Keller, E. (1987). Ultrasound measurement of tongue dorsum movements in articulatory speech impairments. In J.H. Ryalls (Ed.), *Phonetic Approaches to Speech Production in Aphasia and Related Disorders* (pp. 93-112). San Diego, CA: College-Hill Press.

ULTRASOUND MEASUREMENTS
OF TONGUE DORSUM MOVEMENTS
IN ARTICULATORY SPEECH IMPAIRMENTS

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ABSTRACT

A system is presented which is capable of measuring different aspects of speech motor control and speech motor impairments by means of ultrasound recordings of vertical tongue dorsum movements. To illustrate the instrumental evaluation of such impairments, several cases of motor disturbance recorded with this system are presented (i.e., patients with parkinsonism, senile dementia, stuttering and probable cranial trauma). Variables found to be impaired include: excessive variability in movement amplitude and duration, insufficient inter-articulatory coordination, insufficient maintenance of movement amplitude, and insufficient spatial and temporal differentiation of short and long movements.

INTRODUCTION

In many cases, cerebral lesions have direct effects upon the motor aspects of speech. In the case of lesions affecting cortical or subcortical areas with prerolandic focus, disturbances characteristic of motoric types of aphasia are typically observed (esp. Broca's aphasia), while in the case of lesions affecting the primary motor cortex, the thalamus and of the basal ganglia, the pyramidal and extrapyramidal pathways, the cranial nerves and the cerebellum, disturbances typical of various types of dysarthria can be found.

Utterances of motoric types of aphasia are generally characterized by slowness, intermittent phonetic errors, the presence of a large number of substitutions, omissions and additions of phonemes and, less frequently, the incidence of grammatical and lexical disturbances. On the other hand, dysarthric utterances are identified by the continuous presence of phonetic distortions and by the general absence of grammatical or lexical disturbances.

Research on aphasia has traditionally remained in advance of research on dysarthria, essentially because the errors produced by aphasic patients are relatively easy to transcribe and analyze, while the articulatory disturbances of dysarthric subjects are difficult to describe and almost impossible to transcribe. In spite of important attempts to establish perceptual criteria for the various forms of dysarthria (e.g., cerebellar, parkinsonian or spastic dysarthria; Darley, Aronson & Brown, 1969; 1975), the contemporary clinician generally cannot distinguish them with certainty. Judged according to the Darley et al. criteria, most dysarthric patients present similar perceptual signs, in particular imprecise consonants, monopitch, reduced syllable stress and hypernasality (cf. tables presented in Darley et al., 1969; 1975).

The instrumental measurement of articulatory movements (i.e., the speech kinematics), promises to provide improved tools for the analysis and the diagnosis of speech motor disturbances, including different forms of dysarthria. In combination with the concepts of contemporary motor theory (in particular, action theory, see e.g., Keller, in press a, b), the main objective of this approach is to identify the control and impairment variables within the speech motor system.

The following discussion focuses on the instrumental and conceptual approach which we are developing in this context. The ultrasound recording method for tongue dorsum movements in use in our laboratory is summarized, and some measurement parameters for the evaluation of speech motor disturbances are proposed.

METHOD

Instrumentation

Our approach involves a computerized system for ultrasound measurements of tongue dorsum movements, developed specifically for two speech control laboratories located in Montreal (Keller & Ostry, 1983). Transducer placement and the recording system are schematized in figures 1 to 3.

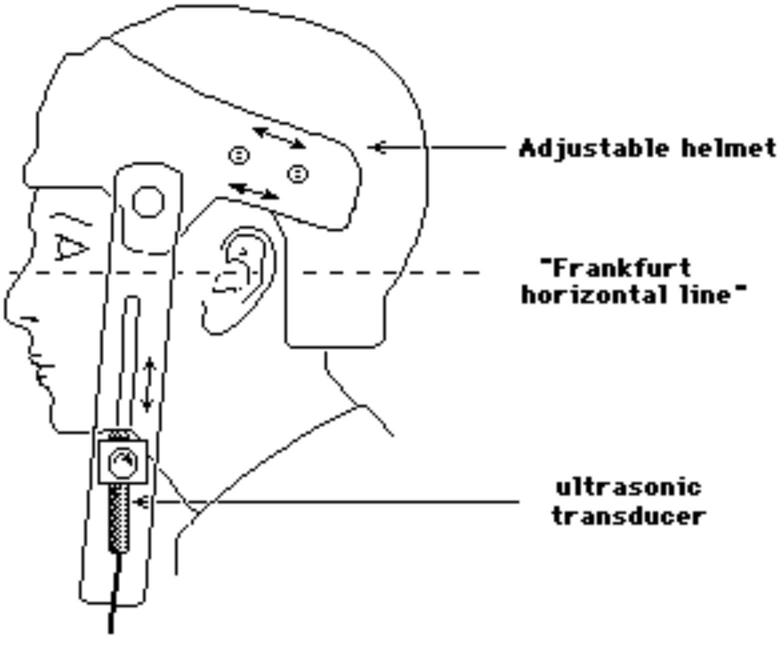

Fig. 1. Ultrasound transducer placement. The transducer is initially placed in vertical position (90o to the Frankfurt horizontal line) at the midline below the inferior mandible, and is adjusted so as to measure successively greater descending movement amplitudes for [ku], [ko], and [ka]. Recordings employing such a helmet attachment have been found to show negligible variability induced by head and mandible movements (Keller & Ostry, 1983).

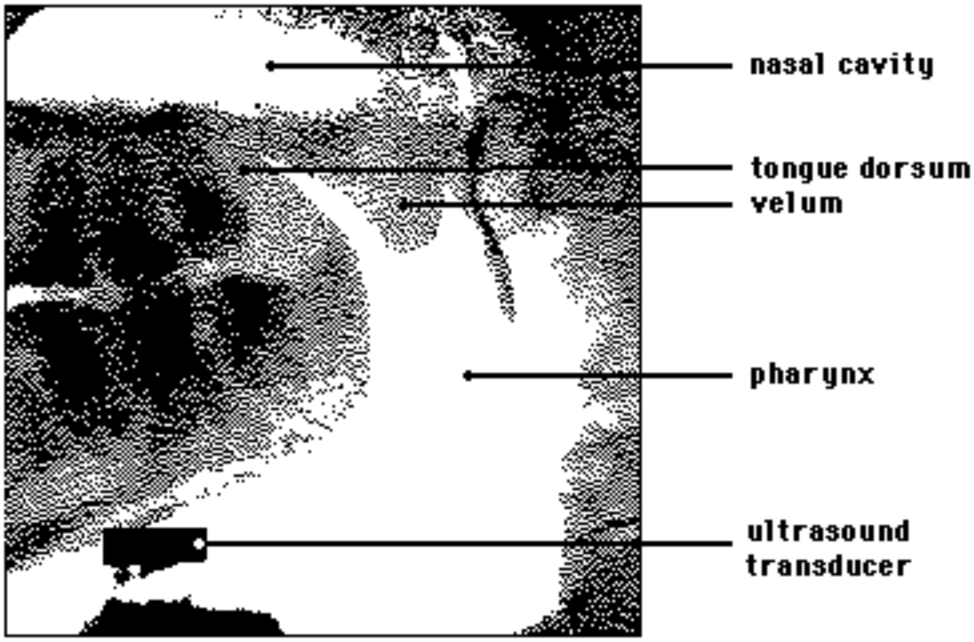

Fig. 2. X-ray of posterior oral, nasal and pharngeal cavities, showing a transducer placed according to the noted criteria. It appears that the ultrasound beam traverses the posterior lingual mass in vertical direction and forms an echo at the tissue-air interface lying opposite the posterior end of the hard palate.

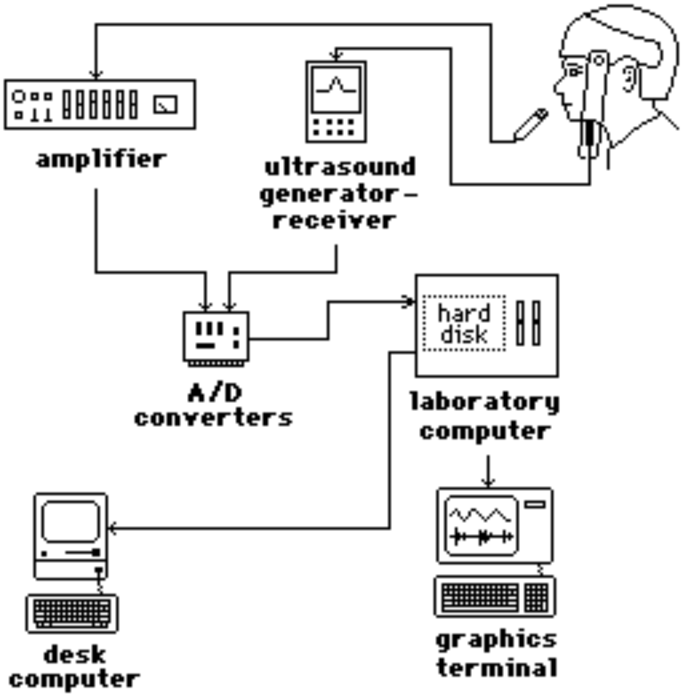

Fig. 3. Present instrumental arrangement. Ultrasound and acoustic data are acquired via an ultrasound generator-receiver and an audio amplifier, are converted to a 1kHz digital signal by a special circuit, and are stored in a laboratory computer. Initial data smoothing and analysis involve the use of a graphics terminal, while statistical evaluations are performed on a desk computer.

In order to measure tongue dorsum movements, an ultrasound transducer is placed in a vertical position beneath the chin along the inferior midline of the mandible, and the delay is repeatedly measured between the emission of a short ultrasonic burst (4 µs, 3.5 MHz) and the reception of its echo. In the median plane, the transducer is initially placed at a 90º angle to the Frankfort line (a line connecting the inferior margin of the left ocular orbit with the superior margin of the left external auditory meatus). The final adjustement in this plane requires that there be a greater lingual displacement for [ko] as compared to [ku], and for [ka] as compared to [ko] (p. 310, Keller & Ostry, 1983).

At each millisecond interval, a measurement corresponding to the distance between the transducer and the tongue dorsum is obtained. Specifically, a major echo formed at the interface between the linguo-muscular tissue and the ambient air is located within the ultrasonic reflections, and the time between burst emission and the reception of this echo is measured. Measurements of this delay, corresponding to the distance between the transducer and the tongue dorsum, as well as the accompanying digitized acoustic signal, are continuously stored in a microcomputer over a period of 4.5s (adjustable to 12 s).

Once the recording is completed, the kinematic signal is subjected to curve smoothing by means of spline functions. Cubic functions not only permit one to follow the central tendency of the movement, but also provide the first and second derivatives of the tongue displacement, that is, its instantaneous velocity and acceleration (not shown here).

Measurement variables

On the basis of graphic displays of the ultrasound and voice recordings, several demarcations of the lingual and laryngeal movements are identified in syllables of the type [k + vowel] (see Figure 4)[1]. For example, the lingual movement of the syllable [ka] is considered to begin at the point of its highest position prior to movement descent (velocity 0, point 1 on Figure 4), the descending movement reaches its maximum velocity at point 2 and terminates at point 4. At point 3, the onset of the acoustic effects of the regular vocal cord vibration for vowels can be

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[1] For reasons of ultrasound reflection and recording precision, the syllable [ka] provides the most reliable kinematic information using this technology. The recording of more anterior consonants is inhibited by the presence of the anterior sublingual air pocket, and the relatively long lingual movement from [k] to [a] provides a better signal-to-noise ratio than other [k + vowel] combinations, which involve shorter movements.

noted. The ascending movement from the vowel [a] to the consonant [k] starts at the point of lowest position (velocity 0, point 4), reaches its maximum velocity at point 5 and finishes at point 6. In all measurements making reference to points on the velocity curve (all points except point 3), the rightmost measurement is chosen if several measurements are similarly close to zero or to maximum velocity. For point 3, the first glottal pulse in the acoustic voice trace is defined as the first regular pulse deviating from the background noise observed during the preceding linguo-palatal closure. From these reference points, simple calculations of displacement and duration of different sections of the movement provide a number of measurements associated with potential speech motor control variables (see Table 1).

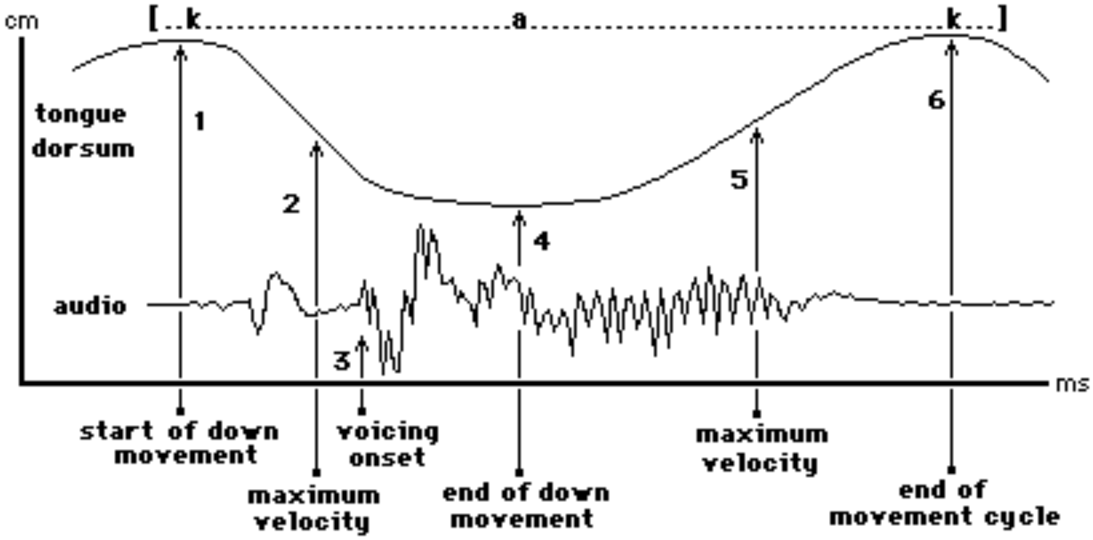

Fig. 4. Measurement points in a typical observation of the syllable [ka]. The top trace shows the tongue dorsum displacement in cm, while the bottom trace shows the accompanying acoustic signal. See text for definitions of the six measurement points.

Table 1: Some pertinent measurement variables

	VARIABLE	DEFINITION
1	Displacement, descending movement	distance 1 - distance 4[1]
2	Displacement, ascending movement	distance 4 - distance 6
3	Displacement to peak velocity, descending	distance 1 - distance 2
4	Displacement to peak velocity, ascending	distance 4 - distance 5
5	Cycle duration	time 1 - time 6[2]
6	Duration, descending movement	time 1 - time 4
7	Time to peak velocity, descending	time 1 - time 2
8	Time to peak velocity, ascending	time 4 - time 5
9	Linguo-laryngeal delay (LLD)	time 1 - time 3

10	Maximum velocity, descending movement	velocity at time 2
11	Maximum velocity, ascending movement	velocity at time 5

[1] Displacements: a difference of distance x - distance y refers to the vertical distance in cm traversed by the tongue between point x and point y in figure 4. E.g., distance 1 - distance 4 corresponds to the vertical displacement between points 1 and 4.

[2] Durations: a difference of time x - time y refers to the time in ms elapsed between point x and point y in figure 4. E.g., time 1 - time 6 corresponds to the duration between points 1 and 6.

Kinematic variables of speech impairment

The specific variables associated with speech motor disturbances are still being investigated. However, recent observations on both normal and abnormal speech (e.g., Keller, in press c) suggest that the variables presented in Table 2 may be useful for more detailed instrumental analyses of speech motor control. In the next section, cases of disturbances affecting movement extent and regularity, durational extent and regularity, as well as maintenance of movement amplitude, intactness of inter-articulatory delays and pathological tremor will be presented. Other possible analyses (not illustrated here) concern movement velocity and its regularity, as well as muscular rigidity.

Table 2: Some impairment variables

	IMPAIRMENT VARIABLE	ESTIMATOR
1	Movement amplitude	Mean of displacement, descending movement
2	Movement duration	Mean of duration, descending movement
3	Variability of	Coefficient of variation[1] of displacement, movement amplitude descending movement
4	Variability of	Coefficient of variation[1] of duration, movement duration descending movement
5	Variability of cycle duration	Coefficient of variation[1] of cycle duration
6	Variability of inter-articulatory coordination	Coefficient of variation[1] of linguo-laryngeal delay (LLD)
7	Maintenance of	Degree of decrease in successive movement amplitude displacements, descending movement
8	Movement velocity	Mean of maximum velocity, descending movement
9	Differentiation of long and short movement amplitudes	Ratio of displacements for long and short descending movements
10	Differentiation of long and short movement durations	Ratio of durations for long and short descending movements
11	Rigidity	Slope of the linear relation between the displacement of the descending movement and its maximum velocity
12	Tremor	An important presence of information in the movement spectrum between 6 and 12 Hz.

[1] Coefficient of variation = s.d./mean.

Task variables

Three task variables are manipulated in the current protocol: (1) linguistic status, (2) rate of presentation (or syllable duration), and (3) degree of motor habituation. In order to vary linguistic status, the protocol distinguishes the syllable [ka] in the context of normal speech from the diadochokinetic (contextfree) repetition of the syllable [ka]. The rate of presentation, or syllable duration, is varied, by opposing, in continuous speech, an accentuated syllable (macaque) to a non-accentuated syllable (lac à canards)[2], and in the diadochokinetic

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[2] No French context could be found in which the syllable [ka], embedded between two other [ka]-syllables, does not cross a morpheme boundary. However, once a smooth delivery is established, no phonetic effect of the morpheme boundary could be discerned in the speech of subjects and patients recorded to date.

repetition, by contrasting normal and fast utterance rates (see Table 3). Finally, the degree of motor habituation is varied by asking the subject to produce the stimulus protocol twice, once normally and once with clenched teeth.

Table 3: Task variables

	CONTEXTFREE REPETITION	REPETITION IN LINGUISTIC CONTEXT
Normal speech rate/ Long vowel(s)	"...kakaka..." [..ka:ka:ka:...]	"le macaque assommé" [..ka:ka:ka:...]
Fast speech rate/ Short vowel(s)	"...kakaka..." [..kakaka...]	"le lac à canards" ..kakaka...]

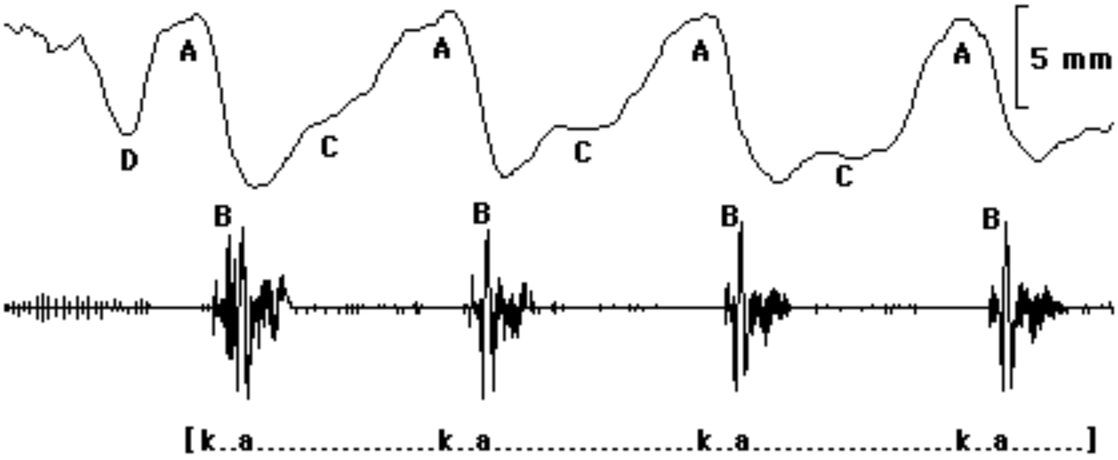
Between 20 and 40 samples of the syllable [ka] for each of the eight conditions are obtained by means of this protocol. A recording session takes about 45 minutes, including ultrasound transducer adjustments, stimulus presentation and recording.

ARTICULATORY SPEECH IMPAIRMENTS

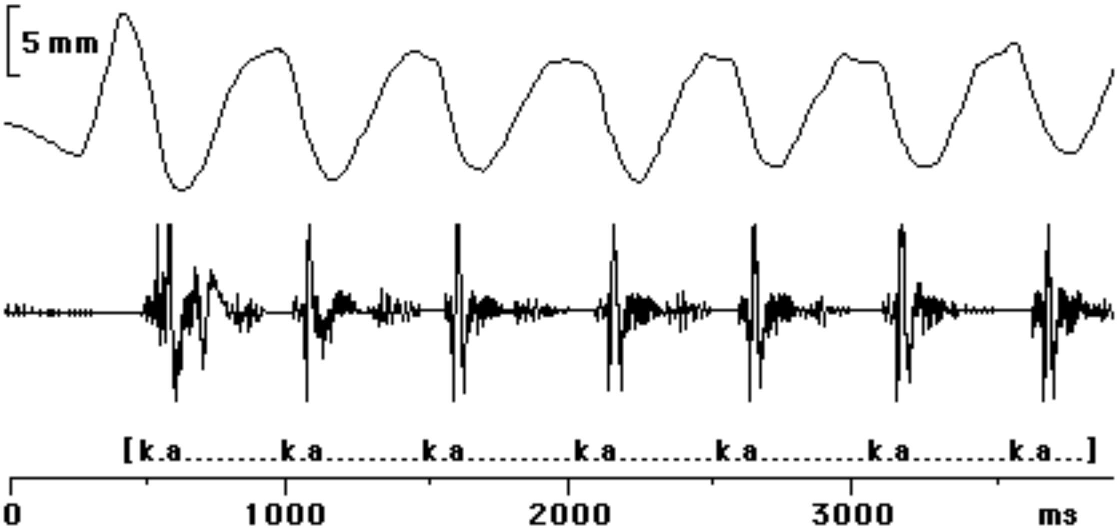
The reference norm: A randomly selected normal subject

To illustrate the recordings of a normal case, data from a subject chosen randomly among the twelve normal subjects recently recorded in our laboratory are presented here. This is a 23-year-old francophone, female, of middle class background, and free of known linguistic disturbances. Figure 5a shows vertical lingual movements for the repetition of context-free [ka], produced at a subject-paced, normal utterance rate.

Normal Subject SB
Slow repetition of [ka]



Fast repetition of [ka]



Figs. 5a and 5b. Tongue dorsum movements and acoustic wave forms in contextfree repetitions of [ka] by a randomly-selected normal subject. A = point of linguo-palatal contact, B = onset of regular glottal pulse oscillation visible in audio track, C = "hesitation platform" during ascending movement (corresponding to syllable offset), D = preparatory movement prior to first articulated syllable.

Several aspects can be noted in this figure. First, the extent and duration of the descending movements are quite regular. Also, the descending movements are rapid and always carried out without hesitation, while the ascending movement is often executed with a hesitation occurring between the lowest point and the final part of the ascension towards the highest point of the movement (points C on figure 5a). A comparison of this illustration with the next figure (Figure 5b) indicates that the presence of such "platforms" is one of a number of variables (such as extent and duration of movement) which distinguishes slower from more rapid productions of [ka] in the speech of this subject.

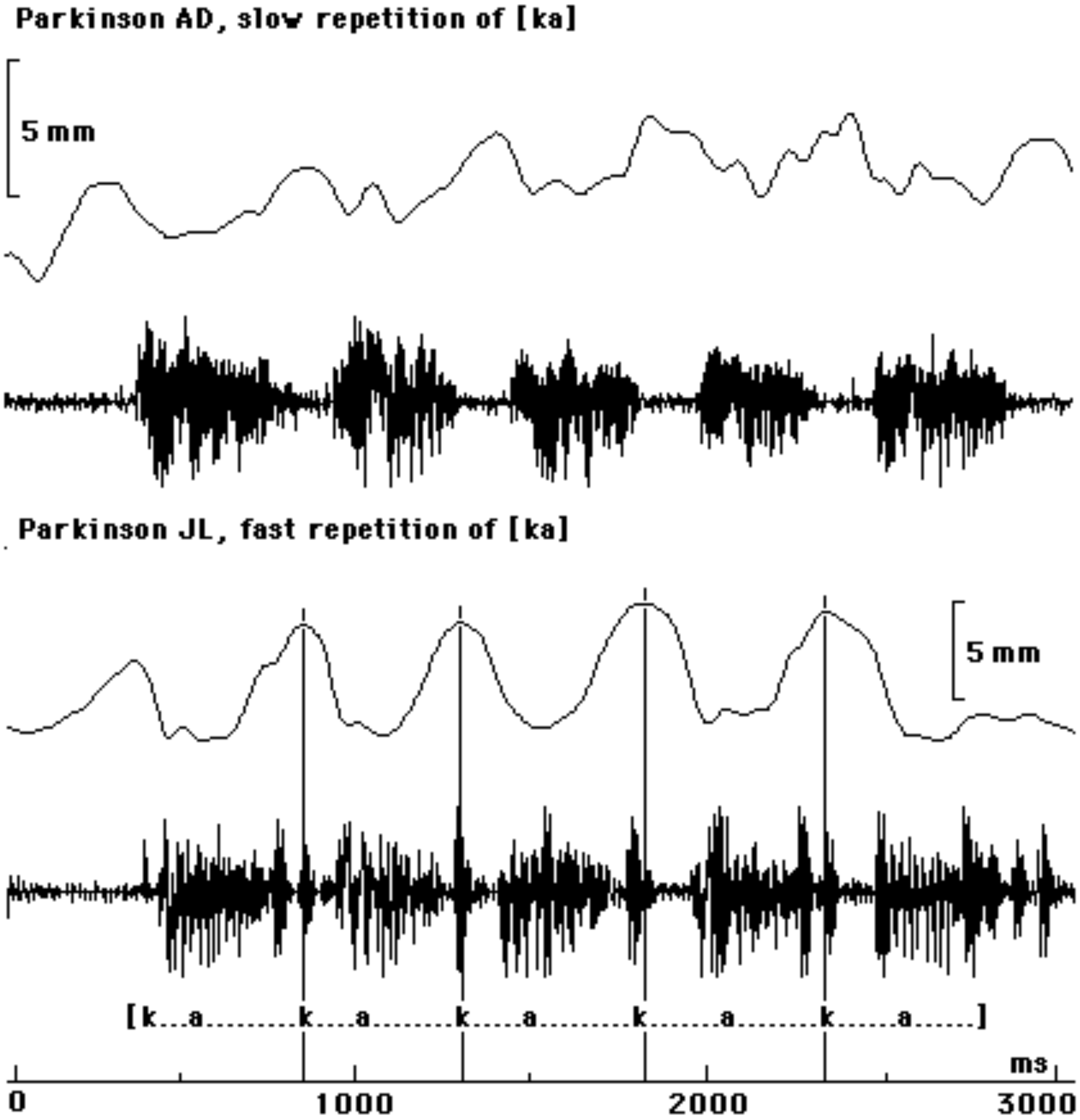
Further, it can be seen that the coordination between lingual movement and laryngal activity is rather regular in the normal subject. The onset of laryngal activity (the B points on Figure 5a) follows the beginning of the lingual activity (the A points) within a predictable delay (40-60 ms in the fast-rate conditions and 80-150 ms in the normally-paced conditions).

Finally, it is possible to observe a preparatory movement prior to the articulation of the stimulus syllables (point D). This movement regularly preceeds the descending movement associated with the first syllable [ka]. Its likely function is to provide the subsequent descending movement with sufficient momentum to produce a satisfactory air plosion in opening from [k] to [a].

Movements associated with a fast production of [ka] (e.g., Figure 5b) differ from those of slow movements primarily with respect to duration. The short syllables produced by this subject lasted about 500 ms, while the long syllables measured approximately 900 ms. In contextfree speech production, this time reduction tends to be associated with an elimination of the hesitation "platforms" at the beginning of the ascending movement.

Parkinson's disease

The first two individuals with speech motor impairment are affected by Parkinson's disease. The first patient, a 63-year-old man, was recorded five years after the diagnosis of his illness. To the ear, this patient presented certain well-known signs of parkinsonian dysarthria, such as reduced stress and monopitch. On Dworkin's examination of facial and oral motor control (1978), he experienced difficulties in bulging his cheeks and in blowing into a balloon, in moving the mandible forward and in raising the soft palate for the production of [a]. Yet the same examination showed no disturbance in the motor control of the lips, the tongue or the larynx. Let us recall that in the lingual tasks, the subject must (1) protrude his tongue, (2) follow a tongue-depressor with his tongue, (3) open his mouth as wide as possible and raise his tongue as high as possible inside the mouth, and (4) push with his tongue hard against the tongue depressor.



Figs. 6a and 6b. *6a:* Normally-paced contextfree repetition of [ka] by a patient with Parkinson's disease. Articulations were highly irregular, even though the orofacial motor control examination showed no disturbance of tongue movements. *6b:* Fast contextfree repetion of [ka] in another patient with Parkinson's disease. In three out of four articulations, the point of linguo-palatal closure coincided with vocal cord activity, yet the auditory impression remained consistent with a dysarthric production of the stop [k].

On the other hand, the ultrasound recording of slow repetition of [ka] (6a) shows an irregular movement, measurable both in terms of displacement and duration. During fast repetition (not shown), the movement appeared to be somewhat more regular, but still abnormally variable. Thus, the kinematic recording was able to detect articulatory impairments which were not evident in a clinical examination of orofacial motor control.

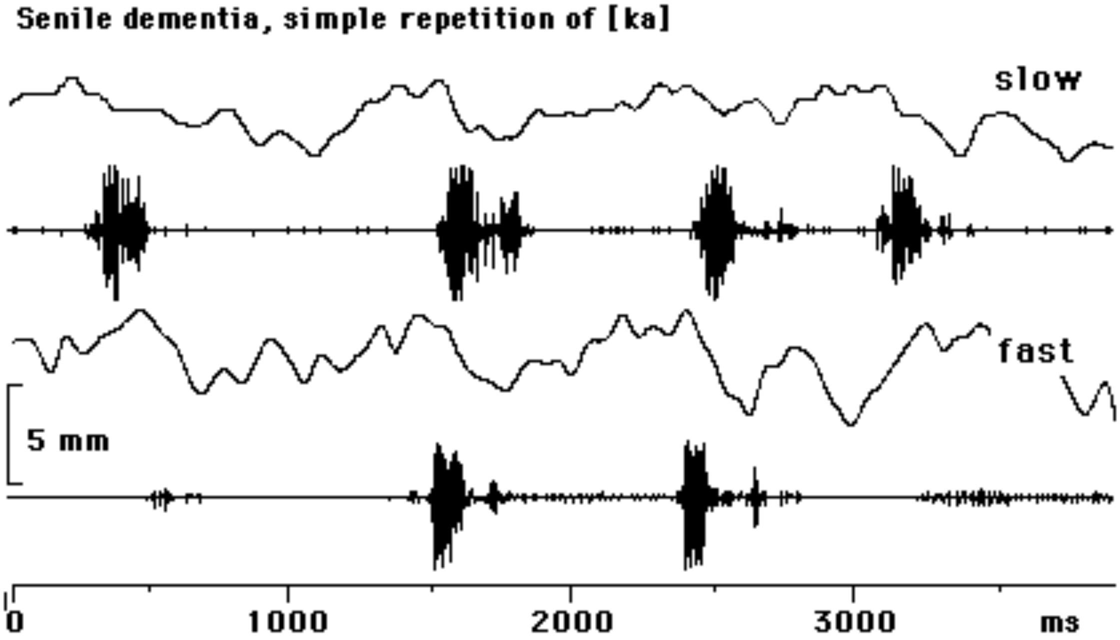
The second case of Parkinson's disease (Figure 6b) shows another form of disturbance. This is a 62-year-old man, recorded six years post-diagnosis. On clinical examination of his orofacial motor control, this patient showed difficulties only with respect to control over soft palate movements. Judged in terms of his age, time elapsed since the establishment of the diagnosis, and the results of the orofacial motor control examination, this patient seemed comparable to the previous case. Yet in contrast, his ultrasound recording showed few irregularities.

On the other hand, he presented a pronounced lack of coordination between lingual and laryngeal activity; Figure 6b shows that the vocal cords were frequently vibrating at the very moment that the tongue touched the palate for the consonant [k] (confirmed by "zoom"-type verifications of detailed segments of the articulation, not shown here). All the same, the auditory impression of the consonant articulations of this recording remained consistent with the stop [k]. This disturbance is likely to be of clinical relevance because this type of dyscoordination has never been observed in any of our normal francophone or anglophone subjects.

Senile dementia

The following observations concern a 68-year-old woman with senile dementia. Among the visible signs of her motor disturbance, there was a severe tremor of the inferior mandible, both during speech production and at rest. Furthermore, this person talked with a harsh and low voice, and with distorted articulation. She also persevered beyond the 4.5 s recording periods by repeating stimulus sequences such as "le macaque assommé" or "le lac à canards" for up to several minutes subsequent to the recording. In addition, she walked slowly and with difficulty.

The ultrasound recording analysis (Figures 7a and 7b) shows a severe lingual motor control disturbance. First, there is a general irregularity of movement, with a substantial reduction in the movement's amplitude. Instead of an 8-10 mm displacement, characteristic of slow repetition in normal subjects, this patient produced displacements measuring 2-3 mm, and maximally 6 mm. Also, the patient was unable to distinguish slow and fast repetition rates, and she produced a repetition about every 900 ms in both stimulus conditions. This is a rate characteristic of slow repetition in a normal subject, while fast repetition in the normal subject usually results in syllable productions at 3 to 5 times this frequency. This patient thus appears to have selective difficulties in programming the motor parameters of fast speech production.



Figs. 7a and 7b. Normally-paced ("slow") and (supposedly) fast-paced contextfree repetitions of [ka] by a patient with senile dementia. Evident are reductions in movement amplitude and an inability to produce distinctively faster-than-normal rates of syllable repetition.

Finally, a spectral analysis of several of her lingual movements was performed, in order to verify if tongue movements were also affected by tremor. In normal subjects, voluntary repetitions of the syllable [ka] usually occur at a 0.5 to 6 Hz rhythm, while involuntary, tremorlike movements are usually reported to be substantially faster (6 to 12 Hz). A spectral analysis (Fast Fourier Transform) can distinguish slower and faster regular movements by showing their frequency in the form of amplitude peaks within a display of the movement's temporal components.

The results of this analysis were somewhat ambiguous (see Figure 8). Although certain peaks were visible between 8 and 10 Hz, their amplitude was inferior to the one usually associated with tremor (see e.g., Hunker & Abbs, 1984). Thus, it was concluded that the involuntary movement elements noted in this spectral analysis were most probably secondary consequences of the severe inferior jaw tremor, and were not representative of lingual tremor *per se*. In view of the prominent hypothesis which suggests a central origin of the oscillatory motor commands for tremor (e.g., Hassler, Mundinger & Riechert, 1970), it is possible that at such a central level, the jaw musculature is controlled independently of the lingual musculature.

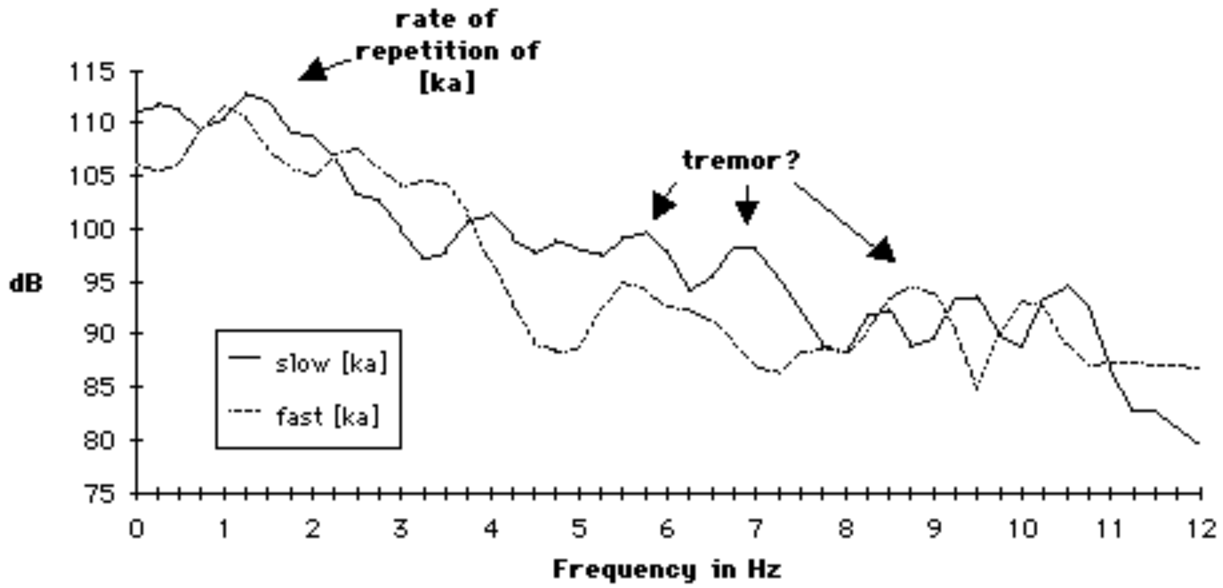


Fig. 8. A spectral analysis of two typical 2048-ms segments of tongue dorsum movement for contextfree, normally-paced ("slow") and fast repetitions of [ka] by the patient with senile dementia (cf. Figs. 7a and 7b). The peaks at 1.1 and 1.2 Hz correspond to the patient's rate of syllable repetition in the two utterance segments, while peaks at around 6, 7 and 9 Hz correspond to involuntary, regular movements superimposed on the articulatory movements.

Adult stuttering

The next case concerns the motor effects of stuttering. Several explorations of the speech impairments of stutterers have been performed in our laboratory. For instance, in comparing two adolescent severe stutterers to two normal controls, Garcia (1981) observed that displacements of the syllable [ka] were significantly more variable in the stutterers than in the normal subjects.

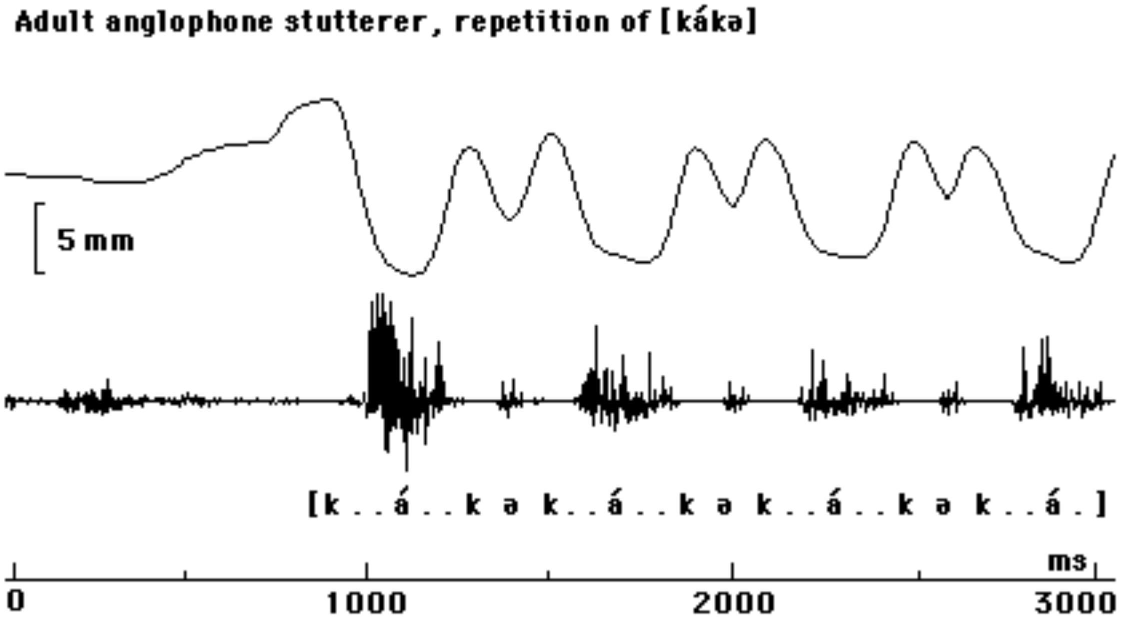


Fig. 9. Tongue movements in a repetition of [k'ak∂] by an adult anglophone speaker with a mild stuttering impairment. Evident are an excessive movement amplitude (1.3 mm) for the initial syllable, an insufficient distinction of movement amplitudes for stressed [k'a] and unstressed [k∂] syllables, and a decrease of kinematic abnormalities with successive articulations.

While this irregularity is less obvious in the repetition of the stimulus [k'ak4], produced by a 40-year-old anglophone stutterer with mild impairment (Figure 9), other disturbances can be noted in this subject. First, the initial movement seems exaggerated in comparison with normal subjects' initial movements (see Figures 5a and 5b). This observation can be related to the common observation that the initial syllable of a stuttered utterance tends to be more impaired than non-initial syllables. Figure 9 also shows that the amplitude of lingual movements decreases over stimulus repetitions, which is an unknown phenomenon in normal subjects.

Another motor difficulty lies in the distinction between the short movements of the [k4] syllable and the long movements of the [k'a] syllable. While normal anglophone subjects' short movements tend to measure between ‹ and › of the amplitude of long movements (not illustrated here), the three stuttering subjects recorded in our laboratory produced "short" movements measuring about fi of the amplitude of "long" movements. Figure 9 indicates that the difference between the two types of movement becomes more pronounced with each stimulus repetition, again indicating that motor control improves over several post-initial repetitions of the same stimulus.

These findings on excessive variability, decreasing movement amplitude and insufficient distinction of movement amplitudes for short and long syllables are comparable to observations commonly made with patients affected by neurological lesions. Although it is evident that the generality of stutterers are not affected by gross neurological lesions, these results do support the hypothesis that their articulation difficulties are related to a still ill-defined imbalance of neuromotor control. If at some future point it can be established that these signs are the exclusive consequence of neurological lesions, this type of observation would support the notion of a constitutional origin of stuttering[3] (see e.g., Sussman & MacNeilage, 1975; Wood, Stump, McKeehan, Sheldon & Proctor, 1980).

Probable cranial traumatism

The last case, affected by a particularly mild speech impairment, was referred for instrumental speech evaluation by his neurologist in order to establish if he was indeed suffering from a measurable speech motor control disturbance. This was a 65-year-old retired truck driver, who had hit his head 16 years ago in a fall on a delivery platform. At the time of the accident, no mnesic loss was noted, but during the eight days following the accident, he was, according to self-report, unable to speak. The medical history notes a probable subdural hematoma over the left hemisphere, but at the time, no CT-scan was taken. A recently taken CT-scan was normal, suggesting that whatever neurological lesion may have been present at the time of the accident, may in the meanwhile have been resorbed.

His present conversational speech is normal, but when he tires, his voice amplitude fades. Moreover, he complains that "it stutters" when he talks fast. The clinical examination indicated a very slight orofacial motor control problem: for instance, the patient could not touch his superior lip with his tongue, while remaining capable of turning it towards his chin. He also had difficulty in alternating two oral movements (kissing and tongue clicking). He had difficulties in maintaining lateral pressure against a tongue depressor to the right; furthermore, he pushed vertically against the tongue depressor with apparently spastic strength.

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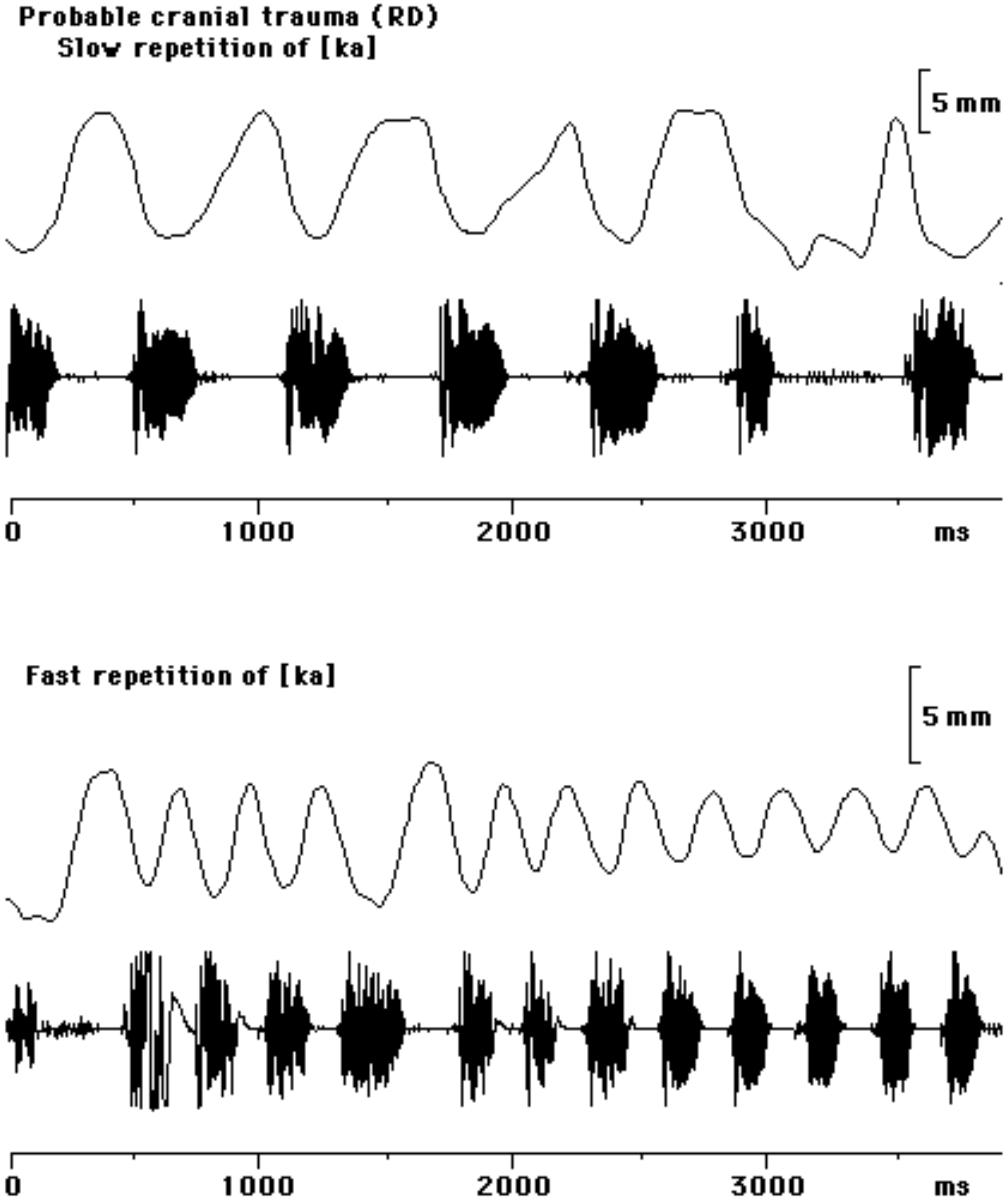
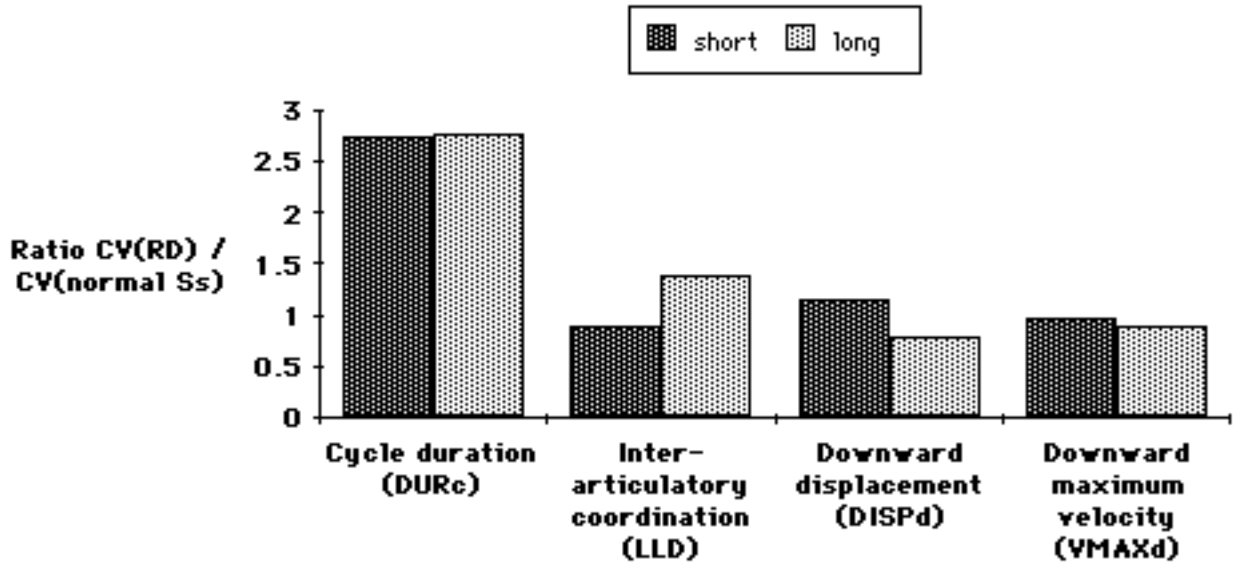
[3] Although the precise manifestations and the evolution of stuttering are clearly influenced by the social environment's reaction to the stutterer and by the stutterer's adjustments to and compensations for his impairment.



Figs. 10a and 10b. Normally-paced ("slow") and fast contextfree repetitions of [ka] by a patient (RD) affected by a cranial trauma probably experienced 16 yrs. prior to recording. Although the speech of this patient was essentially normal, ultrasound recordings showed a selective disturbance of durational variables (Fig. 10a) and a decrease of movement amplitudes over successive articulations (Fig. 10b).

The instrumental examination revealed impairments which had not been evident to the ear (Figures 10a and 10b). Irregular movements can be noted, particularly along the temporal axis, as well as progressive decreases in movement amplitude in fast repetition (Figure 10b). A statistical evaluation revealed that measures of movement duration were consistently more variable than those of normal controls (Figures 11a and 11b). This was especially true of syllable duration, which when analyzed by coefficients of variation (s.d./mean), was between 2.3 and 2.7 times more variable than those of normal subjects (exception: short, unaccented [ka] in "le lac à canards"). None of the 12 normal francophone and two normal anglophone subjects tested with the same protocol showed anywhere near that degree of variability on these durational variables. At the same time, movement amplitudes or velocities were by and large not different from those of control subjects (Figures 12a and 12b). These results will be reported in greater detail in Keller, Cot & Labrecque (in preparation).



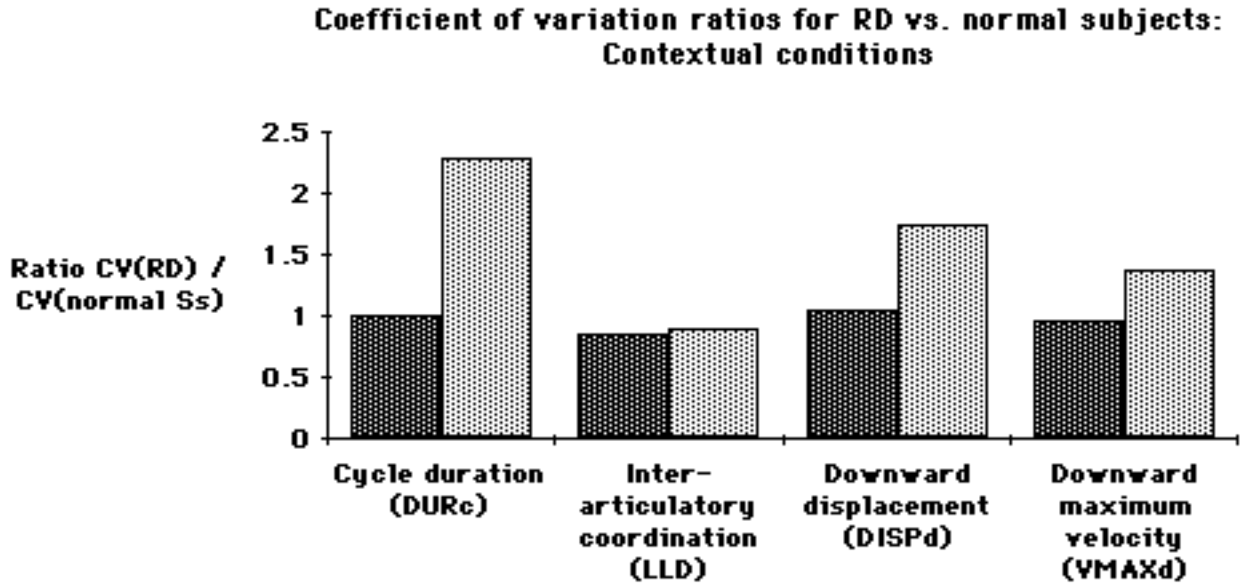

Coefficient of variation ratios for RD vs. normal subjects: Contextual conditions

Fig. 11. (Cf. with Fig. 10) Patient RD's variability on various measurements, as compared with the average variability shown by normal subjects. The statistic used is the ratio of the respective coefficients of variation (s.d./mean). E.g., a ratio of 2.7 on cycle duration shows that patient RD was 2.7 times more variable than the average normal subject with respect to this measurement parameter.

On the basis of this information, it was concluded that this patient's probable cranial traumatism, suffered 16 years ago, indeed affects his speech motor control to some degree. A selective programming error for the temporal variables of speech motor control is in evidence, which affects the patient's ability to maintain regular syllable rhythm throughout the utterance.

CONCLUSIONS

These observations permit a number of methodological and clinical conclusions. First, it appears that the ultrasound evaluation of lingual motor control constitutes a promising methodology in the analysis of speech neuromotor disturbances. Several cases presented here showed only minimal disturbances in the clinical examination for speech and orofacial motor control, while severe speech motor disturbances were clearly evident in the ultrasound recordings. Moreover, the quantitative information available by means of this method is by far more detailed than that obtained through a clinical examination, rendering it accessible to more extensive statistical evaluation.

On the other hand, the present method also has its limits. In our experience, one out of five subjects presents serious recording problems. The most frequent problem is that the ultrasound echo is too weak for a reliable recording. Since this seems to be due to the limits of power and resolution inherent in the system in present use, it is probable that this type of problem can be resolved by employing more up-to-date instruments with greater penetration and resolution.

Another difficulty has been noted with respect to the tremor, or involuntary movements, present in certain patients. Evidently, only those patients who can hold their head in a stable and well-balanced position during at least 15 minutes can be recorded satisfactorily with this method.

It is also important to consider radiation hazards in this context. In our laboratory, the potentially harmful effects of ultrasound are carefully controlled. The Picker A-scan instrument, model 103, used here operates by means a single ultrasound beam and is destined for clinical use. Furthermore, during the positioning of the transducer, the amplitude of the emitting crystal is reduced to a minimum, and it is ascertained that only muscular tissue is irradiated. Finally, it merits recalling that there have been no reported harmful ultrasound bioeffects on adult humans at diagnostic amplitudes employed in clinical settings.

In conclusion, several kinematic parameters available by means of this method can probably serve to assess and further elucidate a number of aspects of speech motor control disturbance. In particular, the following perturbations have been observed in a number of patients:

(1) excessive variability in movement amplitude,

(2) excessive variability in movement duration,

(3) insufficient coordination between different articulatory organs,

(4) insufficient maintenance of movement amplitude throughout an utterance,

(5) insufficient spatial and temporal differentiation of short and long movements,

(6) and perhaps, the presence of tremor superimposed upon the lingual movement.

In further research, it will be explored if it is possible to reliably associate these deficits with specific syndromes, and it will be attempted to integrate these observations with current theory of human motor control. It is hoped that this type of measurement of speech articulation will permit rational and theoretically sound associations between observations on speech motor disturbances on the one hand, and findings on normal speech motor control on the other.

ACKNOWLEDGEMENTS

The author wishes to thank Ms. A.E. Simon and F. Cot, speech therapists, for performing clinical examinations of orofacial motor control in three of the patients presented here, as well as Drs. Serge Gauthier, F. Demonet, and R. Labrecque for referring a number of these cases to me for instrumental analysis. I also wish to thank Ms. G. Ladouceur for performing various data and statistical analyses. Finally, particular thanks are due to Ms. M. Daoust whose translation of a French-language address to the Société Québecoise de recherches en psychologie (Nov. l985), forms the basis of this text. This research is supported by the National Science and Engineering Council of Canada (NSERC) (grant A1034), by the F.C.A.R. - Quebec (team 128), by the "Programme de l'aide financière aux chercheurs et aux créateurs" (P.A.F.A.C.C.) of the Université du Québec à Montréal and by the Medical Research Council of Canada (M.R.C.C.) (grant PG-28 to the Centre de recherche, CHCN).

BIBLIOGRAPHY

Darley, F.L., Aronson, A.E., & Brown, J.R. (1969). Differential diagnostic patterns of dysarthria. *Journal of Speech and Hearing Research, 12*, 246-269.

Darley, F.L., Aronson, A.E., & Brown, J.R. (1975). *Motor speech disorders.* Philadelphia, PA: W.B. Saunders Company.

Dworkin, J.P. (1978). II. Differential diagnosis of motor speech disorders: The clinical examination of the speech mechanism. *Journal of National Student Speech and Hearing Association, December*, 37-62.

Garcia, L. (1981). *Ultrasonic Measurement of Tongue Displacement in Stutterers*. Masters degree project, McGill University.

Hassler, R., Mundinger, F., & Riechert, T. (1970). Pathophysiology of tremor at rest derived from the correlation of anatomical and clinical data. *Confinia Neurologica*, *32*, 79-87.

Hécaen, H., & Angelergues R. (1965). *Pathologie du langage*. Paris: Larousse.

Hunker, C.J., & Abbs, J.H. (1984). Physiological analyses of parkinsonian tremors in the orofacial system. In, M.R. McNeil, J.C. Rosenbek, & A.E. Aronson (Eds.), *The Dysarthrias: Physiology, Acoustics, Perception, Management* (pp. 69-100). San Diego, CA: College-Hill Press.

Keller, E. (in press a). The cortical representation of motor processes of speech. In E. Keller & M. Gopnik (Eds.), *Motor and sensory processes of language*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Keller, E. (in press b). Analyse fonctionnelle des perturbations neurologiques de la motricité de la parole. To appear in H. Cohen (Ed.), *Perspectives contemporaines en neuroscience*. Montréal: Études Vivantes.

Keller, E. (in press c). Factors underlying tongue articulation in speech. *Journal of Speech and Hearing Research*.

Keller, E., Cot, F., & Labrecque, R. (in preparation). A case of selective impairment of temporal aspects of speech articulation.

Keller, E. & Ostry, D. (1983). Computerized pulsed echo ultrasound measurements of tongue dorsum movements. *Journal of the Acoustical Society of America, 73*, 1309-1315.

Sussman, H.M. & MacNeilage, P.F. (1975). Hemispheric specialization for speech productin and perception in stutterers. *Neuropsychologia, 13,* 19-26.

Wood, F., Stump, D., McKeehan, A., Sheldon, S., & Proctor, J. (1980). Patterns of regional cerebral blood flow during attempted reading aloud by stutteres both on and off haloperidol medication: Evidence for inadequate left frontal activation during stuttering. *Brain and Language, 9,* 141-144.