CHAPTER 11

765

Noninvasive Instrumentation in the Treatment of Stuttering

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Watson and Alfonso present a rationale for incorporating noninvasive instrumentation into the clinical environment to identify and treat movement abnormalities in the respiratory and laryngeal systems as well as aerodynamic irregularities associated with stuttering and other disorders of speech motor control. Illustrative examples demonstrate the potential value of kinematic monitoring devices in identifying physiologic abnormalities and in facilitating training of therapeutic targets.

1. *Describe clinical and laboratory evidence that abnormalities in control of the respiratory and laryngeal systems may be associated with stuttering.*
2. *Summarize several practical advantages of incorporating noninvasive instrumentation into therapy procedures.*
3. *How can attainment of therapeutic goals be facilitated through use of noninvasive kinematic biofeedback?*

To date, the use of noninvasive instrumentation for monitoring physiologic events during speech production has been confined primarily to the laboratory setting. One important application of this instrumentation has been to identify and characterize physiologic deficits associated with disruptions of speech motor control observed in clinical populations. Results of this research have begun to suggest meaningful applications of noninvasive instrumentation in clinical settings. The goal of this chapter is to present a rationale for clinical use of noninvasive instrumentation to identify, characterize, and remediate certain physiologic deficits associated with stuttering. We focus on deficits revealed in movements of the respiratory and laryngeal systems or as reflected in patterns of airflow through the vocal tract. We do not specifically address direct monitoring of movements of the supralaryngeal articulators because this instrumentation is complex, often invasive, and expensive. Airflow measures are less complex and can be used to infer movements of the supralaryngeal articulators. We also discuss some practical issues regarding clinical applications of instrumentation. Our discussion of these issues is not intended to provide a "cookbook" for therapy, but to highlight specific advantages and disadvantages. Finally, we present several illustrative examples of initial applications of noninvasive instrumentation in the treatment of two speech disorders: stuttering and spasmodic dysphonia. These examples highlight the general applicability of noninvasive instrumentation.

While we will show that noninvasive instrumentation is appropriate for the treatment of deficits presented in a variety of clinical populations, our rationale emerged from research findings and clinical observations taken from the stuttering literature. This rationale is based on several assumptions. First, we assume that speech characteristics of stutterers are associated with disruption of the normal coordination of events within and between the respiratory, laryngeal, and articulatory systems. Furthermore, certain characteristics of these disruptions are observable in kinematic and airflow signals. Second, we assume that certain physiologic (i.e., kinematic) disruptions may precede the perceived moment of stuttering. That is, by the time the moment of stuttering is manifested in the speech acoustic signal, the physiologic disruption has already occurred. Third, we assume that certain physiologic disruptions are not perceptually evident or clearly identifiable in the acoustic signal. In fact, stutterers' perceptually "fluent" speech may be different from the fluent speech of nonstutterers at some physiologic level(s). Consequently, feedback of the acoustic signal alone is inadequate for developing compensatory strategies designed to avoid or minimize these disruptions. Finally, we assume that certain characteristics of physiologic disruptions associated with the moment of stuttering can be detected, quantified, and displayed to clients, and that this process will facilitate the development of strategies for reducing the magnitude of the disruption and thereby improve fluency.

Use of biofeedback in the treatment of stuttering is not a new concept. Guitar (1975) described a therapy program in which output from surface electrodes modulated an acoustic signal presented to subjects. As the amplitude of muscle activity increased, the frequency of the acoustic signal increased. Biofeedback representing level of muscle activity was effective in helping subjects reduce activity levels (i.e., facilitated relaxation) and improve fluency. The approach proposed here differs from that used by Guitar. That is, we propose the use of biofeedback to change specific laryngeal and respiratory behaviors in order to facilitate the production of fluent speech.

We begin developing our rationale by reviewing clinical observations and research findings associating disruption of respiratory and laryngeal coordination with stuttering. The goal of this review is to highlight salient characteristics of these disruptions. In so doing, we may provide a rationale for appropriate clinical targets for therapeutic intervention.

RESPIRATORY DISRUPTIONS

During speech production, the respiratory system provides expiratory airflow and adequate driving pressure to support phonation. This function is realized by a rapid prephonatory increase in lung volume followed by maintenance of a relatively stable positive pressure across a decreasing lung volume. Maintenance of the relatively stable expiratory driving pressure is accomplished by a balance of nonmuscular forces (i.e., gravity) and forces generated by the contraction of inspiratory and expiratory muscles (cf. Zemlin, 1988). Clinical observations of respiratory abnormalities in stutterers include reduced tidal volume, marked delay between onset of expiratory airflow and onset of phonation, continued speech production at inappropriately low lung volumes, interruption of speech by inspiratory gasps, and speech production on inspiration (Van Riper, 1982). These observations suggest that certain stutterers have difficulty coordinating respiratory events for speech.

Laboratory investigations of respiratory kinematics in stutterers are consistent with clinical observations. For example, Travis (1927) reported both prolonged duration of inspiration relative to duration of expiration and tremor of the abdominal wall. Travis also described pronounced antagonistic movements of the thoracic and abdominal walls. However, oppositional movements of the rib cage and abdominal wall have been observed in normal speakers and reflect the relatively independent contributions of changes in volumes of the thoracic and abdominal cavities to changes in total lung volume (cf. Hixon et al., 1973). So, oppositional movements alone do not necessarily reflect abnormal respiratory kinematics. Murray (1932) observed (1) increased variability in both amplitude and duration of inspiratory and expiratory gestures in stutterers relative to nonstutterers during a silent reading task, and (2) greater variability in amplitude of stutterers' inspiratory gestures during silent reading than during resting breathing. Nonstutterers showed an opposite pattern; they reduced variability of the inspiratory gesture during the reading task. Thus stutterers were apparently unable to meet increased demands for stability of the respiratory system during the reading task. Seth (1934) described respiratory disruption during a stuttering block as characterized by "halts, interruptions, sudden releases, and complete reversals" of expiration and inspiration.

The respiratory deficits noted above were observed during the moment of stuttering by all the researchers mentioned except for Murray (1932). Consequently, it is not clear to what extent these phenomena precipitate the stuttering episode or reflect stutterers' attempts to restore control over speech production. In a recent study, Watson and Alfonso (1986) observed several respiratory deficits before and during stutterers' voice onset for production of a perceptually fluent vowel. First, severe stutterers—unlike a mild stutterer and nonstutterers—rarely used prephonatory preparation intervals to execute gestures associated with inflation of the respiratory system. Indeed, analysis of kinematic signals in terms of changes in relative lung volume revealed that significantly lower prephonatory increases in lung volume were achieved by severe stutterers than by the mild stutterer and nonstutterers. Severe stutterers also frequently began respiratory compression (expiratory gestures) for phonation onset well before the moment of vocal fold closure. This pattern suggests inefficient management of the expiratory airstream. Again, analysis of kinematic data in terms of relative changes in lung volume supported this finding. Severe stutterers showed significantly greater reduction in lung volume before voice onset than did the mild stutterer or nonstutterers. That is, severe stutterers waste pulmonic air before voicing begins.

Taken together, clinical observations and laboratory findings suggest that disruption of normal respiratory function is associated with, and may precipitate, the moment of stuttering. In addition, this review suggests several targets for a therapy program designed to minimize contributions of respiratory disruption to stuttering. For example, therapy might focus on (1) ensuring adequate prephonatory inflation; (2) establishing smooth, uninterrupted airflow; (3) eliminating attempts to phonate on inspiration; and (4) facilitating efficient airflow management through appropriate organization of respiratory and laryngeal events.

LARYNGEAL DISRUPTIONS

Wingate (1967) noted that smooth transitions between voiced and voiceless segments are critical for fluent speech. Therefore an important dimension of laryngeal control during connected speech is rapid onset and offset of vocal fold vibration for the production of contiguous voiced and voiceless segments. Vocal fold vibration is a consequence of the interaction of myoelastic properties of the vocal folds and aerodynamic phenomena (e.g., transglottal pressure) (van den Berg, 1958). Consequently rapid voice onset and offset adjustments require precise regulation of vocal fold tension, medial compression, and position as well as transglottal pressure (Stevens, 1977). Clinical observations suggest a relation between stuttering and disrupted control of voice onset and offset. For example, stuttering is more likely to occur in association with voice onset for the initial word of an utterance or phrase (Brown, 1938).

Stutterers' ability to initiate and terminate voicing has been investigated using a variety of experimental paradigms. For example, some investigations compare frequency of stuttering and/or amount of adaptation on passages containing only voiced segments with passages containing both voiced and voiceless segments (Adams & Reis, 1971, 1974; Adams, Riemenschneider, Metz, & Conture, 1975; Manning & Coufal, 1976; Hutchinson & Brown, 1978). Most of these studies report greater frequency of stuttering and less adaptation for passages containing both voiced and voiceless segments. The interpretation most often applied to this finding is that increased frequency of stuttering or failure to adapt or both reflect stutterers' difficulty executing rapid voice onsets and offsets.

The reaction time paradigm is used to assess vocal control in terms of stutterers' ability to rapidly initiate voicing. The measure of interest is stutterers' voice onset latency relative to presentation of an external reaction signal (e.g., a tone or a light). Specifying the phonetic nature of the response (i.e., isolated vowel or consonant-vowel syllable) minimizes specific contributions of the articulatory system to reaction time values. Consequently delays in voice onset are presumed to reflect primarily respiratory-laryngeal deficits. Results of reaction time studies suggest that stutterers as a group have difficulty rapidly initiating phonation (cf. Adams & Hayden, 1976; Cross & Luper, 1979; Cullinen & Springer, 1980; Reich, Till, & Goldsmith, 1981; Starkweather, Hirschman, & Tannenbaum, 1976; Watson & Alfonso, 1982, 1983, 1987).

Insights into physiologic events associated with stutterers' apparent difficulty controlling both the laryngeal system and interactions between the respiratory and laryngeal systems derive from studies of laryngeal and respiratory physiology during stutterers' perceptually fluent or dysfluent speech. Conture, McCall, and Brewer (1977), based on fiberoptic filming of the vocal folds during connected speech, described abnormal positioning of the vocal folds associated with moments of dysfluency. Freeman and Ushijima (1978), recording electromyographic (EMG) signals from intrinsic laryngeal muscles, observed abnormal levels of activity and inappropriate reciprocity in antagonistic laryngeal muscles during dysfluencies. Shapiro (1980) observed similar EMG abnormalities.

Using electroglottography (EGG), Borden, Baer, and Kenney (1985) investigated laryngeal events associated with stutterers' production of perceptually fluent and dysfluent words in a counting task. The EGG signal provides information regarding changes in vocal fold contact area during a cycle of vibration. Analysis of the rise-time of the amplitude envelope of the EGG signal yields information corresponding to abruptness of voice onset. For example, abrupt onset of voicing is associated with a rapid increase in the amplitude of the EGG signal. In addition, as shown in Figure 11.1, landmarks in the EGG signal can be identified that correspond to increasing vocal fold contact (glottal closing), decreasing vocal fold contact (glottal opening), peak contact (glottal closure), and minimum contact (open glottis).

Borden et al. (1985) reported several differences between EGG patterns produced by normal speakers and those associated with stutterers' dysfluencies or attempts to recover from a dysfluency. Following a dysfluency, stutterers often demonstrated a more gradually increasing amplitude envelope of the EGG signal. This pattern was interpreted as a physiological correlate of perceptual judgments of "easy onset of voicing." Indeed, the authors suggest that the EGG signal provides a more reliable index of easy onset than the acoustic signal because it is independent of filtering effects imposed by the supralaryngeal vocal tract. With respect to details of the vibratory cycle after a dysfluency, severe stutterers in particular demonstrated a pattern of rapid glottal opening and an open period of relatively short duration. Borden et al. (1985) suggest that this pattern reflects stiff vocal folds. This suggestion was confirmed by acoustic analyses that showed an increase in fundamental frequency when voicing was initiated after a block. The positive relationship between increases in vocal fold stiffness and increases in fundamental frequency in chest register is well documented (Gay, Hirose, Strome, & Sawashima, 1972). In summary, two aspects of the Borden et al. study are particularly relevant to our goal. First, this study demonstrates that the EGG signal can be a reliable indicator of easy onset of voicing and that changes in the fine structure of the EGG waveform can be used to infer vocal fold stiffness. Second, EGG biofeedback may facilitate establishment of fluency-enhancing techniques (clinical targets) and aid in reducing certain laryngeal abnormalities (such as increased vocal fold tension). These changes may in turn facilitate fluency.

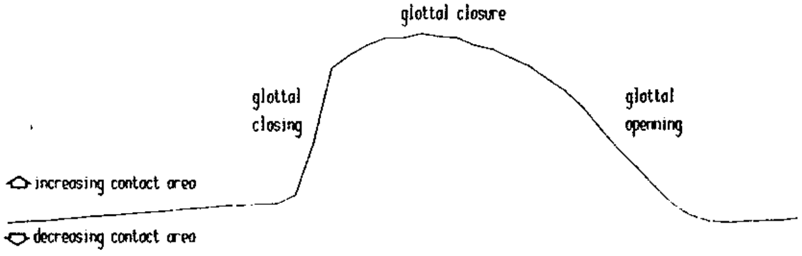

Figure 11.1 Electroglottographic signal corresponding to one cycle of vocal fold vibration. Important landmarks are indicated.

Laboratory studies also reveal stutterers' deficits in organizing laryngeal and respiratory events. Watson and Alfonso (1987) reported abnormal delays in stutterers' onsets of vocal fold abduction and adduction gestures as well as evidence of inappropriate timing of vocal fold closure and onset of expiratory airflow associated with perceptually fluent onsets of isolated, voiced vowels. Peters and Hulstijn (1987), based on an analysis of patterns of prephonatory increases in subglottal pressure, also reported evidence of abnormalities in temporal coordination of respiratory and laryngeal events.

Taken together, studies of laryngeal function in stutterers highlight two classes of abnormality: (1) inappropriate levels of muscle activity that may be associated with increased vocal fold tension and laryngeal resistance to airflow; and (2) temporal disruption in the organization of laryngeal opening and closing gestures with respiratory inspiratory and expiratory gestures.

AERODYNAMIC DISRUPTIONS

The consequence of appropriate organization of respiratory and laryngeal events leading to voice onset is the generation of expiratory airflow that is modulated at the level of the larynx and then further modulated and filtered by altering the shape of supralaryngeal cavities. Hutchinson (1974) recorded airflow through the vocal tract and intra-oral air pressure in an attempt to characterize aerodynamic patterns produced by stutterers and to relate these patterns to dysfluency type. He identified seven distinct aerodynamic patterns associated with stuttering. While many of these patterns primarily reflected abnormalities in intra-oral air pressure, some of them were characterized by abnormal patterns of airflow. For example, the most frequently observed dysfluency ("abbreviated vowel element") was associated with abrupt cessation of airflow. Another example, "prolonged silent blocks," was associated with an absence of airflow. Hutchinson was able to simulate abnormal patterns associated with abbreviated vowel element dysfluencies by executing a glottal stop gesture. The pattern associated with prolonged silent blocks was simulated by "very stable posturing of the articulators with no variations in respiratory driving force." Further, he reported the sensation being "locked into one articulatory gesture" during the simulation. This sensation parallels that reported by stutterers during tonic blocks. The suggestion that specific dysfluency types may be associated with specific aerodynamic patterns implies that monitoring airflow during the production of phonetically specified utterances may be informative in identifying salient aerodynamic characteristics of a stutterer's dysfluencies and may aid in developing a strategy for modifying these patterns to facilitate fluency.

In sum, there is ample evidence—derived from both clinical observation and laboratory investigation—to conclude that abnormalities in respiratory and laryngeal function and in patterns of airflow through the vocal tract are associated with stutterers' dysfluencies. Furthermore, the evidence suggests that specific aspects of respiratory and laryngeal function may be amenable to modification by providing clients with biofeedback of kinematic (i.e., respiratory and laryngeal) and aerodynamic signals. For example, clinical targets that may be achieved through biofeedback of kinematic and aerodynamic signals include the following:

1. Adequate respiratory inflation before attempted speech onset
2. Maintenance of a smooth expiratory gesture during speech production
3. Appropriate organization of laryngeal opening and closing gestures with respiratory inspiration and expiration gestures
4. Appropriate levels of vocal fold resistance (i.e., stiffness)
5. Phonetically appropriate patterns of airflow through the vocal tract

CLINICAL APPLICATIONS: ADVANTAGES AND DISADVANTAGES

The next step in the development of a rationale for therapeutic application of noninvasive instrumentation is to consider advantages and disadvantages of an instrumented biofeedback approach as an adjunct to traditional approaches. The important consideration here is adjunct. We do not advocate replacing current therapy techniques with a purely instrumented approach. Instead, instrumentation provides additional information that can facilitate development of therapy goals and implementation of therapy procedures. Advantages of an instrumented approach include objectivity, quantifiability, real-time visual feedback, and long-term data storage. Disadvantages include the obvious expense of the instrumentation (monitoring, display, and storage devices), possible generalization difficulties, and clients' possible negative reactions to the instrumentation.

Objectivity and quantification are valuable in identification and treatment of deficits associated with any speech disorder. The ability to identify salient characteristics of physiologic deficits in particular should aid in focusing therapeutic efforts to match deficits presented by the client. For example, Watson (1983) found that delays in voice onset for a group of stutterers were associated with two different patterns of respiratory-laryngeal organization. The first pattern was characterized by significant delays between the moment of vocal fold closure and the onset of respiratory compression gestures. The second pattern was characterized by significant delays between the onset of compression gestures and the moment of vocal fold closure. Idiosyncratic differences in temporal sequencing of prephonatory respiratory and laryngeal events may be important in developing appropriate therapeutic strategies. While therapy emphasizing easy voice onset (i.e., onset of exhalation before the moment of vocal fold closure) may be appropriate for a stutterer who demonstrates the first pattern described above, this approach may not be appropriate for a stutterer who demonstrates the second pattern. Instead, this client may benefit from therapy designed to minimize the delay between onset of respiratory compression (i.e., exhalation) and the moment of vocal fold closure.

Apart from the ability to clearly characterize physiologic deficits contributing to an individual's stuttering behavior, quantification of deficits has practical benefits for both clinician and client. In the current atmosphere of increased demands for accountability in health care professions, documentation of both baseline abnormality and changes over time is important in establishing a clear strategy and goals for therapy and in documenting benefits of therapy.

Real-time visual feedback of kinematic signals is advantageous for other reasons. First, clients can more clearly appreciate the nature of physiologic disruptions and what steps can be taken in therapy to minimize their impact on speech production. This appreciation can increase motivation. Second, the process of minimizing these disruptions is facilitated because both client and clinician receive immediate feedback regarding the success of attempted strategies. Immediate feedback assists the clinician in tailoring therapy strategies and assessing their viability. Immediate feedback assists the client in mastering these strategies and incorporating them into a new pattern of speech production.

Advantages of long-term data storage parallel those of quantification. The ability to maintain records of baseline measures and periodic assessments of progress during therapy is important in meeting demands for accountability and for providing clients with a tangible chronology of their progress. In addition, periodic review of these data may aid clinicians in identifying the strategies most successful in facilitating improvement in a subgroup of clients. This process will in turn assist in the development of more efficient and effective treatment programs.

Potential limitations associated with clinical application of instrumentation arise from the interaction of client with equipment. For example, Borden and Watson (1987), in their discussion of laboratory use of instrumentation, noted that attaching monitoring devices to subjects seems to produce a decline in the frequency and severity of stuttering behaviors. That is, there is a novelty effect associated with the instrumentation. Clients who experience this effect may not produce stuttering behaviors. As a consequence, certain subtle physiologic deficits may not be identified. However, repeated experience with the instrumentation will lessen the novelty effect. Indeed the novelty effect can be used to great advantage to document physiologic events associated with this "artificial fluency."

The following discussion describes noninvasive instrumentation currently used in many speech science laboratories. These devices may be effectively integrated into a biofeedback therapy program designed to address the aspects of respiratory and laryngeal function described above.

RESPIRATORY MONITORING

With respect to respiratory kinematics, research and clinical observations suggest that stutterers may benefit from feedback regarding coordination of thoracic and abdominal movements during inspiration and expiration as well as coordination between movements of the respiratory and laryngeal systems.

Respiratory kinematics can be evaluated by monitoring changes in the chest wall in several dimensions. For example, Hixon, Goldman, and Mead (1973) describe a magnetometer system for monitoring changes in rib cage diameter and in abdominal diameter. Baken (1977) describes a mercury strain-gauge system for monitoring changes in the anterior hemicircumference of the thorax and abdomen. Finally, Cohn, Watson, Weisshaut, Stott, and Sackner (1975) describe an inductance-coil plethysmograph system (Respitrace) for monitoring changes in the total circumference of the rib cage and abdomen. Although differing with respect to specific principles of operation, all three systems provide information regarding coordination between the thoracic and abdominal cavities. All three systems can also be calibrated to reveal changes in relative or absolute lung volume.

LARYNGEAL MONITORING

The above review of laryngeal behavior associated with stuttering suggests that certain stutterers may benefit from increased control over several aspects of vocal fold vibration as well as coordination of laryngeal and respiratory movements. Noninvasive monitoring of vocal fold activity may be achieved using electroglottography (for a comprehensive review of electroglottography, see Childers and Krishnamurthy, 1985). An electroglottograph (EGG) is sensitive to changes in vocal fold contact area. Briefly, this device detects changes in resistance to a high-frequency, low-amplitude signal transmitted between surface electrodes attached superficially to the laminae of the thyroid cartilage (Baken, 1987). Increased vocal fold contact decreases resistance while decreased contact increases resistance.

Resistance changes detected by the EGG may reflect relatively slow articulatory adjustments of the vocal folds (i.e., abduction and adduction) or rapid changes in contact area during each cycle of vibration. Most commercially available EGG devices provide separate output of both a slow signal (associated with postural adjustments) and a fast signal (associated with vibratory details). However, caution must be used in inferring abductory and adductory vocal fold movements since the slow signal is affected by changes in structures remote from the glottis (e.g., jaw movements or tension in strap muscles) as well as vertical displacement of the larynx. For this reason, the most widely accepted use of EGG is to infer vibratory characteristics of the vocal folds.

Baken (1987) summarizes the primary threats to the validity of the EGG signal. In general, many of these threats are reduced if the electrodes are secured in place at the level of the vocal folds and head movements are kept to a minimum. An additional method of minimizing movement artifacts in the fast EGG signal is to route the EGG output signal through a highpass filter. This eliminates low-frequency components associated with head movements, contraction of strap muscles, and abduction-adduction movements.

AERODYNAMIC MONITORING

In addition to monitoring respiratory and laryngeal kinematics, treatment of dysfluencies may be aided by use of aerodynamic measures. Airflow is monitored by channeling the expiratory airstream through a flow transducer coupled to a face mask (Baken, 1987). When respiratory driving pressure is held constant and laryngeal resistance is known, airflow measures can be used to infer the degree of vocal tract constriction. That is, as the degree of constriction increases, aerodynamic resistance increases and airflow decreases. In addition, several transducers (e.g., pneumotachygraph) differentiate between egressive and ingressive airflow (Baken, 1987). Thus an airflow monitoring system may serve as an important supplement to feedback of respiratory kinematic information to document continuity of expiratory airflow during speech.

CLINICAL EXAMPLES

As noted in the Introduction, clinical examples will illustrate the potential value of noninvasive instrumentation in the identification and treatment of patients with two respiratory and laryngeal abnormalities: stuttering and spasmodic dysphonia. These patients share the characteristic of disordered vocal motor control (McCall, 1974). Consequently they are appropriate for illustrating clinical use of respiratory and laryngeal kinematic monitoring devices. Figure 11.2 illustrates the placement of respiratory and laryngeal monitoring devices. In the following examples, respiratory kinematics were transduced using a Respitrace inductance plethysmograph (Ambulatory Monitoring Systems, Inc.). A single inductance coil was placed around the subject's chest wall and provided a gross measure of respiratory system displacement. This is a nonstandard recording procedure. Use of one inductance coil does not permit unambiguous identification of the unique contributions of rib cage and abdominal wall displacements to changes in lung volume during respiration. In many clinical applications, use of separate rib cage and abdominal coils will be more informative. Laryngeal kinematics were transduced using an electroglottograph (Synchrovoice, Inc.). Electroglottographic signals were routed through a highpass filter (Glottal Enterprises, Inc., model LPHP-2A) to eliminate low-frequency artifact. The resulting signal reveals changes in vocal fold contact area during the vibratory cycle.

Identification of Abnormalities

The first example illustrates an application of the EGG signal to identify physiological disruption associated with stuttering. Figure 11.3 shows EGG and acoustic signals recorded from an adult male stutterer during two readings of a short passage. Upward deflection of the EGG signal corresponds to increasing vocal fold contact area, or the closing phase of a vibratory cycle. Downward deflection corresponds to decreasing vocal fold contact area, or the opening phase of the cycle. Positive peaks in the EGG signal represent the closed phase and negative peaks represent the open phase of a cycle.

The top set of traces was recorded as the subject produced a double-unit repetition of the initial /s/ in "sister." The EGG signal shows no

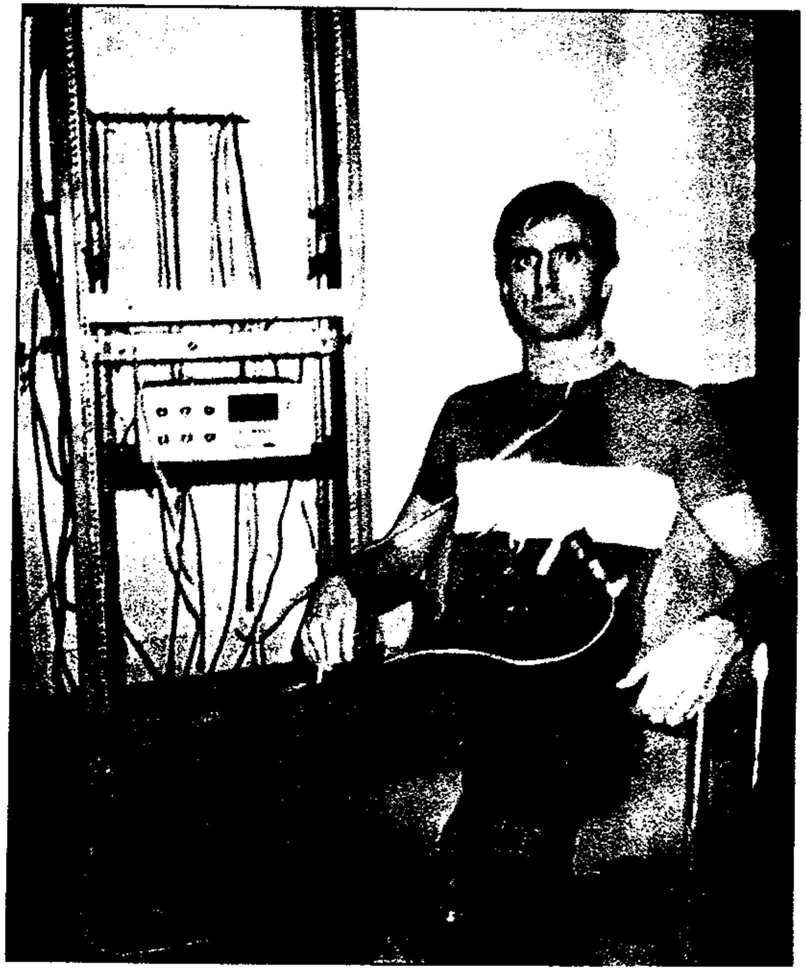

Figure 11.2 Placement of the electroglottograph and a single Respitrace band for clinical applications.

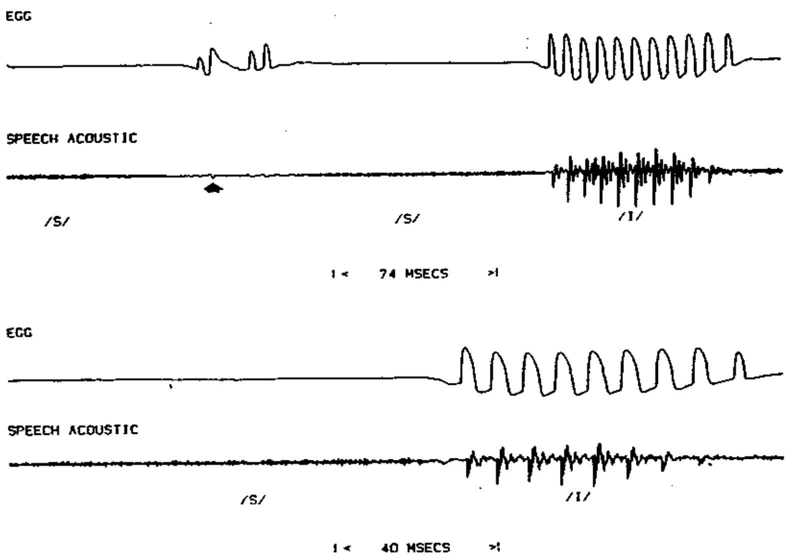

Figure 11.3 Simultaneous electroglottographic and acoustic signals recorded during a stutterer's perceptually dysfluent and fluent productions of the word "sister." EGG signal reveals that repetition of voiceless /s/ in the dysfluent production is associated with inappropriate laryngeal activity.

changes in vocal fold contact area during the initial period of frication seen in the acoustic signal (corresponding to the initial /s/). Next, the EGG signal shows multiple changes in vocal fold contact area that, although appearing as low amplitude pulses in the acoustic signal (indicated by the arrow), are not perceptually evident. Finally, the EGG signal shows no change in vocal fold contact area during production of the second /s/. Perceptually, this was a voiceless repetition. The acoustic signal shows no obvious evidence of voicing during the repetition. The EGG signal, however, shows *multiple changes in vocal fold contact during the dysfluency.* These changes in contact area appear to represent an aborted attempt to initiate voicing. That is, this perceptually voiceless dysfluency is associated with inappropriate laryngeal activity.

The bottom set of traces was recorded during this client's perceptually fluent production of the same material. Note that the EGG signal shows no changes in vocal fold contact area during fluent production of the voiceless /s/. Finally, apparent differences in fundamental frequency for the vowel /I/ in the two acoustic traces reflect the different time scales used in this figure and do not appear to be related to differences in the fluency of these productions.

In this example, the EGG signal permitted identification of an inaudible laryngeal abnormality associated with a voiceless dysfluency. Inappropriate laryngeal activity during voiceless dysfluencies has been documented in laboratory settings through analysis of electromyographic signals (Freeman & Ushijima, 1978) and fiberoptic films (Conture, McCall, & Brewer, 1977). This example illustrates, however, that inappropriately organized laryngeal-articulatory activity can be documented in the clinical setting using noninvasive instrumentation. With this information, therapy can focus on eliminating inappropriate laryngeal gestures by instructing the subject to keep the EGG signal at a "neutral" position during voiceless consonants.

The next example illustrates an application of the Respitrace signal. Figure 11.4 shows speech acoustic and Respitrace signals recorded from a stutterer during production of a multiunit syllable repetition. Upward deflection of the Respitrace signal corresponds to expansion of the respiratory system; downward deflection corresponds to compression. The dashed line shows the shape of the predicted, normal respiratory compression gesture for this utterance. In this example, the dysfluency is associated with a disruption in the normal continuity of the compression gesture. Specifically, each repetition unit is preceded by expansion of the chest wall. These cyclic expansion gestures interrupt the compression gesture. Identification of this abnormality motivates implementation of therapy procedures designed to increase the continuity of expiratory gestures during speech. This may provide a foundation for improved fluency.

The preceding examples show that certain characteristics of the physiologic disruption associated with a stutterer's dysfluency can be identified when noninvasive, kinematic instrumentation is used in conjunction with traditional acoustic recordings. These examples also illustrate that much of the clinically valuable information associated with dysfluencies may occur during silent periods. That is, kinematic records can be important in obtaining sufficiently detailed descriptions of dysfluent speech for design of appropriate therapy goals.

Treatment

The next example illustrates a therapeutic application of the EGG signal. Figure 11.5 shows acoustic and EGG signals recorded as a stutterer attempted to use continuous voicing. The top set of traces illustrates an unsuccessful attempt. Note the clear discontinuity in the EGG signal. The bottom set of traces shows a successful attempt. Here the EGG signal and voicing, as indicated in the acoustic signal by continuation of the vertical pulses (waveform), are continuous. This figure also illustrates the advantage of using EGG signals as evidence of continuous

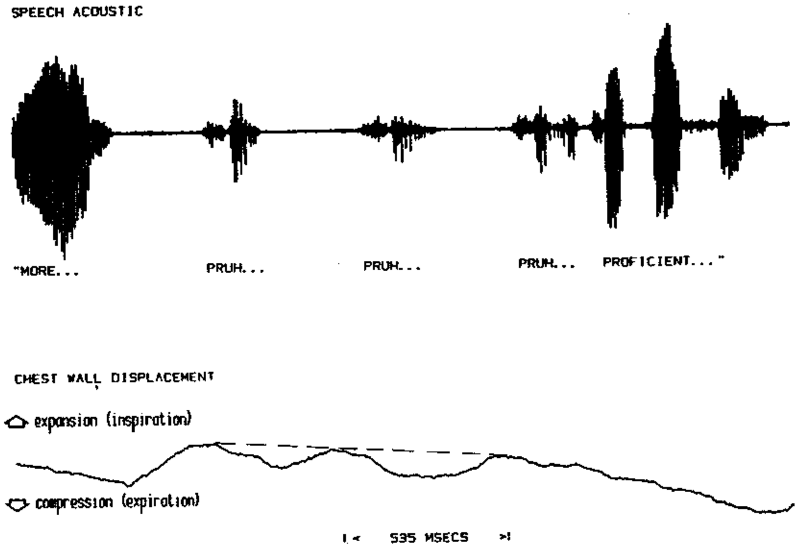

Figure 11.4 Simultaneous Respitrace and acoustic signals recorded during a stutterer's perceptually dysfluent production of the word "production." The dashed line indicates the predicted normal respiratory pattern. Repetitions are associated with inspiratory chest wall gestures that interrupt exhalation.

voicing. Specifically, amplitude of the acoustic signal is markedly reduced during the period of oral closure for /n/ in /man/. The EGG signal, however, displays a constant amplitude, since it is not subjected to damping properties of the vocal tract. Consequently the EGG signal provides a more stable and reliable index of the activity of the vocal folds than does the acoustic signal.

This example also illustrates a procedural issue regarding visual feedback of kinematic signals. At issue is the duration of the window over which immediate feedback is provided. The temporal window in Figure 11.5 is 500 msec. This window is too long to provide meaningful feedback to the client. That is, too much information is presented. Figure 11.6 shows the effect of decreasing the duration of the window. A portion of the EGG signal shown in the top half of Figure 11.5 is repeated here in a 100 msec window. The discontinuity in vocal fold vibration is more pronounced when shown in this shorter window. Clients report little difficulty monitoring the EGG signal when the window is relatively short (i.e., 50–100 msec). However, longer windows (i.e., 2–5 sec) are useful in providing clearer feedback of the slower-moving respiratory kinematic signal.

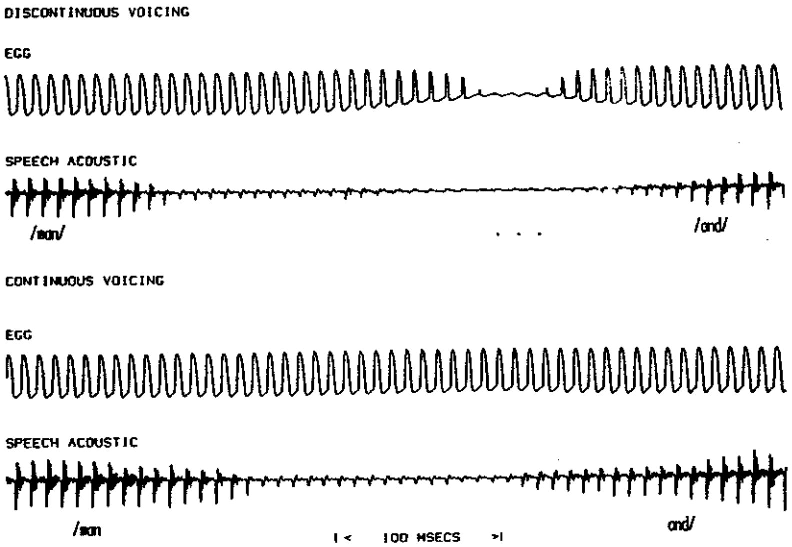

Figure 11.5 Simultaneous electroglottographic and acoustic signals recorded during a stutterer's unsuccessful (top) and successful (bottom) attempts to produce an all-voiced passage using continuous phonation. Note the obvious discontinuity in the EGG signal during the unsuccessful attempt.

The final example illustrates use of EGG signals to document change as a function of therapy and the applicability of noninvasive instrumentation in assessing and treating a variety of motor speech disorders. Figure 11.7 shows pre- and post-therapy recordings of acoustic and EGG signals recorded from a client with spasmodic dysphonia. Both sets of tracings show this client's attempts to initiate the isolated, voiced vowel /a/. Pretherapy tracings, shown in the top half of the figure, reveal multiple interruptions in the attempt to initiate voicing. Note that the initial, aborted attempt is associated with a short rise-time in the EGG signal. Rise-time refers to the interval between onset of the acoustic signal and the point of maximum signal amplitude. This pattern is consistent with high levels of medial compression likely to be associated with the laryngospasm.

A brief trial therapy was conducted to (1) identify and stabilize an optimal vocal pitch, and (2) establish soft voice onsets. Therapy procedures involved visual feedback of acoustic and EGG signals using a Visi-Pitch (Kay Elemetrics) installed on a personal computer. Optimal pitch was stabilized by instructing the client to either increase or decrease

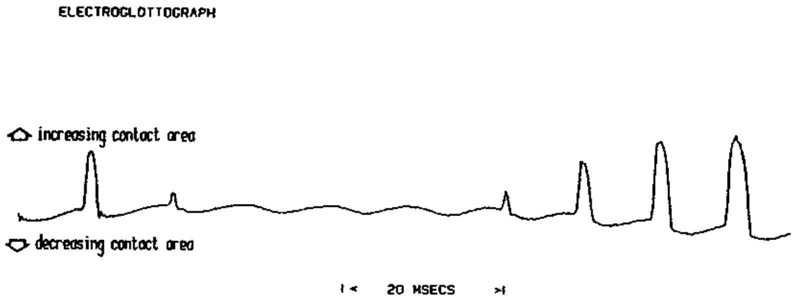

Figure 11.6 Expanded version of the discontinuity in the EGG signal shown in Figure 11.5. The shorter time window shown here facilitates client use of visual feedback of the EGG signal.

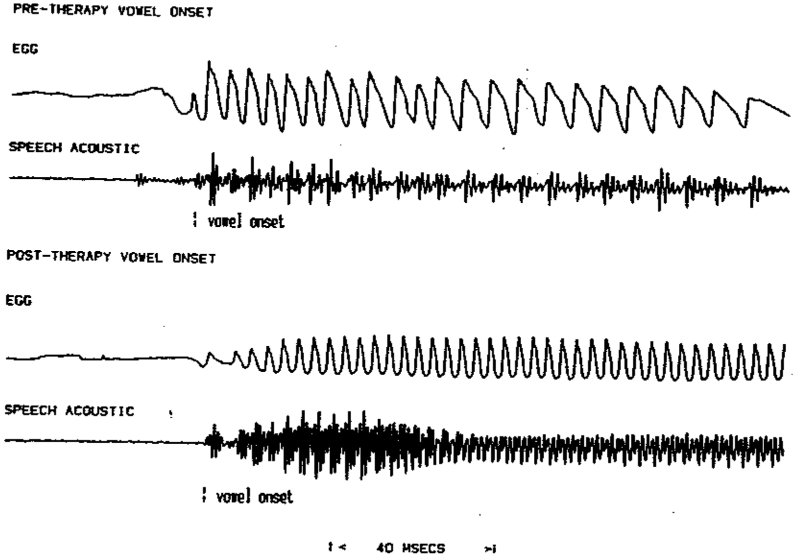

Figure 11.7 Simultaneous electroglottographic and acoustic signals recorded during pre- and posttherapy attempts by a patient with spasmodic dysphonia to initiate an isolated voiced vowel. Pretherapy EGG signal shows abrupt amplitude rise-time and asymmetrical pattern of changes in vocal fold contact. Posttherapy EGG signal shows more gradual amplitude rise-time and more symmetrical pattern of changes in vocal fold contact.

the number of cycles of vocal fold vibration (as shown in the EGG waveform) displayed on the Visi-Pitch screen. A slightly breathy vocal quality was established and stabilized by instructing the client to increase the duration of the open phase of the vibratory cycle as revealed in the EGG signal. Finally, soft voice onset was trained by instructing the client to increase the rise-time of the amplitude envelope of the acoustic signal (i.e., the interval from onset of the acoustic signal to maximum amplitude).

After one 20-min therapy session, the client produced the vowel onset shown in the bottom half of Figure 11.7. Note that voicing was initiated without interruption. Also note the gradual rise in the overall amplitude of the EGG signal. Finally, note the increased consistency in the shape of the EGG waveform. Gradual rise-time of the posttherapy acoustic signal suggests that the client was using a softer mode of vocal attack. Greater periodicity of vocal fold vibration is also evident in the EGG signal. In sum, this example illustrates an application of laryngeal kinematic information in documenting change in vocal control as a direct result of therapy. In addition, therapy techniques used to produce the documented change relied heavily on visual feedback of information obtained using noninvasive kinematic instrumentation.

SUMMARY AND CONCLUSIONS

We have presented a rationale for incorporating noninvasive kinematic and aerodynamic instrumentation in the clinical setting to facilitate identification and treatment of deficits associated with disordered speech motor control. Several examples illustrated the potential benefits of this approach. To date, we have used visual feedback from noninvasive instrumentation, particularly the EGG signal, to treat vocal symptoms associated with stuttering, spasmodic dysphonia, and head trauma.

Our observations and clients' comments support the potential value of clinical applications of this instrumentation. For example, insights gained into the nature of physiologic events associated with perceptual symptoms facilitate the development of relevant therapeutic goals. Realization of therapy goals is also facilitated. Clients can "see" the underlying abnormal physiological gesture and the correct physiological gesture. This information helps clients to understand the rationale for therapy techniques. Finally, the visual display can be explained to clients at different levels of cognitive complexity. For example, simple descriptions of shapes and patterns may be appropriate for many children and cognitively impaired adults, while more complex descriptions of the physiologic mechanism(s) producing the display may be appropriate for other clients. We have successfully applied this approach with a cognitively impaired, post-head-trauma patient and believe programs can be developed for young children.

Finally, clinical application of noninvasive instrumentation will facilitate an exchange of ideas and information between clinics and laboratories. Often the most interesting and rewarding research has its origins in clinical observations. Increasing the precision and sensitivity of these observations will no doubt generate important research questions. On the other hand, clinicians often correctly question the clinical applicability of laboratory findings. A shared technology between clinic and laboratory can facilitate the transfer of laboratory findings to clinical efforts. In the final analysis, more meaningful interaction between clinic and laboratory permitted by a shared technology will benefit client, clinician, and researcher.

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TREATING DISORDERED SPEECH MOTOR CONTROL

For Clinicians by Clinicians

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