VOICE ONSET TIME CHARACTERISTICS OF SELECTED PHONEMES IN YOUNG AND OLD MALE SPEAKERS

THESIS

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The purpose of the investigation was to compare mean voice onset time in young and old male subjects, as well as to examine variability of VOT productions with age for prevocalic bilabial, alveolar, and velar voiced and voiceless stop consonants. Forty-five Caucasion males were divided equally into three age groups. Ten tokens of six stimulus words were recorded and wide band spectrograms were made. Results of an analysis of variance revealed no significant differences in VOT with age when averages of the phonemes were used for analysis; however, a significant interaction between age and voiced phonemes was found when individual trials of phoneme productions were used for analysis.

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CHAPTER I

INTRODUCTION

The increasing percentage of older individuals in the world population is stimulating greater interest in the effects of the normal aging process. Recent investigation have shown a number of normal and abnormal changes in the anatomy and physiology of aged individuals. An important consequence of these age-related changes is the loss of mobility and a general biomechanical inefficiency of the phonatory, respiratory, and supralaryngeal structures. Poor coordination among the various elements of the vocal tract will result in perceivable voice changes. These changes may explain why and how listeners differentiate between young and old voices (4) and make accurate predictions of a speaker's chronological age (5; 6). The ability of a listener to perceive age differences in the voice suggests the phonatory process undergoes identifiable and predictable age-related changes.

Investigators have already examined several acoustic and perceptual aspects of speech which are affected by age-related changes. These areas include pitch, intensity, quality and selected measurements of rate and duration. With respect to measurements of rate and duration, investigators have examined age-related changes in rate of speech, maximum vowel duration, pause time, and voice onset time. Voice onset time is defined as the time interval between the release of articulatory constriction and the beginning of quasi-periodic vocal fold vibration (1). It has been described as the most significant acoustic cue for the perception of voicing in prevocalic stop consonants (2).

Investigators have reported that perception and production of voice onset time changes as a function of age in children (8; 9). Little information, however, is available concerning voice onset time changes in the geriatric population. Neiman, Klich, and Shuey (3) reported no significant differences in voice onset time between young and older women. Similarly, Sweeting and Baken (7) reported that mean voice onset time for bilabial stops /p/ and /b/ produced by males and females did not increase as a function of age, although older subjects' productions were characterized by significantly greater variability about the mean. However, no information is available concerning changes in voice onset time variability with age for alveolar and velar stop consonants in males. Therefore, this investigation will examine changes in mean voice onset time and voice onset time variability associated with age in male subjects.

The present investigation will describe age-related changes in the structures which control speech production and review current literature regarding acoustic and perceptual changes in the speech of aged individuals.

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CHAPTER II

REVIEW OF THE LITERATURE

This chapter will review current literature regarding physiological changes associated with the aging process and their effect on speech production, with emphasis on voice onset time. Specific investigations exploring the relationship between voice onset time and age will be discussed in depth.

Physiological Changes Associated With the Aging Process

Central Nervous System

The aging brain undergoes a loss in weight (21) as well as a decrease in volume (20). An examination of the surface structure reveals a widening and deepening of the sulci and a decrease of the mass and width of the gyri. (2, 6). The most widely reported microscopic change of the aging brain is the loss of neurons (11; 16). Other microscopic changes include an increase in lipofuscin pigmentation (48), accumulation of senile plaques (70), and the occurrence of neurofibrilary tangles (17; 71). A decrease in the electrical activity of the brain, primarily in the alpha rhythm, which is a measurement of electrical activity during the non-alert, awake state, has been reported (51; 55). Surwillo (68;68) postulated that the alpha rhythm served as a gating mechanism which controls how information is analyzed in the central nervous system. Callaway (14) stated that the alpha rhythm pattern has been reported to influence the development of accurate spatial-temporal patterns of the speech signal (22).

Muscular and Neuromuscular Changes

A reduction in muscular strength, endurance, and agility as well as a decrease in the number of muscle fibers is a common manifestation of the aging process (5; 59). A decline in motor function associated with the aging process may also result from a reduction in the number of functioning motor units because of denervation (13; 29). The effects of such changes on function of elderly persons is usually measured through the reaction times of aged individuals. Reaction time values involve measurements of the time required by an individual to respond to a stimulus. An increase in reaction time with age has been reported by Brindley and Botwinick (10), and Botwinick (8). Weiss (72) and Botwinick and Thompson (9) reported that greater change exists in the amount of time between the presentation of the stimulus and the initiation of the motor response as compared to the length of the actual motor response. According to these investigators, the change in reaction time associated with the aging process is the result of the slower stimulus perception or processing rather than a decrease in the actual motor speed. Woodruff (73) reported a correlation between the EEG alpha rhythm and reaction time, although Brody (12) found no such correlation in two experimental designs.

Researchers of the central nervous system have presented evidence of a general reduction in speed of neural functions as a result of the aging process (9; 67). The EEG alpha rhythm which was reported to influence the development of accurate spatial-temporal patterns of the speech signal (22) has also been reported to slow with age (51; 55). In addition to slowing of neural functions, a decrease in muscular strength, endurance, and agility due to a decrease in the number of muscle fibers is a common manifestation of the aging process (5; 59). This manifestation is particularly evident with the structures involved with speech and language.

Respiratory Changes

The major functional change in the respiratory system associated with the aging process has been described as a decrease in the elasticity or recoil property of the lungs (4; 47). This change leads to an increase in the residual volume (the amount of air remaining in the lungs following exhalation) and results in a reduction in the vital capacity of the lungs (47). Such a decrease in vital capacity reduces the amount of air available for speech production (37).

Layrngeal Changes

Laryngeal musculature changes associated with the aging process include atrophy and degeneration of the intrinsic muscles (3) as well as the vocal fold musculature (33). Ossification and calcification, which occurs in aged larynges as a result of bone and calcium formation respectively (15), decreases the ability of extrinsic muscles to adjust the laryngeal cartilages (75; 27). In addition, stiffening of the joints of the laryngeal cartilage resulting from decreased elasticity of ligaments has also been observed in aging larynges, and may also decrease the mobility of the larynx (46).

Pharyngeal Changes

Atrophy and weakening of pharyngeal muscles occurs with increased age (38). This results in higher levels of nasalance (the acoustic measurement of the perceptual phenomenon of nasality) reported in the speech of subjects fifty years of age and older (36).

Oral Changes

Changes in the tongue, teeth, tempromandibular joint, oral muscles and oral mucosa associated with the aging process may result in slower movement of the articulators and, as such, alter coarticulation and prosody of speech. Evidence for this is presented in reports of slower diadokokinetic rates (the speed of rapid, alternating movements, usually measured by syllable repetition) in aging persons

(57). A possible influencing factor is the drying and other associated changes in the oral mucosa which may in turn affect movement of the tongue and articulation (37). Based on their cinefluoroscopic studies of the upper digestive tract, Kahan (37) stated that different neuromuscular mechanisms may be responsible for movements of the tongue during speech production and swallowing, and that those responsible for speech production may be more susceptible to age-related changes than those controlling swallowing or mastication.

In summary, structural changes in the speaking mechanism associated with the aging process include atrophy and degeneration of laryngeal and vocal fold musculature (3; 33), and ossification and calcification of the laryngeal cartilage (46). These physiological changes affect the ability of the larynx to make the fine adjustments necessary for speech production, as well as to coordinate the interaction between the respiratory, laryngeal, and supralaryngeal systems. Moreover, these changes in physiological ability explain the basis for speech changes associated with the aging process.

Speech Changes Associated With the Aging Process

Evidence of the ability of listeners to identify age from voices has been presented by researchers (36; 57; 62). Shipp and Hollien (62) reported a strong positive correlation ($r = .88$; $p < .05$) between estimates of chronological age by listeners and actual chronological age of the speaker. Such identifiable characteristics in the speech of older persons has led to the use of terms such as aged voice, old voice, senile voice, and senescent voice when describing the speech of aged individuals (50). Several acoustic parameters have been examined by investigators in an attempt to identify and explain vocal behaviors characteristic of the senescent voice.

Pitch

One of the characteristics associated with the male senescent voice has been described as a rise in pitch during both impromtu speech and oral reading (52). Mysak and Hanley (52) examined both pitch changes in three age groups of male subjects. They reported an average habitual speaking pitch, or mean fundamental frequency, during oral reading of 110.3 Hz. for subjects 30 to 62 years of age, 124.9 Hz. for subjects 65 to 79 years of age, and 142.6 Hz. for subjects age 80 to 92. A similar rise in fundamental frequency measurements occurred during impromptu speech. Based on comparisons of fundamental frequency measurements reported by other investigators of male subjects from infancy to adulthood (19; 24; 31), the authors concluded that there is an apparent progressive lowering of fundamental frequency from infancy to middle age, followed by a progressive rise during the sixth, seventh, and eighth decades of life.

Hollien and Shipp's (32) study of 174 males age 20 to 79 years concurred with the results of Mysak and Hanley (52) concerning the rise in fundamental frequency during middle age.

Mysak and Hanley (52, pg. 309) also examined "pitch sigma," a measure of pitch variability or flexibility determined by standard deviation of the distribution of an individual's vocal frequencies. The investigators reported an increase in the standard deviation of the distribution of vocal frequencies in the older males, thereby indicating that pitch becomes more varied as age increases. The greatest flexibility was reported for the 80 year-old and older group, who also had the highest medial fundamental frequency, suggesting a possible relationship between pitch level and pitch variability (52).

Maximum pitch range was examined by Ptacek, Sander, Maloney, and Jackson (58). The authors employed a group of young adults (under 40 years of age) and a geriatric group (over 65 years of age). Both males and females were tested. Pitch ranges were determined by obtaining the lowest and highest pitches the speakers were able to phonate. The results indicated a statistically significant reduction in the total pitch range of the male ($t = 5.11$, $p < .01$) and female ($t = 4.77$, $p < .01$) geriatric subjects when compared to that of young subjects.

Intensity

Another acoustic feature of the aging male voice is an increase in intensity during oral reading and impromptu speech for subjects 70 years and older (60). Although speaking intensity reportedly increases with age, older subjects (over age 65) experience a decrease in the maximum vocal intensity they are able to phonate (58). The authors reported a statistically significant difference ($t = 3.60$, $p < .01$) between the maximum vocal intensity of young (under age 40) and old (over age 65) male subjects when phonating /a/ without regard to pitch. Furthermore, they also reported a decrease in vital capacity and maximum vowel duration measurements of the older subjects, suggesting an overall decrease in proficiency of tasks associated with respiratory functioning which may in turn affect maximum intensity capabilities in older subjects.

Quality

Although limited acoustic information is available on quality changes of the voice associated with the aging process, Hutchinson, Robinson, Nerbonne (35) reported higher nasalance values in older subjects. Nasalance was defined by Fletcher (28) as the percentage of nasal acoustic energy compared to the sum of nasal and oral acoustic energy, and according to Fletcher (28, pg. 104-105), " ... corresponds rather closely with those vocal resonance characteristics identified as 'nasality' by a human listener." This increase in nasalance with age was reportedly greater in females than in males (35).

Rate and Duration

Acoustic measurements involving aspects of rate and durational changes associated with age include measurements of rate of speech (employing measurements of words per minute and words per minute per sentence), maximum vowel duration, duration of pause time (employing a phonation per time ratio), and voice onset time. Measurements of rate of speech in aged subjects have been obtained during both oral reading and impromptu speech. Mysak (53) investigated the relationship between pause time and age in a study which employed data obtained in an earlier investigation (52) using subjects between the ages of 30 and 79 years. A phonation/time ratio was calculated for each subject during oral reading of the first paragraph of the "Rainbow Passage" (26) and during an impromptu speech of approximately thirty seconds. The results showed a progressive reduction in magnitude of the phonation/time ratio with increased age, indicating a non-significant, increased amount of pause time occurring in the speech of aged talkers. The mean ratios range from .56 in the youngest group (age 30 to 62 years) to .48 in the oldest group (age 80 to 92 years). The ratios of all subjects were smaller than those reported for college males in previous studies (31; 65).

Mysak and Hanley (52) also measured rate of speech by calculating words spoken per minute by the subjects during oral reading and impromptu speech. They reported a progressive decline in rate of oral reading from 172.2 words per minute for subjects 30 to 62 years of age to 123.8 words per minute for subjects 80 to 92 years of age. No such progressive decline in rate with age was reported during impromptu speech, causing the authors to speculate that the decline in rate during the oral reading task may have been due to reading and attention problems developed during advanced age.

Ryan and Burk (60) also examined changes in rate associated with age by employing measurements of both words per minute and words per minute per sentence. Subjects who ranged in age from 40 to 80 years were divided into four decade age groups, and were asked to read the first paragraph of Fairbanks' (26) "Rainbow Passage," and to give an impromptu speech of approximately 30 seconds on the topic of his choice. Rate measurements were calculated during both tasks. Mean oral reading rates of words per minutes and words per minute per sentence ranged from 182.4 to 222.3 words during the fifth decade and from 162.1 to 191.5 words during the eighth decade. Standard deviations reported for all age groups were large, indicating large variability among speakers within each age decade group. Despite large standard deviations, mean oral reading rates were significantly ($f = 3.70$, $p < .05$) greater than mean impromptu speech rates in all experimental age groups. Furthermore, both words per minute and words per minute per sentence measurements showed a progressive decline with age during both oral reading and impromptu speech, although the decline was not statistically significant for impromptu speech. Ryan and Burk (60) reported that when inter-sentence pause time was eliminated, rate of both oral reading and impromptu speaking still revealed a decrease as a function of age. Ryan and Burk (60) concluded that characteristics other than length of pause time affected the rate of oral reading for speakers, and postulated that changes associated with aging occur in the articulatory musculature as a result of increased effort to maintain an adequate level of oral sensory feedback.

In summary, available evidence suggests that listeners are able to identify the speakers' age from listening to samples of their speech (57; 62). The reported perceptual changes in the voice of aged male subjects includes a rise in pitch (61), a decrease in intensity (57), a tense vocal quality with air loss and tremor, and slow, imprecise articulation (61).

The changes cited in the preceding studies give evidence for age-related acoustic events in the human voice. One potential research area for the further discovery of such cues involves selected temporal measurements of rhythm such as voice onset time (VOT).

Voice Onset Time Measures Associated With the Aging Process

Definition and Significance of VOT

Voice onset time (VOT) is defined as the time interval between the release of articulatory constriction and the beginning of quasiperiodic vocal fold vibration (52). This relative timing of stop release and onset of voicing has been described as the most important cue for distinguishing between prevocalic voiced and voiceless sounds (45). Therefore, VOT is a perceptually important contrast in timing between the opening of the articulatory occlusion and the start of voicing (7). In English, VOT distinguishes between the perception of homorganic bilabials /b/ and /p/, alveolars /d/ and /t/, and velars /g/ and /k/. Collectively these phonemes are referred to as stops (7). A negative VOT, often referred to as a voicing lead, means that the voicing begins before the burst or release of articulatory constriction, whereas a positive VOT value, referred to as a voicing lag, means that the voicing begins after the release of the articulatory constriction (42).

In English, an interval of less than twenty milliseconds between the burst release of the articulatory constriction and the onset of voicing is perceived by listeners as a voiced stop, whereas an interval of more than twenty milliseconds is perceived as a voiceless stop (42). The perception of voicing may also be affected by the place of articulation of the stop. Specifically, English speakers perceive a stop as voiceless if the interval is over 23 milliseconds for bilabials, 37 milliseconds for alveolars, and 42 milliseconds for velars (44). Therefore, the further back the articulatory constriction occurs in the oral cavaty, the longer the VOT needed for the perception of a voiceless stop. Although these are exact values given, the ability of listeners to distinguish between voiced and voiceless cognates falls within a narrow boundary or zone. Zlatin (76) demonstrated this for the cognates /p/ and /b/. VOT may also vary depending on the surrounding vowels. Klatt (39) reported that VOT may be longer in the context of high vowels. He further hypothesized that this was due to mechanical changes in the larynx resulting from production of the high vowels /i/ and /u/ which delay the onset of voicing.

Although Lisker and Abramson (45, pg. 770) stated that "voice onset time is the single most effective measure whereby homorganic stop categories in languages generally may be distinguished physically and perceptually," other acoustic cues may also be important for the perception of the voice - voiceless distinction in stop consonants. These may include format transitions to and from adjacent vowels (63), the burst of stop release force (43; 63), aspiration (43), and fundamental frequency, duration and intensity of adjoining vowels (40; 56; 63). Even if the aforementioned acoustic measures may be less important than the VOT value for the perception of voiced and voiceless stop consonants, the voiced - voiceless distinction, depending on the language and speech context, may be dependent on a number of these attributes in addition to VOT (64).

Additional Acoustic Cues for the Perception of Stop Consonants

Halle, Huges, and Randley (30) reported correlations between place of articulation of the stop consonants and second format transitions of adjacent vowels. Massaro and Oden (49) reported that the voiced - voiceless distinction between stop consonants was dependent on voice onset time values as well as second and third format transitions. Slis and Cohen (74) reported that initial format transitions are more important for the voice - voiceless distinction than are final ones. Therefore, format transition patterns of adjacent vowels may also provide important perceptual information for place of articulation and voicing of the stop consonants.

In addition, voiced and voiceless consonants have an acoustic impulse or burst at the moment of release of the closure that may also serve as an important acoustic cue. Based on their study of the perception of the synthesized words "rapid" and "rabid," Liberman (41) demonstrated that longer burst intervals were associated with voiceless stop judgements whereas shorter intervals were associated with voice judgements. Slis and Cohen (64) reported similar results for noise burst durations of Dutch plosives. Slis and Cohen (64) also reported that the amplitude of noise bursts of voiceless Dutch plosives were 50% greater than the voiced cognate. The authors reported the same pattern for perception of voiceless - voiced plosives in that higher noise intensity led to voiceless plosive identifications. The concentration of energy of the burst may be an indicator of place of articulation of the stop consonants. Halle et. al. (30) reported concentration of energy during bursts between 500 and 1500 Hz. for bilabial stops /p/ and /b/, above 4000 Hz. for alveolar stops /t/ and /d/, and between 1500 and 4000 Hz. for velar stops /k/ and /g/. Liberman (41) reported similar findings regarding burst cues for perception of place of articulation.

Lisker and Abramson, (43) stated that differences in aspiration, the audible explosions of the stop and interlude of noise associated with the voiceless stops /p/, /t/, and /k/ in initial and medial positions may act independently or with differences in voicing to separate the voiced and voiceless stop consonants. In English stops, aspiration and voicing do not occur simultaneously. Voicing is prominent only when aspiration is minimal, and aspiration is prominent only when voicing is minimal (43). Therefore, aspiration may be regarded as the automatic result of a large delay in voicing (43).

The fundamental frequency, duration and intensity of vowels adjacent to stop consonants may be different for voiced and voiceless stops. Vowels preceding voiced consonants have been found to be longer than those preceding voiceless ones (34; 56). With regard to fundamental frequency of vowels following voiced and voiceless stop consonants, a difference in the control of the fundamental frequency was noted (64). The fundamental frequency of vowels following voiceless consonants was found to decrease gradually, whereas vowels following voiced stops were found to have an initial increase in fundamental frequency followed by a gradual decrease (64). A higher intensity in vowels adjoining voiced stops than in vowels adjoining voiceless stops was reported by Lehiste and Peterson (40). Similarly, Fairbanks (26) reported a higher intensity for vowels embedded in voiced contexts as compared to those embedded in voiceless contexts.

Perception of VOT as related to Linguistic Experience

Based on cross - language studies of VOT, Yeni-Komshian, Preston, and Benson (74) and Abramson and Lisker (1) reported that perception of VOT values is dependent on the phonemic system of the listener. Strange and Jenkins (66) reported that Spanish, French, and Thai speakers use different voice onset time criteria for determining voicing contrasts than do English speakers.

Evidence that perception of VOT is dependent on the linguistic system of the listener prompted investigators to examine the relationship between perception of VOT and the development of speech and language. Eimas, Siqueland, Jusczyk and Vigorito (23) concluded that infants as young as one month of age reacted to changes in VOT which signaled a change in voicing. While monitoring the sucking response of infants of varying ages, the authors presented a /ba/-like stimulus with a +20 VOT value, then rapidly presented a /pa/-like stimulus with a +40 VOT value. The infants' rate of sucking increased indicating that they had perceived a change in the stimulus sound. When pairs of stimuli were presented which did not cross the phonetically significant VOT boundary, such as +40 and +60 (both perceived as /pa/), no change in the sucking response of the infants was observed. The authors concluded that infants as young as one month of age perceive acoustic stimuli changes in VOT with the same general criterion as adults do.

Zlatin and Koenigsnecht (77) investigated the perceptual development of the voicing contrast in two-year-old, and six-year-old children and adults. The subjects were required to identify synthesized, meaningful, monosyllabic speech stimuli with labial, alveolar, and velar voiced and voiceless stop consonants ranging in VOT from -150 to +150 milliseconds. The authors reported significant age-dependent differences in perception of the voicing contrast. Based on these findings, the authors stated that the magnitude of VOT differences required for distinguishing between prevocalic stop cognates decreases as a function of age of the listener.

Employing the same subjects as those of the previous study, Zlatin and Koenigsknecht (78) used the acoustic cue of VOT to examine the productive development of the voicing contrast in two-year-old, and six-year-old children and adults. Productions of bilabial, alveolar, and velar voiced and voiceless stop cognates were obtained for each subject. The VOT were measured, and the individual production distributions of bilabial, alveolar, and velar stops were plotted for each subject. Mean VOT was then calculated for each distribution. Means and standard deviations were also calculated for each age group. Results indicated that although mean VOT differed significantly as a function of age ($f = 3.81$; $p < .05$), the VOT characteristics within age groups was relatively stable.

VOT Changes Associated with the Aging Process

Limited information is available with regard to VOT changes associated with the aging process. Neiman, Klich, and Shuey (54) examined VOT changes with age for voiced and voiceless bilabial and velar stops in the context of high and low vowels. The authors collected VOT values for twenty women between the ages of twenty and thirty years and ten women between the ages of seventy and eighty years. Subjects were required to produce three trials each of the stimulus words "pop, Bob, cot, got, peep, keep, and geese" embedded in the carrier phrase "Say _______ again". Spectrograms were made of the recorded productions, and VOT was measured from the point of release of constriction to the point of the first vertical voicing striation for the vowel.

Analysis of the data revealed no statistical difference between overall mean VOT associated with voiced and voiceless consonants for the young and old women. Mean voice onset times for the older women were 47.5 milliseconds, whereas mean voice onset times for the younger women were 50.4 milliseconds. The only significant differences between the young and old subjects' productions was in the three-way interaction involving place of consonant production, vowel context, and subject age. Mean VOT for velars was found to be significantly ($f = 397.62$; $df = 1.18$; $p < .05$) longer than mean VOT for bilabials in both young and old subject groups. Although vowel context was not significant, vowel context did interact significantly with consonant production ($f = 4.22$; $df = 1.18$; $p < .05$), in that mean VOT for bilabials with /a/ was significantly longer than for bilabials with /i/. The significant three-way interaction ($f = 5.49$; df 1.18; $p < .05$) among age, place and vowel context revealed significant differences between younger and older women in both vowel contexts for bilabials and in the /i/ context for velars. The mean difference between vowel contexts was not found to be significant with either velars or bilabials in the older group and only with bilabials in the younger group. In the younger group only, the mean VOT for velars in the /i/

context was significantly longer than for velars in the /a/ context.

Based on these results, the authors concluded that mean VOT did not change as a function of age, and that differentiations between bilabial and velar stops on the basis of VOT are the same for young and older women. The authors further stated that the non-significant effect of vowel context on VOT for the aged subjects found in the present investigation is a result of pharyngeal changes such as those reported by Kiuchi et. al, (38) which affect articulatory interactions among the tongue, pharyngeal, and laryngeal structures. Also, the finding that VOT for voiceless stops was significantly longer with /a/, but the voiced stops had a longer VOT with /i/ was interpreted by the authors as evidence that vowel context influences VOT in an inconsistent manner.

Based on reports of reduced speech associated with the aging process on several types of tasks, Sweeting and Baken (69) hypothesized that older subjects would differ significantly from young subjects with respect to measurements of both VOT and vowel duration. Employing three age groups of ten subjects each, the investigator measured VOT and vowel duration using spectrographic analysis. Group 1, which served as the control group, consisted of male and female subjects between the age of 25 to 39 years. Group 2 was composed of male and female subjects age 65 to 74, and Group 3 included male and female subjects over age 75. All subjects were free of any current or previous hearing, cardiovascular, respiratory, neurological, or laryngeal disorders. Subjects were asked to record phrases which included the words "beat, Pete, and bead" in the carrier phrase "It's a ________". These stimuli were chosen for vowel duration measurement purposes. Each phrase was written one time on thirty separate index cards, resulting in a total of 90 cards. The cards were then randomized for each subject to read. Twenty-five of thirty spectrograms made were measured using criterion suggested by Lisker and Abramson (43) for VOT and by Peterson and Lehiste (56) for vowel duration.

Spectrograms of utterances produced by the older talkers were noticeably different from those produced by their younger counterparts. The characteristic spectrographic components produced by older speakers included the following: poorly defined release and closure of plosives, the presence of noise throughout the vocalic portion of the spectrum, "slow rise and decay time for glottal pulsing" (69, pg. 69), pitch pertruberations, intermittent devoicing, and shifting format patterns. The results of the analysis showed that mean VOT did not increase significantly with age although variation about the mean was significantly greater with increased age for measurements of both /b/ and /p/. The mean VOT for /b/ was reported as 12.90 milliseconds, 14.50 milliseconds, and 14.48 milliseconds for Groups 1, 2, and 3 respectively (males and females combined). Mean VOT for /p/ was reported to be 78.6 milliseconds, 80.7 milliseconds and 71.5 milliseconds for groups 1, 2, and 3 respectively. The standard deviations for productions of /p/ were also noted to increase with age. In addition, the separation between /b/ and /p/ with regard to format boundaries on the voiced - voiceless continum decreased significantly with age. The upper boundary of /b/ was found to increase slowly and the lower boundary of /p/ decreased sharply resulting in a 23.11 millisecond reduction in the mean separation between the cognates for the older subject group. This was due primarily to a reduction in the mean VOT for /p/. The author stated that "This pattern combined with increased variability about the mean resulted in a situation where older speakers increasingly produce tokens of a word that fall within the zone of perceptual overlap for distinguishing voiced from voiceless cognates" (69, pg. 70). Figure 1, reprinted from Sweeting and Baken (69), illustrates this pattern. Sweeting and Baken (69) stated that the reduced precision in achieving temporal targets found in the older speakers may lead to the perception of imprecise articulation in older individuals as reported by Ryan and Burk (61).

Further analysis of productions of /b/ and /p/ for each group resulted in frequency distributions between the phonemes which were very different. The frequency distributions of /b/ were distributed normally with strong

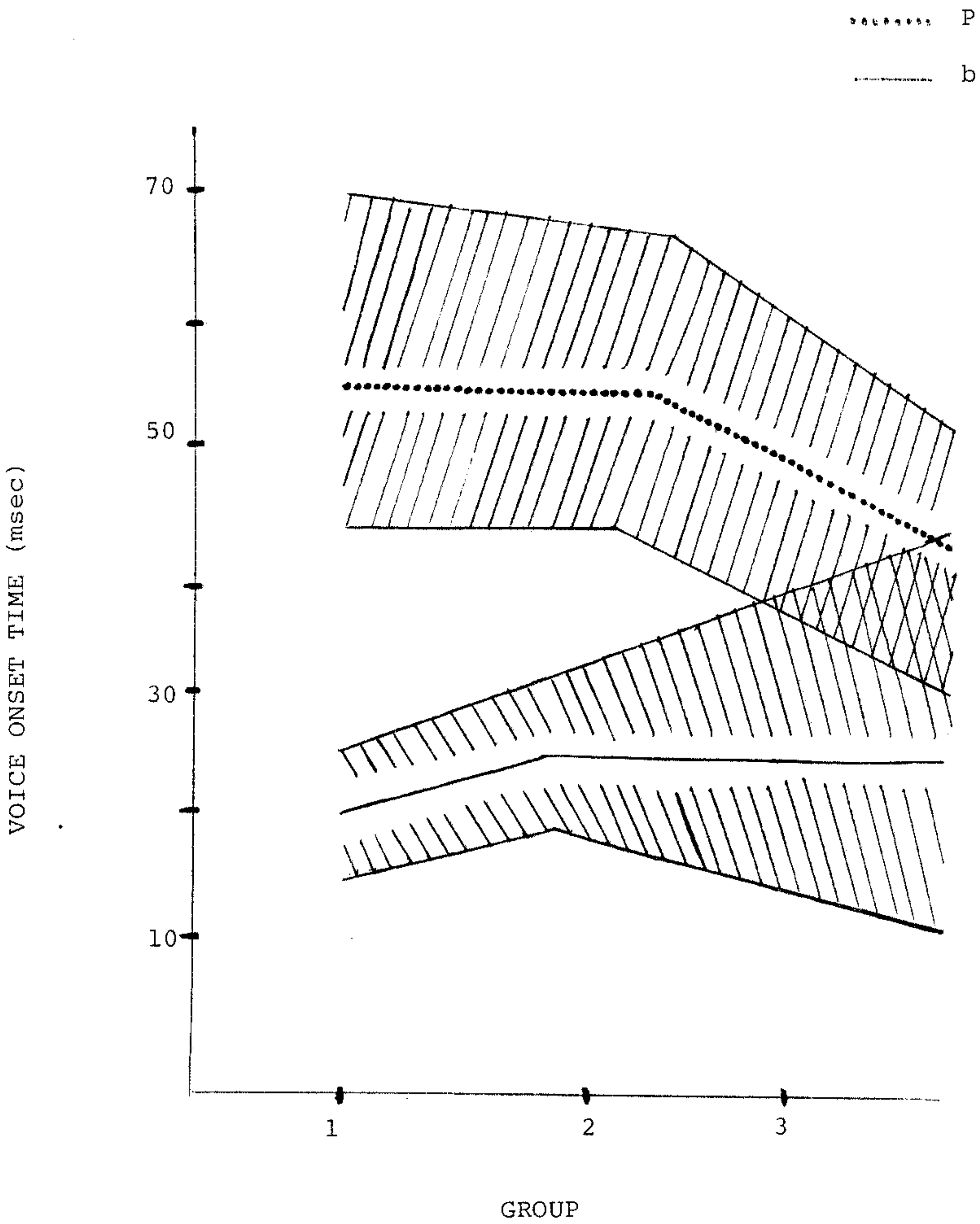

Figure 1. Illustration of Sweeting's finding of the decreased separation between /p/ and /b/ with regard to format boundaries on the voiced-voiceless continum. The drawing represents the average maximum VOT for /b/ and the minimum VOT for /p/ for the three age groups. The distance between the means is the average minimum separation of the cognate phones. Shaded portions are ± 1 standard deviation. (Reprinted with permission.)

mean and modal points; however, distributions of /p/ were flat and a-modal. The author stated that these findings suggest that the inhibition of voicing as represented by the delay required for production of /p/ is a more difficult task, achieved with less precision than the rapid initiation of voicing for /b/. The frequency distributions for the age groups closely resembled each other for both /p/ and /b/, indicating that the observed differences in production of /p/ and /b/ are characteristic of both young and old speakers. Results of measures of vowel duration obtained by Sweeting and Baken (69) were similar to those of VOT, in that length did not increase significantly with age, although there was an increase in variation about the mean.

Summary

In summary, VOT has been described as the most significant acoustic cue for the perception of voicing in pre-vocalic stop consonants (45). Depending on the language and speech context, other lessor important acoustic cues may assist the listener in the perception of voice - voiceless distributions (64). In addition, another investigation (77) reported the magnitude of VOT differences required for distinguishing between the cognates decreases as a function of the age of the listener. However, limited information is available regarding VOT changes associated with the aging process. The research results available (54; 69) are inconclusive, particularly with male voices.

Summary and Statement of Problem

Aging changes have been shown to correlate with coordination changes in laryngeal musculature (3; 15; 27; 33; 37; 75) and in other subglottic (4; 47; 37) and supraglottic structures (38) during speech. These coordination changes have been documents by way of temporal measures of the acoustic speech signal (58; 59; 60). One temporal measure, however, which has failed to demonstrate any significant covariance with age is voice onset time (VOT) (54; 69). The lack of any significant covariance is surprising since the previously reviewed literature suggests a diminution of fine motor control for voice with increasing age. VOT should be representative of the fine motor coordination required to maintain articulatory - laryngeal adjustments during speech production (71). However, Neiman et. al., (54) reported that mean VOT values for bilabial and velar stops were generally the same for both older and younger women, and that vowel context affects VOT in an inconsistent manner. Based on their study of VOT for bilabial stops /p/ and /b/, Sweeting and Baken (69) also reported no significant difference in mean VOT values between young and old male subjects. Their results, however, indicated that VOT in older subjects is characterized by a significant increase in variability about the mean as indicated by large standard deviations. Furthermore, the separation between /b/ and /p/ on the voiced - voiceless continum decreased significantly with age. Sweeting and Baken (69) hypothesized that this decreased separation between the phoneme boundaries with regard to the voiced - voiceless continum, combined with increased variability about the mean resulted in a situation where older speakers increasingly produce parts of a word which fall within a zone of overlap for perception of the voiced - voiceless distinction. Their conclusions, however, were based on VOT values for bilabial prevocalic stops /p/ and /b/ only. No information is available concerning VOT variability with age for alveolar and velar English prevocalic stop consonants. Furthermore, the frequency which older and younger individuals produce words which fall into this zone of diminished perceptual certainty has not been examined.

Further information is needed concerning mean VOT and VOT variability changes in males with age, particularly with regard to alveolar and velar prevocalic stop consonants. Therefore, the purpose of the present investigation is to compare mean voice onset times in young and old male subjects, as well as to examine intersubject and intrasubjects' voice onset time variability with prevocalic alveolar and velar voiced and voiceless stop consonants. The investigator will also examine mean VOT and inter and intrasubject variability for bilabial consonants /p/ and /b/ for the purpose of comparison with the results obtained by Sweeting and Baken (69).

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CHAPTER III

METHODOLOGY

Subjects

The speakers who were employed in the present investigation consisted of forty-five Caucasian males who ranged from twenty-five to seventy-nine years of age. Subjects were divided into three age groups including one control and two experimental groups. The control group consisted of fifteen males between the ages of twenty-five and thirty-nine years. The younger group was chosen for control purposes since previous investigators have demonstrated the absence of any known age-related vocal changes prior to age forty. The experimental subjects were divided into two decade groups of fifteen subjects each: sixty to sixty-nine and seventy to seventy-nine years of age. An attempt was made to distribute subjects evenly throughout the decade.

All subjects were living independently, and were considered to be embedded in the social structure of the community. The subjects were native speakers of English and were raised in homes in which only English had been spoken. Subjects were free of any reported chronic or debilitating disease, received no treatment with medications known to affect speech and/or language, and reported negative histories for cardiovascular, respiratory, neurological, and laryngeal disorders. A standard reading sample (the

"Rainbow Passage") was read by each speaker in order to exclude any articulatory, phonatory, serious visual or reading problems.

An audiometric screening test was conducted for each subject at 1000, 2000, and 3000 Hz. Those geriatric subjects who demonstrated a hearing loss greater than 35 dB in the better ear and those control subjects who exhibited a hearing loss of greater than 25 dB in either were excluded from the study.

Stimuli

The stimuli employed consisted of the following six words embedded in the carrier phrase "Say __________ again": beat, Pete, team, deep, geese, and keep. The use of a carrier phrase encouraged natural productions of each stimulus word as well as minimized intrasubject variability in stress patterns and fundamental frequency. These stimulus words were employed in order to obtain a measure of VOT for word- initiated bilabial, alveolar, and velar voiced and voiceless stops. These bilabial stimulus words "beat" and "Pete" were included for comparative purposes with the results obtained by Sweeting and Baken, who used the same stimulus words. Only stimulus words which contained the high vowel /i/ were employed in the present investigation, since VOT may be affected by adjacent vowels. Each phrase was presented on a separate five inch by eight inch unlined, white index card, which was prepared in large print. All sixty-six cards were completely randomized for each subject using a random number table.

Recording Procedures

All speakers were recorded in an audiometric suite (Transacoustics RS 143-8). Located on a table in the test room was a tape recorder (Revox B77) to which a microphone (ElectroVoice 636) was coupled. A constant mouth-to-microphone distance of six inches was maintained for each subject. The microphone fed the speech signal to the tape recorder, which recorded the signals on 1.0 millimeter polyester tape (Apex 641). Subjects were asked to hold the index cards during the recording of the stimuli. Each speaker was instructed to use a normal articulation pattern and a comfortable conversation rate. In addition, the speakers were instructed to pause between each phrase. The subjects were provided with as much practice time as they wanted in order to assure that they were comfortable with the task.

Measurement Procedures

A wide-band spectrogram was made for each of the eleven repetitions of the stimulus phrase using a Kay Sonograph (Model 6165). In order to facilitate accurate measurements of VOT, a 16 Hz analyzing filter was employed and the time base adjusted so that the spectrograms represented 1.28 seconds of speech, and each division on the spectrograms represented five milliseconds. Voice onset time measurements were made of the first ten spectrograms of each phoneme judged adequate for analysis. VOT was measured based on criteria established by Lisker and Abramson (1). This procedure involved marking off the interval between the release of the stop and the onset of glottal vibration (voicing) on the spectrogram, and measuring the distance between the two. Oral closure was determined by the absence of acoustic energy in the format frequency range. Oral release was determined by the abrupt onset of energy in the format frequency range. Measurements of voicing onset were made by locating the regularly spaced vertical striations which indicate glottal pulsing.

Statistical Analysis

Measurements of voice onset time were analyzed according to an analysis of variance with repeated measures. A three by six design was used in order to test the interaction of three groups of age with six factors place of articulation, (bilabial, alvedor, or velar) voicing (voiced and voiceless) and trials.

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CHAPTER IV.

RESULTS

The purpose of the present investigation was to compare mean voice onset time (VOT) in young and old male subjects, as well as to examine variability of VOT productions with age for prevocalic alveolar and velar voiced and voiceless stop consonants. Mean VOT and variability of bilabial consonants /b/ and /p/ were also examined for the purpose of comparing the results with an earlier investigation (2).

Measurements of VOT were analyzed according to a three by six repeated measures analyses of variance (3). These measurements were grouped as follows:

age by VOT for voiceless phonemes

age by VOT for voiced phonemes

age by VOT for bilabial phonemes

age by VOT for alveolar phonemes

age by VOT for velar phonemes

age by trial of VOT.

Analysis of variance was also conducted for the productions of each experimental phoneme by the three groups. The three by six repeated measures design allows for the determination of the effect of age on VOT for the variables of voicing, place of articulation, as well as variability of production. The analysis of variance for each experimental phoneme allows for determination of the effect of age on VOT for repeated measures of each stop, and also allows for the examination of the effect of age on variability of production for each of the stops.

For these reasons, the .05 level of confidence was chosen as the rejection point since the examination of differences among these variables was of an exploratory nature.

Table I presents the means of the production of the experimental phonemes for each of the ten trials by the three age groups. Table II presents a summary of the mean voice onset times and standard deviations for voiced and voiceless stops produced by the three age groups of males. All VOT values were averaged and standard deviations were calculated.

Examination of the mean VOT of the three age groups revealed longer VOT for voiceless stops (see Table II). This pattern was anticipated because of previously reported findings by Lisker and Abramson (1). Further examination of the standard deviations of the voiceless and voiced stops revealed the standard deviations of the voiced stops to be smaller in all cases for all age groups than the standard deviations of the voiceless cognate. There was no apparent differences between the standard deviations of the young and old male speakers with regard to voice onset time variability for the /b/ phoneme. However, standard deviations for the /p/ phoneme did show increased heterogeneity for the older subjects. The standard deviations of productions of all phonemes were greatest in

TABLE I

MEANS OF THE PRODUCTION OF THE EXPERIMENTAL PHONEMES
FOR EACH OF THE TEN TRIALS BY THE
THREE AGE GROUPS

Trials

1	2	3	4	5	6	7	8	9	10
Group 1 (25 - 40 years)									
639.5	744.6	751.4	644.6	698.2	717.8	725.0	735.7	644.6	732.1
905.3	883.9	837.5	907.1	853.5	876.7	930.3	851.7	860.7	821.4
883.9	894.6	937.5	980.3	846.7	946.4	919.6	866.0	932.1	921.7
119.6	153.5	128.5	128.5	146.4	132.1	141.0	139.2	133.9	253.7
230.3	210.7	292.8	213.5	232.5	214.2	228.2	225.0	212.5	242.0
383.9	407.1	373.2	303.5	346.4	387.5	392.8	376.7	390.3	385.7
Group 2 (60 - 69 years)									
587.5	683.9	616.0	600.0	589.2	591.0	610.7	616.0	662.5	635.7
764.2	714.2	762.5	758.9	765.2	742.8	730.3	741.0	676.7	848.2
848.2	882.1	933.9	964.2	882.1	847.8	980.0	907.1	855.3	866.0
110.7	142.8	117.8	112.5	137.1	140.7	137.5	135.7	121.4	123.2
207.1	207.1	214.2	198.2	217.8	203.5	120.3	171.4	203.5	192.6
310.7	325.0	330.3	271.4	328.5	335.7	353.5	317.1	326.7	285.7
Group 3 (70 - 79 years)									
605.7	625.0	628.4	609.6	680.7	600.0	575.0	642.3	568.4	576.9
834.6	875.0	817.5	905.7	823.0	775.0	789.0	898.3	909.6	834.6
873.0	1028.8	995.7	986.5	911.5	967.3	844.9	878.8	876.9	1550.0
140.0	123.7	130.7	107.6	138.5	150.0	134.6	120.7	121.8	116.1
251.9	217.3	200.0	419.2	251.9	203.8	182.4	207.6	213.8	313.8
303.8	373.0	309.6	363.5	521.1	338.4	365.3	334.6	280.7	324.6

TABLE II

A SUMMARY OF MEAN VOICE ONSET TIME (MSECS) AND STANDARD DEVIATIONS (IN PARENTHESES) FOR TEN TRIALS OF VOICED AND VOICELESS STOPS PRODUCED BY THREE AGE GROUPS OF MALES

Phonemes	Age Groups: 25 - 39 years N=12	60 - 69 years N=15	70 - 79 years N=15
/p/	67.40 (12.76)	54.33 (12.12)	57.94 (18.76)
/b/	13.35 (4.50)	13.39 (3.15)	12.13 (4.26)
/t/	86.36 (14.02)	70.82 (22.80)	77.31 (27.09)
/d/	21.50 (8.39)	25.97 (20.86)	21.20 (9.69)
/k/	85.51 (25.07)	87.33 (26.40)	80.05 (31.64)
/g/	24.81 (13.03)	32.00 (6.42)	31.30 (11.33)

the oldest subject age group (70 to 79 years) compared to the younger aged group (60 to 69 years) with the exception of the phoneme /d/. The standard deviation of /d/ for the 60 to 69 year old group was observed to be much larger than the standard deviation for the control group or the oldest group.

The results of the multivariate analysis of variance of average VOT for a combination of all experimental phonemes by the three age groups indicated that no main effects for age were found ($F\ 2,38 = 1.01$, $p > .05$). When analysis of individual sounds was made, a similar lack of age effects was noted ($f\ 12, 64 = 1.65$, $p > .05$). These results reveal no effect of age on productions of VOT for the six experimental phonemes.

The effect of age on trials of productions of the six phonemes was also examined as a measure of variability within persons. The results, presented in Table III reveal no statistically significant effects across trials for any of the experimental phonemes.

The effect of age on productions of voiceless, voiced, bilabial, alveolar, and velar stop consonants utilizing averages across ten trials per phoneme is presented in Table IV. The effect of age on averages of the phonemes was calculated given the lack of a trials effect for any of the individual phonemes. These results are presented in Table IV. When the averages were utilized, no significant age effect was found for any of the phoneme groupings (by

TABLE III

RESULTS OF THE ANALYSIS OF VARIANCE OF THE EFFECT OF AGE ON TRIALS OF PRODUCTIONS OF THE SIX PHONEMES

Phonemes	Group	Trials	Group x Trials
/p/	1.88[a]	1.16[b]	1.03[c]
/t/	2.19	.68	1.51
/k/	1.10	1.26	1.72
/b/	1.14	.83	[illegible]
/d/	.62	.78	.68
/g/	1.58	1.33	.84

[a] df = 2, 38
[b] df = 9, 30
[c] df = 18, 58

TABLE IV

RESULTS OF ANALYSIS OF VARIANCE FOR EFFECT OF VOICING AND PLACE OF ARTICULATION UTILIZING AVERAGES OF TEN PHONEME TRIALS

Phoneme group	F ratio
voiceless	1.23
voiced	.32
bilabial	1.78
alveolar	.05
velar	.29

df = 2, 38

voicing or place of articulation. When individual trials of the phoneme were used in the analysis instead of the average, age was found to interact significantly with voice ($F_{6, 70} = 2.44$; $p < .05$). These results are presented in Table 5. The effect of age on the production of both bilabial and velar when using individual phonemes was found to be not significant at the .05 level of confidence, but was significant at the .10 level.

Further pattern analysis was attempted by visual inspection of the actual spectrograms and comparisons of the older and younger subjects productions. Two patterns were noted. First, increased noise throughout the vowel portion was observed for the older population. This noise was represented by irregular waveforms across the entire measured vowel spectrum. Secondly, the older speakers produced poorly defined release and closure of the plosive consonant, particularly with the velar plosives. The poorly defined release and closure was characterized by the presence of voice during the closure phase and a poorly visible spike at the time of release. This occurrence was identified by the investigator in sixty-three productions of velar consonants and thirty-seven productions of bilabial and alveolar consonants among the older subjects. This rate compared to twelve occurrences in velar and nine occurrences in bilabials and alveolar stops for the young subject groups suggests that these patterns by be characteristic of older speakers.

TABLE V

RESULTS OF ANALYSIS OF VARIANCE FOR EFFECT OF VOICING AND PLACE OF ARTICULATION UTILIZING INDIVIDUAL PHONEMES

Phoneme group	F value
voiceless	1.23
voiced	2.44*
bilabial	2.12[c]
alveolar	.81
velar	2.27

df = 6, 70

* p = .05

c p = > .05 but < .10

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CHAPTER V

DISCUSSION

Aging has been reported to result in structural and functional changes in laryngeal musculature (1; 4) and in other subglottic (4; 7) and supraglottic structures (5). Researchers have correlated changes in selected temporal measures of the acoustic speech signal with aging (6; 8). One temporal measure, however, which has failed to demonstrate any significant covariance with age has been voice onset time (VOT) (10; 13).

Sweeting and Baken (10) reported no significant difference in mean VOT values between young (25 to 39 years of age) and older (65 to over 75 years of age) male and female subjects for productions of bilabial stops /p/ and /b/. Similarly, Neiman, Klich, and Shuey (9) examined VOT changes with respect to age in younger (20 to 30 years of age) and older (70 to 80 years of age) females. The analysis of the production of bilabial and velar stops revealed no significant mean differences between the two age groups. Despite information provided by these previous investigators, no information has been available concerning voice onset time productions for alveolar and velar stop consonants in aging males. Furthermore, no information has been available concerning variability of voice onset time productions for alveolar and velar stops in young and old male speakers. Therefore, the purpose of this investigation was to compare mean voice onset time and voice onset time variability of velar and alveolar voiced and voiceless stop consonants in younger and older male speakers.

Forty-five Caucasian males were divided equally into three age groups ages twenty-five to thirty-nine, sixty to sixty-nine, and seventy to seventy-nine years of age. All speakers recorded eleven tokens of six stimulus words "beat", "Pete", "team", "deep", "geese", and "keep", which were embedded in the carrier phrase, "Say ________ again." Wide band spectrograms were made for each of the eleven stimulus phrases using the Kay Digital Sonograph (7800). VOT was measured for the first ten of the eleven stimulus trials based on criteria established by Lisker and Abramson (6). Measures of VOT were subjected to an analysis of variance (ANOVA) utilizing a three by six repeated measured design.

Results of the present investigation has revealed no significant differences in voice onset time productions of each of the six individual phonemes tested. These findings are in agreement with findings reported by Sweeting and Baken (10) in the mean VOT of /p/ and /b/ did not increase significantly with age for male speakers. Sweeting and Baken (10) did, however, report significantly increased variability about the mean with increased age for measurements of /b/ and /p/. The results of this investigation do not support this finding in that age was not found to influence variability of production of any of the experimental phonemes. Furthermore, variability of production of the entire group of phonemes was not found to differ significantly with age.

When place of articulation and voicing were examined for age effect, two methods of calculation for the analysis of variance were utilized. First, averages across the ten trials per phoneme were used to calculate the effect of age on productions of bilabial, alveolar, velar, voiceless and voiced stop consonants. The effect of age on averages of the ten productions was calculated given the lack of trials effect for any of the individual phonemes. When the averages were utilized, no significant age effect was found for any of the phoneme groupings (by voicing or place of articulation). This finding indicated no significant difference in VOT productions occurred in the three age groupings.

Analysis of variance was then calculated utilizing individual trials of the phoneme productions instead of the averages. These results revealed a significant interaction between age and voiced phonemes. Furthermore, while the effect of age on the production of both bilabial and velar phonemes was found not to be significant at .05 level of confidence, the age factor was significant at the .10 level of confidence.

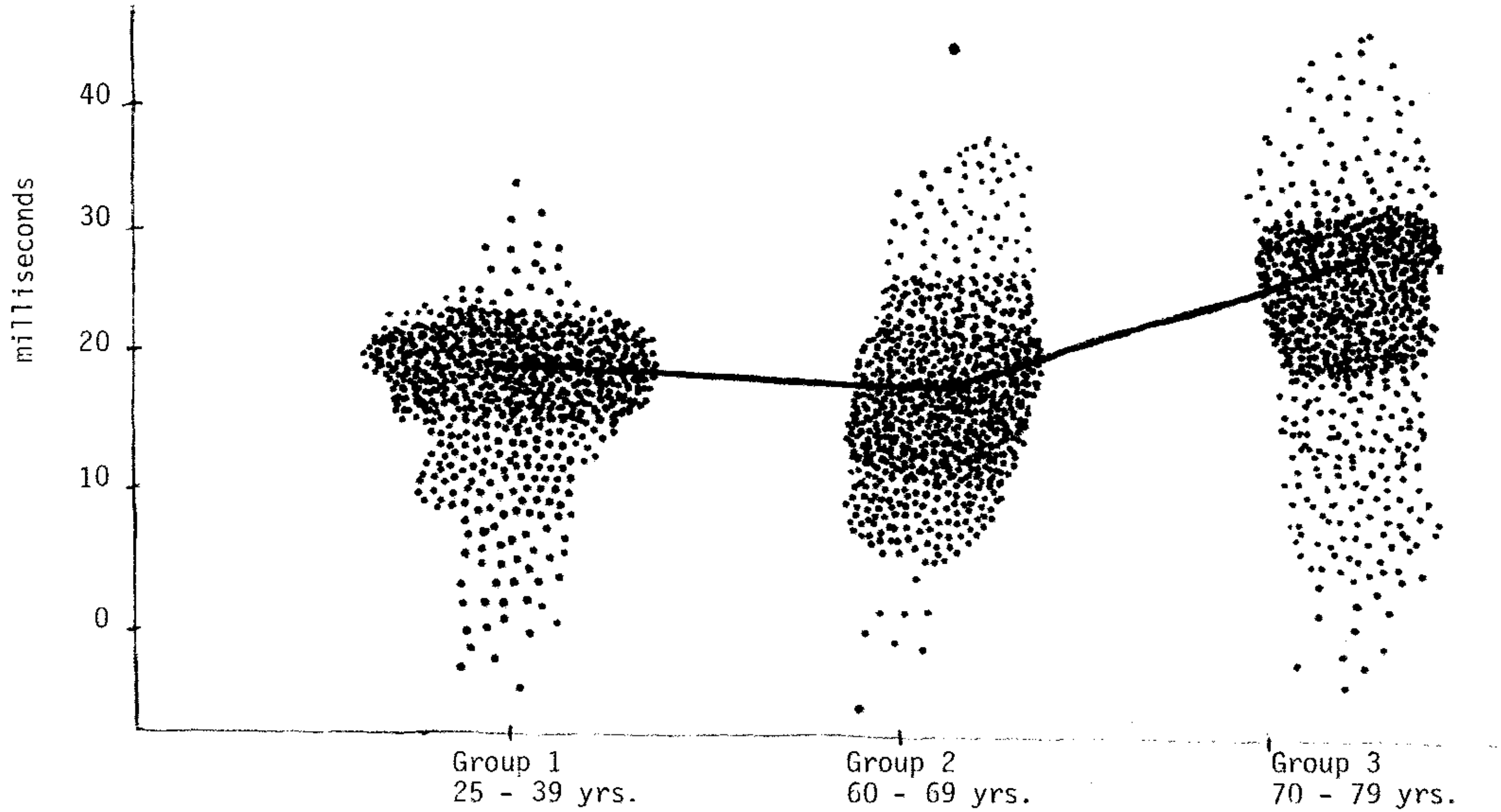
The significant interaction between age and voicing obtained when individual phoneme productions were utilized in the analysis of variance suggests that averaging the productions makes the analysis less sensitive to slight variation in VOT between the three age groups. Although this variation in production was not large enough to be statistically significant for any of the individual phonemes, the variance may have been more prominent when the phonemes were grouped for analysis by place of articulation and voicing. Therefore, interactions between VOT and age by place of articulation and voicing were only detected when individual productions of the phonemes instead of the average of the productions were utilized in the analysis. This may explain the lack of significant difference in VOT productions with age reported by previous investigations.

When the voice onset time values of each production of the voiced phonemes were plotted and a regression line was drawn, results indicated that the oldest subjects (age 70 to 79) voice onset times were greater than the younger subjects (Figure 2). Therefore, the significant interaction between age and VOT for voiced phonemes was due to longer voice onset times for the subjects 70 to 79 years of age.

This finding suggests that the initiation of voicing was slower in the older subject group as indicated by greater voice onset time values. Thus, there is an apparent longer delay between the burst release of the articulatory constriction and the onset of vocal fold vibration (voicing). Since the onset or production of voicing is a highly coordinated interaction among the central and

FIGURE 2

PLOTTING OF VOICE ONSET TIME VALUES OF EACH PRODUCTION OF THE VOICED PHONEMES FOR THE THREE AGE GROUPS WITH REGRESSION LINE



peripheral nervous systems, the laryngeal and the respiratory musculature, any changes in these structures associated with the aging process must be considered as a possible explanation for the results obtained in this investigation.

The major functional change in the respiratory system associated with the aging process has been described previously. A decrease in the elasticity or recoil property of the lungs leads to an increase in the volume of residual air remaining in the lungs following exhalation and, therefore, results in a reduction in the vital capacity of the lungs (7). This decrease in vital capacity reduces the amount of air available for speech production. This reduction, however, is usually associated in the literature with reduced ability to sustain phonation rather than influence speed of initiation of phonation.

Atrophy and degeneration of laryngeal musculature associated with the aging process may impair the speed and mobility of laryngeal tissue, including the vocal folds (3). This tissue degeneration reduces the speed of initiation of voicing in older individuals by reducing speed of adduction of the vocal folds. Thus far, most studies which cite laryngeal atrophy as a primary suspect in voice related changes have examined pitch or pitch range and variability rather than speed of adduction (2, 6, 9). Recent advances in technology such as use of an Electrolaryngograph allow an examination of vocal fold adduction and abduction during phonatia could perhaps answer this question.

Age related alterations in the central or peripheral nervous system which activate the laryngeal musculature for adduction of the vocal folds, may also result in a slower initiation of voicing in older individuals. For example, the EEG alpha rhythm which was reported to influence development of accurate spatialtemporal patterns of the speech signal has been reported to slow with age (8).

Finally, since the production of voice is such an integrated, highly coordinated process, a slowing in the speed of initiation of voicing observed in the 70-79 year old subject group may result from small simultaneous alterations in laryngeal function, respiratory function, as well as central and peripheral nervous systems. The combination of the small alteration could summate to effect the efficiency of the entire process.

Based on frequency distributions obtained in their study of VOT and age in males and females, Sweeting and Baken (10) hypothesized that the inhibition of voicing (for a voiceless stop) is a more difficult task achieved with less precision than rapid initiation of voicing (for production of a voiced sound). These findings were reported by the authors for both young and old speakers. The results of this investigation, do not support this hypothesis. On the contrary, voicing was found to interact significantly with age. Subjects 70-79 were found to have longer voice onset times, suggesting that the initiation of voicing is affected by age.

Other results of this investigation were in agreement with previous research findings. First mean VOT for voiceless stops was slightly shorter for the older geriatric group, with the exception of /k/, which agrees with findings reported by Neiman et. al. (9). The mean VOT for bilabials /p/ and /b/ was noted to decrease with age whereas an increase in the standard deviation of /p/ occurred in the older group. Both of these findings support previous results obtained by Sweeting and Baken (10). Furthermore, the standard deviation of all the experimental phonemes was noted to be greater in the seventy to seventy-nine year old group compared to the sixty to sixty-nine year old group except for the phoneme /d/. Although this finding may support conclusions by Sweeting and Baken (10) that VOT productions become more variable with age, it also indicated that this is not a consistent pattern.

The two patterns observed in vidual inspection of the spectrograms have been reported previously. Sweeting and Baken (10) described increased noise throughout the vowel production as well as poorly defined release and closure of the stops in their older subjects' productions. The authors further stated that such findings provided spectrographic evidence of characteristics of the aged voice previously identified by Hoolien and Shipp (2). These two patterns are apparently real phenomena associated with the aging process and deserve further investigation.

In summary, the results of the present investigation indicate that age does not affect production of VOT when examined for individuals phonemes, or when examined by place of articulation. However, when VOT is examined by voicing, a significant effect of age was found. Further analysis of this interaction revealed that this result was due to larger VOT productions for the 70 to 79 year old group. These results indicate that age appears to significantly influence laryngeal control for the rapid initiation of voicing necessary for production of voiced stop consonants.

In the present investigation, this result may have been influenced by several factors. First, the use of chronological age versus physiological age may not have allowed for the most accurate measurement of changes that occur as a result of the aging process. Secondly, the use of the digital sonograph which allows for precise measurement of VOT may explain discrepancies between this and earlier investigations. Third, the method of analyzing VOT variability was found to influence the results greatly in this investigation. In addition, the complexity of speech at the level examined in the current investigation (phrase length productions) may be resistant to change with age whereas other more complex speech tasks not be as resistant.

Finally, the observable spectographic patterns of increased noise during vowel production and poorly defined release and closure of plosives in the older speakers should be considered as a possible contribution to characteristics of the aged voice.

The results of this investigation indicate voice onset time is a viable technique for studying the aging voice. Several possible variables have been identified which need to be further examined. The definition of aging, methods of statistical analysis and length of stimulus material should be evaluated in regard to voice onset time. Continued research is needed to explore fully the relationship between voice onset time and aging.

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