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MINIMAL VOLUNTARY REACTION TIMES FOR VOICE INITIATION

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Moim Rodzicom

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ABSTRACT

MINIMAL VOLUNTARY REACTION TIMES FOR VOICE INITIATION

Krzysztof Izdebski

This study investigated simple reaction time latencies for the voluntary initiation of phonation in 15 neurologically normal males (mean age 29 years) and 15 females (mean age 23 years). The study's major thrust was the description of the maximum speed with which voice may be initiated by normal healthy adults. Specifically, this study was designed to describe minimal reaction times for voice initiation as a function of 1) stimulus type: auditory tone: 1 kHz 75 dB SPL, and somesthetic stimulus: drop from 6 cm H_2O in intraoral air pressure to atmospheric pressure, 2) abducted, adducted and uncontrolled prephonatory vocal fold positions, and 3) 75%, 50% and 25% of subjects' lung volumes. Further, auditory-manual reaction times were obtained from these same subjects. All vocal and manual responses irrespective of experimental conditions were produced to stimulus onset following a warning signal and a subsequent randomized prephonatory interval.

The fastest vocal reaction times were 120 msec; however, the average minimal latency across subjects was 180 msec. Generally faster vocal reaction times were produced from abducted prephonatory vocal fold position than from adducted prephonatory vocal fold position. Although auditory-vocal reaction times were somewhat faster than the somesthetic-vocal reaction times, these differences were not significant. Faster auditory-vocal reaction times were obtained when phonation was initiated at mid lung volumes than at both low and high extremes of lung volumes. Manual reaction times were found to be significantly faster than vocal reaction times; however, comparable manual and vocal threshold reaction times were obtained for some subjects. The female reaction times were slightly slower than the male reaction times, but this difference was not significant.

The results of this study were discussed in terms of 1) phonatory and respiratory anatomy, physiology, and mechanics, 2) sensory feedback utilization in speech production, and 3) reaction time models. The vocal and manual motor responses are discussed in terms of relative differences between the phonatory and other neuromuscular systems in the human body.

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CHAPTER I

INTRODUCTION

The psychophysiological methodology of simple reaction time has been instrumental in studying and describing the temporal events of various human sensory-motor responses since eighteen-fifty by Herman von Helmholtz; however, it was Scripture (1927) who first advocated the usefulness of the reaction time paradigm in the speech sciences. Since then, simple reaction time studies have been undertaken to investigate a number of sensory-motor aspects in speech production involving normal and pathological populations. With the exceptions of some preliminary studies by Kaiser and Allard van der Wal (1959), Ladefoged (1960), van den Berg (1962) and Adams and Hayden (1976), the few phonatory reaction time studies conducted have resulted in limited data as well as varied results. For example, phonatory reaction times by neurologically normal adults have been variously reported to occur between 30 and 320 msec. These inconsistent reports with large variability of phonatory reaction time latencies underline the need for more comprehensive and systematic pursuits.

This study was undertaken to examine some temporal aspects of the phonatory system for voice production using simple reaction time methodology. The major thrust was the description of the minimal voluntary total neuromechanical reaction time latencies for phonation initiation in normal adult males and females.

As reaction time data have been shown to be influenced by various subject-intrinsic and stimulus-intrinsic factors, certain physiological and anatomical parameters pertinent to voice production were taken into consideration: stimulus type, vocal fold position, lung volume and subject sex.

Since auditory and somesthetic feedback mechanisms are assumed to be used for control of phonation and speech, both auditory and the somesthetic modalities were stimulated, enabling a description of possible heterogenity in phonatory reaction times as a function of these diverse stimuli. As the execution of the phonation onset may vary from an abrupt to a "breathy" initiation, the phonatory reaction times were also investigated as a function of the extremes of prephonatory vocal fold position. Further, because of the concomitancy of respiration with phonation, phonatory reaction times were investigated as a function of different lung volumes. The combined sex differences in laryngeal anatomy, voice frequency and consistently reported differences in the reaction times between males and females encouraged additional investigation of phonatory reaction times as a function of sex. Lastly, since few studies have compared reaction times in different response modalities for the same experimental population, the present study investigated both phonatory and manual reaction behavior for each subject, thus, comparing the reaction times for two different motor systems.

In summary, the phonatory voluntary total neuro-mechanical reaction time latencies were investigated as a function of: 1) two types of sensory stimuli, 2) prephonatory vocal fold position, 3) lung volume, and 4) sex. Finally, auditory reaction times for a non-speech response were obtained from the same experimental population.

CHAPTER II

LITERATURE REVIEW

Introduction

Extensive studies of the speed of various human sensory-motor responses using reaction time methodology have been conducted during the last century. Despite the variety of modifications, a simple reaction time model has been the principal experimental paradigm. This model enables the researcher to make certain observations about the nature and characteristics of the reaction time latencies, defined as the temporal period between the stimulus presentation and the subject's response. This period may be subdivided into two substages: the first is neural time, which corresponds to the sum of afferent, cortical and efferent components; the second is mechanical time, which includes the time from the initiation of the muscular contraction to the onset of the response. Since the substance of the present study was the investigation of phonatory reaction times in normal adult males and females, the literature review covers only those studies directly relevant to the experimental design of this investigation. The results of reaction time studies are frequently affected by several parameters, some of which are difficult or often impossible to account for or to control. A general overview as well as a more detailed account of these parameters follows. This review also considers pertinent data on various sensory-motor reactions with specific attention to speech-type reaction time responses. Further, the functional anatomy and physiology of laryngeal system with particular focus on unidirectional glottal adjustments is presented and, finally, selection of stimuli for eliciting voluntary phonatory responses is discussed in the light of some relevant and contemporary theories of speech production.

Parameters Affecting Reaction Time Latencies

Since the early investigations carried out by Helmholtz (1850), it has been recognized that the results of simple reaction time experiments may be biased by factors which are stimulus-intrinsic or subject-intrinsic. The stimulus-intrinsic parameters comprise its physical characteristics such as type and intensity. Usually these factors are amenable to control and experimental manipulation by the investigator. The subject-intrinsic parameters are multiple, often unknown, and unpredictable and include age, sex, habits, health and psychological state. These factors may account for considerable variation in simple reaction time resulting in biased total neuro-mechanical latencies; hence, the results of simple reaction time experiments may be a function of separate or additive factors, intrinsic to the stimulus or subject.

Stimulus Type

A variety of signals within the three sensory modalities - hearing, vision and somesthesia - have been used as stimuli in reaction time studies. Examination of the results of these experiments indicates considerable differences in reaction time latencies as a function of stimulus type. Many studies agree that auditory and somesthetic stimuli result in equally short reaction times with only small inter-sensory variability. Several writers acknowledge a typical difference approximating 40 msec between the simple visual, auditory or tactile reaction times, with a typical visual reaction time approaching 180 msec (Woodworth and Scholssberg, 1954; Goldstone, 1968 and Glickstein, 1972). Both Elliot (1968) and Kohfeld (1971) have questioned, however, the existence of the typical difference between the visual and auditory reaction times.

Physical Characteristics of Stimuli

The physical characterisitcs of each stimulus type may influence response time latencies. The notion prevails that long latencies are obtained to stimuli presented at thresholds, while considerably shorter reaction times are obtained to moderate and high intensity stimuli.

The intensity of auditory st-mulus seems to be of prime importance in the speed of the reaction time independent of response type. Chocholle (1940) investigated reaction time as a function of sound intensity and found decreasing latencies with increasing intensities. There was approximately 300 msec difference in reaction times when the signal was presented at threshold as compared to very high intensities. Chocholle found a sharp increase in reaction time latencies below 30 dB, while reaction times above 30 dB did not change appreciably. Recently, Stevenson (1973) investigated reaction time for speech recognition presented at varying intensities and found his data to behave in the fashion observed by Chocholle. Murray (1970) investigated stimulus intensity and reaction time in terms of decision-theory and also found an inverse relationship between stimulus intensity and reaction time.

An auditory signal has been a common stimulus in reaction time studies with 1000 Hz being the frequency most often used. The intensity of stimulus presentation may vary, but levels approximating the intensity of normally spoken speech are used most often. A 1000 Hz tone ranging in intensity from 60-80 dB (SPL) was used by Birren and Botwinick (1955); Buchsbaum and Callaway (1965); Miller and Glickstein (1964); Siegenthaler and Hochberg (1965); Roberts, Simon and Thomas (1972); Weiss (1965); Murray (1970); Surwillo (1971, 1972); Luschei, Saslow and Glickstein (1967); Shagass, Straumanis and Overton (1971) and by Ritter, Simon and Vaughan (1972). A 600 Hz

(50 dB SPL) tone was used by Kaiser and Allard van der Wal (1959). A 500 Hz (85 dB SPL) tone was used by Simon, Craft and Webster (1971) and by Netsell and Daniel (1974). A 400 Hz tone at 75 dB was used by Botwinick and Thompson (1966), while Costa, Vaughan and Gilden (1965) used clicks at 10, 30 and 90 dB above subjects' individual hearing levels. Others have used uncalibrated auditory stimuli (Ladefoged, 1960) or the stimulus characteristics used in the study were not specified (van den Berg, 1962).

Responses to the Onset and Offset of the Stimulus

Reaction time latencies may be affected by the subject's response to stimulus onset or to stimulus termination. There is substantial disagreement as to which condition results in faster responses. Woodrow (1915) found no difference in reaction time as a function of onset or offset of a light or tone. Grier (1966a, 1966b) reported shorter latencies for the tone-off than the tone-on stimuli when the rise and decay time were each 100 msec. Goldstone (1968), using rapid rise and decay in visual and auditory stimuli, found shorter reaction times to stimulus onset than offset. Similarly, significantly faster reaction times were obtained to auditory stimulus onset than offset by Simon, Craft and Webster (1972). Electrocutaneous stimulation with rapid rise and decay gave faster reaction times to the stimulus-on than to the stimulus-off (Sticht and Foulke, 1966).

Anticipation, Randomization and Refractory Period

Another possible biasing factor in simple reaction time studies is the subject's anticipation of the stimulus resulting in false responses. To control for the anticipatory phenomena, investigators have employed randomization procedures for stimulus arrival. The reports of Woodworth and Schlossberg (1954), Botwinick and Thompson (1966), and Luschei, Saslow and

Glickstein (1967) on manual reaction time have shown that randomization of the interval between the warning and the stimulus presentation in the range of 500 msec to 4000 msec resulted in minimal response time and limited subject variability. No normative data on best prestimulus interval for speech reaction times are found in the literature. Netsell and Daniel (1974), studying speech reaction times to tone offset, used the randomization procedures employed by Botwinick and Thompson (1966) and by Luschei, Saslow and Glickstein (1967). They turned the signal off randomly at 2.0, 2.5, 3.0, 3.5 or 4.0 second intervals. Adams and Hayden (1976) used a 13-second window during which three tones of varying duration were presented with various intertone intervals as the subjects produced vocal responses to both the tone onset and the tone offset. The results of the prestimulus interval on reaction times in the last two studies were not discussed.

Beginning with Craik (1947, 1948), numerous investigators have examined the effects of inter-stimulus and inter-response interval and the psychological refractory period on the reaction time (Welford, 1952, 1967; Reynolds, 1964; Smith, 1967; Keele, 1967; Herman and Kantowitz, 1970; and Kahneman, 1973). Although still somewhat controversial, the findings, in general, suggest that when two stimuli, each requiring a successive response, are separated by less than 500 msec, the second response is markedly delayed irrespective of the second signal's magnitude. On the other hand, Greenwald and Shulman (1973) were able to eliminate the effects of refractory period in choice reaction time tasks when the responses were ideomotor compatible. As anticipation and the rapid succession of stimuli may increase reaction time latencies, preknowledge of the tasks has been shown to decrease response latencies (Spiess, 1973).

Reaction Time and the Respiratory Cycle

There is disagreement in the literature on the relationship between the phase of respiration and reaction time. Faster finger reaction times for stimuli presented during inhalation were reported by Hildebrandt and Engel (1963). Beh and Nix-James (1974) found reaction time to be significantly shorter for stimuli presented during inhalation than for those presented during either exhalation or breath holding. Gaskill (1965) and Buchsbaum and Callaway (1965) reported faster reaction times to stimuli presented during exhalation, while Weiss (1960) found no differences in reaction times as a function of the respiratory cycle.

Reaction Time and Ear-Hand-Correspondence

Ear-hand-correspondence and ear-response-location compatibility, as well as ear preference, also influence reaction time latencies. Significantly faster digital reaction times were shown when the content of the verbal directional command (i.e. "right") correspond to the ear stimulated and when the response key was located on the same side of the body midline as the directional command (Simon and Rudell, 1967; Simon and Small, 1969). The studies of Simon, Hinrichs and Craft (1970) also indicated that at least two components, ear-hand and ear-response-location correspondence, may account for the stimulus compatibility if only the information on locus is provided by the stimulus; however, if the relevant symbolic content is embedded into the stimulus, the ear-response-location alone may account for the stimulus-response compatibility.

No data about ear-vocal response compatibility have been reported. Netsell and Daniel (1974), however, used monaural right ear presentation for the auditory stimuli for speech reaction time.

Reaction Times as a Function of Sex

Various writers report that reaction times for the female population lag behind the latencies obtained for males. For example, shorter manual reaction times were obtained for males to auditory or visual stimuli when the experimental populations were matched for age (Bellis, 1933; Goldfarb, 1941; Simon, 1967). Recently, Netsell and Daniel (1974) studied speech-response reaction times to auditory stimuli for males and for females and found male reaction times faster although there were no statistically significant differences between sex group scores. Bellis (1933) indicated that the male-female differences in the reaction times become greater in childhood and late maturity than in young adulthood. Although sex differences have been reported often, explanations have been given rarely. Sundberg (1974) found female reaction times for pitch changes to be shorter than male reaction times and suggested that this may be due to the difference in the pitch regulating systems in that there is more muscle force needed per unit of mass to be moved in female larynxes.

Reaction Times as a Function of Age

Reaction time as a function of age has been well documented. Results of simple reaction time experiments indicate that the response latencies increase significantly with age (Milles, 1931; Szafran, 1951; Singleton, 1954; Pierson and Montoye, 1958; Dupree and Simon, 1963; Weiss, 1965; and Surwillo, 1968; 1972). Birren and Botwinick (1955) also have shown that elderly subjects were significantly slower than young subjects for foot, finger and jaw reaction times and hypothesized that central nervous system and not peripheral changes connected with aging were responsible for the longer reaction times in the geriatric population. The study of Bellis (1933) has shown, however, that fastest auditory-manual reaction times were obtained for both sex groups between ages 20 to 30 years than for children or older adults.

Locus of Reaction Time

The notion of "locus of reaction time" considers whether the magnitude of reaction time depends on central or peripheral mechanisms. Locus of reaction time has been studied by electromyographic and electroencephalographic techniques. Davis (1940) measured prestimulus electromyography and found that a greater muscle signal amplitude corresponded to faster reaction times. He argued on this basis that speed of reaction time is a domain of the periphery. Weiss (1965) stated that mechanical time did not vary as a function of the prestimulus interval, while the total reaction time did; thus, he felt there was a central locus of the reaction time. Botwinick and Thompson (1966) found no correlation between the mechanical time and the neural time, but found a good correlation between reaction time and the neural time and, like Weiss (1965), also believed that reaction time is a function of a neural process probably of central origin.

Meijers and Eijkmam (1974) argued that motor control in simple reaction time is under direct cortical control. They proposed a model in which a motor program for simple skilled movement is set by well organized commands in which execution demands involvement of cortical time.

Central Influences on Reaction Time

Alertness, or increased perceptual ability, has been associated with certain brain activity, particularly with the alpha wave. Surwillo (1961, 1963a, 1963b, 1964, 1968) hypothesized that the alpha brain wave is responsible for temporal limitations of data processing in the brain by gating the sensory input to cortical cells, thus affecting reaction time latencies. He found statistically significant inter- and intra-individual correlations between the reaction time for auditory stimulus and the alpha period. Lansing (1957) could not substantiate any inter-individual correlations for visual reaction time and alpha brain wave while Williams _et al_. (1962) found only intra-individual correlations. Boddy (1971a, 1971b) found only a non-significant inter-individual correlation between occipital alpha period and visual and auditory reaction time latencies. Shorter reaction times were found when a stimulus was preceded by an alpha blockade (Lansing _et al_., 1959).

Several investigators have shown that quantitative electroencephalography and evoked sensory potential changes accompany intra-individual variations in reaction time tasks. Shorter reaction times were shown with faster electroencephalographic frequencies (Surwillo, 1963a, 1963b, 1964; Williams _et al_., 1962; and Morrell, 1966).

Faster reaction times were shown to be associated with increased amplitude of the evoked sensory potential to visual stimuli (Donchin and Lindsley, 1966; and Morrell and Morrell, 1966). Similar results were obtained for auditory reaction times (Karlin _et al_., 1971), although Wilkinson and Morlock (1967) and Waszak and Orbist (1969) disagreed that evoked potential enhancement within the subject results in faster reaction times.

Several writers have addressed themselves to the question of central processing or the cortical time of the reaction time process (Brainrad _et al_., 1962; Evarts, 1966; Glickstein, 1972; and Meijers and Eijkman, 1974). Temporal estimates of the cortical time made by Hunt and Stubbs (1973), Weller and Bird (1973), Kirwan (1973), and Netsell and Daniel (1974) suggest that 70 to 80 msec may be spent in the central processing of the reaction time irrespective of response modality. Since the direct observations of cortical component of the reaction time are not accessible, these estimates have to be understood as highly speculative.

Other Effects

In addition to the discussed effects, simple reaction times may be biased as a function of various other parameters. Practice or familiarity with the task is shown to decrease response time latency for both simple and choice reaction times (Murray, 1970). Subject physique (weight, height, etc.) has been thought to affect reaction times, with obese and short individuals having slower reactions (Smith and Boyarsky, 1943). Upward shifts in the body temperature are reported to decrease reaction time latencies (Kleitman, Titelbaum and Feiveson, 1938), while position of the body in space, on the other hand, does not affect digital reaction times (Munnich, 1940). Cotten, Thomas and Stewart (1971) state that cigarette smoking temporarily slows reaction time for a short period, and suggested forbidding smoking immediately prior to the experimentation. Huntly (1974) studied effects of alcohol, uncertainty and novelty using verbal reaction time and showed that high blood alcohol concentration had little effect on reaction time for highly familiar associations, while significant effects were shown for novel stimuli. He also suggested that the selection of the response rather than the stimulus recognition was impaired.

The latency of simple reaction time is often associated with the level of alertness. When alertness was attenuated by chemical agents (Thornton, Holck and Smith, 1939) or behavioral means (Wilkinson and Stretton, 1971; and Zubek, 1969), the reaction time was shown to be slower. Experimentally induced mental effort on reaction time was also studied by Kahneman (1973), and as a function of rest, mental work and Transcendental Meditation (Appele and Oswald, 1974). Simple reaction times have also been shown to increase as a function of word length to be repeated (Brennan and Cullinan, 1976).

Summary

The preceding review of reaction time studies suggests multiple influences on reaction time latency. Simple reaction time may be most significantly affected by stimulus type, stimulus intensity, and subject age. The dependence of reaction times on variance in pre-stimulus interval, interstimulus duration, stimulus onset or offset, sex, alpha state, novelty, alertness, respiratory cycle remain controversial. It should also be noted that the differences in experimental protocols make comparisons among studies difficult.

Studies of Speech Using the Reaction Time Model

Various aspects of speech production and perception have been studied using both simple and choice reaction times methodology. In most studies, however, speech was used as the stimulus rather than as a response modality; that is, subjects were required to respond to speech stimuli usually with manual responses. Attention is focused here only on the basic studies where speech activity was all or part of a response.

There are only sporadic accounts in the literature of these basic reaction time studies of speech. Kaiser and Allard van der Wal (1959) studied phonatory reaction times to auditory (600 Hz, 50 dB, 440 msec tone), visual and tactile electrical stimuli in 11 normal subjects (eight males and three females aged 18 to 28 years). In the two sets of experiments, they instructed subjects to sustain vowels /a/ and /o/ as the stimuli were presented. Reaction times for pitch and intensity changes (partly due to laryngeal and partly due to respiratory musculature) were recorded oscillographically and kymographically. The results indicated that the range of the response latencies was 30 to 300 msec. Shorter reaction times were obtained in all experimental conditions to both the auditory and the tactile stimuli than to visual stimulus. The writers concluded that shorter reaction time latencies were obtained for the laryngeal responses, while longer latencies were obtained for the respiratory musculature responses.

van den Berg (1962) reported a pilot study (conducted by Shervanian and van den Berg) involving five normal subjects' reaction times of various speech muscles to auditory, visual and electrical stimulations. Subjects' age and sex as well as the research methodology were not reported; however, reaction times were measured on the basis of electromyographic signals displayed on an oscilloscope. The study was designed to investigate reaction times of independent muscles or groups of muscles as they participate in speech. They found that typical reaction times were 120 msec for the abdominal muscles, 162 msec for the inter-arytenoid muscles, 140 msec for the vocalis and cricothyroid muscles as voice fundamental frequency was changed, 138 msec for the cricothyroid, 146 msec for tongue and velum, 159 msec for lip opening, and 170 msec for lip closure. A rough estimate of the writers' finding would indicate a mean phonatory reaction time to be approximately 165 msec, with a range of 120-170 msec, with the respiratory responses being the fastest and labial responses being the slowest.

Ladefoged (1960) reported reaction time experiments sampling simultaneously muscle activity in the internal intercostals, esophageal air pressure and acoustic voice signals. In the first experiment, a subject was instructed to produce the syllable /ma/ as quickly as possible following an auditory stimulus onset. The latencies were measured between the stimulus onset and the onset of EMG activity in the internal intercostal muscles and between the onset of this muscle activity and the voice onset. The range of the stimulus-to-muscle activity latencies was from 140 to 320 msec, while the interval between the internal intercostals activity and the sound production was stable at about 48 msec. These data suggest that the minimal total neuro-mechanical reaction time for voice onset was about 190 msec. In the second experiment the subject repeated the spoken digits as quickly as possible. Again, the duration between the onset of muscle activity and the first sound was measured and showed a constant latency of about 50 msec.

Chistovich and Klaas (1962) reported on voluntary vocal reaction time experiments in which eleven subjects repeated as quickly as possible different Russian vowels, which varied in duration from 15 to 200 msec. They found that fastest responses were obtained with the vowel /a/, with a mean latency of about 220 msec, and that both for high front and back vowels there were significant increases in reaction times. They also reported that the actual duration of the stimulus vowel to be repeated did not affect the reaction times.

Recently, Netsell and Daniel (1974) reported total neuro-mechanical, mechanical and neural reaction time latencies for lip movement in speech to an auditory stimulus in ten normal males and females aged 20 to 35 years. They sampled orbicularis oris muscle activity, intra-oral and intra-nasal air pressures and acoustic voice recordings of the subjects as they produced a syllable following offset of an auditory stimulus. They measured latencies between the stimulus offset and the onset of the muscle activity, which was called "neural time" and between the onset of the muscle activity and the onset of upper lip-lower lip contact, which was termed "mechanical time." Reaction time was derived by adding the neural time and the mechanical time. Two experimental conditions were used: stabilized jaw and free jaw.

The mean reaction time pooled across experimental condition, phone types and sex was 206 msec. The mean neural time for the group was 140 msec, and the mean mechanical time was 60 msec. Thus, 70% of the reaction time was occupied by neural transmission and 30% by mechanical events. Faster mean reaction times were obtained for males than for females for all experimental conditions; however, the female subjects' mean neural time for the jaw-stabilized condition was faster than the males'. These differences, as well as differences between the stabilized and free jaw experimental conditions, were found not to be statistically significant. Netsell and Daniel concluded that "...regardless of the jaw condition or phone type being produced (/p/, /b/, or /m/), the physiologically normal speaker executes this reaction time task in a little over 200 msec." (p. 612)

Laryngeal Anatomy and Physiology

Functional laryngeal anatomy and physiology have been subject to numerous investigations comprising both human and experimental animals. A review* of the laryngeal anatomy and physiology with particular attention to the laryngeal behavior in phonation can be summarized as follows.

The larynx is located in the neck at the level of the 4th to 6th cervical vertebre, and may be considered as a link between the trachea and the confluence of the esophagus and the oropharynx. The larynx itself (see Figures 1 and 2) consists of a number of intrinsic and extrinsic muscles, various membranes and ligaments and a complex cartilaginous framework. The entire larynx is suspended superiorly from the hyoid bone and attached inferiorly to the first tracheal ring. The vocal folds are positioned within the cartilaginous framework of the larynx and are attached anteriorly to the posterior

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*The critical articles on laryngeal anatomy and physiology on which this review is based are listed in Appendix A.

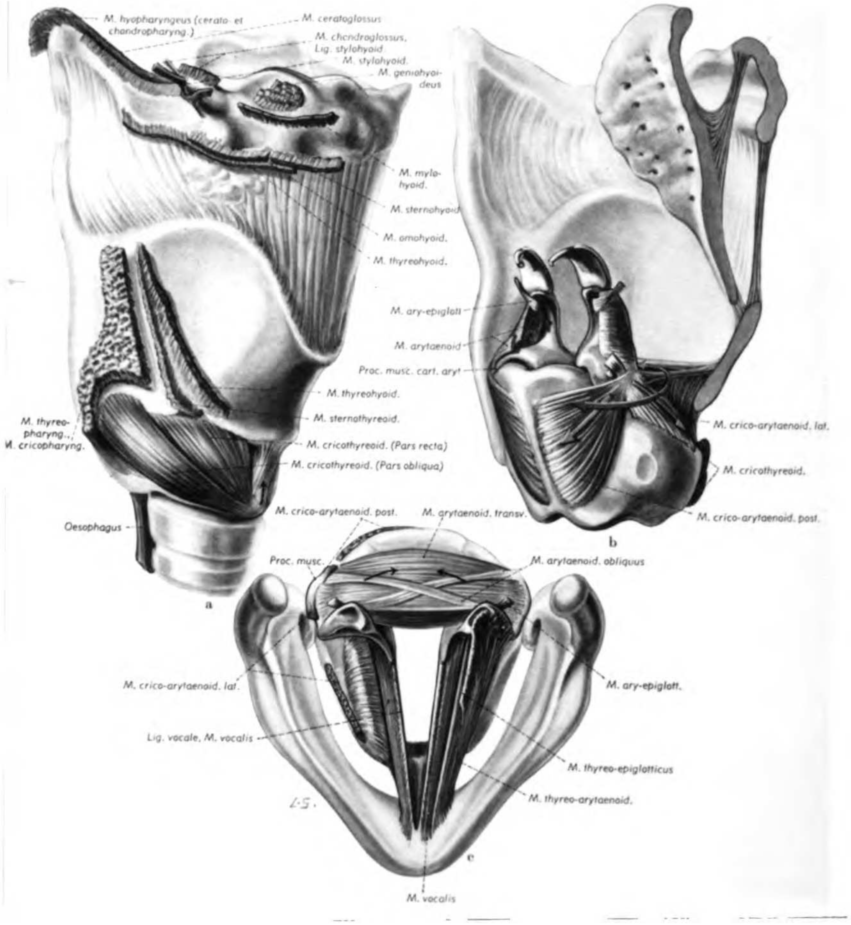

Figure 1

The laryngeal muscles; a) ventro-lateral view b) posterior view, c) superior view. (From Pernkopf, E., Atlas of Topographical and Applied Human Anatomy, 1963. Courtesy of W. B. Saunders Co., Philadelphia and London)

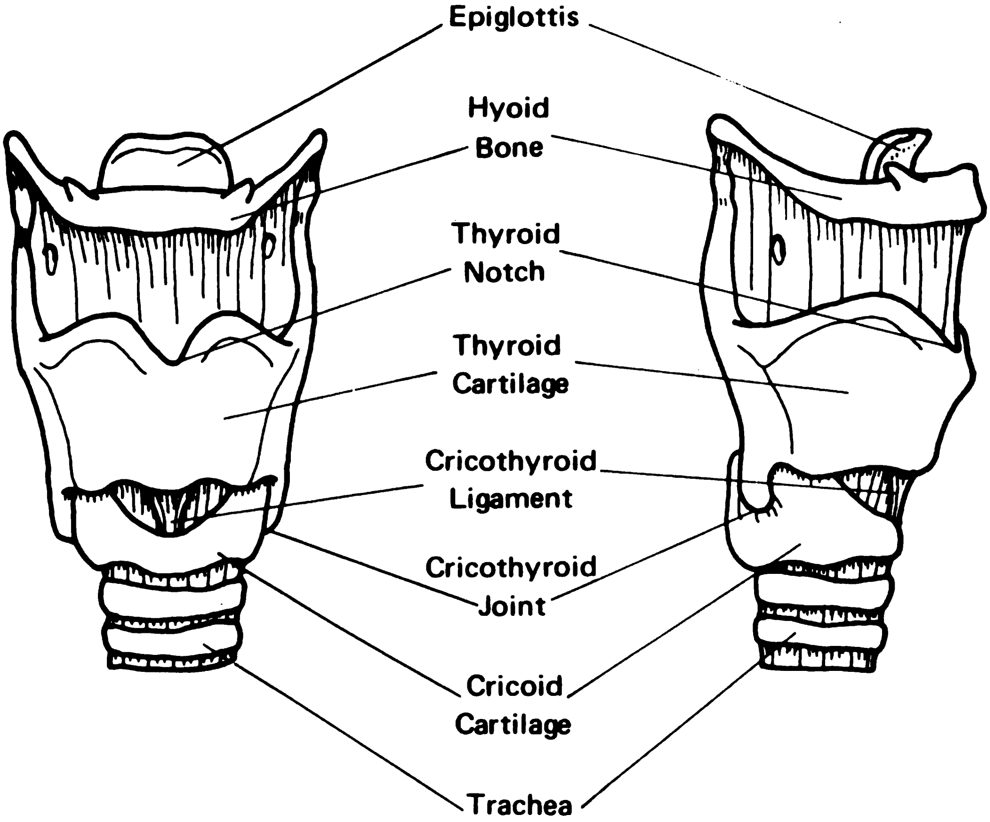

Figure 2

Schematic representation of laryngeal cartilages showing anterior view to the left and right lateral view to the right. (From, Moore, G.P., Organic Voice Disorders, 1971, Courtesy of Prentice-Hall, Inc., Englewood Cliffs, N.J.)

wall of the thyroid cartilage, while their posterior ends are attached each to the vocal processes of the two arytenoid cartilages resting on the arytenoid facets of the cricoid cartilage. This anatomical arrangement forms a "V"-like shape with the open area between the medial edges of the vocal folds (see Figure 3). This medial area, called the glottis, can be subject to a variety of adjustments (see Figure 4). At rest, or during respiration, the glottis remains open; it closes for phonation. In other words, two principal unidirectional glottal adjustments are recognized: from the open glottis towards the midline to closed glottis for adduction and from closed glottis away from the midline to open glottis for abduction. This adductory-abductory action is accomplished principally by a contraction of the intrinsic laryngeal muscles with perhaps some assistance by extrinsic laryngeal muscles. Adductory movement is accomplished by at least two sets of intrinsic muscles: the lateral cricoarytenoid and the interarytenoid muscles. The transverse and oblique bundles of the interarytenoid muscles contract to draw the arytenoid cartilages together upon contraction, closing the glottis. The lateral cricoarytenoid muscles assist in shortening the vocal folds and in rocking the arytenoid cartilages down and up to approximate the vocal folds more closely. Contraction of the posterior cricoarytenoid muscles results in spiral rocking of the arytenoid cartilages up and out. By this action the two arytenoid cartilages are abducted and the vocal folds are pulled away from the midline.

This principal significance of the adjustments for speech is that these abductory-adductory movements control and interrupt the bi-directional air flow and allow initiation and termination of phonation.

The intrinsic laryngeal muscles are among the extremely fast and highly innervated type of muscles, exceeded only in contraction time by the extraorbital muscles. The contraction time for the various intrinsic laryngeal

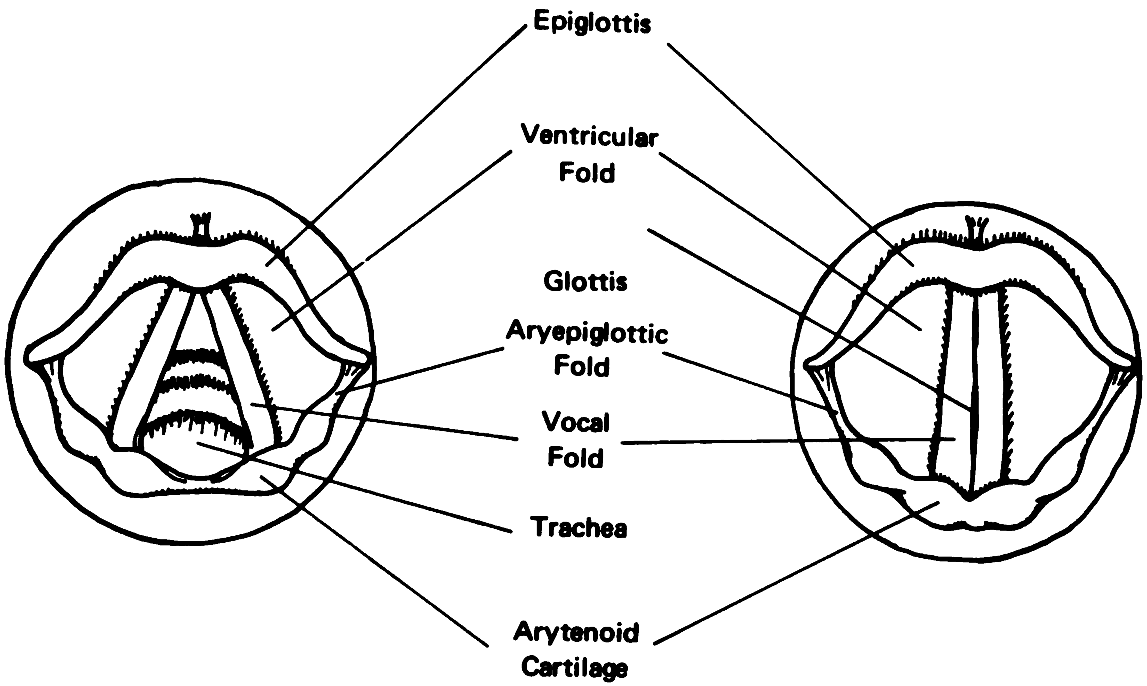

Figure 3

Schematic representation of the glottis as viewed with a laryngeal mirror. On the left the glottis is abducted for respiration; on the right the glottis is adducted for phonation. (From, Moore, G.P., Organic Voice Disorders, 1971, Courtesy of Prentice-Hall, Inc., Englewood Cliffs, N.J.)

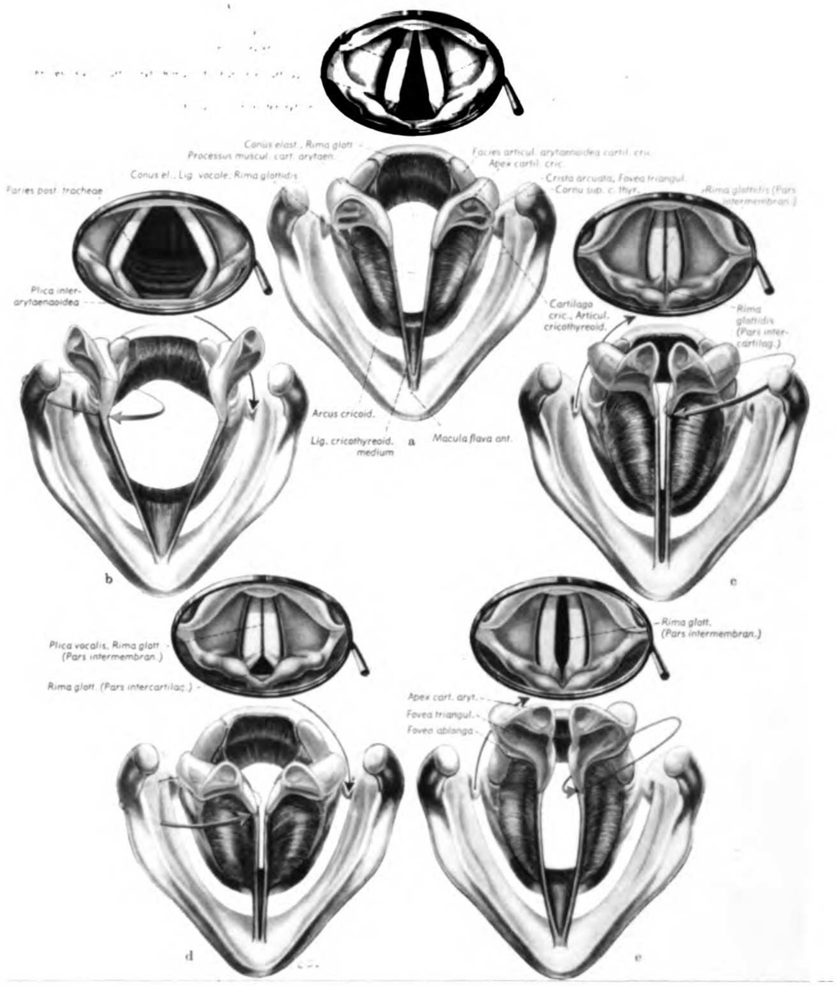

Figure 4

Various glottal adjustments as seen on the skeletal preparation and reflected in the laryngeal mirror. a) resting phase, b) respiratory phase, c) phonation, d) whisper, e) falsetto. (From, Pernkopf, E., Atlas of Topographical and Applied Human Anatomy, 1963. Courtesy of W.B. Saunders, Co., Philadelphia and London.)

muscles vary, with the fastest contraction time found for the thyroarytenoid, next fastest for the interarytenoid and lateral cricoarytenoid, slower for the posterior cricoarytenoid and slowest for the cricothyroid. These data show that the adductory muscles have faster contraction times than the abductory muscles, suggesting that adduction may take longer than abduction. The average adduction-abduction ratio was reported to be about 1.70 (Moore and von Leden, 1958; Werner-Kukuk and von Leden, 1970; and Gall and Hanson, 1973). The kymoelectroglottographic calculations of opening speed velocity and closing speed velocity suggest that the average unidirectional adductory movement was about 540 mm/sec while the average abductory movement was about 320 mm/sec (Gall and Hanson, 1973).

Unidirectional Glottal Adjustment Time

Reports vary on the speed with which the unidirectional glottal gesture may be achieved prior to the onset of the first cycle of phonation. Rothenberg (1968), interpreting Martensson and Skoglund's (1964) data, states that less than 100 msec may be fully adequate for accomplishment of unidirectional abductory glottal movement. He also suggested that even less time may be needed for accomplishment of unidirectional glottal adduction. Soron and Lieberman's report (1963) based on high speed laryngeal photography on three normal subjects, indicated that the inward movement of the vocal folds from the respiratory position takes approximately 100 msec. Baer (1975) stated that high speed film data suggests a typical value of 150 msec for the movement of the vocal folds from the breathy position to the moment just prior to the initiation of vibrations. Zemlin (1968) reports 160 msec for adduction of the vocal folds. Kim (1970) also agrees that vocal fold adduction is accomplished within 100 msec. Shimizu (1961) reported on X-ray measures that minimal duration of the abduction-adduction cycle of the vocal folds is about 150-180 msec.

Difference in Laryngeal Anatomy Due to Sex

Considerable anatomical differences between male and female larnygeal anatomy have been reported (Negus, 1929; 1949; Luchsinger and Arnold, 1965; Zemlin, 1968; and Maue, 1970). These differences involve weight, size of cartilages, degree of angles between the different structures, size and length of muscles, etc. Maue (1970) showed a 4.13 mm greater distance in male larynx between the arytenoid facets. She, as well as Hollien (1960a, 1960b, 1962), Hollien and Colton (1969) and Pawlikowski, Karasek and Pawlikowski (1973) has also shown a considerable difference in male-female vocal fold length. Maue (1970) summarized this sex difference in laryngeal anatomy as follows: "The most that can be said is that the male larynx tends to be larger than the female larynx, that some intercartilage dimensions tend to be larger or smaller than the others, and that there are definable sex differences." (p. 19)

Control Mechanisms

Some theoretical postulates have been substantiated on the basis of neuroanatomical, neurophysiological, perceptual and linguistic evidence to account for the existence of both auditory and somesthetic feedback control in speech.

The neuromuscular control of phonation has been classified as conscious and unconscious by Wyke (1974). There is disagreement as to the occurrence, ratio and character and role of various sensory receptors lining the vocal tract. Nevertheless, it is currently believed that these receptors may be responsible for afferent feedback: they are thought to convey afferent messages to the central nervous system from the vocal tract during phonation and speech, complementary to the acoustic information obtained via the auditory system.

Subglottal air pressures may be monitored via slow and fast adapting mucosal mechanoreceptors (Konig and von Leden, 1961a; Kirchner and Suzuki, 1968; Wyke, 1967, 1971, 1974; Wyke and Kirchner, 1974). The forces exerted on the muscular tissues during phonation are thought to be monitored via slowly adapting myotatic mechanoreceptors such as muscle spindles and spiral nerve endings (Abo-El-Enein and Wyke, 1966a, 1966b; Wyke, 1971, 1973, 1974; Baken, 1969, 1970; Baken and Noback, 1971; Wyke and Kirchner, 1974; Hirano, 1975). Joint mechanoreceptors are thought to provide supplemental feedback to the information received from the reflexogenic feedback of the myotatic and mucosal afferent signals (Kirchner and Wyke, 1964a, 1964b, 1964c, 1965a, 1965b; and Wyke, 1974).

Various types of receptors have been found in the supra-and-subglottal vocal tract. Chierici (1976) found extremely sensitive and fast-adapting proprioceptive receptors in the periodontal membrane. Different receptors are believed to be found in the respiratory tract, diaphragm and the intracostal musculature (Huber, 1902; Bouhuys, 1974).

Auditory feedback may be limited to monitoring of a posteriori effects, while somesthetic feedback may be used to monitor "on-line" effects. Much of this thinking has been advanced in the so-called open or closed-loop theories. A review of arguments for both theories may be found in Ohala (1970).

MacNeilage (1970), for example, believes that both open and closed loops exist for feedback of motor control in speech. For him, the gamma-efferents stand for the closed-loop while the linguistic information is controlled via an open loop. Perkell (1969), on the other hand, suggested that the closed-loop makes use of myotatic type of feedback based on intraoral air pressures. Malecot (1966) found in normal subjects an ability to monitor intraoral air pressures in speech with a sensitivity of one cm H_2O difference limen. The relative constancy of intraoral air pressure within subjects as a function of time as well as the lack of an apparent relationship between the oral cavity size and the peak intraoral air pressure were reported by Brown and McGlone (1969a, 1969b). Although the variability in peak intraoral air pressure for production of various speech segments has been reported (Malecot, 1966; Subtelny, Worth and Sakuda, 1966; Arkebauer, Hixon and Hardy, 1967; Rothenberg, 1968; Brown and McGlone, 1969a, 1969b; Lisker, 1970; McGlone and Shipp, 1972; Tatham and Morton, 1972; Warren and Hall, 1973; and Shipp, 1973), it can be assumed that the intraoral air pressure approximating 6 cm H_2O may be an average value of the intraoral air pressure developed in normal speech for a stop constant implosion in both male and female speakers.

Further, a support for using both auditory and somesthetic feedback for speech control comes from experiments in which deterioration of articulation followed temporary obliteration of auditory feedback or partial temporal deafferentiation of the oral cavity (Scott and Ringel, 1971; Putnam and Ringel, 1972, 1976; Borden, Harris and Oliver, 1972; Hutchinson, 1973; and Prosek and House, 1975).

Summary

The foregoing review of the literature suggests the following:

1. Simple reaction time methodology is a useful model to study the speed of responses within various human sensory-motor systems.
2. There are various subject-intrinsic and stimulus-intrinsic parameters which may affect the reaction time results.
3. The reaction time latency comprises at least the following stages: afferent time, cortical time, efferent time and mechanical time.
4. Several sensory-motor systems have been studied, including some aspects of speech; however, few and conflicting data have been reported on the phonatory system's reaction times.

5. The principal importance of the larynx for the communicative purposes is to function as a fast-acting air valve.
6. There are conflicting data on the time domain for vocal fold adductory or abductory gestures, but a reasonable average is approximately 100 msec.
7. There are important anatomical differences in the laryngeal structures between males and females.
8. The laryngeal musculature is extremely fast relative to the other muscles in the body.
9. The vocal tract seems to be equipped with various sensory receptors throughout its entire length.
10. Auditory and proprioceptive afferent signals are at least two of the important types of feedback recognized for purposes of speech control.

CHAPTER III

PROCEDURES

Introduction

The present study follows a simple reaction time model, allowing observations of temporal latencies within a stimulus-response sequence. The paradigm followed in this study required that all possible stimulus-intrinsic and subject-intrinsic factors be controlled, so that maximally fast responses and small variability would be obtained. Normal male and female subjects selected at random were pretrained and prewarned and they responded as quickly as possible following stimulus onset. Pretraining involved trial recordings and familiarization with tasks prior to actual experimental data collection. Prewarning involved alerting the subjects in some fashion to attend to a stimulus. The stimuli used were either auditory or somesthetic.

Two types of responses were obtained from the subjects during the various experimental conditions. The first response was vocal, in the form of phonation initiation and the second was manual, in the form of an upward index finger extension. For the vocal response the vowel /a/ was produced with no control exercised for voice intensity, frequency or quality. Phonation initiation was studied as a function of 1) stimulus type, 2) prephonatory vocal fold position and 3) lung volume. The manual response used only an auditory stimulus.

The experimental data were recorded on FM tape and later displayed on an oscillograph. Measurements consisted of the latencies in milliseconds between the activation of the warning signal and the stimulus onset (prestimulus interval) and between the stimulus onset and the response onset (reaction time). The tabulated data were submitted later for statistical analyses using computer methodology.

Experimental Subjects

The following requirements served as the subject selection criteria: 1) sex: distribution of 15 males and 15 females; 2) age: 20 to 40 years; 3) health: no manifestation of pathologies of the communicative system; 4) habits: abstinence from drugs and heavy smoking; 5) voice: lack of formal vocal training; 6) handedness: right predominance.

These requirements were posted at several local colleges and universities for subject recruitment. Prospective subjects were initially screened by telephone. During this telephone interview the experimenter described the study, the subject's rights, and the recommendations of the Committee on Human Experimentation. Later, on the telephone, the subjects were administered the short form of the Edinburgh Handedness Inventory Test (Oldfield, 1971; see Appendix B). Thirty individuals, 15 males (mean age 29 years) and 15 females (mean age 23 years) fulfilled the criteria and were admitted as the experimental subjects. On the day of the experimental procedure they were reacquainted with the general purpose of the experimentation and were given a static vital capacity test to assure compliance with the recommended respiratory norms (Morris, Koski, and Johnson, 1971). Further, the subjects were given a consent form to read and to sign, with rights to withdraw from the procedures at any time without prejudice (see Appendix C). Upon completion of the experiment each subject was paid $20.00. The review of the events during the experimental procedures and the consent form are listed in Appendix C and D.

Stimuli

The auditory and somesthetic stimuli used in this study were produced and delivered via an array of instrumentation - the schematic arrangement of which is shown in Figure 5.

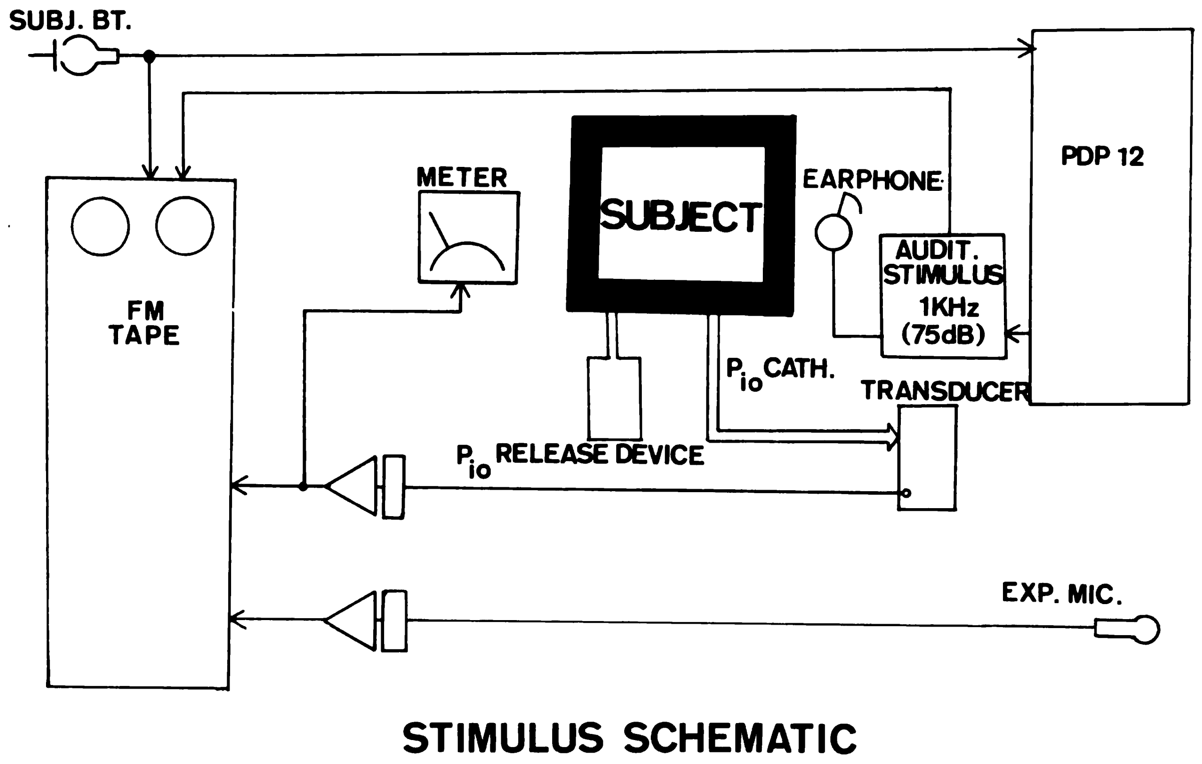

Figure 5

Schematic representation of the stimulus delivery and recording instrumentation.

Auditory Stimulus

The auditory stimulus used for both vocal and manual responses was a 1000 Hz 75 dB SPL (re: $2X10^{-5}N/m^2$) auditory signal produced by an audio signal generator (Hewlett Packard Model 206A). The signal was recorded on a magnetic tape recorder (Sony Model TC-800B) and then played back through an interface system with a PDP-12 computer for switching the signal into or out of the subject's earphone. The computer was programmed for random delays, so that the 250 msec signal could be presented at random prestimulus intervals within a range of 200 to 3600 msec after the subject pushed the ready-warning signal button. The auditory signal was calibrated at 75 dB SPL prior to each experimental session using an Allison 300 calibration unit. Once calibrated, the signal was delivered monaurally to the subject's right ear via a Telephonics earphone (TDH 39-10Z).

Somesthetic Stimulus

The somesthetic stimulus was an intraoral air pressure drop from 6 cm H_2O to atmospheric pressure delivered via a special-purpose, custom built device. This pressure release device is a modification of similar instrumentation used initially by Vencov (1965). The present device consisted of two polypropeline tubes connected in series with a soft flexible plastic hose. The total length of the device was 150 mm with an inside diameter of 10 mm (see Figure 6). The proximal end of this device was flattened to form a shape similar to a smoker's pipe mouthpiece. This proximal end when placed in the subject's mouth, was gripped by the subject's incisor teeth, while its outside diameter was then sealed tightly with the subject's lips. The distal end of the tube was mounted in a sturdy framework attached to a fixed stand on the laboratory floor. Once mounted into the framework and gripped at its proximal

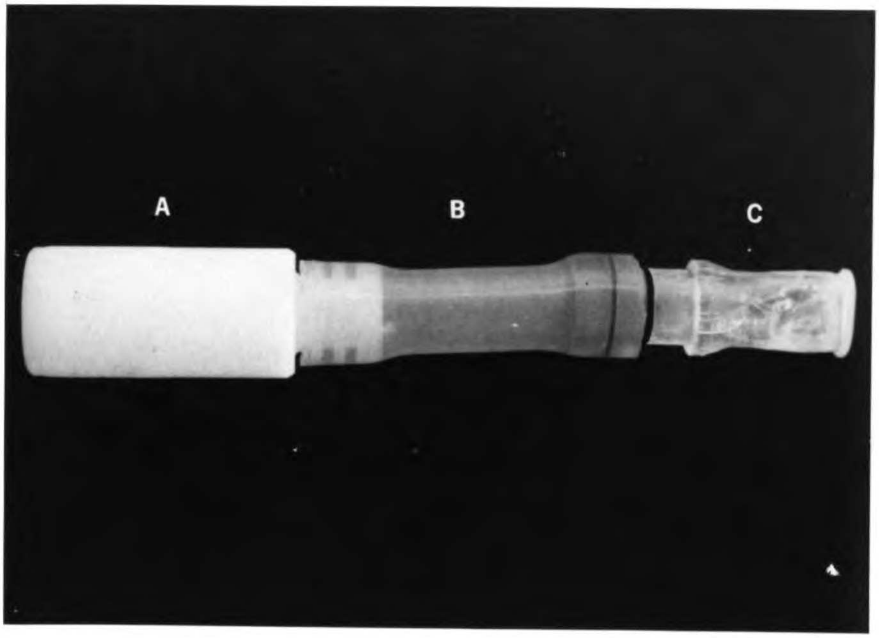

Figure 6

Intraoral air pressure release device. A) Distal end, B) Flexible connector, C) Proximal mouth piece end.

end by the subject's incisor teeth, the device was then sealed off by the experimenter's finger tip at the distal end. Additionally, an intraoral catheter suitable for sampling the intraoral air pressure was placed in the subject's mouth and connected to a pressure transducer (Statham PM 131). The intraoral air pressure was calibrated in two centimeter steps from atmospheric pressure to 10 cm H_2O, using a U-tube water manometer. The voltage signal obtained from the pressure transducer was led to Honeywell Accudata Amplifiers Model 120 and 105. This amplified signal was monitored by both the subject and the experimenter on a voltmeter suspended at the level of the subject's face. This voltage output was also recorded on one channel of the FM tape system for future retrieval. The subject was asked to build up the 6 cm H_2O intraoral air pressure by monitoring the voltmeter needle with respect to the target number. When the desired meter level that corresponded to 6 cm H_2O was reached, the subject stabilized the pressure and closed his/her eyes while maintaining this constant pressure. At the moment of eye closure, the subject depressed the ready-warning button, which put a DC signal on an FM tape channel. This manually controlled prestimulus interval was kept within the range of 50 to 4000 msec similar to that of the auditory prestimulus intervals. The experimenter rapidly released the intraoral air pressure no less than 50 msec and no later than 4000 msec after stabilization of the desired intraoral air pressure. Eye closure was a necessary precaution to prevent the subject from obtaining visual feedback from the voltmeter when the device was opened. This rapid intraoral air evacuation from the achieved pressure level to atmospheric pressure served as the somesthetic stimulus. The events shown in Figure 7 depict: 1) the intraoral air pressure buildup period from zero intraoral air pressure to 6 cm H_2O; 2) the intraoral air pressure maintenance period; 3) the eye closure moment; 4) the intraoral air pressure release mo-

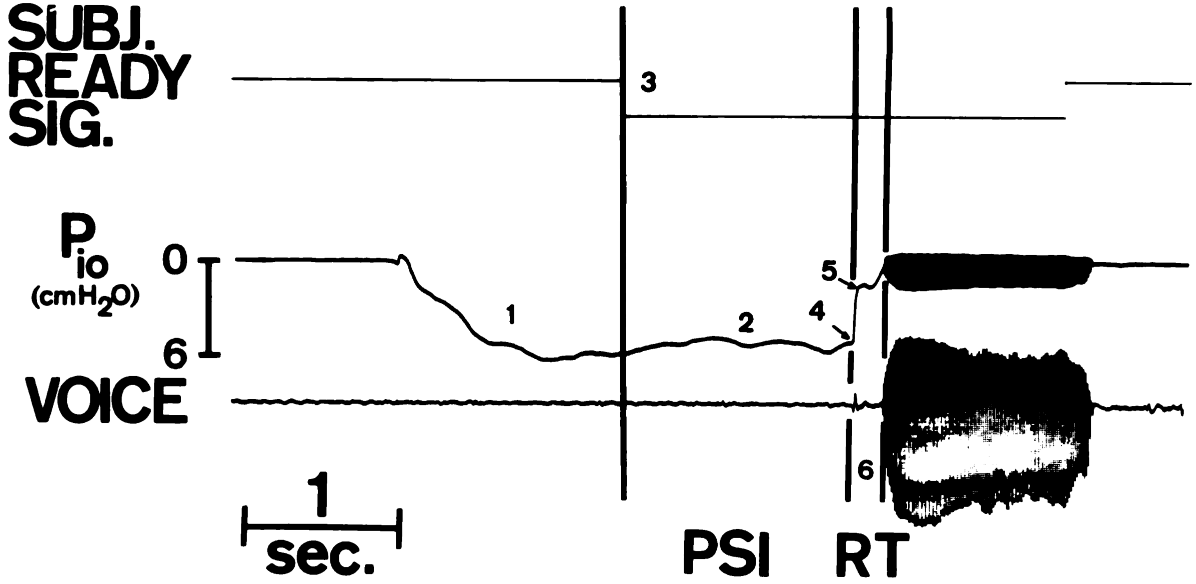

Figure 7

Events during somesthetic-vocal reaction-time task. 1) intraoral air pressure buildup period from zero to 6 cm H_2O, 2) intraoral air pressure maintenance period, 3) eye closure moment, 4) intraoral air pressure release moment, 5) intraoral air pressure evacuation, and 6) latency of the vocal response.

ment; 5) the intraoral air pressure evacuation and 6) the latency of the vocal response. The device anchored in the subject's mouth, with the intraoral catheter, transducer, voltmeter, mounting framework, and the frame to which this instrumentation was attached, is shown in Figure 8.

Responses

For the experiment, the subjects were requested to produce both vocal and manual responses as quickly as possible following stimulus onset. The instrumentation for delivery and monitoring the responses is shown schematically in Figure 9.

Vocal Responses

Vocal responses were in the form of phonation initiation of the vowel /a/ produced at a most comfortable effort level with the intensity, frequency, and quality of responses not subject to experimental control.

The vocal responses to both stimulus types were monitored by a laryngeal contact microphone (Bruel and Kjaer Model 4131), placed laterally on the subject's neck at the level of the thyroid cartilage prominence. Figure 10 shows a subject with the instruments in place for monitoring the vocal response.

The vocal responses were studied as a function of stimulus type, prephonatory vocal fold position and percentage of lung volume.

Prephonatory vocal fold position. Vocal responses were produced during three types of gestures designed to reflect different prephonatory vocal fold positions.

Modified valsalva or adducted vocal fold position. In this condition, the subject was instructed to adduct his vocal folds and to raise subglottal air pressure. The initiation of phonation was executed from this adducted vocal fold position.

Figure 8

Experimental subject with the instrumentation for delivery and monitoring of intraoral air pressure (somesthetic stimulus) in place. 1) Pressure release device mounted in the tubular framework, 2) intraoral air pressure catheter connected to a PM 131 pressure transducer, and 3) a voltmeter serving as a monitor for the intraoral air pressure buildup.

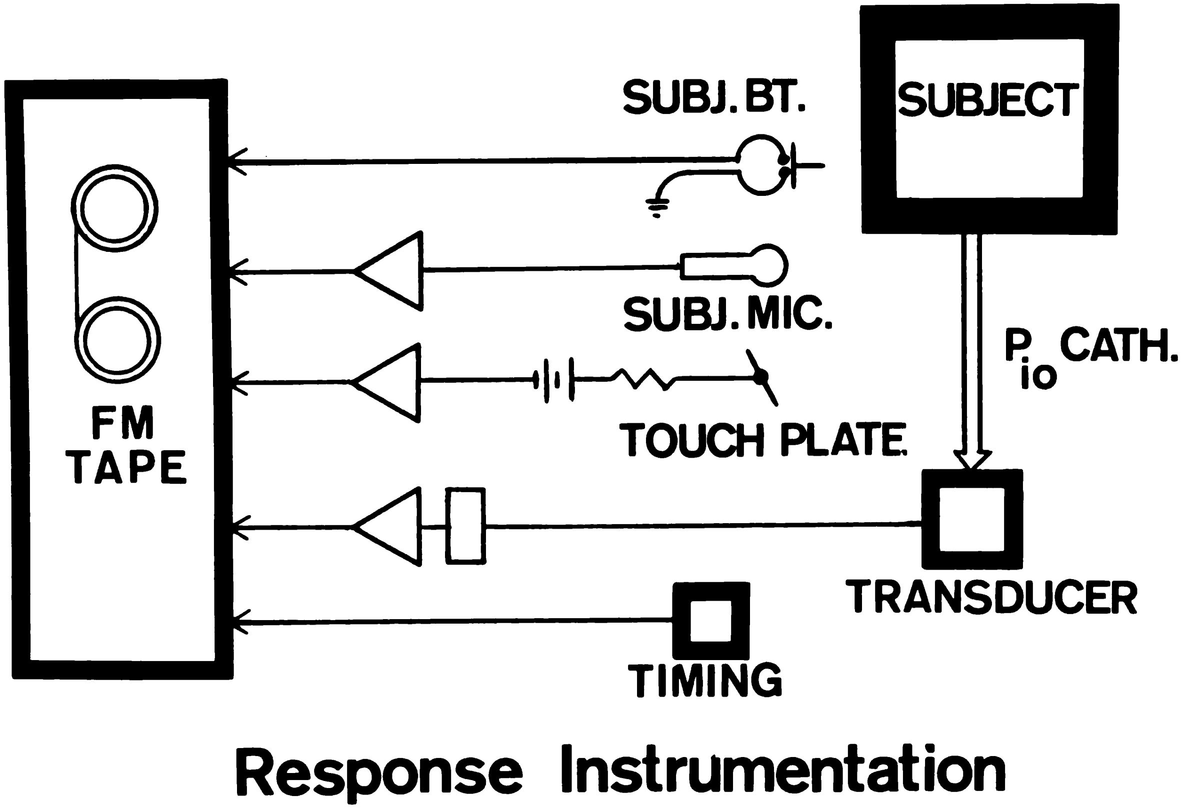

Figure 9

Schematic representation of response instrumentation.

Figure 10

Experimental subject with auditory stimulus instrumentation in place. Laryngeal microphone held against the neck at the level of thyroid lamina, the earphones cover right ear only. In the left hand is the subject's ready warning button for activation of the stimulus delivery and randomization program.

Expiratory air flow or abducted vocal fold position. To assure vocal fold abduction at the onset of the auditory stimulus, the subjects were instructed to exhale while producing continuously the consonant /s/. As soon as possible after the onset of the stimulus, the subject was instructed to change from producing an /s/ sound to an /a/ sound.

Subject's method or uncontrolled vocal fold position. The subject initiated phonation without concern for the prephonatory vocal fold position. This condition was used to see if the other two experimental treatments imposed artificial restraints on the subject's ability to initiate phonation rapidly.

Lung Volume Instrumentation

Vocal responses to the auditory stimulus were studied as a function of controlled lung volumes. The respirometer instrumentation was a Vitalometer TM, single breath spirometer used to measure the lung volume of each subject. This single bellows spirometer permitted direct measurements of a subject's lung function at any time during the stimulus-response sequence. As the subject exhaled into the apparatus, the respirometer stylus deflected, recording directly on calibrated paper the volume of air input in centiliters. The instrument was operated in a manual mode so that the deflection of the stylus produced straight vertical lines. Figure 11 shows the subject exhaling into the respirometer.

Lung volume measurement techniques. In the controlled lung volume condition, the auditory-vocal reaction times for phonation initiation were studied as a function of each individual subject's 75, 50 and 25 percent of lung volume. To establish these percentage points each subject first performed the static vital capacity test involving inspiring fully and exhaling maximally into the respirometer. After five of these maneuvers, the largest indicated

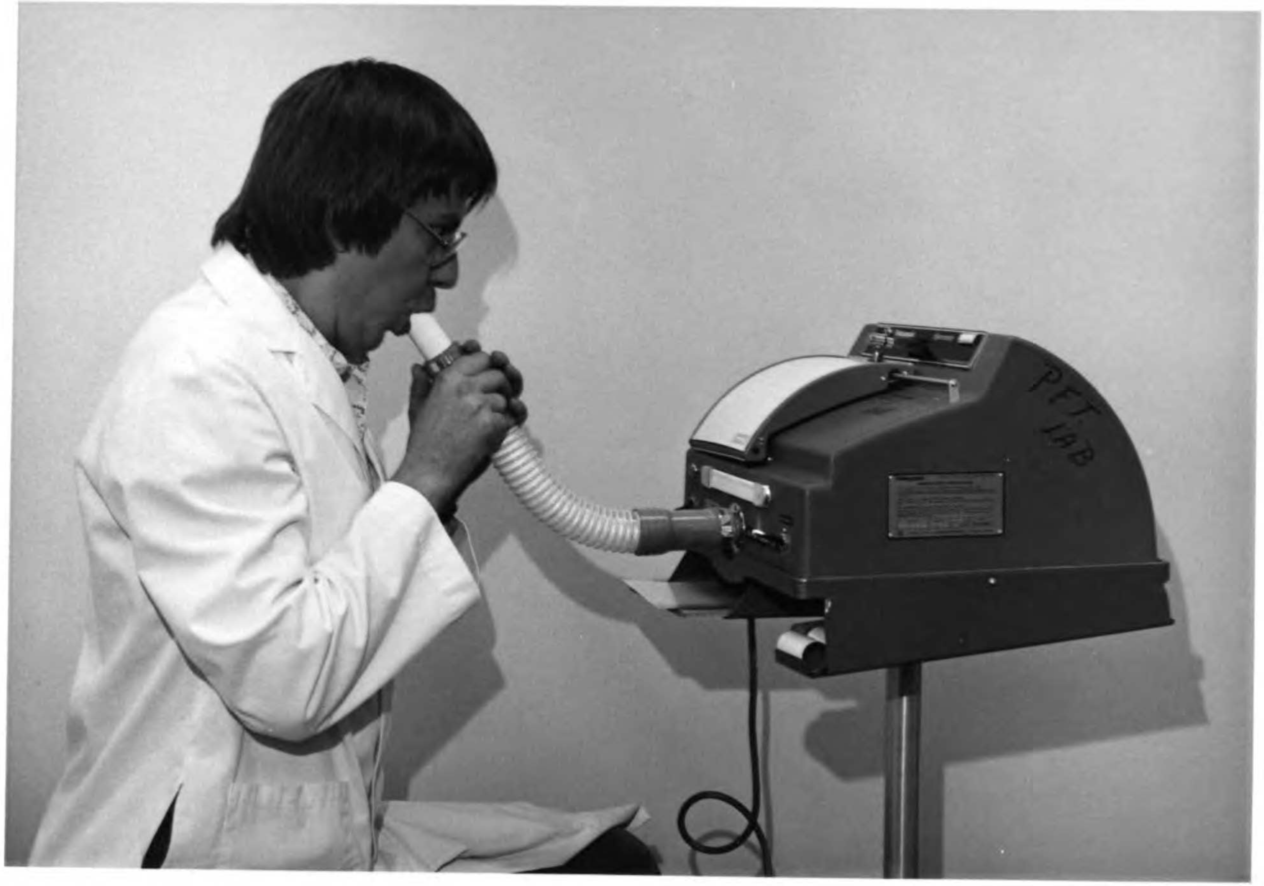

Figure 11

Experimental subject performing static vital capacity test using a respirometer apparatus.

vital capacity was assigned the value of 100% lung volume. Next, this 100% baseline was divided into 75, 50, and 25% parts and marked on the respirometer chart. The chart was mounted on the respirometer face and lines used as a guide for the subject to perform the tasks. For example, a male subject exhaled from 100% lung volume, stopped at the 75% mark, pressed the ready button and waited for the auditory stimulus while holding his breath. The subject then produced phonation as quickly as possible following stimulus onset. After the brief phonatory response and without breaking the air seal to the respirometer or inhaling, the subject exhaled into the respirometer until the stylus indicated the 50% lung volume mark. Here the subject again held his breath until the phonatory response was executed. The subject then performed in the same manner at 25% lung volume level. This full task was performed on one exhaled breath group and took about 15 seconds to accomplish. The subjects were trained in this condition before actual recording began. Because of the nature of the instrumentation in this condition, reaction times were studied only to the auditory stimulus and with the vocal folds adducted.

Manual Response

The manual response was the upward extension of the right hand index finger following the auditory stimulus only. Figure 12 shows the instrumentation for monitoring the manual responses. The subject was seated in a comfortable position with the right arm at about a 90° angle, with the forearm pronated and the palm resting on a low table slightly above knee level. The subject's right index finger was coated with a film of electrode paste and was in contact with a stainless steel metal plate located on the right side of the subject's body midline. A silver surface disc ground electrode was taped to the smooth skin of the subject's forearm. The lead from the electrode was

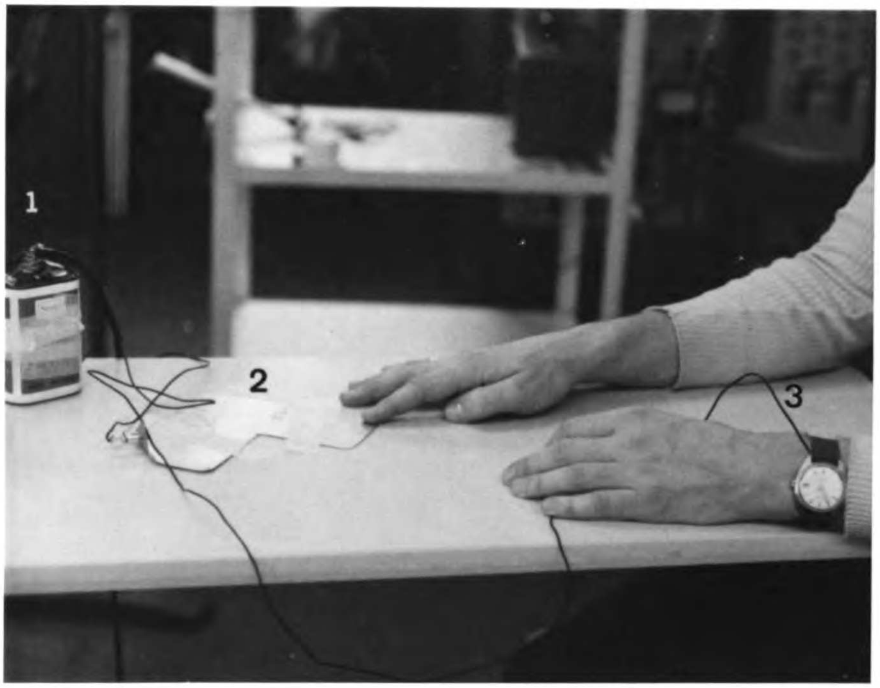

Figure 12

Subject in experimental position for auditory-manual response task. 1) dry batter, 2) touch-plate, and 3) ground electrode.

grounded and connected to the negative pole of a 6 volt battery. The positive lead from the battery was connected to the metal plate through a 100K ohms resistor. The flow of the current through this circuitry (consisting of a battery, the plate, and the subject's forearm) was interrupted instantaneously whenever the subject broke the contact with the plate by an upward extension of the finger.

Data Acquisition and Equipment

Data collected during the experimental conditions consisted of a variety of signals and physiological recordings: 1) the auditory and the somesthetic stimuli; 2) the vocal responses; 3) the manual responses; 4) the subject's ready-warning signal; 5) the experimenter's microphone; 6) the intraoral air pressure signal; and 7) the time markers. During the experiment, all signals were monitored on three sets of oscilloscopes (Honeywell RM 502A dual-beam, Tektronix RM 564 4-beam, and Hewlett-Packard Model 120 B single-beam).

Instrumentation for Data Acquisition

All physiological data were led from the appropriate pickup points to Honeywell Accudata biological amplifiers and the signals then fed to a 14-channel FM tape recorder (Honeywell 7600). The recorder operated in a double-extended mode at 15 ips, gaining a data band width of DC to 10 kHz. Six data tracks were used: timing signal, auditory stimulus, intraoral pressure, subject's response, DC shift from ready-warning signal button and the experimenter's voice. Lung volume data were recorded on the respirometer cards and later correlated with the other experimental data.

The data channels from the FM recorder were displayed on an optical oscillograph (Honeywell Visicorder, Model 1108) operating at a chart speed of 100 mm/sec.

Timing Signal

The timing signal was produced using an Audio Signal Generator (Hewlett Packard Model 206A) calibrated via a Hewlett Packard electronic counter (Model 5212A) and run through a custom-built timing mark generator, the output of which was a 100 Hz pulse signal that was led to one channel of the FM recorder.

Measurements

The data measurements included the latencies in milliseconds for the vocal and manual reaction times and their prestimulus intervals for each observation. Each segment to be measured was delineated and vertical lines drawn at the boundaries to the accompanying timing signal channel on the oscillographic writeout. The duration of each segment was calculated by counting the number of 10 msec pulses between boundary lines.

Vocal Responses Data Measurement

Vocal responses to the auditory stimulus were measured in milliseconds for both the total neuro-mechanical reaction time and the prestimulus interval. The measurements for the total neuro-mechanical reaction time latencies from phonation initiation were taken from the stimulus onset, represented by initial deflection of the DC tracing to the onset of the first cycle in the voice tracing as shown on the oscillographic paper. The prestimulus interval latencies were measured from the deflection of the DC trace, indicating activation of the ready signal, to the onset of the stimulus. These measurements are presented in Figure 13.

As with the auditory stimulus condition, the reaction time and the

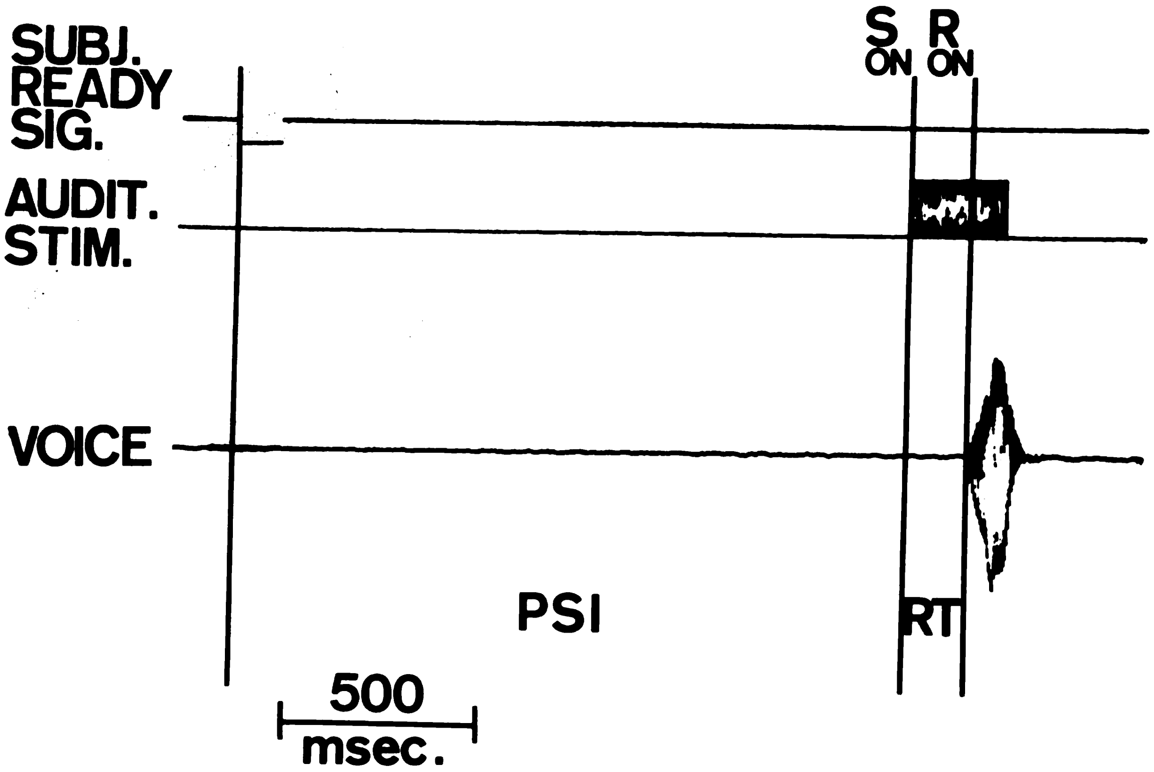

Figure 13

A typical auditory-vocal reaction time tracing obtained from the oscillograph. The temporal interval between the deflection of the subject's ready-button and the stimulus onset indicates the prestimulus interval (PSI). The temporal interval between stimulus onset and the response in the form of voice initiation indicates reaction time latency (RT).

prestimulus interval for the somesthetic stimulus were measured in milliseconds. The prestimulus interval was measured as the period between the initial deflection of the DC signal and initial deflection in the intraoral air pressure signal, indicating the opening of the pressure release device. The total neuro-mechanical reaction time for phonation initiation as a function of the somesthetic stimulus was measured between the initial deflection or the intraoral pressure tracing and the onset of the first cycle in the subject's voice tracing (Figure 7). In addition, the amount of the intraoral pressure deflection was measured in centimeters of water according to the calibration curve obtained for each individual subject.

Manual Responses Data Measurements

The prestimulus interval was measured as the period in milliseconds between the onset of the stimulus activation and the onset of the auditory stimulus. The total neuro-mechanical reaction time for the manual response was measured as a period in milliseconds between the onset of the auditory stimulus and the deflection of the 4V DC tracing when the subject's finger extension broke the electrical contact (Figure 14).

Experimental Error

All reaction time data were displayed on the optical oscillograph paper and were measured by hand, with reference to the simultaneously acquired timing signal so that no flutter or wow in the tape recording or playback mechanisms or in the oscillographic drive system could bias the results. If the measurement fell between the 10 msec timing marks, the absolute values were rounded upward to the next 5 milliseconds.

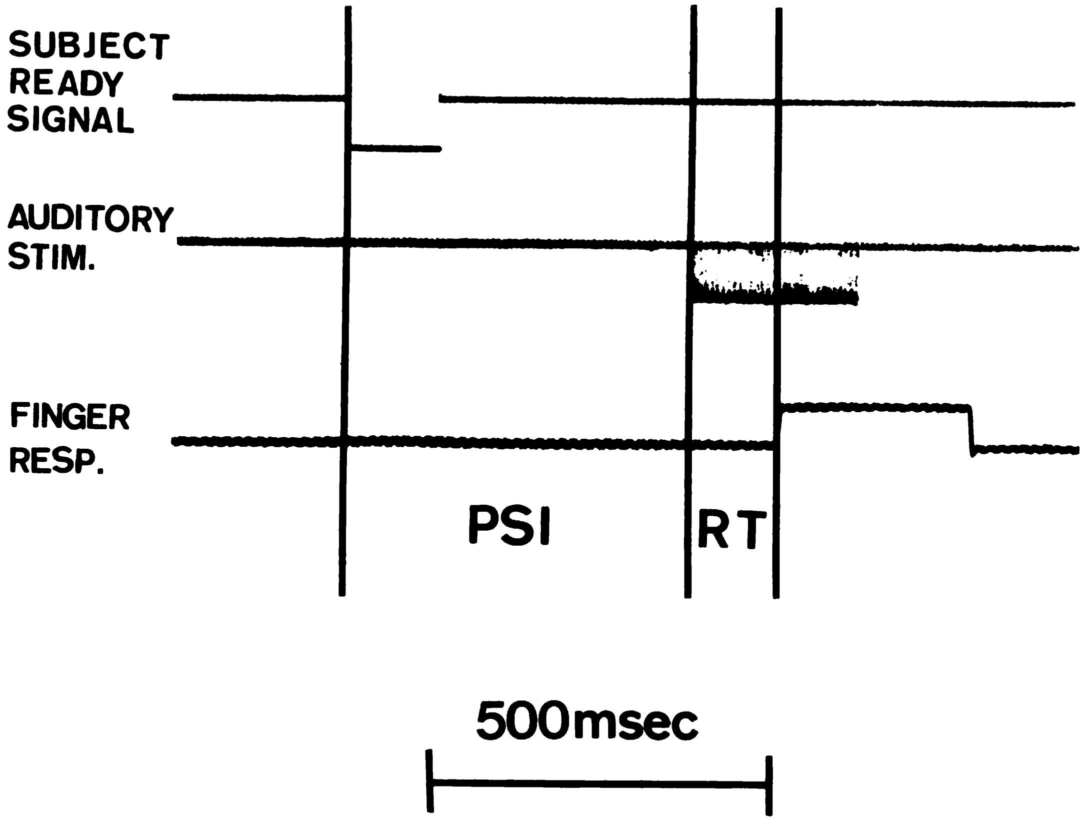

Figure 14

A typical auditory-manual reaction time tracing obtained from the oscillograph. The temporal period between the deflection of the subject's ready signal button and the stimulus onset and the response onset in form of finger lift indicates reaction time latency (RT).

Data Processing

Initially, the raw data were collated by subject, sex, and experimental condition, and were then key punched on IBM cards. These raw data were subjected to computer processing using the University of California, San Francisco computer facility. A variety of statistical analyses were performed using both Statistical Package for Social Sciences (SPSS) and Biomedical Computer Programs (BMD)[1] subprograms, as well as the special purpose Fortran written programs. A Fortran program was used on all response data to detect outlier datum. This program was based on the statistical methodology for outlier detection recommended by Grubbs (1969). Once found, the outliers were eliminated from the data core and a new corpus was disc-allocated. From these observations the minimal total neuro-mechanical reaction time data were later selected for each individual subject for each experimental condition and allocated at a separate address. This dual allocation permitted easy access to each data corpus; the main corpus comprising all observations, and the secondary corpus comprising only the fastest responses; thus allowing a simplified approach for statistical treatment of each data set as it was needed.

The following types of statistical analyses were used. The programs are listed according to the source.

1. One-way analyses of variance. One-way analyses of variance using SPSS ONEWAY subprogram. This subprogram permits one-way analyses of variance with optional tests for 1) the trends across categories of the independent variables, 2) _a priori_ contrasts specified by user and 3) _a posteriori_ contrasts specified by user. Detailed description of the ONEWAY subprogram can be found in SPSS Manual (1970) pp. 422-433.

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[1] The BMD programs were developed at the Health Sciences Computing Facility, at University of California, Los Angeles. The UCLA Health Sciences Computing Facility is sponsored by NIH Special Resources Grant PR-3.

2. t-Tests. A variety of t-tests statistics were performed using SPSS subprograms T-TEST: Descriptions and options of these subprograms can be found in SPSS Manual (1970) pp. 267-275.
3. Correlations and Regressions. Pearson Correlation Coefficients were performed using SPSS PEARSON CORR Subprogram (SPSS Manual 1970, pp. 280-288). When used with SCATTERGRAM subprogram the program provides the user with options for regression statistics.
4. Two-way analyses of variance (with covariance options) including repeated measures. These statistics were performed using BMD P subprogram, named BMD P2V (this program was revised July 7, 1975, manual date 1975). The description of this program is given in BMD P Manual (1975) pp. 711-760. In essence the BMD P2V program is used to perform the analysis of variance as described by Winer (1971).
5. Other statistics. The non-parametric Kruskal-Wallis analysis of variance by rank (Winer, 1971) was performed using a specially written FORTRAN program. The outlier detection program based on the statistical methdology for outlier detection (Grubbs, 1969) was performed using a specially written FORTRAN program.
6. Supporting Statistics. The scattergrams and histograms were done using both the SPSS and BMD P subprograms. The SPSS SCATTERGRAM and HISTOGRAM subprograms were used with options permitting scaling, and data transformation. The one-page BMD P5D UNIVARIATE PLOTTING PROGRAM (revised July 7, 1975, manual date 1975) subprograms with options as listed in the BMD P 1975 manual was used.

Summary

The sample selected for this study consisted of 30 individuals (15 males and 15 females) mean age 26 years, whose total neuro-mechanical reaction time latencies for voice initiation and finger extension were studied in various experimental conditions. The study followed a simple reaction time model in which the subjects were pretrained, prewarned, and were to respond as quickly as possible following stimulus onset.

Vocal responses were studied as a function of stimulus type, prephonatory vocal folds position, and lung volume.

The manual responses were studied using the auditory stimulus only.

To establish the latencies of the total neuro-mechanical reaction times for both response types, the following methodology was used: The experimental reaction time data were displayed on the oscillographic paper and the interactions between the various signals were measured in milliseconds with reference to the simultaneously-acquired timing signal. The time lag between the onset of the stimulus, and the first cycle in the subject's voice trace for vocal responses or the deflection of the voltage tracing from the base line for the manual response constituted the total neuro-mechanical reaction time latency.

All data obtained in this fashion were tabulated and then allocated in the computer at UCSF Computer Center. Initially, a set of procedures was applied to establish both 1) the validity of the entire body of data and 2) to create a second data corpus consisting of minimal total neuro-mechanical reaction times for each experimental subject for each experimental condition. These two sets of data were computer examined for the relationships among or within the various experimental conditions and subject sex.

CHAPTER IV

RESULTS

Introduction

The temporal reaction time data generated in this study are described according to the separate experimental procedures. The vocal reaction time data are described as a function of 1) prephonatory vocal fold position, 2) stimulus type, and 3) percentage of lung volume. The manual reaction time data are presented and contrasted with the vocal reaction time.

Prephonatory Vocal Fold Position

For the primary purpose of this study, phonation was initiated from the two extreme prephonatory vocal fold positions: abducted vocal folds in the expiratory air flow condition, and fully adducted vocal folds in the modified valsalva condition as well as an uncontrolled condition called "Subject's Method." Table 1 shows the fastest vocal reaction time latencies for each of the 15 male subjects to the auditory stimulus as a function of the two experimental prephonatory vocal fold positions, as well as the group means, standard deviations and medians.

The mean auditory-vocal reaction time latencies for the male subjects were, 177 msec (SD=37) for adducted vocal fold position, 170 msec (SD=32) for the abducted vocal fold position, and 175 msec (SD=23) for the subject's method. The ranges of the values were 150 msec (130-280) for the adducted vocal fold position, 110 msec (125-235) for the abducted vocal fold position and 90 msec (135-225) for the subject's method condition.

Table 1

Minimal auditory-vocal reaction times in milliseconds for individual male subjects in adducted and abducted prephonatory vocal fold positions, as well as group means, standard deviations and medians.

	Prephonatory Vocal Fold Position		
Subject Number	Adducted (msec)	Abducted (msec)	Uncontrolled (msec)
1	170	125	180
2	130	135	135
3	150	125	150
4	155	170	180
5	180	235	185
6	200	225	170
7	140	160	170
8	160	160	180
9	200	185	190
10	195	165	205
11	185	160	165
12	280	210	180
13	195	160	190
14	185	185	225
15	130	165	140
Means	177	170	175
SD	37	32	23
Medians	180	165	180

The fastest auditory-vocal reaction time for each experimental condition was 135 msec for the adducted vocal fold position, 125 msec for the abducted vocal fold position, and 135 msec for the subject's method condition.

As seen from the means, slightly faster auditory-vocal reaction times were obtained for the abducted vocal fold position, and the spread of responses was smallest in the uncontrolled vocal fold condition. An examination of the individual male subjects' data indicated two subjects having equally fast reaction times for adducted and abducted prephonatory vocal folds position, five subjects had faster reaction times for the adducted vocal fold position, six had faster reaction times for the abducted vocal fold position, and two had faster reaction times for the uncontrolled vocal fold condition. To account for these differences between the various experimental conditions, the mean reaction time data were compared using a matched pair by subject _t_-test. The results of these tests indicated that the difference in the auditory-vocal reaction time as a function of the prephonatory vocal fold position was not statistically significant for the male group.

Table 2 shows the same auditory-vocal reaction times for the 15 female subjects as shown in the previous table for males.

The mean auditory-vocal reaction time latencies for the female subjects were 204 msec (SD=33) for the adducted vocal fold position, 180 msec (SD=32) for the abducted vocal fold position, and 189 msec (SD=35) for the uncontrolled vocal fold position. The ranges of the values were 130 msec (160-290) for the adducted vocal fold position, 125 msec (125-250) for the abducted vocal fold position, and 130 msec (145-275) for the uncontrolled vocal fold position.

Table 2

Minimal auditory-vocal reaction times in milliseconds for individual female subjects in adducted and abducted prephonatory vocal fold positions, as well as the group means, standard deviations and medians.

Subject Number	Adducted (msec)	Abducted (msec)	Uncontrolled (msec)
1	215	225	190
2	290	265	275
3	205	180	195
4	180	160	155
5	215	185	205
6	185	160	190
7	220	185	185
8	180	210	185
9	185	155	150
10	250	180	195
11	220	185	250
12	160	160	145
13	205	155	190
14	175	140	160
15	185	160	170
Means	204	180	189
SD	33	32	35
Medians	205	180	190

The fastest auditory vocal reaction time for the experimental conditions was 160 msec for the adducted vocal folds, 140 msec for the abducted vocal folds, and 145 msec for the uncontrolled vocal fold position.

These findings are somewhat similar to the male data. The fastest mean reaction time and the smallest standard deviation for the female group were obtained for the abducted vocal fold position. When the individual data were examined, one subject showed equally fast reaction times for the adducted and abducted conditions, but with fastest reaction time for the uncontrolled vocal fold position; one subject had the fastest reaction time for the adducted vocal fold position; nine subjects had faster reaction times for the abducted vocal fold position; and one subject had equally fast reaction time for the uncontrolled vocal fold position and abducted vocal fold condition, and four subjects had faster reaction times for uncontrolled vocal fold position.

The differences between the means for these experimental conditions for females were tested using a matched pair by subject _t_-test. The results, summarized in Table 3, shows a significant ($p < .01$) difference in auditory-vocal reaction times between abducted and adducted glottis, as well as between adducted and subject's method condition.

Table 3

Means and standard deviations in milliseconds of the female auditory-vocal reaction times for adducted and abducted prephonatory vocal fold position and adducted uncontrolled vocal fold position and the results of the matched pair by subject _t_-test.

Prephonatory Vocal Fold Position	Means (msec)	SD (msec)	Difference Btwn Means (msec)	_t_ Value	p
Adducted	204	33	24	-3.97	.01
Abducted	180	32			
Adducted	204	33	15	-3.00	.01
Uncontrolled	189	35			

Examination of sex group means, standard deviations and medians indicated that the male auditory-vocal reaction time data were faster for all three experimental conditions. To test for the significance of these differences, two sets of statistics were applied. A two-tailed *t*-test was used to test for the difference between the means and a non-parametric Kruskal-Wallis analysis of variance by rank was performed on the medians. The results of the *t*-test are summarized in Table 4.

Table 4

Means and standard deviations of vocal reaction time in milliseconds and the *t*-test results for sex interaction with the auditory-vocal reaction times for adducted and abducted and uncontrolled prephonatory vocal fold position. (DF=28)

Prephonatory Vocal Fold Position	Sex	Means (msec)	SD (msec)	*t*-Value	p
Adducted	Males Females	177 204	37 33	-2.14	.05
Abducted	Males Females	170 180	32 32	-0.80	NS
Uncontrolled	Males Females	175 189	23 35	-1.48	NS

The *t*-test results indicated that the inter-sex differences in minimal auditory-vocal reaction times in abducted vocal fold condition and in the uncontrolled vocal fold condition were not significant, whereas mean inter-sex differences were found to be statistically significant ($p < .05$) for the adducted vocal fold position.

The inter-sex differences for reaction times in the adducted vocal fold condition when examined by Kruskal-Wallis analysis of variance by rank on medians were also found to be statistically significant ($p < .05$).

Stimulus Type

Besides the auditory-vocal reaction times, the somesthetic-vocal reaction time latencies were also studied. The nature of somesthetic stimulus employing the pressure-release device precluded initiation of phonation from the adducted vocal fold position; therefore, the somesthetic vocal reaction times were obtained only in the abducted vocal fold position.

The fastest individual somesthetic-vocal reaction time latencies for each of the male and female subjects as well as the means, standard deviations and medians for each sex group are shown in Table 5.

The mean somesthetic-vocal reaction time latency for the abducted vocal fold position for the male subjects was 174 msec (SD=29), the median was 170 msec, the range was 85 msec (135-220), while the fastest reaction time was 135 msec.

The comparison of male somesthetic-vocal reaction time data with the auditory-vocal reaction time data for abducted vocal fold position indicated that somesthetic-vocal mean and median reaction time data were slightly slower than auditory-vocal reaction time data. Further, the standard deviations for the somesthetic-vocal reaction time were found to be smaller than the auditory-vocal standard deviations. In order to account for these intrasex differences for phonatory reaction times as a function of stimulus type, a matched pair by subject *t*-test was performed. The results of this analysis revealed no statistically significant difference (p=0.549) between the phonatory reaction times as a function of stimulus type.

The fastest individual somesthetic-vocal reaction time latencies for abducted prephonatory vocal fold position for the 15 female subjects, as

Table 5

Individual male and female minimal somesthetic-vocal reaction time latencies in milliseconds for abducted vocal fold positions, including sex group means, standard deviations and medians.

	Abducted Prephonatory Vocal Fold Position	
Subject Number	Males	Females
1	150	190
2	155	150
3	135	180
4	135	120
5	205	150
6	220	235
7	155	240
8	135	270
9	200	140
10	175	185
11	175	190
12	195	200
13	170	195
14	200	220
15	210	175
Means	174	189
SD	29	40
Medians	170	190

well as group means, standard deviations and medians, also are shown in Table 5.

The mean somesthetic-vocal reaction time latency for the female subjects was 189 msec (SD=40), the median was 190 msec, the range was 150 msec (120-270), while the fastest reaction time was 120 msec.

The comparison of the female somesthetic-vocal reaction time data to the auditory-vocal reaction time data for the abducted vocal fold position showed that mean and median somesthetic reaction times were slightly slower, as was the case for the male data; however, the standard deviations for the male somesthetic-vocal reaction time data were larger than for the female auditory-vocal data.

The matched pair by subject *t*-test was used to test for the intra-sex differences between the means of the female auditory-vocal and the auditory-somesthetic reaction times. The results of this *t*-test showed these differences were not statistically significant (p=0.529).

As in the case of auditory-vocal reaction times, both the means and medians of the somesthetic-vocal reaction times were found to be faster for the male subjects. The two-tailed *t*-test and the Kruskal-Wallis non-parametric analysis of variance by rank were used to examine these results of these inter-sex assymetries for the somesthetic-vocal reaction times. The results of these analyses indicated that the inter-sex difference was not statistically significant (*t*-test: p=0.263, Kruskal-Wallis: p=0.617).

Lung Volume Effects

Phonatory reaction times were also studied as a function of 75, 50 and 25% of lung volumes. Only an auditory stimulus was used and phonation was initiated from the adducted vocal fold position. Table 6 shows fastest

Table 6

Fastest individual male auditory-vocal reaction times in milliseconds as a function of lung volumes (75, 50, 25%) as well as group means, standard deviations and medians.

	Adducted Prephonatory Vocal Folds Lung Volume Percentage		
Subject Number	75% (msec)	50% (msec)	25% (msec)
1	140	120	125
2	150	145	125
3	150	145	150
4	205	190	180
5	190	180	210
6	205	195	230
7	160	165	185
8	180	190	180
9	245	215	210
10	330	240	370
11	170	150	170
12	305	335	295
13	220	190	175
14	245	195	190
15	145	140	165
Means	202	186	197
SD	57	51	63
Medians	190	190	180

individual male auditory-vocal reaction time latencies for adducted prephonatory vocal folds at the three experimental lung volumes. This table also shows group means, standard deviations and medians.

The mean minimal auditory-vocal male reaction times for adducted prephonatory vocal fold position at the three controlled lung volumes were 202 msec (SD=57) for the reaction times at 75% of lung volume, 186 msec (SD=51) for the reaction times at 50% of lung volume, and 197 msec (SD=63) for the auditory-vocal reaction times executed at the 25% of lung volume. The ranges were 190 msec (140-330) for the 75% of lung volume, 215 msec (120-335) for the 50% of lung volume, and 195 msec (125-370) for the reaction times at the 25% of lung volume.

The fastest auditory-vocal reaction time latencies for the male group were 140 msec for the reaction time for the 75% of lung volume, 120 msec for the reaction time at the 50% of lung volume, and 125 msec for the reaction time at the 25% of lung volume.

The minimal individual auditory-vocal reaction time latencies for each of the 15 female subjects for the three experimental lung volumes (75, 50, and 25%), as well as group means, standard deviations and medians are shown in Table 7.

Table 7

Fastest individual female auditory-vocal reaction times in milliseconds for adducted prephonatory vocal folds and lung volumes (75, 50, and 25%), including group means, standard deviations and medians.

	Adducted Prephonatory Vocal Folds Lung Volume Percentage		
Subject Number	75% (msec)	50% (msec)	25% (msec)
1	295	225	250
2	300	300	290
3	210	220	205
4	175	180	170
5	485	330	320
6	310	240	245
7	215	190	195
8	205	205	230
9	150	165	175
10	180	185	200
11	240	205	225
12	190	205	165
13	215	240	240
14	160	135	155
15	160	180	170
Means	232	213	215
SD	86	49	47
Medians	210	205	205

The mean female auditory-vocal reaction times for the adducted vocal fold position at the three lung volumes were 232 msec (SD=86) for the responses at 75% of lung volume, 213 msec (SD=49) for the reaction times at the 50% of lung volume, and 215 msec (SD=47) for the phonation initiation at the 25% of lung volume. The range of female responses were 335 msec (150-485) for the phonation initiation at the 75% of lung volume, 195 msec (135-330) for the auditory-vocal reaction times at the 50% of lung volume, and 165 msec (155-320) for the auditory-vocal reaction times at the 25% of lung volume.

The fastest reaction times for phonation initiation at the different lung volumes were 150 msec for the reaction times at the 75% of lung volume, 135 msec for the reaction times at 50% of lung volume, and 155 msec for the auditory-vocal reaction time at the 25% of lung volume.

Examination of the male data showed that 46% of individual subjects gave their fastest responses at the 50% of lung volume, 40% gave fastest responses at 25% of lung volume, 6.5% gave fastest responses at 75% of lung volume and 6.5% gave equally fast responses at two lung volumes.

In the female population approximately 33% of subjects gave fastest responses at both 75% and at 50% of lung volume, 26% gave fastest responses at 25% of lung volume and 6% gave equally fast responses at two different lung volumes.

The mean auditory-vocal reaction time data for both sex groups was fastest at 50% of lung volume, slower at 25% of lung volume, and slowest at 75% of lung volume. Further, the male auditory-vocal reaction times were faster than the female auditory-vocal reaction times across all lung volumes. This relationship is presented in Figure 15.

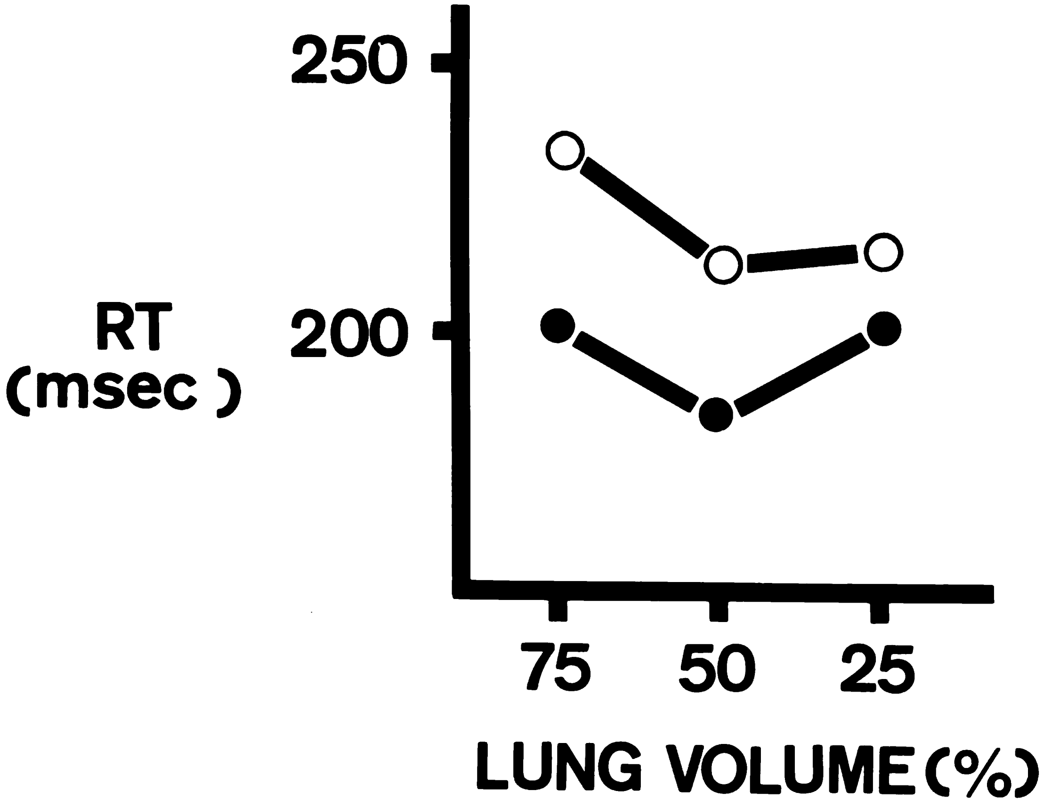

Figure 15

Group mean auditory-vocal reaction times in milliseconds for adducted vocal folds position at 75, 50 and 25% of lung volume. Females, open circles; Males, filled circles.

The auditory-vocal reaction times for each sex group were submitted for the analysis of variance to account for the effect of the three experimental lung volumes on the phonatory responses. The results of this analysis for the male group are shown in Table 8.

Table 8

Results of the analysis of variance for the male reaction times for the auditory-vocal responses initiated from adducted vocal fold position at 75, 50 and 25% of lung volumes.

Source	df	Mean Square	F	p
Between Subjects	14	9063.11	189.58	.000
Within Subjects	30			
Lung Volume	2	1058.87	2.067	.145
Linear Trend	1	213.33	0.539	.475
Quadratic Trend	1	1904.40	3.027	.104
Lung Volume X Subjects	28	512.32	2.067	
Linear Trend X Subjects	14	395.47	2.539	
Quadratic Trend X Subjects	14	629.16	3.027	

The results of the analysis of variance for the male subjects showed that the quadratic relation between reaction time and the three controlled lung volumes although not statistically significant approached significance (p=.104). The linear trend was also shown not to be statistically significant (p=.475).

Table 9 shows the results of the analysis of variance for the female subjects.

Table 9

Results of the analysis of variance for the female reaction times for the auditory-vocal responses initiated from the adducted vocal fold position at 75, 50, and 25% of lung volumes.

Source	df	Mean Square	F	p
Between Subjects	14	10654.45	205.66	
Within Subjects	30			
Lung Volume	2	1635.00	1.960	.160
Linear Trend	1	2167.50	1.842	.196
Quadratic Trend	1	1102.50	2.245	.156
Lung Volume X Subjects	28	833.81	1.960	
Linear Trend X Subjects	14	1176.43	1.842	
Quadratic Trend X Subjects	14	491.19	2.245	

The results of analysis of variance for the female subjects showed that the quadratic relation between the auditory-vocal reaction times and the experimental lung volume conditions was not statistically significant (p=.156). As in the case of males, the linear relationship between the reaction times and lung volumes was also found not to be statistically significant (p=.196).

A two-way analysis of variance (Sex x Lung Volume) was used to account for the effect of lung volume on the reaction times. The results of this analysis are summarized in Table 10.

Table 10

Results of the two-way analysis of variance (Sex x Lung Volume) for the auditory-vocal reaction times as a function of lung volume percentage (75, 50, and 25%).

Source	df	Mean Square	F	p
Between Subjects	29			
Sex	1	14364.69	1.457	.237
Subjects within Groups	28	9858.77		
Within Subjects	60			
Lung Volume	2	2411.42	3.583	.034
Linear Trend	1	1870.41	2.380	.134
Quadratic Trend	1	2952.43	5.270	.029
Sex X Lung Volume	2	282.43	0.420	.659
Sex X Linear Trend	1	510.41	0.650	.427
Sex X Quadratic Trend	1	54.45	0.097	.758
Lung Volume X Subjects within Groups	56	673.06	0.420	
Linear Trend X Subjects within Groups	28	785.95	0.649	
Quadratic Trend X Subjects within Groups	28	560.17	0.097	

This two-way analysis of variance (Sex x Lung Volume) showed no statistically significant effect of sex, or any statistically significant interactions with sex. The main effect of lung volume was, however, statistically significant (p=.034). This effect can be attributed to the quadratic relationship between reaction time and lung volume (p=.029). The overall linear trend was not statistically significant (p=.134).

Influence of the Respirometric Equipment on the Auditory-Vocal Reaction Time Latencies

A respirometer was used for the purpose of measurement and control of the three experimental lung volumes for the auditory-vocal responses. To examine the possible biasing of the experimental data due to the use of the respirometer, the phonatory respones for adducted vocal folds were measured twice: once without the interference of the respirometer and once while the respirometer was in use. Table 11 shows the results of these two experiments for both male and female subjects.

When the mean male and female data without and with respirometer are contrasted, it can be seen that slightly slower auditory-vocal reaction times were obtained when the respirometer was used.

A matched pair by subject, two-tailed _t_-test was used to examine the effect of the respirometer on the auditory-vocal reaction time data, for both sex groups. The results of this analysis are shown in Table 12.

The two-tailed _t_-test results indicated that no statistically significant difference between the reaction times for the respirometer and no respirometer conditions existed for both sex groups. The female group differences approached significance (p=.067). Further, when the one-tailed probability test on calculated _t_-value was applied, a statistically significant difference was found between the no-respirometer and respirometer mean data ($p<.05$) for the female population, and a statistically significant difference was appraoched in males (p=.100).

The results of this matched pair by subject _t_-test also showed a strong positive correlation between auditory-vocal reaction times for respiro-

Table 11

Fastest individual male and female auditory-vocal reaction times in milliseconds, for adducted vocal folds, taken while the respirometer was not in use (NoR) and while the respirometer was in use (R). Means, standard deviations and medians are included.

	Auditory-Vocal Reaction Times Adducted Vocal Folds			
	Male		Female	
Subject Number	NoR (msec)	R (msec)	NoR (msec)	R (msec)
1	170	170	215	385
2	130	120	290	325
3	150	155	205	205
4	155	170	180	140
5	180	190	215	260
6	200	215	185	285
7	140	150	220	280
8	160	150	180	170
9	200	240	185	165
10	195	195	250	295
11	185	160	220	195
12	280	325	160	180
13	195	200	205	275
14	185	200	175	155
15	130	115	185	185
Means	177	183	204	233
SD	37	51	33	72
Medians	180	170	205	205

meter (R) and for no respirometer (NoR) conditions for individual subjects. This correlation was interpreted as a similarity in the behavior of the individuals in the two experimental conditions (with and without respirometric measurements). In other words, this correlation indicated that subjects whose reaction time latencies were relatively slow or fast in one condition were so in the other.

Table 12

Means and standard deviation in milliseconds and correlations for the auditory-vocal reaction times for the experimental conditions with the respirometer (R) and without the respirometer (NoR) for each sex group, including the *t*-test results.

Sex	Condition	Mean (msec)	SD (msec)	Diff.Bt. Means (msec)	Correl. by Subj. Coeff.	Correl. by Subj. Two-tailed Prob.	*t* Value	Two-tailed Prob.of Diff.Bt. Means
Male	NoR	177	37					
	Valsalva			7	+0.961	p .001	-1.34	NS
	R	183	51					
Female	NoR	204	33					
	Valsalva			29	+0.670	p .01	-1.98	NS
	R	233	72					

Comparison Between Systems

Both the phonatory and manual reaction times were obtained within this study for the purpose of comparison of two motor systems response latencies to the same stimuli in the same subjects. This experimental design allowed subjects to be their own controls. Table 13 shows the individual fastest male and female manual reaction time latencies in milliseconds, as well as the group means, standard deviations and medians.

Table 13

Fastest individual male and female auditory-manual reaction time latencies in milliseconds including means, standard deviations and medians.

	Manual Reaction Times	
Subject Number	Male (msec)	Female (msec)
1	130	150
2	125	240
3	120	160
4	145	145
5	145	120
6	145	120
7	140	150
8	135	125
9	155	150
10	145	165
11	150	160
12	235	150
13	160	120
14	180	140
15	125	135
Means	149	148
SD	28	29
Medians	145	150

The data presented in this table indicate that the mean fastest male auditory-manual reaction time was 149 msec (SD=28) and the median was 145 msec. The mean fastest female auditory-manual reaction time was 148 msec (SD=29) or one msec shorter than the mean male data, while the median was 150 msec, or 5 msec longer than the male median.

A *t*-test was used to examine these differences between the means of the male and the female auditory-manual reaction time latencies. The results showed no statistically significant difference (p=.975) between the male and female auditory-manual reaction time latencies.

When contrasted with mean auditory-vocal reaction time data, the mean auditory-manual reaction time latencies are faster for both sex groups. Table 14 summarizes male and female means, standard deviations and medians of the three auditory-vocal experimental conditions of adducted, abducted, and uncontrolled vocal folds and for the auditory-manual responses.

Table 14

Comparison of the male and female means, standard deviations, and medians for the auditory-vocal and auditory-manual reaction time latencies in milliseconds.

		Auditory Vocal			Auditory-Manual
		Vocal Fold Position			Finger Extension
Sex		Adducted (msec)	Abducted (msec)	Uncontrolled (msec)	Upward (msec)
Male	Mean	177	170	175	149
	SD	37	32	23	28
	Median	180	165	180	145
Female	Mean	204	180	189	148
	SD	33	32	35	29
	Median	205	180	190	150

A series of analyses of variance (Vocal vs. Manual x Sex) was used to test for the differences between the auditory-manual and the three experimental auditory-vocal conditions of adducted, abducted and uncontrolled vocal fold position. The results of these analyses are shown in separate tables (Table 15, Table 16, and Table 17). Table 15 shows the results of the analysis between auditory-manual and auditory-vocal reaction times.

Table 15

Results of two-way analysis of variance (Vocal vs. Manual x Sex) for the difference between auditory-vocal reaction times in adducted vocal fold position and the auditory-manual reaction times.

Source	df	Mean Square	F	p
Between Subjects	29			
Sex	1	2801.79	1.50	.232
Subjects within Groups	28	1873.09		
Within Subjects	30			
Vocal vs. Manual	1	26459.86	123.48	.001
Vocal vs. Manual X Sex	1	2940.00	13.72	.001
Vocal vs. Manual X Subjects within Groups	28			

The results of this analysis showed a significant difference ($p < .001$) between the auditory-vocal and auditory-manual reaction times. Further, it also showed a significant interaction ($p < .001$) of sex with experimental conditions.

Table 16 shows the results of the analysis between the auditory-manual and auditory-vocal reaction times with abducted prephonatory vocal fold positions.

Table 16

Results of two-way analysis of variance (Vocal vs. Manual x Sex) for the difference between auditory-vocal reaction times in abducted vocal folds and the auditory-manual reaction times.

Source	df	Mean Square	F	p
Between Subjects	29			
Sex	1	317.46	0.21	.650
Subjects within Group	28	1504.42		
Within Subjects	30			
Vocal vs. Manual	1	10719.99	27.63	.001
Vocal vs. Manual X Sex	1	365.07	0.94	.340
Vocal vs. Manual X Subjects within Groups	28	388.10		

The results of the analysis of variance for the manual reaction times and the uncontrolled prephonatory vocal fold position reaction times are shown in Table 17.

The results indicated no statistically significant sex effect ($p=.495$); however, as was the case in the preceding condition, a statistically significant difference ($p<.001$) was found between the auditory-vocal and auditory-manual reaction times.

To account for the maximum speed with which subjects were able to initiate a response within the two motor subsystems, the fastest individual vocal reaction times were pooled across all experimental conditions, and were contrasted with the manual responses. These fastest vocal reaction times and the manual reaction times, as well as group means, standard deviations and medians, are shown for each sex group in Table 18.

Table 17

Results of two-way analysis variance (Vocal vs. Manual x Sex) for the difference between auditory-vocal with uncontrolled prephonatory vocal fold position and auditory-manual reaction times.

Source	df	Mean Square	F	p
Between Subjects	29			
Sex	1	640.34	.48	.495
Subjects within Groups	28	1341.47		
Within Subjects	30			
Vocal vs. Manual	1	17136.46	44.30	.001
Vocal vs. Manual X Sex	1	707.28	1.83	.187
Vocal vs. Manual X Subjects within Groups	28			

Table 18

Fastest individual male and female phonatory reaction times in milliseconds pooled across all phonatory experimental conditions and manual reaction times, as well as group means, standard deviations and medians.

Subject Number	Fastest Vocal Reaction Times Pooled Across All Conditions		Manual Reaction Times	
	Male (msec)	Female (msec)	Male (msec)	Female (msec)
1	120	190	130	150
2	120	150	125	240
3	125	180	120	160
4	135	120	145	145
5	180	160	145	120
6	170	160	145	120
7	140	185	140	150
8	150	170	135	125
9	185	125	155	150
10	165	180	145	165
11	150	185	150	160
12	180	125	235	150
13	160	155	160	120
14	160	135	180	140
15	120	160	125	135
Means	151	158	149	148
SD	23	23	28	29
Medians	150	160	145	150

The examination of Table 18 suggests that when the fastest vocal reaction times are compared with manual reaction times, a statistically significant difference does not exist. The results of a two-way analysis of variance (Vocal vs. Manual x Sex, see Table 19) confirmed this observation, showing that when these two motor responses are compared, no statistically significant difference is found (p=.329).

Table 19

Results of two-way analysis of variance (Vocal vs. Manual x Sex) for the difference between minimal phonatory reaction times pooled across all vocal conditions and manual reaction times.

Source	df	Mean Square	F	p
Between Subjects	29			
Sex	1	232.10	0.254	.618
Subjects within Groups	28	913.56		
Within Subjects	30			
Vocal vs. Manual	1	470.40	0.986	.329
Vocal vs. Manual X Sex	1	273.06	0.572	.456
Vocal vs. Manual X Subjects within Groups	28	477.44		

Relative Difficulty of Tasks

It can be noted from the data reviewed that any neuro-muscular task can be expected to generate highly variable scores in a randomly selected group of subjects. To account for this observation the data were examined for relative task complexity. A one-way analysis of variance was performed on all responses in the major corpus for each subject by experimental condition.

According to this statistic, the inter-subject variability was highly significant ($p < .001$) for both sex groups, indicating that the subjects differed greatly from each other. The range of means for males was 142-359 msec for vocal reaction times and 142-308 msec for the manual reaction times; the range of means for females was 184-395 msec for the vocal reaction times and 149-295 msec for the manual response. This highly significant difference among subjects was found despite the fairly large variance among reaction time observations within subjects.

Further, it was found that the subjects tended to behave consistently across tasks wherein the fast subjects were fast in all experimental conditions, while the slow subjects were slow irrespective of motor tasks or sensory stimulation.

The results of the one-way analysis of variance also indicated that the intra-subject variability was less for the responses taken with the respirometer apparatus than for the reaction times taken without the use of the respirometer.

The relative difficulty of tasks was further investigated on the basis of the standard deviations of all subjects' scores for all observations for each experimental condition. Table 20 shows the standard deviation for each experimental condition for both males and females.

Table 20

Standard deviations in milliseconds for all reaction time scores for each experimental condition for both sex groups. NoR indicates measures taken without respirometer apparatus interference and R indicates measurements taken with the respirometer apparatus.

VOCAL RESPONSES

	Auditory Stimulus						Somesthetic Stimulus	Auditory Stimulus
	Vocal Fold Position			Lung Volume			Abducted Vocal Fold Position	Finger Extension
	Adducted	Abducted	Uncontrolled	75%	50%	25%		
	NoR (msec)	NoR (msec)	NoR (msec)	R	R (msec)	R	NoR (msec)	NoR (msec)
Males	69	58	59	109	96	101	82	50
Females	76	98	91	131	110	105	87	58

It can be observed that in both groups smallest standard deviations were obtained for the manual motor responses. Within the phonatory motor responses, the reaction times to auditory stimuli for males showed smaller variations than the motor responses to the somesthetic stimuli, while only small differences were shown for the female subjects. It was also observed that the females had less variability in reaction time scores to somesthetic stimuli than did the male subjects. The rank order of the relative difficulty of tasks by experimental conditions for each sex group based on the standard deviations is shown in Table 21.

Table 21

Rank order of intra-subject variability for each experimental condition by sex group, based on standard deviation. One (1) indicates smallest variability; NoR (no respirometer), R (respirometer used); M (males), F (females).

EXPERIMENTAL CONDITIONS		RESPONSES All Vocal & Manual (NoR & R)		Auditory Vocal (NoR)		All Vocal Aud. and Som. (NoR)	
		M	F	M	F	M	F
Modified	NoR	4	2	3	1	3	4
Valsalva	R	8	6	4	4		
Expiratory Air Flow	NoR	2	5	1	3	1	3
						2	2
Subject's Method	NoR	3	4	2	2		
Percentage of	75%	9	9				
Lung Volume R	50%	6	8				
	25%	7	7				
Intraoral Pressure	NoR	5	3			4	1
Manual	NoR	1	1				

Based on the results summarized in Table 22, the most homogeneous task for both sex groups was auditory-manual reaction time, while the auditory-vocal reaction times at 75% of lung volume were least homogeneous. Within the auditory-vocal reaction times some inter-sex assymetry becomes apparent showing less variation in male expiratory air flow condition, less female variation in modified valsalva but similar variation for both sex groups in subject's method condition. Generally, however, the somesthetic-vocal reaction times seem to have the least variance for the females, and most variance for the males.

Summary of Results

The following results were obtained: faster auditory-vocal reaction times were found for the abducted than adducted prephonatory vocal fold position for both sex groups, but only in females was this difference statistically significant. The male reaction times were faster than female reaction times for both prephonatory vocal fold positions; however, this difference was statistically significant only for the adducted vocal folds position.

The comparison of auditory-vocal and somesthetic-vocal reaction times in abducted prephonatory vocal fold positions showed no statistically significant difference for male and female sex groups. The somesthetic-vocal reaction times were found to be faster for males than females; however, this difference was not statistically significant.

The comparison of auditory-vocal reaction times in the adducted vocal fold position at 75, 50, and 25% of lung volumes showed that for either males or females alone, the linear trend was not found statistically significant, while the quadratic relation between reaction times and across lung volumes approached significance. When the data on lung volumes were pooled for both sex groups using a two-way analysis of variance, the main effect of lung volume was found to be statistically significant.

It was also found that although the overall linear trend was not statistically significant, the statistically significant effect of lung volume was attributed to a quadratic relationship between reaction time and lung volume with 50% of lung volume being the fastest.

The manual reaction times were found to be significantly faster within each sex group than vocal reaction times. When the fastest vocal responses pooled across all vocal experimental conditions were compared with manual responses, no statistically significant differences were obtained between these two motor systems. Also, there was no statistically significant inter-sex difference for the manual reaction times or for the fastest pooled vocal reaction times.

Longer reaction times for both sex groups were obtained for the vocal responses when the respirometer apparatus was used.

Highly significant inter-subject variability was found for all conditions for both sex groups, despite the fairly large variance among reaction time observations within subjects.

Individual subjects behaved fairly consistently across all experimental conditions. The manual condition was relatively easier for all subjects in both sex groups, while the vocal conditions varied in difficulties for subjects within and between sexes.

Lastly, for a total overview, all possible relationships between experimental conditions are summarized in Table 22.

TABLE 22

Summary of results between experimental conditions; F, statistically significant for females only; B, statistically significant between sex groups; A, statistically significant results of two-way analysis of variance (Sex X Experimental Condition).

	Subject's Method	Modified Valsalva	Expiratory Air Flow	Lung Volumes			Intraoral Air Pressure	Manual
				75%	50%	25%		
Subject's Method	NS^{B}	.01^{F}	NS	.005^{A}	.05^{A}	.010^{A}	NS	.001^{A}
Modified Valsalva		.05^{B}	.01^{F}	.05^{F}	NS^{A}	.10^{A}	NS	.001^{A}
Expiratory Air Flow			NS^{B}	.01^{A}	.01^{A}	.01^{A}	NS	.001^{A}
Lung Volume 75%				NS^{B}	.05^{A}	NS^{A}	.05	.001^{A}
50%					NS^{B}	NS^{A}	NS	.001^{A}
25%						NS^{B}	.05^{A}	.001^{A}
Intraoral Air Pressure							NS^{B}	.001^{A}
Manual								NS^{B}

CHAPTER V

DISCUSSION

This study investigated the temporal limitations of the phonatory system for initiation of phonation using simple reaction time methodology. The major thrust of this study was the description of the maximum speed with which voice could be initiated by normal, healthy adult females and males as a function of stimulus type, prephonatory vocal fold position and respiration.

Although the available literature provides some information about various temporal aspects of speech based on sensory-motor responses, only marginal research has been directed towards the description of temporal constraints on the sensory-motor interaction for the production of phonation, while the maximum speed of responses has been considered only sporadically. To evaluate the obtained data in the present study, the findings will be compared with other phonatory reaction time studies, with other speech system reaction time data, as well as with the relevant non-speech reaction time findings.

Phonatory Reaction Time Data, Comparison with Other Studies

The shortest voluntary reaction time for phonation initiation by a normal adult in the present study was 120 msec; however, the average minimal vocal reaction time data across subjects and conditions was 180 msec. This difference of about 60 msec demonstrates the principle of reaction time compressibility as proposed by Woodworth and Schlossberg (1954). Thus, the reaction time can be reduced to a certain minimum value representing the neuromechanical limits of the system involved.

When compared with other relevant studies, the present study showed that the 180 msec average fastest reaction time was faster than the 200 msec average reaction time for lip movement reported by Netsell and Daniel (1974), faster than the 194 msec average reaction time data for jaw movement reported by Birren and Botwinick (1955), faster than the mean value of 220 msec found for /a/ vowel repetition by Chistovich and Klaas (1962) and was also faster than the 337 msec mean reaction time data for monosyllabic word repetition reported by Brennan and Cullinan (1976). The present data were, however, well within the 30 to 300 msec phonatory reaction time data reported by Kaiser and Allard van der Wal (1959) and the 190-360 msec range of vocal reaction time latencies reported by Ladefoged (1960). The present study's mean reaction time findings were slightly slower than the 162 msec average muscle response time for voice termination or the average 140 msec muscle response time for pitch change reported by van den Berg (1962), as well as the 130 msec average tongue tip movement reaction time data reported by Siegenthaler and Hochberg (1965).

The rather small differences between the present study findings and the average reaction time data for lip movement (Netsell and Daniel, 1974) or jaw movement (Birren and Botwinick, 1955), and shortest reaction time for phonation initiation reported by Ladefoged (1960) can be explained by the differences in the complexity of tasks, the different pathways presumably involved, different sample size and experimental factors in the design such as stimulus characteristics and stimulus type.

The differences between the average tongue tip reaction time data for non-speech movement reported by Siegenthaler and Hochberg (1965) and the present phonatory reaction time data requiring more complex abductory-adductory movements coordinated with the respiratory behavior, may account for the moderate differences between latencies in the two studies.

The faster reaction times reported by van den Berg (1962) included only the neural transmission times from stimulus onset to onset of muscle activity, whereas the present study's data include both the neural time and the subsequent mechanical time, which accounts for the longer reaction times reported in the present study.

The wide discrepancy between the present data and the 30 msec minimal phonatory response reported by Kaiser and Allard van der Wal (1959) is difficult to explain. Their extremely fast reaction times are somewhat surprising since these values appear to cross the neuro-muscular temporal boundary, and are not even closely approached by any other reaction time study.

The differences in reaction times between the present study and similar measures reported by Chistovich and Klass (1960) and by Brennan and Cullinan (1976) can be explained on the basis of relative task complexity; that is, the present study utilized a simple phonatory response whereas the other two studies required a more sophisticated linguistic response (specific vowels or syllables).

The general overview of presently available speech reaction time data suggests a distribution of latencies on a continuum, with simple phonatory reaction times such as those generated in the present study at one extreme and linguistically more complex response tasks, such as vowel or syllable repetition, at the other extreme.

The present study's reaction time findings show that the fastest cortically monitored and executed phonatory event to a somesthetic or an auditory stimulus may be accomplished within 120 msec, with a more typical total neuro-mechanical time exceeding 180 msec. These temporal values are of some interest in light of speculations regarding monitoring and control of articulatory events in ongoing speech. These auditory or somesthetic neuro-mechanical stimulus-response latencies seem to be too lengthy to account for the cortically executed articulatory corrections of ongoing speech, and are thus supportive of those speech control models postulating extremely fast subcortical feedback pathways for articulatory adjustments (MacNeilage, 1970; and Ohala, 1970, 1976).

In summary, presently derived phonatory reaction time data suggest good agreement with the previously reported speech or phonatory reaction time data. It appears that as the linguistic form is superimposed on the basic driving physiological events, the reaction time becomes longer, and this elongation seems to pertain to the cortical stage of the total neuro-mechanical time. The present study, though designed to elicit the fastest, simplest vocal response, may not have obtained data representing the absolute physiologic thresholds attainable for the initiation of phonation.

Prephonatory Vocal Fold Position

In both sex groups faster auditory-vocal reaction times were obtained for abducted vocal fold conditions than for the adducted vocal fold position; however, this difference was statistically significant only in the female group. Further, the male reaction times were faster than female for all vocal fold conditions, although a significant difference was found only for the adducted vocal fold condition.

Straightforward explanations for the differences in auditory-vocal reaction times as a function of prephonatory vocal fold position are difficult. Some possible considerations may encompass evidence based on the myoelastic-aerodynamic theory of voice production (van den Berg, 1958) and on mechanics of vocal fold motion (van den Berg and Tan, 1959; Lieberman, 1968; Flanagan, 1972; Titze, 1973; and Baer, 1975).

In the modified valsalva condition, the vocal folds are fully adducted and a certain degree of subglottal air pressure is present in the trachea. To initiate phonation in this condition, the vocal folds must be blown apart, allowing transglottal air flow to take place with the resultant Bernoulli effect. In terms of Lieberman's vocal fold motion model (1968), the aerodynamic forces are opposed by the increasing tissue forces as the glottis is blown apart. In the expiratory air flow condition, there is a continuous air flow through the somewhat narrowed glottis for /s/ production.

Sawashima and Miyazaki (1974) have shown the glottis to narrow somewhat during expiration and to narrow further for voiceless consonant production. Thus, it can be presumed that subjects during the expiratory air flow condition were producing the pre-phonatory /s/ with vocal folds abducted, although positioned substantially more medially than when fully abducted such as during rapid inspiration. There may also be a temporal advantage for phonation initiation in the expiratory air flow condition because of the shorter adductory than abductory muscles contraction times (Martensson, 1968; Martensson and Skoglund, 1964). The faster phonatory reaction times in the abducted vocal fold condition may, therefore, result from the combined phenomena of differential muscle properties, established transglottal air flow and the relatively short distance the folds have to travel prior to their being activated by the Bernoulli effect.

Stimulus type

No significant differences in mean minimal total neuro-mechanical voluntary reaction times for phonation initiation were found using either an auditory or a somesthetic stimulus type. A somesthetic stimulus in the form of intraoral air pressure release has not been used previously by other investigators, which necessitates a comparison of the present study's findings with other types of somesthetic stimuli and other motor responses reported in the literature. The latency durations from the present study agree with the phonatory reaction times to auditory and tactile (electric shock) stimuli as reported by Kaiser and Allard van der Wal (1959) and to the speech-like data for the rapid tongue movement to auditory and tactile stimuli reported by Siegenthaler and Hochberg

(1965). Further, the results of the present study agree with the reaction time data for manual tasks using both auditory and tactile stimuli reported by Woodworth and Schlossberg (1954) and Elliot (1968), and also by Glickstein (1972), who found no statistically significant difference between the reaction times to auditory and somesthetic stimuli. When compared with other studies, the auditory-vocal and somesthetic-vocal reaction time data obtained in this study are approximately 40 msec longer than the average nonvocal reaction time data to auditory and tactile/cutaneous stimuli reported in the literature (Woodworth and Schlossberg, 1954; Elliot, 1968; Glickstein, 1972; and Siegenthalter and Hochberg, 1965).

When the individual minimal auditory-vocal and somesthetic-vocal reaction times are compared, however, there appears to be no difference between the study's vocal reaction times and published nonvocal reaction time data.

The compatibility of auditory-vocal and somesthetic-vocal reaction time proves to be an interesting finding in light of the theories postulating both auditory and somesthetic feedbacks utilization for control of speech production (Perkell, 1969; MacNeilage, 1970; Ohala, 1970; and Hardy, 1970). The present data seems to support the hypothesis that both types of feedback may be used since at least comparable temporal efficiency for the two systems has been shown.

Lung Volumes

It will be recalled that faster group reaction times were obtained for males and females without than with the respirometer apparatus. Clearly, the respirometric apparatus did influence somewhat the observations of the reaction times at the three controlled lung volumes. Moreover, it was observed that respirometric interaction was more prominent for female than male reaction times.

Auditory-vocal reaction times for adducted vocal fold position were fastest for both sex groups when phonation was initiated at 50% of lung volume, next fastest at 25% and slowest at 75%. Lack of similar investigations for vocal, speech or other sensory-motor responses precludes the possibility of comparing the results with previously published data.

Support for the findings of faster reaction times for phonation initiation at mid-lung volumes is the evidence that initiation of normal conversational speech occurs typically between the 60% and 40% of lung vital capacity (Hoshiko, 1965; Hixon, Goldman and Mead, 1973; and Bouhuys, 1974). Hixon (1973; 1976), Hixon, Goldman and Mead (1973), and Hixon, Mead and Goldman (1976) have shown that at about 50% of lung volume respiratory muscular pressure and relaxation pressures are equal. At lung volumes above the mid range, and certainly at 75% lung volume, the relaxation pressure is great and muscular checking action is also great in order to combat relaxation pressure to avoid rapid evacuation of gases from the lungs. At mid and at low lung volume ranges, the respiratory muscular effort and the relaxation pressure are both working in the expiratory direction. At extremely low volumes such as 25%, a greater effort in initiation of air flow must take place, and no complementary relaxation pressure is available to aid expiration. These data seem compatible with the present study's findings of the faster reaction times at 50% of lung volume, next fastest at 25% and slowest at 75%.

Vocal vs. Manual Reaction Times: A Comparison of Inter-Systems

For both sex groups and in all experimental conditions, significantly faster manual reaction times were obtained than the vocal reaction times; however, when the fastest vocal responses were pooled across all experimental conditions, no significant difference was found.

Since different sensory-motor responses have seldom been investigated within the same experimental population, only limtied comparions with previous work are possible. Birren and Botwinick (1955) showed no statistically significant differences in reaction times for hand, foot and jaw movement in the same experimental population.

Although a wide range for the digital reaction time latencies to auditory stimuli have been reported, a typical simple reaction time latency for the auditory-digital responses is about 140 msec (Woodworth and Schlossberg, 1954; Goldstone, 1968 and Elliot, 1968). The results of the present study agree with the majority of the literature.

The manual task can be considered to be a simple skilled movement, while phonation initiation may be thought to represent a more complex neuromuscular effort. In light of this assumption, the findings of this study become interesting. It may be hypothesized that as a relatively difficult and complex task, phonatory reaction times were significantly slower than the manual responses. When only absolute fastest responses were considered, no significant difference was found. In other words, it can be hypothesized that both vocal and manual systems are capable of responses within the same temporal conditions. In general, though, initiation of phonation requires more neurophysiological organization accounting for longer reaction times.

Inter-Sex Differences

In all experimental conditions, mean fastest female vocal reaction times were slightly slower than mean male vocal reaction times; however, these differences were statistically significant only in the adducted vocal fold condition. The individual fastest latencies were similar between the two sex groups, and virtually no difference in manual reaction times were obtained for the two populations. The somesthetic-vocal reaction times showed less variability for males than females.

Although comparable studies are not available, the general observation of this study, that the female vocal reaction times were slightly slower than the male reaction times, agrees with the data reported for other speech-type reaction times studies (Netsell and Daniel, 1974) as well as for non-speech reaction time responses (Bellis, 1933; Goldfarb, 1941; Woodworth and Schlossberg, 1954 and Simon, 1967). This temporal advantage for the male subjects has also been found for the rate of movement of various articulators in speech (Fairbanks and Spriestesbach, 1950); however, when previous studies tested for the significance of this difference, generally these inter-sex differences were not found to be statistically significant.

Some writers have attempted to explain the apparent inter-sex differences in various tasks. Sundberg (1974) found faster pitch changes for the females than males and postulated that physiological differences in the male-female phonatory system may be responsible for these differences as detailed in Chapter II. Although MacGlone and Kertesz (1973) found no sex differences for cerebral speech laterality, Harshman, Remington and Krashen (1976) did, and postulated that cortical differences between these two sex groups must be responsible. Maccoby and Jacklin (1974) reviewing contemporary literature on the psychology of sex differences, reported only sketchy differences in the sensory perception or the motor ability between sex groups from puberty to adulthood. They postulated that some of these "differences" may be accounted for by physiological factors such as hormones, but that psychological factors are probably most instrumental in accounting for these inter-sex differences.

It is difficult to explain the inter-sex asymmetry as well as the similarities obtained in this study. Significantly faster male reaction times for adducted vocal fold position and lack of the significant difference for the abducted position may be accounted for on the basis of 1) the anatomical differences in the laryngeal structures (Maue, 1970; Malinowski, 1968; Zemlin, 1968; Luchsinger and Arnold, 1968); 2) the hypothesis of Sundberg (1974) regarding differences within male and female phonatory apparatus; and 3) psychological factors (Maccoby and Jacklin, 1974). Apparent lack of difference in the manual reaction times may be substantiated by the observation of Maccoby and Jacklin (1974) concerning relatively faster digital female dexterity, while manual dexterity may be faster in males. Furthermore, judging from the individual male and female vocal and manual latencies, it becomes apparent that both sex groups are capable of similar response times.

In conclusion, although some difference in the mean reaction times between the two sex groups was shown, individuals from both sexes can respond with similar speed. Although these mean differences may be due to biological factors, the psychological factors may be most instrumental in accounting for the inter-sex asymmetries.

Summary and Conclusions

Simple reaction time methodology was used to investigate response latencies for voluntary initiation of phonation in a randomly selected normal adult population comprising 15 males (mean age 29 years) and 15 females (mean age 23 years). The major focus was the description of the maximum speed with which neurologically normal adults initiate voice. Specifically, vocal initiation was studied as a function of 1) stimulus type: auditory (1 KHz 75 dB SPL tone) and a somesthetic stimulus (a drop in intraoral air pressure from 6 cm H_2O to atmosphere), 2) extremes in prephonatory vocal fold position (abducted and adducted) and 3) lung volume (75%, 50% and 25%). Nonvocal auditory-motor (finger lift) reaction time data were also obtained from these same subjects in an attempt to describe and assess the uniqueness of the phonatory system. The subjects were pretrained and prewarned in all experimental conditions and responded as quickly as possible following computer controlled stimulus onset.

This investigation was limited by at least the following factors: 1) the methodology inherent to the reaction time experimentation, allowing limited control of certain parameters, which may potentially bias the results, 2) the makeup of the experimental population and the sample size -- a different random population and a different sample size may give alternative results, and 3) the treatment of the data -- focused as it was on the minimal voluntary reaction times.

Despite these limitations, the following conclusions appear to be warranted. The fastest voluntary reaction time latencies for phonation initiation by neurologically normal adults was 120 msec; however, the average fastest responses across subjects was 180 msec. Faster auditory-vocal reaction times were obtained when phonation was initiated from abducted rather than fully adducted vocal folds position. The phonatory reaction times to auditory stimuli are slightly but not significantly faster than to somesthetic stimuli. Faster vocal reaction times were obtained when phonation was initated at mid lung volumes than at the low or high extremes of lung volumes. Somewhat faster, but not significantly different, vocal reaction times are found for males than females. On the average, vocal reaction times are slower than the manual reaction times; however, the fastest vocal reaction times may approach the manual reaction time latencies.

Implications for Further Research

A review of the speech and speech-related reaction time studies suggests a variety of studies of sensory-motor interactions within the human communicative system using simple or choice reaction time methodology. These psychophysiological methods may also be useful in studying both normal and pathological populations.

At least four valuable research areas become immediately obvious following this study: 1) phonatory reaction time as a function of age, including preadolescent and using both adolescent and geriatric groups as subjects, 2) phonatory reaction times as a function of stimulus intensity of the somesthetic stimulus and matched for perceived equal intensity with the auditory stimulus, 3) reaction times to both auditory and tactile stimuli for other structures within the speech system, and 4) reaction times as a function of increasing linguistic difficulty.

Another valuable research area may include studies of phonation using simple and choice reaction times in trained and untrained populations, i.e. singer vs. non-singer, since there is substantial evidence that the vocal physiology of trained singers differs greatly from untrained individuals, and great variability in simple and choice reaction time is found as a function of training and practice.

An additional research area would include systematic observations of the component of reaction times such as the mechanical, neural and cortical times. As technology becomes available, studies using simultaneous electromyography, electroencephalography, aerodynamics and acoustics would contribute substantially to knowledge of sensory-motor interactions allowing certain direct observations about the various reaction time stages. These studies should include tasks other than phonatory reaction time and extend to observations of various neurophysiological events within the voice reaction time paradigm.

Finally, a fruitful area of investigation might include reaction time studies of pathological populations with neurophysiological involvements such as dysarthics and aphasics and various cranio-facial anomalies, as well as various voice and pulmonary pathologies.

APPENDIX A

Selected references for the section "Laryngeal Anatomy and Physiology"

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APPENDIX B

Medical Research Council Speech and Communication Unit

EDINBURGH HANDEDNESS INVENTORY

Surname ______________________ Given Names ______________________

Date of Birth _______________ Sex _________

Please indicate your preferences in the use of hands in the following activities by putting + in the appropriate column. Where the preference is so strong that you would never try to use the other hand unless absolutely forced to, put ++. If in any case you are really indifferent, put + in both columns.

Some of the activities require both hands. In these cases the part of the task, or object, for which hand preference is wanted is indicated in brackets.

Please try to answer all the questions, and only leave a blank if you have no experience at all of the object or task.

		LEFT	RIGHT
1	Writing		
2	Drawing		
3	Throwing		
4	Scissors		
5	Toothbrush		
6	Knife (without fork)		
7	Spoon		
8	Broom (upper hand)		
9	Striking Match (match)		
10	Opening box (lid)		
i	Which foot do you prefer to kick with?		
ii	Which eye do you use when using only one?		
L.Q.		DECILE	

APPENDIX C

UNIVERSITY OF CALIFORNIA, SAN FRANCISCO

Consent to Act as Research Subject

1. I hereby authorize K. Izdebski and/or any such assistants as may be selected by K. Izdebski to perform the following procedure for the experimental purposes:

   The placing of the earphones on my head, so that a 1000 Hz 75 dB SPL tone can be delivered to my right ear; the placing of a ground surface electrode on my forearm; the insertion of a catheter and a tube into my mouth, so that the pressures inside my mouth can be sampled. I also authorize the experimenter to perform a finger release task on me and I understand that during this time a small (6 volt) current will flow through my arm. I will also complete a handedness questionnaire, prior to the experimentation.

2. I understand that this procedure will take place at the Speech Research Laboratory at the VA Hospital in San Francisco, and that the procedures described in paragraph 1 are necessary for the recording of the experimental tasks. I understand that they will not result in any risk and/or discomfort, other than a possible momentary hyperventilation or emotional frustration, and that the questionnaire will not be released to the general public.

   As it was explained to me, this procedure has no direct benefits for me; however, I understand that the benefits of this procedure are as follows: Through direct sampling of the responses, the investigators are studying the mechanism of phonation. Specifically, this research project is designed to examine how fast phonation can be initiated by adult humans, and how the speed with which voice can be produced compares to the speed of responses of the other sensory-motor systems of the human body.

3. This information was explained to me by ____________________________. I understand that he/she will answer any questions I may have concerning this investigation or the procedures at any time. I may reach him/her at _________________________. I understand that my participation in any study is entirely voluntary and that I may decline to enter this study or may withdraw from it at any time without jeopardy to my future treatment. I understand that the investigator may drop me from the study as long as it is not detrimental to me. The payment to me, for participation in this investigation, will be $20.00 including training.

Subject ______________________________

Date _________________________________

APPENDIX D

Description of Events During The Experimental Session

Upon arrival at the Speech Research Laboratory, the subjects were reacquainted with the purpose of the experiment and were given the consent form to read and to sign, after which the experimental session began. Initially, subjects underwent a static vital capacity test. Next, the auditory-vocal reaction time tasks were explained and pretraining was given for each particular experimental condition prior to the actual data acquisition. The subjects were seated and an earphone was placed on the right ear while a laryngeal contact microphone was held in place by the experimenter. Subjects held the ready subject warning signal button in the left hand and by depressing it they activated a computer-controlled randomization and signal delivery sequence. A task was considered completed when at least twelve successful auditory-vocal responses were acquired. Next, a new auditory-vocal condition was explained and pretrained, after which data recording began. When all auditory-vocal conditions were completed, the laryngeal microphone was removed and the auditory-manual test was explained, pretrained and finally recorded. During this procedure subjects remained seated in the chair and a small adjustable table was positioned in front of them. The touchplate connected to a battery was placed on this table. The subjects rested their right arm on the table top with the index finger pronated and extended so that it could reach the metal touchplate. The other lead from the battery was grounded via a surface EEG type electrode to the subject's left arm. In this way the battery, the touchplate and the subject created an electrical circuit, which was interrupted as soon as the subject's finger was lifted. As in the case of the auditory-vocal responses, the auditory stimulus delivery was through the subject's activation of the computer program. Upon completion of the manual tasks, the somesthetic-vocal task began. Again, the subjects were pretrained prior to the experimental data recording. The entire procedure ended after the desired number of correct responses was recorded.

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