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ONSET OF VOICING IN STUTTERED AND FLUENT UTTERANCES

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Electroglottographic (EGG) and acoustic waveforms of the first few glottal pulses of voicing were monitored and voice onset time (VOT) measured during an adaptation task performed by stutterers and controls. The fluent utterances of stutterers resembled those of control subjects. After dysfluencies, however, the EGG signal increased gradually, lending physiological support to the technique of "easy onset" of voicing. EGG waveforms also served to help differentiate mild from severe stutterers. Idiosyncratic ritualized laryngeal behavior, sometimes including physiological tremor, was evident in the EGG record.

Physiological studies indicate that initiation of voicing presents particular difficulties for stutterers. Aberrant laryngeal muscle activity (Freeman & Ushijima, 1978) and inappropriate vocal fold positioning (Conture, McCall, & Brewer, 1977) have been found. In addition to abnormally high muscle activity, Freeman and Ushijima found that the usual reciprocity of laryngeal adductor and abductor muscles disappears during instances of stuttering. Conture and his colleagues observed that the vocal folds are fixed during blocks in either a closed or open position. Many methods used to treat stuttering accordingly emphasize easy onset of voicing. Van Riper's (1963) technique of altering the preparatory set directed stutterers to start an utterance from a state of rest. Webster's (1974) "Target-based Therapy" and Weiner's (1978) "Vocal Control Therapy" are two of many approaches that direct attention to the gradual onset of voicing. These techniques are supported by numerous studies demonstrating the fluency-enhancing effects of conditions (such as choral reading, delayed auditory feedback, metronome-timed speech, and auditory masking) that result in altered phonatory states (Wingate, 1969, has presented a review). Also, stuttering episodes were found to become more frequent when changes in voicing were increasingly required (Adams & Reis, 1974).

Even when judged to be fluent, stutterers have been found to be slower than normals in initiating voicing during reaction time experiments (Adams & Hayden, 1976; Cross & Luper, 1979; Starkweather, Hirschman, & Tannenbaum, 1976). Voice onset time (VOT) in CV combinations has also been found to be longer in the perceptually fluent utterances of stutterers than in tokens uttered by normal control subjects (Hillman & Gilbert, 1977), although there have been findings that contradict or qualify the longer VOT results (Metz, Conture, & Caruso, 1979; Watson & Alfonso, 1983). The inconsistency of results in the VOT studies may be due to differences in the degree to which subvocal blocks were successfully eliminated from the sample that was determined to be perceptually fluent. Subvocal blocks are instances in which the utterances are perceptually fluent but physiologically abnormal. Because the incidence of stuttering is known to be significantly higher at the beginning of a phrase than within it (Bloodstein, 1975), the preparatory "set" does seem to be implicated, but the question remains whether these preliminary adjustments are aberrant in stutterers even when they are fluent. On average, stutterers are slower in their speech than nonstutterers and are also slower in counting on their fingers, but when separated into groups according to severity, a significant difference was limited to the severe stutterers; mild stutterers were not significantly slower than their controls (Borden, 1983).

The phenomenon of adaptation in stuttering, in which the frequency of stuttering episodes is usually reduced in repeated oral readings of the same passage, was exploited in this study to provide examples of fluent and stuttered tokens of an utterance for comparative purposes. In addition, we used the technique of electroglottography (EGG), a noninvasive method of indirectly examining activity of the vocal folds. The recorded EGG signal is the change in amplitude of an imperceptible high-frequency current passing between electrodes placed on each side of the thyroid prominence (Fourcin, 1974). To the degree that the vocal folds increase contact with one another, impedance to the transmission of the current decreases, whereas glottal opening increases impedance. Thus, vocal fold movements may be inferred from changes in signal amplitude. Investigations comparing the EGG signal with direct filming of the vocal folds have yielded information on landmarks of the EGG waveform and their correlation with glottal opening, closing, and peak contact

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(Baer, Löfqvist, & McGarr, 1983; Childers, Naik, Larar, Krishnamurthy, & Moore, 1983; Rothenberg, 1981).

Thus, we see that stuttering therapies have focused on voice initiation, physiological research has implicated laryngeal problems in voice initiation, and acoustic research has documented longer voice initiation latencies, even when speakers were judged to be fluent. We were motivated by these facts to look closely at voice initiation in stutterers.

The main aim of the overall experiment, from which this paper is the second report, was to examine the interaction of respiratory, laryngeal, and supralaryngeal movements of stutterers and their controls during speech. The first report (Borden, 1983) focused on initiation time and execution time for speech and manual counting tasks. The present report focuses on voice onset, and the third report will address coordination.

The purpose of this experiment was to study the onset of voicing in stutterers and their controls during an adaptation condition for which they repeated 4-digit number series (such as 4253) until "fluent." Questions that we had in mind were, What can be inferred about voice initiation from acoustic and EGG analysis

. . . in stuttered, aborted attempts to voice?
. . . in successful voicing after a block?
. . . in perceptually fluent utterances?
. . . in normal speech of control subjects?

Initiation of voicing was analyzed by examining the acoustic and electroglottographic waveforms of the first few glottal pulses of each of two number series and by measuring VOT from spectrographic recordings.

METHOD

Subjects

Eight adult stutterers (7 men, 1 woman) aged 21–48 years were matched by sex, age, and general educational/occupational level with 8 nonstutterers aged 20–45. Mean age was 33 for the experimental group and 32 for the control group. College students, teachers, blue collar workers, and professionals were represented in both groups. Subjects were bimodally distributed in terms of the severity of their stuttering. Table 1 shows that 4 of the stutterers were rated as mild and 4 as severe, according to the Stuttering Severity Index (Riley, 1972), the reading and conversational parts of the Stuttering Interview (Ryan, 1974), and subjective judgments of two speech-language pathologists. The subjects classified as severe stuttered on 20 or more words per min, with some blocks lasting more than 2 s. The mild stutterers ranged from an average of 1 to 6 stuttered words per min, and the blocks were fleeting. All subjects in the experimental group had received therapy for their stuttering.

Task

Subjects were asked to count aloud from a visual digital display of two different sequences of the digits 2, 3, 4, and 5. The sequences were *3425* and *4253*. In order to provoke dysfluency, subjects were instructed to say each sequence as quickly as possible, without sacrificing accuracy, upon the sound of a response tone. They were told to expect repeated presentations of the numbers. Each series appeared five times, the first time 1 s before the signal to respond, and the last four times simultaneous with the signal to respond (see Borden, 1983, for further details). If the stutterers were not fluent by the fifth trial of each series, they were instructed to repeat the number series until fluent. All 8 of the control subjects, 3 of the 4 mild stutterers, and one of the severe stutterers repeated each series five times for a total of 10 utterances from each subject. The remaining mild stutterer and 3 of the 4 severe stutterers repeated each series (14,10), (14,10), (10,24), and (11,10) times, respectively. The experimenters noted all instances of stuttering that could be perceived by visual or auditory cues.

TABLE 1. Subjects and their controls for the adaptation study.

Subjects	*Sex*	*Age*	*Severity of stuttering*
Experimental group			
1. JP	M	48	severe
2. DE	M	22	severe
3. DA	M	31	severe
4. LB	M	44	mild
5. DL	F	30	severe
6. MA	M	26	mild
7. GV	M	41	mild
8. SL	M	21	mild
		Mean = 33	
Control group			
1. FS	M	45	
2. TS	M	22	
3. SB	M	30	
4. EG	M	43	
5. NM	F	32	
6. JL	M	29	
7. AL	M	36	
8. DR	M	20	
		Mean = 32	

Instrumentation

The program presenting the test sequences was run on a microcomputer (Integrated Computer Systems). For each sequence, a visual warning signal was followed by a variable interval (300, 400, or 500 ms), after which the 4-digit display appeared. The tone signaling the subject to respond was delayed 1 s after the first display of each series and was simultaneous with the display for the repetitions. Presentation of each display was experimenter-controlled to allow for subject differences in time to complete a response.

An electroglottograph (F-J Electronics ApS) recorded rapid changes in impedance by high-pass filtering (25 Hz–10 kHz) the overall changes in amplitude of a signal transmitted across the larynx at the level of the vocal folds. The onset of these rapid oscillations was abrupt and unambiguous and served to signal the onset of voicing during the adaptation task. The acoustic pressure wave was simultaneously recorded through a microphone placed approximately 1 ft (30.5 cm) from each speaker. Lip/jaw movement was recorded from a small LED, attached to the lower lip, that was exposed to an optoelectronic tracking system; respiratory movements were recorded by a hemicircumference pneumograph. The respiratory and lip/jaw recordings were not analyzed in detail for this report.

Analysis of the Data

Visicorder graphs (2 in. or 5 cm/s) of the physiological and acoustic signals recorded on FM tape were produced for each subject. The adaptation trial records were inspected for any further sign of dysfluency, such as abnormal fluctuations in laryngeal impedance, during voiceless periods. The EGG signal was generally flat for nonstutterers in the absence of voicing. The trials were then digitized from the analog tape for further editing. The experimenters inspected each set of trials on a computer monitor using a 100-ms time frame to magnify the first few periods of rapid vibrations of the vocal folds, enabling a more detailed examination of the electroglottographic and acoustic waveforms. For stutterers, hard copies were made of the first dysfluent and last fluent utterance as judged during the recording session and from further inspection of the physiological records. For nonstutterers, the first and last trial from the series was used. The experimenters sorted the waveforms according to voice initiation patterns into categories as described below. As a check on reliability, a naive judge sorted the waveforms represented in this report. Agreement was 90% between the naive judge and experimenters.

In addition to the waveform recordings, sound spectrograms were produced for all utterances during the adaptation series. A total of 223 spectrograms were generated to measure VOT of the utterance *two* (/tu/). VOT was measured from the onset of the burst for /t/ to the first glottal pulse for /u/. If the utterance was stuttered by repetition of /t/, the measure was taken from the last burst to vowel onset. Measures in millimeters were converted to milliseconds and averaged for each subject and across groups corresponding to (a) utterances of control subjects, (b) fluent utterances of stutterers, and (c) stuttered utterances. Months later, a sample set of 32 new spectrograms (two for each subject) was produced for utterances classified as fluent. The investigators measured VOT on this sample set, and the second measures agreed with 84% of the original measures to within 1 mm (8 ms) and with 69% of them to within 0.5 mm. Reliability was further checked by someone naive to the purposes of the study. Of the VOT measures made by the naive judge, 94% agreed to within 1 mm with those of the experimenters and 72% agreed to within 0.5 mm (4 ms). Speech rate was measured for the first and last fluent sample for each speaker, yielding four measures (two number series) that were then averaged. Measures were taken from the onset of voicing for the first syllable to voice offset for the last syllable, thus eliminating the sometimes ambiguous onset of the initial consonant. The measures in millimeters were converted to milliseconds and divided by 4 for an average time for each syllable. This time divided into 1000 ms yielded an average syllable/second speech rate.

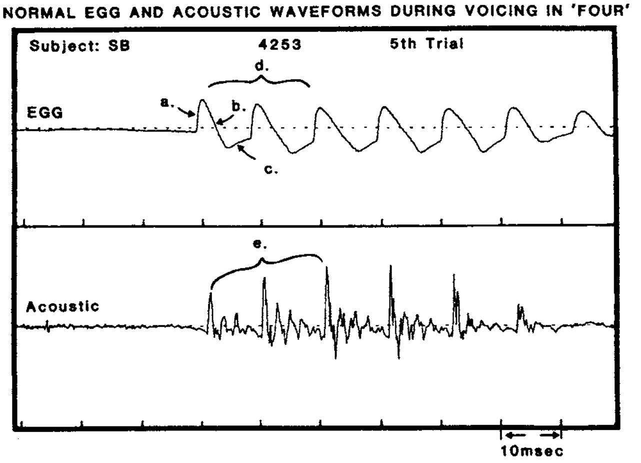

FIGURE 1. Electroglottographic (EGG) and acoustic records at voice onset in the utterance *four* by a normal subject. The EGG waveform is displayed with upward deflection indicating decreasing impedance. The EGG waveform is characterized by steep rise (a) in *vocal fold contact* followed by slower *opening* (b) and *open phase* (c). Amplitude of the first EGG pulses builds rapidly (d), compared with the acoustic waveform (e).

Analysis of the EGG and acoustic waveforms at voice onset was qualitative. Quantitative measures of VOT differences between stutterers and controls were averaged across fluent utterances and the standard deviations computed. Spearman's rho correlation was used to test the relationship between VOT and speech rate.

RESULTS

Electroglottographic and Acoustic Waveforms

Control subjects. The patterns of change in laryngeal impedance recorded by the electroglottograph looked similar for all control subjects. Figure 1 represents the EGG and acoustic waveforms of a male voice initiating /ɔr/ in the word *four*. The polarity of the signal for this analysis is set so that upward deflection indicates the decreased impedance that accompanies increased vocal fold contact, and downward deflection indicates the increased impedance accompanying decreased vocal fold contact. Normally, vocal fold contact increases more abruptly (a) than it decreases (b). There is a relatively stable open phase (c). The EGG envelope grows rapidly in amplitude (d) relative to the typical acoustic waveform for a vowel after /f/, a waveform that is more gradual in buildup of the envelope (e). In previous studies, direct viewing of vocal fold vibration simultaneous with EGG recordings has established these landmarks of the impedance signal (Baer et al., 1983; Childers et al., 1983;

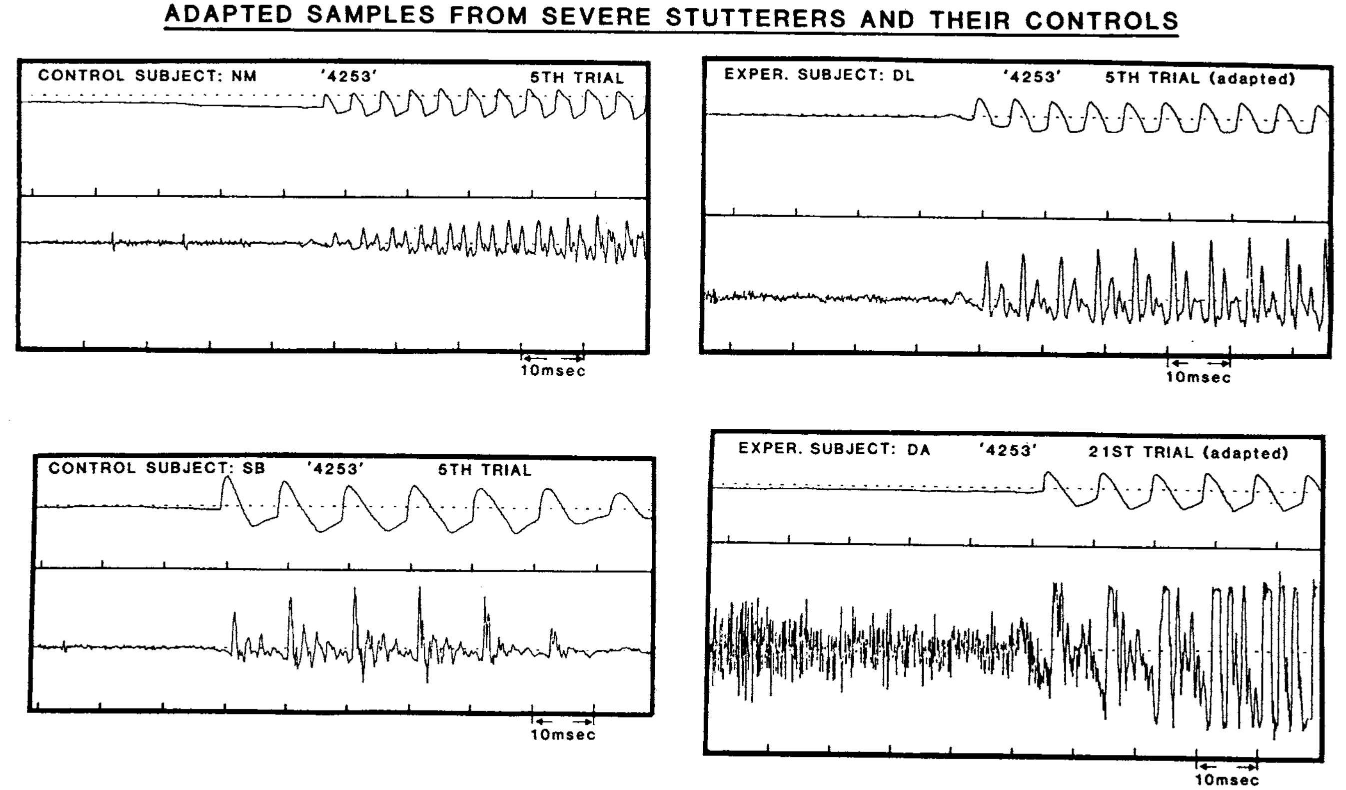

FIGURE 2. Electroglottographic and acoustic waveforms of normal speakers on the left and of stutterers, when fluent, on the right. The top pair is for women; the bottom pair is for men. Stutterers, when fluent, produce EGG waveforms that build rapidly in amplitude like those of control subjects.

Rothenberg, 1981). It is difficult to determine the moment of glottal opening as the folds peel apart during the downward slope of the signal, although sometimes there is a "shoulder" in the downward slope that corresponds with the appearance of a glottal aperture. Peak EGG is fairly reliable, however, as an indication of maximum vocal fold contact, although it does not necessarily indicate complete glottal closure. Occasionally one sees a change of impedance preceding voice onset that does not result in an acoustic pulse. This may reflect some prevoicing laryngeal adjustment.

Stutterers when fluent. The first finding from inspection of the EGG waveforms of stutterers during fluent utterances was that the waveforms looked normal, with abrupt closing, gradual opening, a relatively stable open phase, and a rapid buildup of the EGG envelope. Figure 2 shows the waveforms from a male stutterer (severe) and his control and a female stutterer (severe) and her control. All four samples are from the final trial of the series *4253*, showing onset of voicing in the word *four*. EGG and acoustic waveforms of stutterers when they are fluent show no obvious differences from those of normal speakers.

Stutterers when dysfluent. The second observation from the data on stutterers was that when the stutterers (whether mild or severe) were dysfluent (6 of the 8 subjects), voice initiation after a block was characterized by a gradual instead of abrupt buildup of the EGG signal in all but one of the subjects. Figure 3 illustrates the recordings from the 5 subjects who used gradual EGG onset.

This gradual rise in EGG amplitude is a physiological index of "easy onset of voicing." It is a more reliable indicator than the acoustic waveform, because the sound is often graded in rise time due to an increase in front cavity opening of the vocal tract and perhaps an increase in volume velocity from subglottal air pressure. For an utterance such as *four*, the acoustic waveform typically shows a graded envelope as the oral constriction for the /f/ opens for the vowel. Normally, as we have seen, the EGG waveform is abrupt in the rise time of its envelope, indicating that speakers position their folds for voicing (not necessarily completely adducted) before the aerodynamic forces act upon the folds to set them into vibration. The slow rise time in EGG shown by two of the mild and three of the severe stutterers is abnormal and adaptive. It is a strategy that stutterers apparently use to initiate voicing when they are experiencing difficulty. The strong indication is that under these circumstances the aerodynamic forces are brought into play during a gradual posturing of the vocal folds for voicing, resulting in the slow buildup of the EGG envelope seen in Figure 3. Furthermore, once the stutterers are adapted or "fluent," the EGG envelope is abrupt like that of the control subjects. This style of voice initiation does not seem to be used routinely by stutterers but rather as a method for breaking the block.

Although the phenomenon of gradual EGG buildup

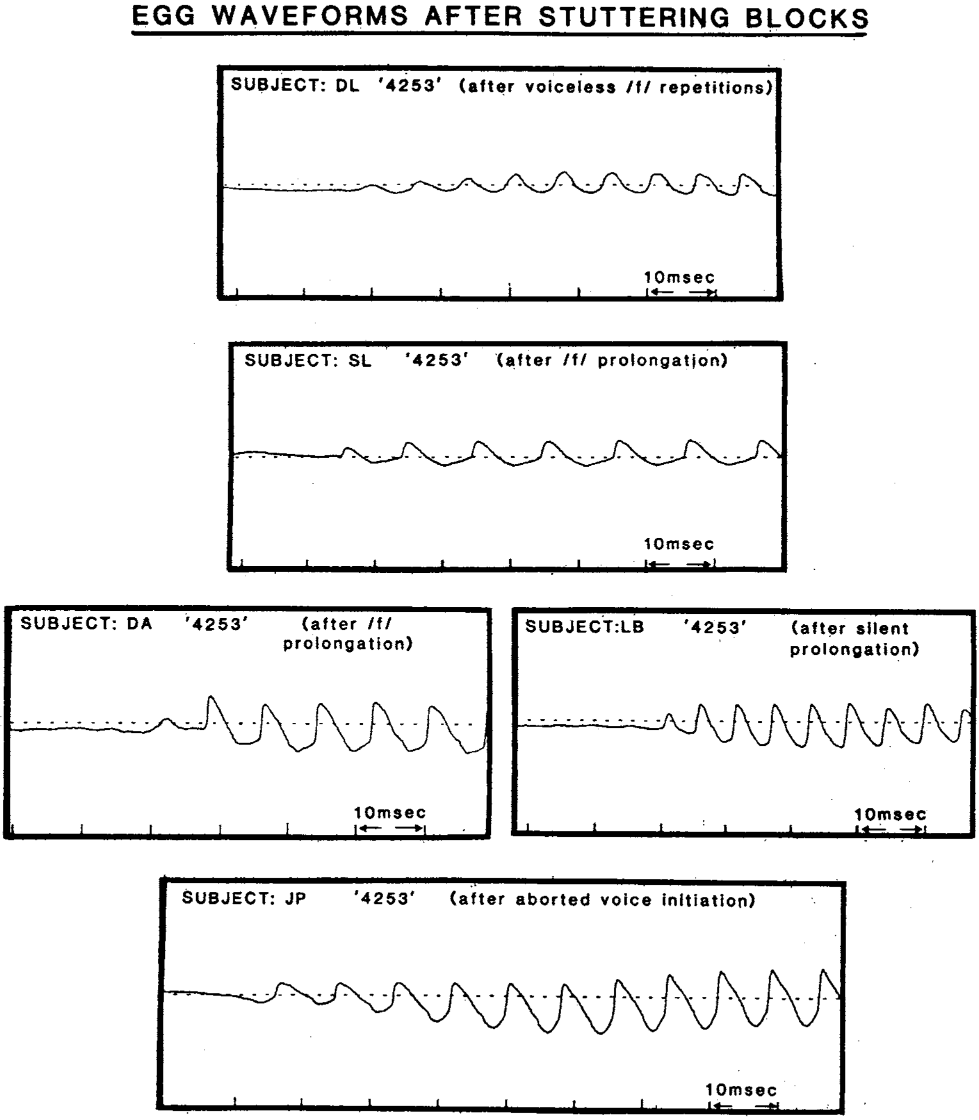

FIGURE 3. Records from 5 subjects showing EGG activity following a stuttering block. The more gradual buildup of the EGG envelope is characteristic of most of the stutterers when they initiate voicing after a block.

was evident for both mild and severe stutterers, two additional characteristics of the EGG waveforms were more common among severe stutterers. Within each cycle, both the normally gradual decline in the signal corresponding to gradual decrease in vocal fold contact as the folds peel apart and the normally stable open phase are less prominent in records from severe stutterers. Figure 4 shows these features. The somewhat steeper decline in the EGG signal and the brief open phase before they snap closed again as seen in the top part of the figure indicate that the folds in the stutterer were more rigid than normal. Additional evidence of a change in stiffness is the corresponding decline in fundamental frequency of the waveforms when adapted. The vibration initiated after the block was 170 Hz, compared with 114 Hz upon adaptation. The bottom part of the figure shows the EGG activity for the control subject.

Table 2 summarizes the features observed. All subjects showed rapidly increasing vocal fold contact during each cycle. Thus, this factor did not distinguish mild from severe stutterers. Two of the mild stutterers evidenced gradual buildup of the EGG signal after a block until adapted. In other respects the waveforms resembled those of control subjects although the open phase for LB was brief. Severe stutterers when dysfluent, however, differed from normal in several respects: a steeper decrease in vocal fold contact, a less stable or prolonged open phase, and a more gradual buildup of the EGG signal. These differences also disappeared upon adaptation. One of the severe stutterers initiated voicing with a normal-looking EGG whether dysfluent or fluent. The relative duration of consonant and vowel was reversed, however. During a dysfluent 3425, silence and consonant noise lasted 400 ms while voicing lasted 200 ms, in

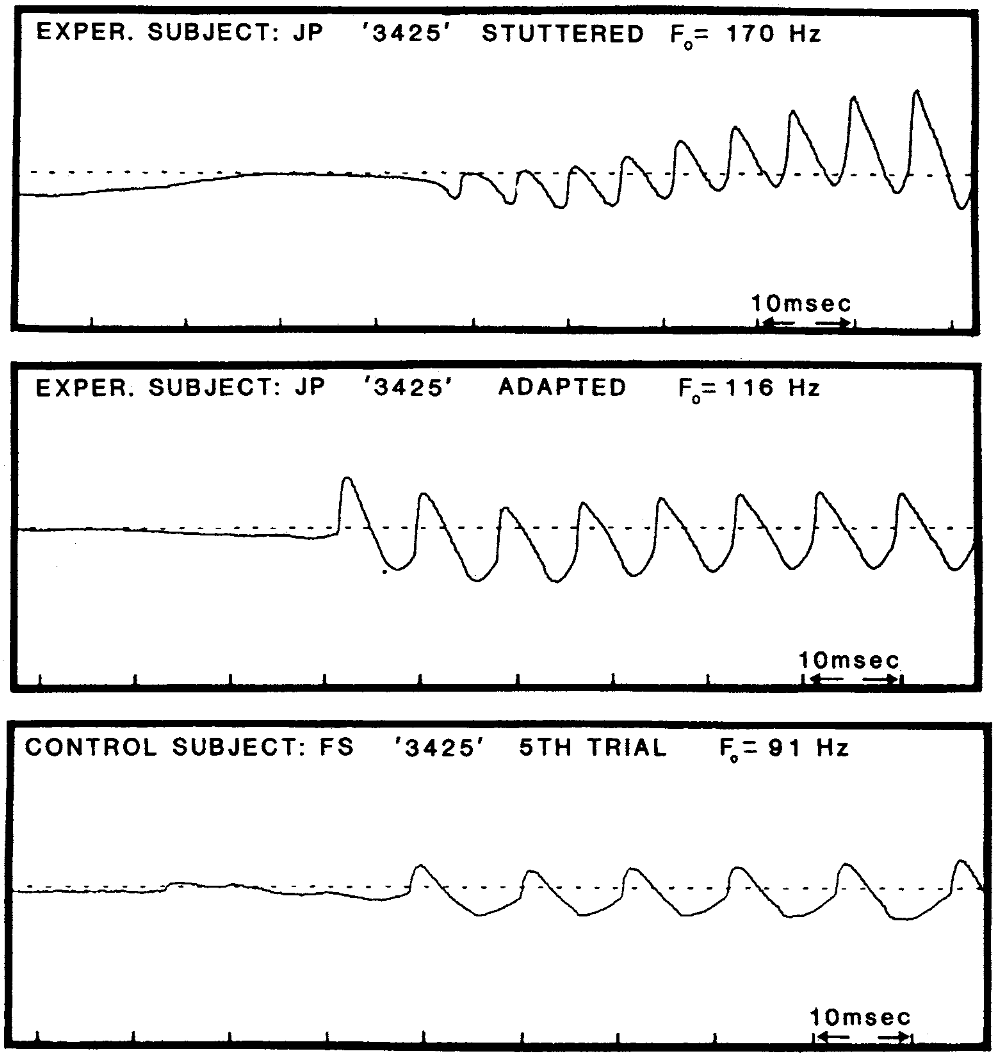

FIGURE 4. Voice initiation (onset of [ri] in *three*) in a severe stutterer and his control. Top waveform is the EGG after a stuttering block with the characteristic slow rise time. The relatively steep decrease in vocal fold contact and brief open phase of the waveform is accompanied by high fundamental frequency. Middle waveform is the same utterance adapted to fluency with slightly longer open phase, normal rise time of the first few pulses, and a lower fundamental frequency. Bottom waveform is the EGG signal for the same utterance by the control subject.

contrast with the fluent sample in which pause and consonant time was 200 ms and voicing was 400 ms. It seems that whatever adjustment this speaker made to proceed was accomplished during the unvoiced period and was not reflected in voice initiation recordings of the EGG. The rest of the stutterers evidenced gradual buildup of EGG amplitude to initiate voicing after a block.

Another observation is the existence of highly ritualized "break-the-block" behavior. One severe stutterer in our sample demonstrated a 3-stage laryngeal maneuver to initiate voicing that looked similar across different utterances. Figure 5 shows the EGG patterns that accompanied the block and final breaking of the block for the utterances *three* [θri] in *3425* and *four* [fɔr] in *4253*. When adapted, this subject had an F_0 of 114 Hz for the onset of voicing in both utterances, but the first part of the 3-stage ritual used to break the block showed a much higher fundamental frequency. In the trials shown in the figure, the first stage had an F_0 of 170 Hz. It can also be seen that as the EGG signal shows larger impedance changes, the corresponding acoustic signal is gradually lowered in F_0 and finally aborted. The second stage is characterized by breathy low-frequency vibrations with acoustic output attenuated as the impedance change excursions are widened. The third stage is always successful in that voicing is initiated and maintained, although it is abnormally graded in its EGG envelope in contrast to the adapted sample seen in the middle part of Figure 4. Except for the graded EGG seen in the final stage, the rest of the break-the-block strategy seems maladaptive, as voicing failed to be maintained.

The final observation from the EGG and acoustic data was the existence of a physiological tremor that is evident

TABLE 2. Summary of characteristics of the electroglottographic waveforms for stutterers and controls.

Subjects	*Rapid increase in VF contact*	*Gradual decrease in VF contact*	*Stable open phase*	*Abrupt envelope*	*Prevoiced adjustment*
Controls	Δ	Δ	Δ	Δ	
	Δ	Δ	Δ	Δ	Δ
	Δ	Δ	Δ	Δ	
	Δ	Δ	Δ	Δ	Δ
	Δ	Δ	Δ	Δ	
	Δ	Δ	Δ	Δ	
	Δ	Δ	Δ	Δ	
	Δ	Δ	Δ	Δ	Δ
Stutterers			Mild		
MA	Δ	Δ	Δ	Δ	
GV	Δ	Δ	Δ	Δ	Δ
SL	Δ	Δ	Δ	–ΔA	
LB	Δ	Δ	–ΔA	–ΔA	
			Severe		
DE	Δ	Δ	Δ	Δ	
DA	Δ	–ΔA	Δ	–ΔA	Δ
DL	Δ	–ΔA	–ΔA	–ΔA	Δ
JP	Δ	–ΔA	–ΔA	–ΔA	
	Not distinctive	Severe differed from mild when dysfluent			Not distinctive

Note. Δ = present. –ΔA = not present when stuttered; present when adapted. The characteristics charted above are illustrated graphically in Figure 1.

in the EGG signal during voiceless blocks. The tremor is maintained throughout the block as the speaker attempts to initiate voicing. The laryngeal tremor is often phase locked with an observable tremor in the lower lip. These tremors were observed in two of the severe stutterers. The subject (DA) represented on the top part of Figure 6 had a 9-Hz tremor and the subject (DL) on the bottom had a 7-Hz tremor. These correspond with the lip tremors of 7–10 Hz that Fibiger (1971) recorded by EMG from the facial muscles of stutterers. Physiological tremor has been linked to heightened stretch reflex due to increased gamma motoneuron activity (Desmedt, 1978; Lippold,

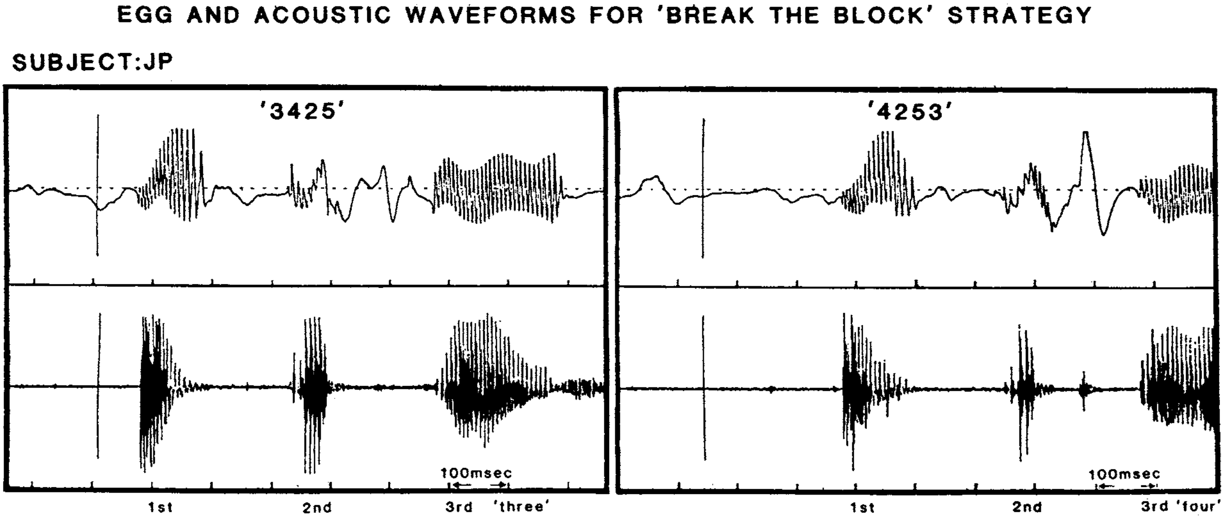

FIGURE 5. EGG (top) and acoustic (bottom) records associated with two stuttering blocks for one subject. This idiosyncratic and ritualized strategy for initiating voicing after a block is similar despite differences in utterance. This figure shows 1 s of time, but can be compared with the same subject in Figure 4, which shows 100 ms of voice initiation for *3425*.

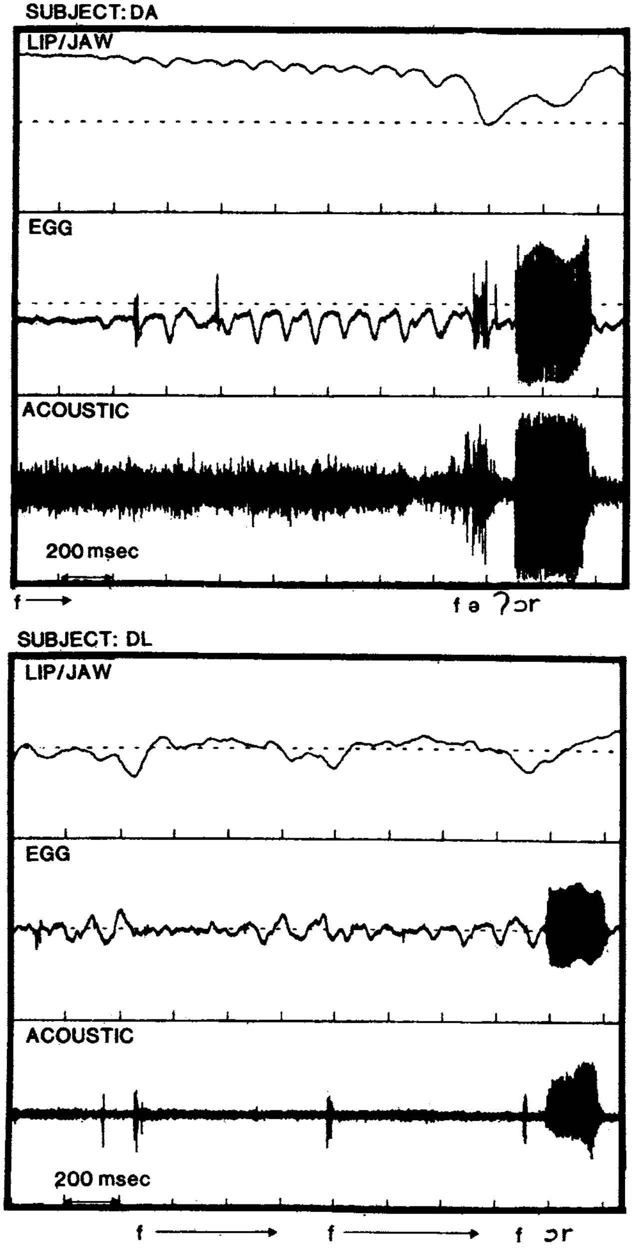

FIGURE 6. Records of lower lip movement, EGG activity, and acoustic signals from 2 subjects. Top part shows a 9-Hz physiological tremor in both lip and larynx as the subject prolongs [f] in an effort to initiate voicing. Bottom part shows several repetitions of [f] with lip lowering for each. Superimposed upon these trials is a 7-Hz tremor in both lips and larynx.

1971). The data from the second subject show the 7-Hz lip tremor superimposed upon a 1.4-Hz trial frequency, as the subject repeated [f]. Interesting to note here is the normal temporal coordination of the lip/jaw system with the laryngeal adductory system for these repeated trials, even though stuttering is usually considered to be "uncoordinated." The lip/jaw and vocal folds act together to lower and adduct respectively in preparation for the voicing that repeatedly fails to occur.

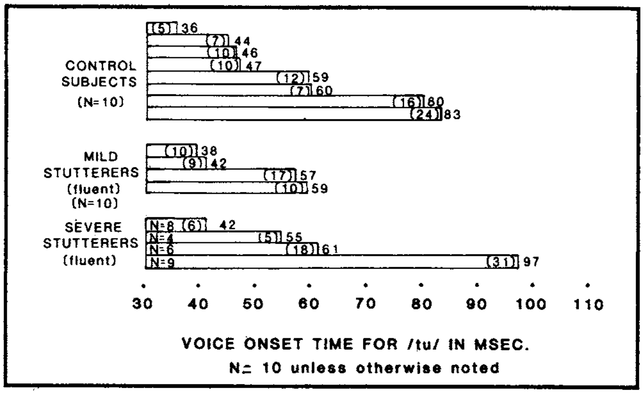

FIGURE 7. Voice onset time (VOT) as measured from sound spectrograms of the fluent utterances [tu] of the stutterers during the adaptation task and those of the control subjects. Each of the 8 control subjects yielded 10 samples of [tu]. Mean VOT for each subject is noted to the right of each histogram, with standard deviations in parentheses.

Voice Onset Time

One index of the temporal coordination of laryngeal and supralaryngeal behavior is the measurement of VOT (Lisker & Abramson, 1964) in syllables that consist of a stop and a vowel. Measurements of the time between the burst for /t/ and the onset of the voicing for /u/ in the utterance *two* were made for all utterances, both stuttered and fluent, in the adaptation task. Figure 7 shows the results. Any utterance that showed aberrant laryngeal activity in the EGG recording was eliminated from the *fluent* category. Thus, the perceptually and physiologically fluent utterances of the mild stutterers were well within normal limits of VOT. The grand mean for all measures of VOT for control subjects in the utterance /tu/ was 57 ms with a standard deviation of 17 ms, which corresponds closely with the mean VOT of the pooled fluent utterances of stutterers of 56 ms with a standard deviation of 19 ms. Two of the control subjects had considerably longer VOT than the others, with one having a mean VOT of 80 ms and the other 83 ms. They also ranked seventh and eighth, respectively, in syllable rate.

There was no significant correlation between VOT scores and rate among the normal-speaking group as a whole (r_s = .43), but extremely long VOT scores corresponded with the slowest rates. The same finding held for the fluent utterances of the experimental group. The correlation between VOT and rate was low and lacked significance (r_s = .27), but at the extremes there was some correspondence in that the subject with the shortest VOT (38 ms) had the fastest speaking rate (when fluent), whereas the subject with the longest VOT (97 ms) had the slowest speaking rate.

The severe stutterers in this study had VOTs that varied depending on whether the block occurred on the utterance *two* or elsewhere. If the block occurred elsewhere in the series of four digits, VOT on /tu/ fell within normal limits, but if the moment of stuttering fell at the junctive of the voiceless /t/ and the voiced /u/, then VOT was either artificially shortened (as when the subject voiced the stop) or it was extremely long (when voicing became difficult to initiate). These data do not suggest an overall deficit in VOT among stutterers unless they are stuttering.

DISCUSSION

When dysfluent, it is in voice initiation that stutterers suffered particular difficulty. Difficulties were manifested in silent blocks, repetitions of the voiceless consonant preceding voicing, or short bursts of voicing that were improperly initiated and were not maintained. After a stuttering block, the most successful strategy for voice initiation was *easy onset of voicing,* evidenced by gradual growth of the EGG envelope. After repeated trials, however, the adapted fluent samples were initiated with abrupt EGG envelopes similar to those of the control speakers. VOT measured from the fluent utterances of the stutterers did not significantly differ from that of the controls. Taken together, the results of the VOT analysis and the observations of EGG and acoustic waveforms indicate that, when fluent, stutterers initiate voicing normally.

Although stuttering may reasonably be thought to be a disorder of timing, the obvious temporal irregularities (abnormal VOT, repetitions, and prolongations of sound or silence) may emerge from a problem that has more to do with improper levels of activity than improper timing. The abnormalities of motor coordination seen in stuttering may not be in essence a problem in temporal coordination but rather a problem in the levels of coordinated activity of the many muscles cooperating for a particular function, such as those that set the position and tension of the vocal folds.

Evidence for this theory lies, on one hand, (a) with the previously noted abnormally high F_0 settings in the aborted voicing trials of some of the stuttering instances, the less gradual opening phase, and less stable open phase of the rapid vocal fold vibrations, all of these factors indicating abnormal stiffness; and on the other hand, (b) in the abnormally slow but extreme impedance changes during some of the stuttering episodes, indicating wide postural excursions of either too much adduction or too much abduction to permit successful voice initiation.

Along with evidence that the settings for the postural and tension prerequisites to voice initiation may be aberrant in stuttering, there is evidence that some temporal coordination is maintained. It is true that VOT as measured in the acoustic signal is abnormal during a stuttering block, but the laryngeal and supralaryngeal systems involved show a remarkable degree of temporal coordination in their movements. The product, the sound, is temporally disorganized due to difficulty in initiating voicing, but the preparatory adjustments are time locked and in this sense are well "coordinated." The physiological tremors seen in the laryngeal and lip-jaw records from two of our subjects agree in frequency and tend to be time locked, and the trials or repetitions demonstrate remarkable temporal bonding of the two systems. It may be that the timing of laryngeal–supralaryngeal coordination is not the parameter at fault in stutterers; rather, it may be that levels of the laryngeal activity previous to voice onset or offset are faulty. Zimmermann and Hanley (1983) have suggested that in adaptation, background muscle activity in stutterers becomes stabilized as arousal decreases.

When fluent, stutterers yielded VOTs well within normal limits. Reasons why this study found no significant difference whereas other studies have found longer VOT in fluent utterances of stutterers than in controls may be (a) that the present study used physiological criteria as well as perceptual judgments to categorize an utterance as *fluent* and (b) that repeating utterances until fluent (adaptation) may be a more reliable method of obtaining a fluent sample than picking fluent samples out of a corpus of stuttered and fluent speech.

The first report on this experiment (Borden, 1983) suggested that stutterers, when they are fluent, are similar to their controls in initiating speech. However, in executing a speech task, severe stutterers had a significantly lower speech rate than controls. This finding indicates that severe stutterers may require more time to make the ongoing adjustments and transitions required in speaking fluently. The present study adds support to the first report in that voice initiation seems normal as observed in electroglottographic waveforms and as VOT measured from spectrograms when stutterers are speaking fluently. When stutterers are dysfluent, however, the folds may not move (the subject with the reversed CV durations), they may go into tremor, or they may exhibit ritualistic patterns involving wide excursions. When voicing is finally initiated successfully after a stuttering block, it is usually by a strategy involving a gradual growth of vibratory amplitude.

These data provide an empirical basis for the use of *easy onset of voicing* techniques in therapy for stutterers. Our observations lead us to caution, however, that easy onset may be revealed more reliably from electroglottographic information than from acoustic waveforms. To the degree that stutterers do initiate voicing normally when fluent, as indicated by the data in this study, another implication for therapy might be that stutterers may profit from enhancing their kinesthetic sense of prevoicing settings when fluent and from trying to recapture that sense when they are having difficulty in voice initiation.

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