality can be heard.*

Amplitude Perturbations

Signal amplitude varies as a function of the speech sound. Vowels are accompanied by relatively large amplitudes, glides (or semivowels), fricatives, nasals and voiced consonants show lesser amplitudes, and voicelesss consonants occasion complete silences. In the clinical context, it is rarely possible to take absolute amplitude measures. However, relative amplitude measures provide interesting indications for the analysis of speech disorders. Through the comparison of different amplitude levels in the production of a prolonged vowel, for example, it is possible to identify a pathological increase or decrease in amplitude, premature voice fading or excessive unevenness. Increases and decreases in amplitude can manifest themselves not only in a prolonged sound, but also in a repeated syllable series.

Sound amplitude as measured at the microphone level is filtered by the superior vocal tract and is not a pure estimator of voice intensity. For example, at the same level of voice intensity, an [i] sound produced with a high degree of linguopalatal constriction is generally characterised by a lower signal amplitude than an [ɑ] sound produced with an open vocal tract.

Still, sound amplitude can be used as an estimator of voice intensity in cases where the patient appears to maintain a relatively stable vocal tract aperture. In those cases, an unstable signal amplitude can be interpreted as a change in voice intensity (Figures 10 and 11).

IMPAIRMENTS OF TEMPORAL CONTROL IN SPEECH

It is perhaps to the analysis of temporal aspects of speech that acoustic phonetic analysis makes its strongest contribution. For reasons that may relate to human evolution, the ear is particularly insensitive to the purely temporal differentiation of speech segments. However, many speech impairments manifest themselves most clearly in the temporal domain, impairments that can easily be rendered visible through acoustic phonetic analysis.

Co-articulatory Impairments

Articulation involves precise delays between the actions of various speech organs. For example, in speakers of English, the plosive consonant [p] in initial syllable position involves a lip opening occurring as late as about 60–80 ms preceding the initiation of vocal fold activity (voice-onset time). A production involving only a 40-ms delay can be interpreted as aberrant ('French accent'), or can be misinterpreted as a voiced plosive consonant [b]. This type of pathology can be found in many dysarthric and aphasic patients. Figure 13 shows a French Canadian patient whose VOT for [pɑ] was 9 ms instead of a delay of about 40 ms.

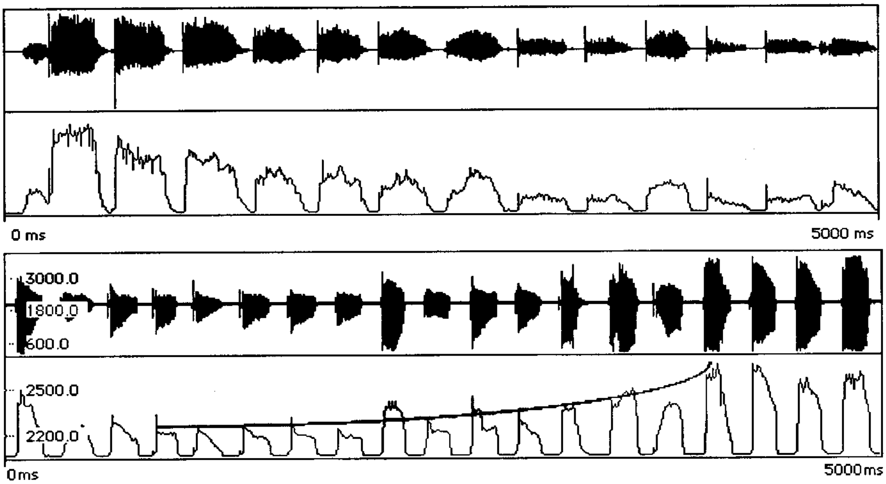

Figure 11: *Amplitude decrease and increase over utterance train: two different patients, Friedreich's ataxia and cerebral palsy. Task: repeated [pɑ] at normal speech rate. A 92.1% decrease and a 77.9% increase in amplitude can be observed. Perceptually, the speech of the patient in the upper set of panels appears to disintegrate in quality over time, while the speech of the patient in the lower set of panels is characterised by a rising tone and an increase in 'urgency of speech'.*

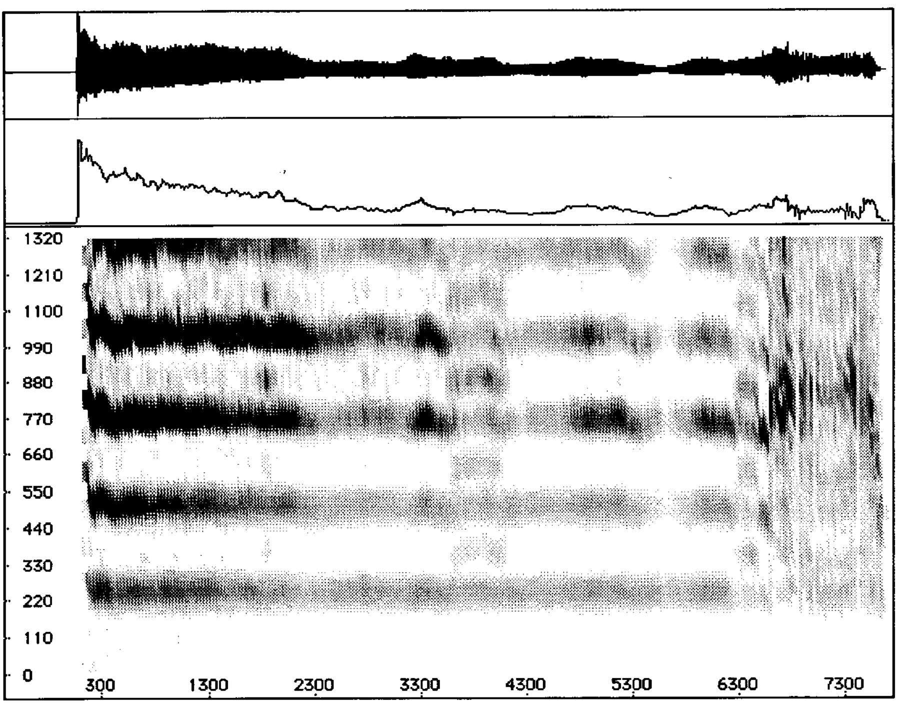

Figure 12: *Decreasing amplitude in held vowel: patient with Friedreich's ataxia. Task: prolonged [ɑ]. The signal shows a 91.4% decrease in amplitude. Note also slight bitonal voice in the middle of the vowel and raspy voice towards the end. Perceptually, a noticeable decrease in voice loudness as well as raspiness can be discerned.*

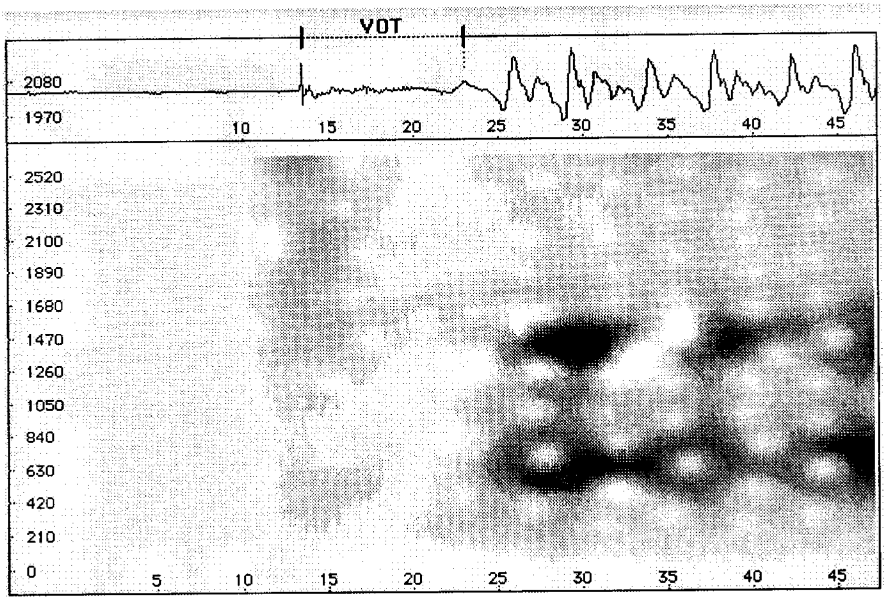

Figure 13: *Short VOT: French language patient with Friedreich's ataxia. Task: repeated [pa] at normal speech rate. Upper panel: signal; lower panel: zoom of wide band spectrogram. VOT is only 9 ms long, while French [p], pronounced at a deliberate, normal speech rate, should show VOTs around 40 ms. Perceptually, this consonant is heard as a [b].*

Perturbations in Segmental Duration and Speech Rate

Dysarthric speech is frequently described as 'slowed' or 'accelerated'. Often, vowels and consonants are affected by such modifications differentially. For example, a patient with Parkinson's disease who had a bilateral ablation of the thalamus was found to speak with at an accelerated rate (Canter & Van Lancker, 1985). However, only his vowels were shortened, and consonants were longer than in normal speech. also intersyllabic pauses were not affected.

The length of different speech segments also tends to be more *variable* in dysarthria. In a recent study (Keller, 1991), all measured segments were observed to show heightened variability with respect to those of normal subjects (Figure 14).

Delayed Initiation and Premature Termination

Another difficulty of temporal control concerns delayed initiation or premature termination of an utterance. Patients with parkinsonism often show delayed initiation of speech and others (such as patients with cerebellar lesions) tend to conclude their syllables prematurely. In previous research, it has been observed that severely impaired Friedreich ataxic patients were not able to produce prolonged sounds for more than 4.3 seconds on the average (fricatives: 4.2 seconds) (Figure 15).

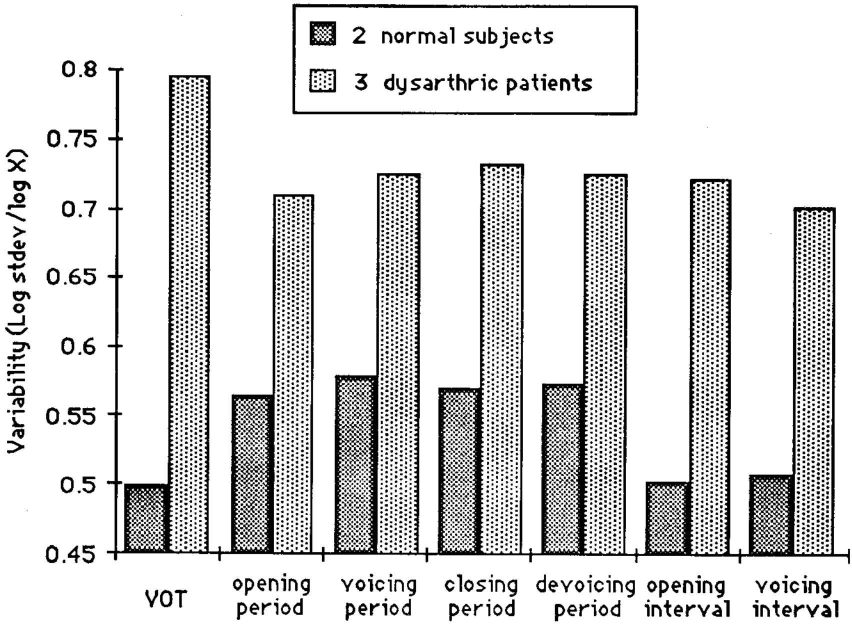

Figure 14: *Durational variability in neurologically impaired speech: two normal subjects and three patients with suspected spinocerebellar lesions producing repeated CV syllables. Opening period: the duration of superior vocal tract opening. Opening interval: the time between two points of superior vocal tract openings. Voicing intervals: the time between two successive onsets of voicing. For all measured speech durations, dysarthric patients were found to show substantially more variability than normal subjects. Differences between types of duration (VOT, periods, intervals) were not significant.*

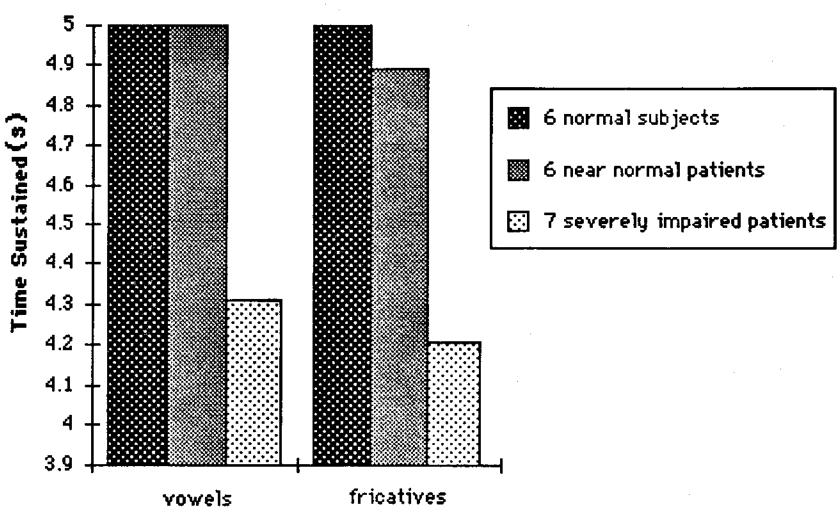

Figure 15: *Premature termination of held vowels: whilst normal subjects have no difficulties prolonging their vowels for 5 seconds or more, patients with suspected spinocerebellar lesions often cannot hold a vowel for the requested 5 seconds. This tendency is especially pronounced in the case of severely impaired patients and affects fricatives slightly more than vowels.*

Perseveration

In contradistinction to premature utterance termination, some neurologically impaired patients cannot cease production of a given stimulus. This can be a repeated stimulus or a simple sentence; however, this phenomenon is relatively rare. It has been observed in patients with parkinsonism (Dubois, Mazars, Marcie & Hécaen, 1966) and in a previous case report on senile dementia (Keller, 1987b, 1987d).

Distinctiveness of Speech Rates

A final, relatively common timing disorder is the inability to distinguish normal and fast speech rates. Typically, patients articulate repeated CV stimuli at the same, normal speech rate when asked to produce fast repetitions. However, stimuli may be modified in other ways characteristic of fast articulations, e.g. by vowel reduction or amplitude attenuation. An example is given in Figure 16.

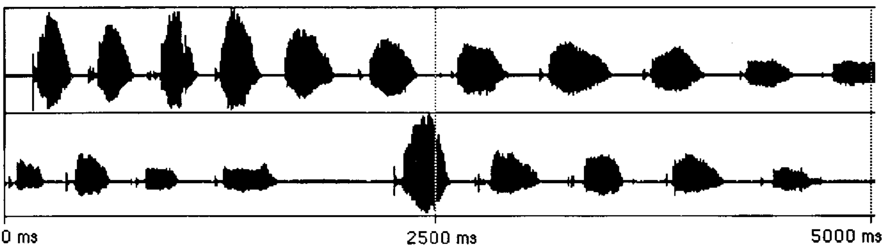

Figure 16: *Lack of distinction of speech rates: patient with Friedreich's ataxia. Upper panel: production of repeated [ka] at normal speech rate; lower panel: production of repeated [ka] at (supposedly) fast speech rate. In fact, the two response trains are distinguished more clearly by amplitude than by an increase of speech rate. Perceptually, the signal in the lower panel is characterised by reduced vowels and thus appears to be produced at a faster speech rate.*

CONCLUSION

By an examination of some common adult speech disturbances by means of a computer-based analysis of the acoustic waveform, various aspects of a general approach to the diagnosis and evaluation of neurogenic speech disorders were illustrated. Patients are tested with a concise protocol comprising tasks of spontaneous speech, diadochokinesis, phoneme distinction, rhythm and intonation. Their disorders are analysed according to the parameters of amplitude, fundamental frequency, speech segment durations and interstimulus intervals. The analysis phase distinguishes disorders at the supralaryngeal, the laryngeal and the durational levels.

It is found that this non-invasive technique permits considerable insights into the detailed nature and possible origin of the disorder. Particularly spectral and durational analysis illustrate aspects of speech disorders that are difficult or impossible to perceive by purely auditory means. It is hoped that systematic research involving large groups of well-documented patients will permit the development of a complete diagnostic approach to adult neurogenic disorders over the next few years.

APPENDIX

SPEECH EXAMINATION

August 1990 [English]

GENERAL INSTRUCTIONS:

1. Each stimulus is presented only once after having verified that the subject is ready). The subject initiates the repetition immediately upon stimulus presentation. The subject neither reads nor sees the written stimuli.
2. Allow the subject at most two attempts at stimulus production.
*3. Request that stimuli be articulated as **clearly as possible**.*
4. In order to assure inter-laboratory comparability of results, tasks must not be modified unilaterally.
5. Instructions to the subject are in italics. Instructions to the experimentor are in brackets.

PLEASE RECORD ON THE CASSETTE:
1. Subject's name and initials
2. Subject's age
3. Education level (last year of school completed)
4. Language status (mother tongue?)
5. Clinical characteristics of disorder
6. Onset of illness
7. Date and time of start of protocol

A-1: SPONTANEOUS SPEECH

Speak about anything you want. [Suggest a non-threatening topic if necessary. One minute.]

A-2: HELD SOUNDS (1)

Take a deep breath and produce the following sounds for at least 5 seconds. [After 6 seconds, the examiner should stop the subject (hold up hand). If the subject stops before 5 seconds, ask for a second production of the sound.]

A-2.1	/i/	as in "she"
A-2.2	/a/	as in "pot" (U.S.) "car" (U.K.)
A-2.3	/o/	as in "so"
A-2.4	/s/	as in "see"
A-2.5	/z/	as in "zoo"
A-2.6	/ʃ/	as in "shoe"
A-2.7	/ʒ/	as in "measure"

A-3: REPEATED SYLLABLES

Repeat the following syllables at a normal speech rate for at least 5 seconds. Use a regular pace ("like a metronome"). [Demonstrate the rhythm to the subject (2 syllables per second).]

A-3.1 /papapa.../
A-3.2 /tatata.../
A-3.3 /kakaka.../

Repeat the following syllables as quickly as possible for 5 seconds. Speak clearly. Be sure to pronounce each consonant clearly.

A-3.4 /papapa.../
A-3.5 /tatata.../
A-3.6 /kakaka.../

A-4: PHONEME DISTINCTION

Repeat each of the following syllable groups for five seconds. Use a normal and regular speech rate without any break. Example: /pi pa pu pi pa pu pi pa pu/. [Demonstrate the rhythm to the subject—2 syllables per second.]

A-4.1	/pi	pa	pu/
A-4.2	/pa	pi	pu/
A-4.3	/pu	pi	pa/
A-4.4	/pu	pa	pi/
A-4.5	/pi	pu	pa/
A-4.6	/pa	pu	pi/
A-4.7	/pi	pu	pa/
A-4.8	/pu	pa	pi/
A-4.9	/pa	pu	pi/

Now we use a different consonant. [Insist on a clear articulation of the /b/.]

A-4.10	/ba	bi	bu/
A-4.11	/bu	bi	ba/
A-4.12	/bi	bu	ba/
A-4.13	/ti	ta	tu/
A-4.14	/ta	ti	tu/
A-4.15	/tu	ti	ta/
A-4.16	/sta	sti	stu/
A-4.17	/sti	sta	stu/
A-4.18	/stu	sti	sta/
A-4.19	/stru	stri	stra/
A-4.20	/stra	stri	stru/
A-4.21	/stri	stra	stru/

A-5: WORDS

Repeat the following words at a normal speech rate and pronounce as clearly as possible.

A-5.1	patience	/ʃ/
A-5.2	stupid	/st/
A-5.3	actor	/kt/
A-5.4	factor	/kt/
A-5.5	resting	/st/
A-5.6	sharpen	/ʃ/
A-5.7	plastic	/st/
A-5.8	shallow	/ʃ/
A-5.9	dictate	/kt/
A-5.10	shiny	/ʃ/
A-5.11	octet	/kt/
A-5.12	nasty	/st/
A-5.13	meshing	/ʃ/
A-5.14	station	/st/
A-5.15	active	/kt/

A-6: HELD SOUNDS (2)

[Repeat section A-2 in order to increase the number of observations.]

A-7: RHYTHM

Repeat each of the following syllables for five seconds at a normal speech rate. [Demonstrate stress pattern to the subject.]

A-7.1 /**pá** pa **pá** pa **pá** pa **pá**.../
[alternating stress]

A-7.2 /**pá pá** pa pa **pá pá** pa pa.../
[2 stressed, 2 unstressed]

A-7.3 /pá pa pa pa **pá** pa pa pa.../
[1 stressed, 3 unstressed]

A-7.4 /pa pa **pá** pa pa **pá** pa pa **pá**.../
[2 unstressed, 1 stressed]

A-7.5 /pa pa pa **pá** pa pa pa **pá**.../
[3 unstressed, 1 stressed]

A-8: INTONATION

Repeat the following sounds. [Use normal speech rate and the given intonation. If necessary, exercise this task first.]

A-8.1 /aaaaa/, /eeeee/, /ooooo/
[as low as possible, 5 seconds]

A-8.2 /aaaaa/, /eeeee/, /ooooo/
[as high as possible, 5 seconds]

A-8.3 /aaaaa/, /eeeee/, /ooooo/
[rising intonation on each, from as low as possible to as high as possible]

A-8.4 /aaaaa/, /eeeee/, /ooooo/
[falling intonation on each, from as high as possible to as low as possible]

A-8.5 /aaaaa/, /eeeee/, /ooooo/
[rising-falling intonation on each, very low, very high, very low]

A-8.6 mom**my**? [9 times]
[strongly interrogative intonation]

A-8.7 **mom**my! [9 times]
[strongly exclamatory intonation]

A-9: SENTENCES

Repeat the following sentences ***in a single breath.*** *[Questions are recorded three times in order to obtain sufficient observations. Be sure to put a rising intonation on the questions.]*

A-9.1	He drank from a flip-top can.	/pt/
A-9.2	He came to a stop sign.	/ps/
A-9.3	The truck took a turn.	/kt/
A-9.4	You pass two lights on the way.	/st/
A-9.5	She tip toed away.	/pt/
A-9.6	Are you on your way home? *[three times]*	/ʔ/
A-9.7	You may guess two times.	/st/
A-9.8	The pope salutes the crowd.	/ps/
A-9.9	Does your TV work? *[three times]*	/ʔ/
A-9.10	This envelope takes one stamp.	/pt/
A-9.11	His grip seems strong.	/ps/
A-9.12	I'll take ten rolls.	/kt/
A-9.13	The mouse took the cheese.	/st/
A-9.14	They had a trap set for him.	/ps/
A-9.15	Getting to the top took hours.	/pt/
A-9.16	The glass tumbled to the floor.	/st/
A-9.17	Did he call? *[three times]*	/ʔ/
A-9.18	She can pack two shirts.	/kt/
A-9.19	The baby's nap time is now.	/pt/
A-9.20	He's got a very sick tummy.	/kt/
A-9.21	His house took years to build.	/st/
A-9.22	Is that a solid line? *[three times]*	/ʔ/
A-9.23	The mock turtle soup was good.	/kt/
A-9.24	The troop saw the general.	/ps/
A-9.25	Is the kettle on the stove? *[three times]*	/ʔ/

Please note the time at the end of the protocol on the cassette and on the protocol sheet.

Translation into English: Dr. Shari Baum, McGill University, Montreal, Quebec.

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