THE EFFECTS OF FILTERED SIDETONE ON SOUND PRESSURE LEVEL, DURATION AND FUNDAMENTAL FREQUENCY OF CONTINUOUS VOCAL OUTPUT

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DONALD L. AYLESWORTH

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Donald L. Aylesworth

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ABSTRACT

THE EFFECTS OF FILTERED SIDETONE ON
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AND FUNDAMENTAL FREQUENCY OF
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By

Donald L. Aylesworth

Most authorities grant the auditory sense some role in the control of vocal output. With the exception of investigations into the effects of delayed sidetone signals, other aspects of the sidetone signals and their effect on continuous vocal output have received little, if any, attention. The need seems clearly indicated for information concerning the nature of the relationship between sidetone and vocal output in order to understand the control function of the auditory sense.

The purpose of this study was to investigate the effect of low-pass filtering of sidetone on the sound pressure level, duration and fundamental frequency of continuous vocal output. It was also the purpose of this study to investigate possible differential effects related to speaker sex.

Four males and four females served as subjects. The mean age was 21.5 years for the males and 20.25 years for the females. Each possessed normal hearing, spoke with a General

American dialect void of clinical level speech deviations and no previous experience in auditory experiments.

Each subject read the first paragraph of Fairbank's Rainbow Passage under six sidetone conditions, and their readings were tape recorded. In the first two sidetone conditions the sidetone signal was amplified 20 dB relative to the sound pressure level of vocal output at the microphone. The remaining four sidetone conditions consisted of low-pass filtering at 2400, 1200, 600 and 300 Hz in addition to the amplification.

The sample of vocal output selected for analysis consisted of the fourth sentence in the reading passage. Graphic level recorder tracings and narrow band spectrograms were made of the recorded readings of the sentence by each subject. The mean amplitude of the graphic level recorder tracings from the baseline converted to decibels composed the vocal intensity measure. The length of the baseline between onset and termination of reading on the same tracings converted to seconds composed the duration measure. The fundamental frequency was computed at eleven different points on narrow band spectrograms of each sample by dividing the number of harmonics between the baseline and frequency calibration referents into the value of the latter. The median value of these computations composed the fundamental frequency measure.

In the analysis of the data comparisons were made among nonfiltered and filtered sidetone conditions and among filtered sidetone conditions. These analyses were first made using the Wilcoxon Matched-Pairs Signed-Ranks Test with pooled data. These analyses were then repeated for male and female subjects separately using the Walsh Test. On the basis of the data within the experimental limitations of this investigation, the following tentative conclusions seem warranted:

1. There is no significant difference in vocal sound pressure level, duration or fundamental frequency between reading prose with frequencies above 2400, 1200, 600, or 300 Hz attenuated in the sidetone and reading prose without attenuation of these frequencies in the sidetone.

2. There is a significant difference in vocal sound pressure level between reading prose with frequencies above 2400 Hz attenuated in the sidetone and reading prose with frequencies above 1200 and 600 Hz attenuated in the sidetone. Increased vocal sound pressure level occurs with attenuation of frequencies above 1200 and 600 Hz attenuated in the sidetone.

3. There is a significant difference in reading duration between reading prose with frequencies above 2400 Hz attenuated in the sidetone and reading prose with frequencies above 300 Hz attenuated in the sidetone. A reduced duration

is associated with attenuation of frequencies above 300 Hz in the sidetone.

4. Male and female subjects do not differ significantly in the direction of changes in vocal sound pressure level, duration, or fundamental frequency with frequencies above 2400, 1200, 600, or 300 Hz attenuated in the sidetone when reading prose.

The present study was exploratory in nature. The data collected suggest areas for further research.

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Donald L. Aylesworth

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CHAPTER I

STATEMENT OF THE PROBLEM

Introduction

One frequently encounters statements in the literature to the effect that hearing one's own vocal utterances are important to the acquisition and stabilization of the speech process. For example, Eisenson, Auer, and Irwin make the following statement:

> The speech development of the congenitally deaf child differs from that of the normal hearing child beyond the babbling stage . . . because he cannot hear the sounds he makes, and so cannot reproduce heard sounds.[1]

Just as frequently, one encounters statements to the effect that self-hearing plays a lesser role in the matured speech process:

> Soon the kinesthetic or tactile feedback is sufficiently stabilized to serve as the dominant control for speech, and the ear feedback, though still present, takes a secondary role.[2]

There are those, such as Carhart, who emphasize that speech is normally controlled by the ear and extend the

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[1]J. Eisenson, J. J. Auer, and J. V. Irwin, The Psychology of Communication (New York: Appleton-Century-Crofts, 1963), pp. 193-194.

[2]C. V. Van Riper, and J. V. Irwin, Voice and Articulation (Englewood Cliffs, N. J.: Prentice-Hall, Inc., 1958), p. 110.

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concept to include the mature speech process, as well as the emerging one. While the former may be a moot issue, there are times when it appears to be markedly demonstrated. As Carhart points out, it is not uncommon to observe clinically increased vocal intensity associated with acquired sensori-neural hearing impairment. It is assumed that this is due, in part, to the incorrect impression the individual has of the loudness of his voice. Further evidence is suggested in the deleterious effect of acquired hearing loss on articulation.[1]

There seems to be little doubt that the auditory sense plays a role of some importance in the control of the speech process. Equally, there seems to be little doubt that this role, in large measure, remains to be defined.

The effect of auditory feedback on vocal output was, according to Black,[2] first reported by Fletcher and his associates in 1918. While studying telephonic communication, they reported the following finding:

> As an approximate relationship the results indicate that in a circuit having a greater equivalent than 30 miles, one mile reduction in sidetone from normal sidetone is equivalent to something more than 1/2 mile increase in receiving efficiency.[3]

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[1]R. Carhart, "Conservation of Speech," Hearing and Deafness. 1st ed. revised, ed. by H. Davis and S. S. Silverman (New York: Holt, Rinehart and Winston, Inc., 1960), pp. 387-402.

[2]J. W. Black, "Systematic Research in Experimental Phonetics: 2. Signal Reception: Intelligibility and Sidetone," Journal of Speech and Hearing Disorders, 19 (1954), 140-146.

[3]Ibid., 143.

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In this manner Fletcher quantified the finding that people talked louder when the sidetone was attenuated.

One is hard pressed to find related studies during the remainder of the first half of this century. One exception is a study by Bekesy, reported in 1941. His investigations led him to hypothesize that for hearing one's voice the magnitude of the impact on the cochlea was equivalent for both air and bone conduction.[1]

In contrast, suggestions as to the importance and emphasis to be given to auditory feedback in remediation of speech problems are more plentiful for the same period. This is particularly true regarding articulatory disorders. Some illustrative examples make the point rather clear. Koepp-Baker suggested:

> . . . try to make a sound which is just like the acoustic pattern you have received from your clinician. . . . The acoustic result is the thing to be emphasized not the mechanics of its production.[2]

Van Riper suggested that the first step in the correction of articulatory errors was ear-training. This he defined as "therapy devoted to self-hearing of speech deviations and standard utterance."[3] West, Kennedy and Carr

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[1]G. V. Bekesy, "The Structure of the Middle Ear and the Hearing of One's Own Voice by Bone Conduction," _Journal of the Acoustical Society of America_, 21 (1949), 217-232.

[2]H. Koepp-Baker, _A Handbook of Clinical Speech_. Vol. II (Ann Arbor, Michigan: Edwards Brothers, 1936), p. 346.

[3]C. V. Van Riper, "Ear Training in the Treatment of Articulation Disorders," _Journal of Speech Disorders_, 4 (1939), 141-142.

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discussed unrelenting, constant, consistent, conscientious practice in training the auditory, as well as kinesthetic and tactile, sense so the ear will detect and reject the faulty sound whenever it is uttered.[1]

Discussing the ability to hear the difference between the correct sound and the error sound, Backus and Beasley suggested, "the real problem in discrimination lies in the ability to tell the difference when HE [the case] is making the two sounds."[2]

Since 1950, the role of auditory feedback has continued to be emphasized by many authorities in the remediation of various speech disorders. Although the topic has shown increased research activity, the vast majority of studies deal with delayed, rather than synchronous, auditory feedback.

Van Riper and Irwin make note of the lack of sufficient investigation by commenting that "the scanty research dealing with the effect of sidetone on speech is full of promise."[3] The disparity between the status of knowledge concerning auditory feedback and the emphasis it has received therapeutically led Black to make the following statement:

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[1]R. West, L. Kennedy, and A. Carr, _The Rehabilitation of Speech_ (New York: Harper Brothers, 1947), pp. 303-304.

[2]O. L. Backus, and J Beasley, _Speech Therapy With Children_ (Boston, Mass.: Houghton-Mifflin Co., 1951), p. 65.

[3]C. V. Van Riper, and J. V. Irwin, _Voice and Articulation_ (Englewood Cliffs, N. J.: Prentice-Hall, Inc., 1958), p. 123.

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> When the story of sidetone is written, we may lament that we did not declare a moratorium on much speech correction, voice and diction courses, . . . until we found the nature of feedback in speech and how to cope with it.[1]

Fulton and Spuehler point out that most research in frequency filtering has concerned itself with recognition and intelligibility, rather than its effect on vocal production.[2] While intelligibility judgments are useful in and of themselves, they do not define specific parameters of vocal output, such as phonation time, pitch, rate, or intensity. The intelligibility score represents the perception of a speaker's utterances by listener judges.

Further, there is some evidence to suggest that frequency filtering of speech has a differential effect on perceived quality, by listener judges, related to the sex of the speaker.[3] This would seem to suggest that the information contained in sidetone may not be equivalent qualitatively for male and female speakers at the same level of filtering. Therefore, the effect on vocal output may also differ as a function of the speaker's sex.

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[1]Black, loc. cit.

[2]R. T. Fulton, and H. E. Spuehler, "Effects of Frequency Filtering and Delayed Sidetone on Vocal Responses," Journal of Speech and Hearing Research, 5 (1962), 382-386.

[3]A. Epstein, and J. Ulrich, "The Effect of High and Low-Pass Filtering on the Judged Vocal Quality of Male and Female Speakers," Quarterly Journal of Speech, 52 (1966), 267-272.

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Purpose of the Study

It is the purpose of this study to investigate the influence of distorted auditory feedback, by filtering of sidetone, on the vocal output of the speaker. Specifically, it is concerned with the effects of low-pass filtering with cut-off frequencies at 2400, 1200, 600 and 300 Hz. It is an attempt to determine whether this method of intervention into the control system for speech manifests itself through variations in pitch, intensity and rate of the vocal output. An additional concern of the study is exploration of a differential effect as a function of speaker sex. The questions to be investigated are as follows:

1. Does the suppression of frequencies in sidetone above 2400 Hz affect the sound pressure level of the vocal output?

2. Does the suppression of frequencies in sidetone above 1200 Hz affect the sound pressure level of the vocal output?

3. Does the suppression of frequencies in sidetone above 600 Hz affect the sound pressure level of the vocal output?

4. Does the suppression of frequencies in sidetone above 300 Hz affect the sound pressure level of the vocal output?

5. Does the suppression of frequencies in sidetone above 2400 Hz affect the duration of the vocal output?

6. Does the suppression of frequencies in sidetone above 1200 Hz affect the duration of the vocal output?

7. Does the suppression of frequencies in sidetone above 600 Hz affect the duration of the vocal output?

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8. Does the suppression of frequencies in sidetone above 300 Hz affect the duration of the vocal output?

9. Does the suppression of frequencies in sidetone above 2400 Hz affect the fundamental frequency of the vocal output?

10. Does the suppression of frequencies in sidetone above 1200 Hz affect the fundamental frequency of the vocal output?

11. Does the suppression of frequencies in sidetone above 600 Hz affect the fundamental frequency of the vocal output?

12. Does the suppression of frequencies in sidetone above 300 Hz affect the fundamental frequency of the vocal output?

13. Is there a differential effect of filtering of sidetone between speaker sexes relative to sound pressure level, duration and fundamental frequency of vocal output?

Importance of Study

Black suggests that the study of sidetone can be justified on the basis that it is inherent in speech.[1] This investigator is inclined to agree. Moreover, much of the research concerning the necessary requisites of speech signal parameters pertain to a listener function. It may seem logical that such information applies when the auditory sense is part of a control system. However, this remains to be demonstrated experimentally.

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[1]Black, loc. cit.

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Therefore, it seems worthwhile to attempt more directly to investigate the loss of information to the auditory sense as part of the results relative to the vocal output. For example, the frequency range 300 to 3000 Hz has long been recognized as important to the perception of speech. However, the contribution they make to the control of vocal output has not been adequately defined. The present study addresses itself to this influence of frequencies approximating the range of the speech frequencies.

The emphasis placed upon self-hearing in the remediation of speech problems was noted earlier. A common clinical technique involves amplification of the sidetone through electronic or other means to intensify the feedback signal. This in itself has been shown to alter vocal output.[1] In addition, there is evidence that the content of the sidetone also contributes to changes in vocal output.[2]

It is hoped that the present study will aid in the definition of the relationship between sidetone content and vocal output. Further, it is hoped that it may identify aspects which may prove fruitful for additional research.

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[1]J. W. Black, "The Loudness of Sidetone," Speech Monographs, 21 (1954), 301-305.

[2]T. A. Zachman, "The Effects of Bandpassed Filtered Sidetone Upon Vocal Production of the Vowel [u]," Journal of Auditory Research, 6 (1966), 441-443.

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Limitations

The subjects participating in the present study were selected on criteria related to age, normal auditory sensitivity, vocal maturity structurally as judged by an otolaryngologist, absence of clinical level speech deviations, speech dialect, and lack of sophistication in auditory experiments. This imposes a limitation in projecting the results of this study to populations not meeting the selection criteria.

The procedures used in the present study differ in several respects from a number of other similar studies. The ultimate level of the sidetone was subject-determined rather than controlled by the experimenter. In addition, the sample of vocal output was continuous speech rather than sustained phonation or the more controlled speech represented in speech intelligibility tests. Comparison of the results of this study with those which differ in these aspects will warrant caution.

Definition of Terms

Sidetone.--Wood defines sidetone as "the auditory signal which gives a speaker information concerning his own speech performance."[1] The auditory experience in self-hearing of

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[1]K. S. Wood, "Terminology and Nomenclature," Handbook of Speech Pathology, ed. by L. E. Travis (New York: Appleton-Century-Crofts, Inc., 1957), p. 64.

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vocal output is, in part, related to two sidetones. One sidetone of the vocal output is returned through bone and tissue to the auditory system of the speaker. The other sidetone is returned to the auditory mechanism of the speaker through air conduction. In the present study the term sidetone, unless qualified, refers to the air conducted acoustic signal generated by the speaker's voice and returned to his auditory mechanism via the external auditory meatus.

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CHAPTER II

REVIEW OF THE LITERATURE

Through the efforts of such men as Norbert Wiener, concepts were developed during the 1940's which led to the establishment of the field of cybernetics. It was conceived that problems and solutions centering about communication and control engineering could be applied to human functions as well. To illustrate the concept, Weiner offered the following example:

> . . . we came to the conclusion that an extremely important factor in voluntary activity is what control engineers term feedback. . . . It is enough to say here that when we desire a motion to follow a given pattern, the difference between this pattern and the actually performed motion is used as a new input to cause the part regulated to move in such a way as to bring its motion closer to that given by the pattern.[1]

The concepts developed in cybernetics led to the study of feedback and control mechanisms in various fields. Fairbanks[2] advanced cybernetic concepts relative to the process of speaking. He conceived the speech process as a servosystem. Within this context the output of the speech

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[1]N. Weiner, Cybernetics (New York: John Wiley and Sons, Inc., 1948), p. 33.

[2]G. Fairbanks, "Systematic Research in Experimental Phonetics: 1. A Theory of the Speech Mechanism as a Servosystem," Journal of Speech and Hearing Disorders, 19 (1954), 133-139.

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system contributes to its control. This is accomplished through a back-flow of information referred to as feedback. Weiner defines feedback as basic to ". . . the property of being able to adjust future conduct by past performance."[1]

In part, the output of the speech process is composed of articulatory contacts, movement of structures associated with speaking and the acoustic events which are produced. These components of the output are viewed as contributing to their control through information provided the system via the tactile, kinesthetic and auditory senses. Use of such feedback for control of the output, or predicting the output's future, provides the basis for viewing the speech process as a closed-loop, or servosystem.[2]

Open-loop systems are capable of carrying out a series of operations in a prescribed manner. However, they do not possess the potential for changing the operations when the results are not the desired ones. By contrast, the closed-loop system is error sensitive, error measuring, self-adjusting, and goal directed.[3]

The auditory sense has long been viewed as part of a listening system. More recently, it has also been viewed as part of a control system. Fairbanks describes a duality of

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[1]Weiner, loc. cit.

[2]Fairbanks, loc. cit.

[3]E. D. Mysak, Speech Pathology and Feedback Theory (Chicago, Illinois: Charles C. Thomas, Publisher, 1966), p. 6.

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purpose for the auditory sense. He notes that there are two different kinds of purposes for which a given instrument may be utilized in making measurements. For example, a set of scales may be used to determine an unknown weight (estimation) or to weigh out some exact amount (control). He applies this duality of purpose to the auditory sense in the following manner:

> When I say a word and you repeat it, your hearing apparatus measures my word for purposes of estimation and then your word (the same word) for purposes of control.[1]

Normal Perception of One's Voice

Bekesy conducted a series of measurements on the intensity of vocalization. He found a 20 to 25 dB attenuation of intensity from the lips to the ear canal, as an average for all vocalization. Attenuation varied somewhat as a function of frequency with higher frequencies showing the greatest attenuation.[2]

Placing cotton filled tubes, 7 cm. in diameter, over the ears was found to provide sound isolation for the air conducted sound of about 30 dB. Occlusion effect was also avoided. In this manner the intensity of the air conducted sound,

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[1]Fairbanks, loc. cit.

[2]G. V. Bekesy, Experiments in Hearing, ed. by E. G. Weaver (New York: McGraw-Hill Book Co., 1960), pp. 184-185.

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relative to the bone conducted sound, was investigated. Speakers perceived their voices as less loud with the tubes in place. Compared with a 1000 Hz bone conducted tone, the decrease in loudness was assessed for both whispered and normal speech. Attenuation due to isolation for air conducted sound approximated 6 dB. The difference between perceived loudness of normal and whispered speech was about 5 dB. Based on these results, Bekesy offered the hypothesis previously noted (Chapter I, p. 3): The hearing of one's voice by bone conduction approximates the magnitude of hearing it through air conduction.[1]

Fry contended that "when we sing or speak, most of the sound which we ourselves hear is conveyed to our ears by bone conduction."[2] He felt that bone conducted feedback is the primary contributor to vocal control. The basis for support of this view seems to stem from his own interpretation of the research available at the time. It would appear to be a very constricted interpretation. Namely, any alteration of sidetone has the primary effect of interfering with bone conducted feedback. Arguments against this view tend to find strong support in studies to be reported later.

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[1]Bekesy, loc. cit., pp. 186-187.

[2]O. B. Fry, "The Experimental Study of Speech," Nature, 173 (1954), 884.

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Black[1] investigated the loudness of sidetone as perceived by the speaker. Twenty-four male subjects attempted to match the intensity of a recorded sample of their sidetone. The sidetone was presented at the same intensity as originally produced by the speaker. Equipment systems included a combination of broad band and narrow band microphones and headsets. Matchings were made in quiet and in noise (114 dB). The results indicated that a speaker tends to generate a higher level of sidetone to his ear than he thinks he does. The narrow band microphone yielded judgments of extra loudness with less signal strength when compared to the broad band microphone. Black concluded that distorted signals may appear to be more intense than they are.

Black, Morrill and Malloy[2] reported a study on the pitch of sidetone as perceived by the speaker. Thirty-two subjects, all but three of whom were trained musicians, served as subjects. The subjects phonated the vowel [u] at four levels which measured 75, 85, 95, and 105 dB sound pressure level at the ear canal. Recordings were made and played back to the subject with the pitch varied. Subjects rephonated the original vowel and adjusted the pitch of the recorded vowel to match. The mean frequency of sustained vowels was lower

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[1] J. W. Black, "The Loudness of Sidetone," Speech Monographs, 21 (1954), 301-305.

[2] J. W. Black, S. N. Morrill, and M. M. Malloy, "The Pitch of Sidetone," Journal of Speech and Hearing Disorders, 22 (1957), 299-342.

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than the mean frequency of the variable stimuli in all instances. The differences were small, less than 2 Hz at the lower three intensities and less than 3 Hz at the highest intensity. The latter was statistically significant.

Effects of Sidetone Intensity

The early work of Fletcher, wherein he determined that people talked louder when sidetone was attenuated, was previously noted (Chapter I, p. 2). It will be recalled that his quantification was in terms of receiving efficiency in telephonic communication.

Lightfoot and Morrill[1] investigated the effect of sidetone intensity upon speaker intensity and intelligibility. Sixteen naval officers read intelligibility word lists. Headsets were worn by the subjects, and a constant level of in-circuit noise was in the headset at all times. The level of the noise was described as comparable to that observed with an open microphone in an airplane. Four levels of sidetone were used. The levels were rather vaguely defined. Three levels were 14, 27 and 38 dB below an unspecified maximum. Further definition of the levels was made by reference to the fact that two settings were above and two below the

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[1]C. Lightfoot, and S. N. Morrill," Loudness of Speaking: The Effect of the Intensity of the Sidetone Upon the Intensity of the Speaker," Joint Project Report No. 4, Bureau of Medical Research Project NM 001.053, 1949 (Pensacola, Florida: U. S. Navy School of Aviation Medicine).

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fixed level found in basic training aircraft. The lowest level was said to require loud speech to produce discernible sidetone.

Vocal output was recorded and the recordings were played to panels of listener judges. They listened to the recordings through headsets at a fixed intensity while sitting in a room filled with 110-114 dB of simulated aircraft noise. The speakers were judged to be progressively more intelligible as sidetone was attenuated. Tracings of a graphic level recorder were used for vocal intensity measurement. Vocal intensity was also found to increase progressively as sidetone was attenuated. The authors also concluded that the experience of comfort in sidetone is not a valid guide to optimal intensity for communication.

In another study Tolhurst[1] required speakers to adjust their voice levels to maintain a set mark on a monitoring meter. Unknown to the subjects, the monitoring meter was adjusted to require increased or lessened vocal effort to maintain the required level. The sidetone intensity was held relatively constant disregarding changes in vocal effort. The speakers read intelligibility lists under quiet conditions.

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[1]G. C. Tolhurst, "Intelligibility as a Function of Constant Sidetone Level When Frequency Response and Speakers Effort are Varied," Joint Project Report No. 46, The Bureau of Medicine and Surgery Project NM 001 104 500.46, 1955 (Pensacola, Florida: Ohio State University Research Foundation and the U. S. Navy School of Aviation Medicine).

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Listener judges heard the utterances in classroom quiet (67 dB, C scale) without headsets. Both vocal intensity and intelligibility were found to follow inversely the attenuation of the monitoring meter.

Black and Tolhurst[1] investigated speaker intelligibility as a function of the path of sidetone. In one condition speakers read intelligibility lists while stationed between two opposing hard, flat surfaces. They read with the ears occluded and unoccluded. Higher intelligibility scores were obtained when ears were occluded. Assuming increased vocal intensity accounted for higher scores in the occluded condition, the authors suggest the attenuation of the air conducted sidetone was the controlling factor. With the ears occluded the bone conducted sidetone is amplified; therefore, one might expect a decrease in intensity. However, the results contraindicate this effect from amplification of the bone conducted signal.

Other findings included increased intelligibility with one ear occluded and the open ear facing a non-reflecting surface. Again, assuming increased vocal intensity contributed to the increased intelligibility, the authors concluded that the speakers had to talk louder to sound normal to themselves.

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[1]J. W. Black, and G. C. Tolhurst, "Intelligibility as Related to the Path of Sidetone," Journal of Speech and Hearing Disorders, 21 (1956), 173-178.

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With one ear facing a flat reflecting surface and the other a convex surface, the intelligibility was not different from the condition where both ears faced flat surfaces. On the other hand, when one ear faced a concave surface, intelligibility decreased. The authors concluded that in the latter instance the air conducted sidetone was amplified by the concave reflector. This being the case, the speaker would be expected to lower his vocal intensity. The results of this study tend not to support the view of Fry regarding the role of bone conducted sidetone.

Effects of Spectrum Changes in Sidetone

Atkinson[1] studied the effect of sidetone spectrum changes on rate and vocal intensity. Fifty subjects read continuous passages under conditions of normal, low-pass and high-pass filter conditions of sidetone. The frequency cut-off for both filter conditions was 1900 Hz. The intensity level of the sidetone was not specified. However, the insertion loss from filtering was not compensated. The results concerning rate were not clear-cut. There was some tendency, however, toward a reduced rate when reading long passages under low-pass filtering. However, the changes in vocal intensity, while

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[1]C. J. Atkinson, "Rate and Sound Pressure Level of Speaking as Affected by Spectrum Changes in Amplified Sidetone," Supplementary Report No. 1, Signal Corps Contract No. DA 36-039 Sc-42562, 1953 (State University of Iowa).

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not large, were statistically significant. The lowest level of vocal intensity was related to the normal condition. The highest level was associated with the low-pass filter condition.

It should be noted that studies previously cited show that increased vocal intensity accompanies attenuation of sidetone. Attenuation of sidetone occurs in the filtering process. In the Atkinson study the loss was not replaced. Therefore, it is not possible to determine whether the increased vocal intensity resulted from the effects of filtering, attenuation of the sidetone, or both.

Another method was used by Tolhurst[1] to alter the spectrum of the sidetone. Three headsets with different frequency responses were used alternately as speakers read intelligibility lists. The speakers read in the presence of 100 dB of aircraft noise. The sidetone level was approximately constant. With the listeners in noise, significant differences in intelligibility scores were not found. With the listeners in quiet, significant differences were found related to the headset condition. The highest scores were associated with speakers' wearing a headset with the flatest and widest range of response.

Peters[2] investigated the effect of sidetone filtering

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[1]Tolhurst, loc. cit.

[2]R. W. Peters, "The Effect of Filtering of Sidetone Upon Speaker Intelligibility," Journal of Speech and Hearing Disorders, 20 (1955), 371-375.

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on speaker intelligibility. Naval aviators served as subjects; reading was done under high-pass filtering conditions with cut-off frequencies at 150, 300, 600, 900, 1200 and 1500 Hz and low-pass filter conditions with cut-off frequencies at 300, 600, 900, 1200, 1500 and 1800 Hz. Attenuator settings for the various filter conditions were based on subjective judgments of equal loudness of filter conditions by three subjects not in the experiment. The sidetone signal was maintained at an intensity level of approximately 80 dB. The voice signal was delivered to the listener headsets at approximately 95 dB. The speakers read in quiet, and the listeners were in 114 dB of aircraft noise.

Differences in intelligibility of speakers among high-pass filter conditions were not significant. Differences among low-pass filter conditions were found to be significant. Speakers were significantly more intelligible when frequencies above 300 and 600 Hz were attenuated than when cut-off frequencies of 1200 Hz and above were used.

To determine whether possible attenuation due to filtering accounted for the improved intelligibility or whether the filtering was accountable, further investigation was undertaken. Test conditions were: (a) frequencies above 600 Hz attenuated with no compensation for decreased sidetone level from filtering, (b) frequencies above 600 Hz attenuated with sidetone level adjusted to sound normal to the speakers, (c) no filtering of the sidetone signal with the level adju

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adjusted to correspond to condition (a), and (d) no filtering of sidetone with the level adjusted to that of condition (b). Speakers were found to be significantly more intelligible when filtering was used.

Fulton and Spuehler[1] investigated the effect of filtered and delayed sidetone on words-per-minute and phonation time. The sidetone intensity was at a level 80 dB above the subject's speech reception threshold. They found that words-per-minute differed only when conditions employing filters were compared with combinations of conditions with delayed sidetone. Phonation-time ratios differed for filtered and filtered plus delayed conditions from non-filtered conditions.

A study by Zachman[2] concerned shifts in frequency peaks of vocal output when sidetone was filtered. Twenty male subjects, fifteen to eighteen years of age and possessing normal hearing, were used in the study. Band-pass filter conditions consisted of the following bands: 1200 to 2400, 2400 to 4800, and 2500 to 6000 Hz. Phonation levels were constant at 70 dB sound pressure level at the microphone position. The voice signal was amplified 15 dB and returned to the speaker. Shifts in frequency peaks in the vocal output while phonating

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[1]R. T. Fulton, and H. E. Spuehler, "Effects of Frequency Filtering and Delayed Sidetone on Vocal Responses," Journal of Speech and Hearing Research, 5 (1962), 382-386.

[2]T. A. Zachman, "The Effects of Bandpassed Filtered Sidetone Upon Vocal Production of the Vowel [u]," Journal of Auditory Research, 6 (1966), 441-443.

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the vowel [u] occurred. The shifts occurred in the 350 to 550 and 950 to 1250 Hz regions. The trend of the shifts was in the direction of higher frequencies.

Discussion

The literature suggests, rather strongly, that an inverse relationship exists between sidetone intensity and vocal intensity. The support for this relationship lies primarily with studies which assume that increased intelligibility is associated with increased vocal intensity. However, some evidence exists from a direct measure of vocal intensity.

The literature dealing with spectrum changes is less definitive. In part, this is related to a lack in specification of the sidetone level, to maintaining sidetone levels regardless of vocal output level, and to forcing the subject to phonate at prescribed levels. However, the evidence does suggest that spectrum changes in sidetone does manifest itself in alterations of vocal output.

There is some contradiction that pertains particularly to the interests of the present study. In Black's[1] study of the intensity of sidetone, he found that when narrow band microphones were used, the judgment of equal loudness was made with less signal than with broad band microphones. He suggested that a distorted signal may be perceived as being more intense than it is.

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[1]J. W. Black, "The Loudness of Sidetone," Speech Monographs, 21 (1954), 301-305.

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Based upon the inverse relationship between sidetone intensity and vocal intensity, it seems logical to assume that filtered sidetone would then show a decrease in vocal intensity when compared with non-filtered sidetone of the same intensity. However, Peters' study shows increased intelligibility under filtered conditions.[1] This is contrary to what one would expect if a decrease in vocal intensity does, indeed, occur from filtered sidetone.

It is perhaps noteworthy to point out that a fairly large portion of the studies reviewed pertained to simulated aircraft communication conditions. The extent to which the findings of these studies apply under other conditions is open to conjecture. The lack of female subjects is readily apparent in all studies, as is the sparse consideration of vocal attributes other than intensity.

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[1] Peters, loc. cit.

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CHAPTER III

SUBJECTS, EQUIPMENT AND PROCEDURES

Subjects

The subjects used in this study were selected from students enrolled in undergraduate courses in Audiology and Speech Sciences at Michigan State University. The criteria used in the selection of subjects included normal hearing, structural vocal maturity, absence of clinical level speech deviations, General American dialect, age between eighteen and twenty-five years and no previous experience in auditory experiments.

Eight subjects, four males and four females, comprised the experimental population. Ages of the subjects ranged from nineteen to twenty-five years. The mean age for female subjects was 20.25 years and the mean age for male subjects was 21.5 years. All subjects had auditory thresholds for pure tones within normal limits for the frequency range 250 to 8000 Hz.

Equipment

The following equipment was utilized in this investigation:

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A. Audiometer (Allison Clinical-Research Audiometer, model 22).

B. Loudspeakers (Electrovoice, model SP12).

C. Artificial ear (Bruel and Kjaer, model 4152).

D. Receivers (TDH-39, MX41/AR Cushions).

E. Filter (Allison, model 25).

F. Tape Recorders (Ampex, models 601 and AG350).

G. Microphone (Electrovoice, model 635A).

H. Subject Chair. A modified wooden chair with adjustable headrest.

I. Sound Level Meter (Bruel and Kjaer, model 2203 with model 1316 filter, and model 4131 and 4132 condenser microphones).

J. Graphic Level Recorder (Bruel and Kjaer, model 2305).

K. Amplifier (Bruel and Kjaer, model 2603).

L. Spectrograph (Voice Print Laboratories).

M. Test Suite (IAC, single wall 400 series and Suttle Corporation double walled room).

N. Compensating Polar Planimeter (Ott, model 34).

O. Metric Ruler.

Material

The following materials were utilized in this investigation:

A. Magnetic Tape (Minnesota Mining Co., type 201).

B. Recording Chart Paper (Bruel and Kjaer, type QP1102).

C. Spectrograph Recording Paper (Voice Print Laboratories).

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D. Stimulus Materials. The Amplifier Passage was used for the speech screening portion of the subject selection process.[1] The first paragraph of the Rainbow Passage was used in the study proper to provide the content of vocal output.[2]

Experimental Environment

Two adjoining rooms of an audiometric test suite provided the environment within which the experiment was conducted. The two rooms were joined by a two-way observation window located on the common wall. The test room served as the experiment room and the control room served as the experimental control room.

The ambient noise level in the experiment room was assessed by octave band measurements. The results of the measurements (re: 0.0002 dyne/cm^2) show levels of 52 dB at 31.5 Hz, 26 dB at 63 Hz and 17 dB or less in higher octave bands. An ambient noise level of 62 dB was observed with C scale measurement.

Procedures

Subject Processing.--A group of potential subjects was selected from students enrolled in undergraduate courses in

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[1] Grant Fairbanks, Voice and Articulating Drillbook (2nd ed.; New York: Harper and Brothers, Publishers, 1960), p. 114.

[2] Ibid., p. 127.

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Audiology and Speech Sciences at Michigan State University. These subjects met the criteria of age and lack of prior experience in auditory research. They were then scheduled for a progressive series of evaluations at the Hearing and Speech Clinic at Michigan State University. The evaluations consisted of speech screening, audiometric testing of pure tone thresholds and vocal structure examination, in that order.

For purposes of speech screening the subjects read the Amplifier Passage (see Appendix A). Observations were made of articulation, vocal quality, pitch, intensity and dialect. Judgments were then made relative to normal speech production. Judgments were made by the experimenter and two other doctoral students in the Department of Audiology and Speech Sciences at Michigan State University. Unanimous agreement was required on the part of the judges for passing this portion of the selection process. Audiometric testing of pure tone thresholds pertained to the frequency range 250 to 8000 Hz. The related criterion was normal bilateral thresholds (re: ISO, 1964) with an air-bone gap not greater than 5 dB. Laryngeal examinations through indirect laryngoscopy were made by an otolaryngologist. He examined for structural maturity and absence of pathology.

Some potential subjects were eliminated at different parts of the selective process when they did not meet the criteria. The first four male and four female subjects comple

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completing the evaluations and meeting all criteria became the experimental subjects for this study.

Instrumentation.--The following is a functional description of the instrumentation. A block diagram of equipment arrangement is shown in Figure 1.

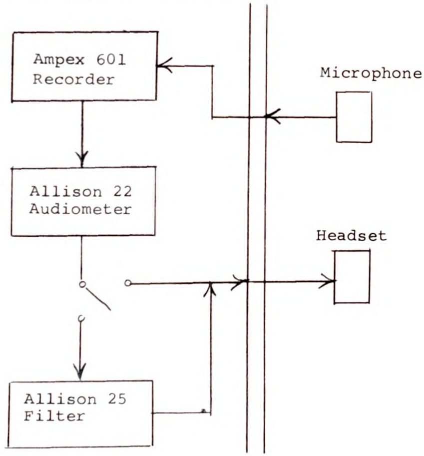

Figure 1. Block diagram of equipment arrangement for recording vocal output and altering sidetone.

The microphone in the experiment room received the voice signal of the subjects and delivered it to the tape recorder in the control room. The signal was simultaneously fed from the line output of the tape recorder to the external input of the audiometer for channel one. Four options were available at t

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at this point: 1) the signal could be terminated, 2) the signal could be returned to the subjects by sending the signal through the speech output of channel one and delivering it to the receivers, 3) the signal could be passed through a filter system with a rejection rate of 30 dB per octave prior to delivery to the receivers, or 4) the signal could be attenuated or amplified when returned to the subjects, via the receivers.

Calibration of the system was conducted in the following manner. A sound level meter was positioned in line with the center of the observation window. The microphone on the sound level meter was forty inches removed from the window at a height of forty-five inches. Broad band white noise was generated through channel two of the audiometer and delivered into the experimental room through two loudspeakers. The intensity level was adjusted until a sound level reading of 70 dB (re: 0.0002 dyne/cm^2) was obtained on the sound level meter (C scale). The attenuator setting for channel two was recorded. The subject microphone was then substituted for the sound level meter and the broad band white noise introduced into the room at the attenuator setting which had produced the 70 dB reading on the sound level meter. Settings for recording level and signal input level to channel one were then made. Effects of various settings were explored in a preliminary investigation with subjects not used in the present study. Also, a 20 dB amplification ratio was found to p

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to provide a noticeable sidetone signal without undue suppression of vocal intensity variations. For purposes of this study, settings on the tape recorder and the audiometer read minus ten on the respective VU meters. The attenuator for channel one was then adjusted until the sound pressure level of the broad band white noise delivered through the receivers equated with that impressed on the microphone (70 dB) and then adjusted to deliver a 20 dB increase (90 dB). These measurements were made with an artificial ear assembly in conjunction with the sound level meter and condenser microphone. The required settings of the channel one attenuator were recorded. The system was calibrated prior to each administration of the experiment and rechecked upon completion. The rejection rate of the filter was measured and found to meet specifications at the outset and termination of the study.

Experimental procedure.--A fifteen second sample of the calibration signal was recorded prior to each administration of the experiment. This served as a reference for calibration of equipment used in the analysis of the intensity of vocal output.

Each subject participated individually in the experiment. Prior to participation the subject was given the following instructions:

> Your task is to read a paragraph aloud. You will be reading the same paragraph a number of times. This is not a test of your reading ability nor a task which one may pass or fail. To familiarize yourself with the paragraph, read the paragraph aloud three times.

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The subject was then given a copy of the paragraph to be read (see Appendix B).

Upon completion of the familiarization readings, the subject was seated in the experiment room. The subject was positioned on line with the middle of the observation room. The back of the subject's head was in contact with an adjustable headrest. This position was maintained throughout the experiment. The microphone was adjusted to a level in line with and ten inches removed from the lips of the subject.

A five-by-eight card containing the reading passage was mounted immediately above the microphone on the arm of the microphone stand. The distance from the eyes of the subject was approximately fifteen inches. A variable range of about three inches was available and the wishes of subjects were considered to this extent.

Without movement of the head, subjects were able to observe the investigator in the control room. Subjects began to read on a hand signal from the investigator.

Subjects read under nine sidetone conditions. The total vocal output for each reading was recorded. The first three conditions were used to allow the subjects to further familiarize themselves with the reading passage and adjust to the experimental environment. These conditions were as follows:

1. Normal: Subjects read with ears unoccluded and no attempt was made to alter sidetone. The sidetone was normal relative to the characteristics of the room.

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2. Normal: Subjects read again under the conditions of 1 above.

3. Headset: Subjects read while wearing receivers. However, no signal was present in the receivers.

The subjects then read under the experimental sidetone conditions consisting of the following:

1. Amplified: The sidetone was delivered to the receivers. It was amplified 20 dB re: the input at the microphone.

2. Amplified: Subjects read again under conditions described in 1 above. Replication of the amplified condition was used to provide the opportunity for changes in vocal output which could be taken to represent normal variation.

3. Filtered: Four low-pass filter conditions with cut-off frequencies at 2400, 1200, 600 and 300 Hz were used.

Four orders of the filter conditions were rotated among both male and female subjects. The order of the filter conditions consisted of the following:

1. 2400, 1200, 600, and 300 Hz.
2. 1200, 300, 2400, and 600 Hz.
3. 600, 2400, 300, and 1200 Hz.
4. 300, 600, 1200, and 2400 Hz.

The intensity level of the filtered sidetone was maintained at the same ratio to the input at the microphone as existed for the amplified condition. The loss with the cutoff frequency at 2400 Hz was 5 dB, at 1200 Hz it was 9 dB, at 600 Hz it was 11 dB and at 300 Hz it was 14 dB. Losses were measured by passing broad-band white noise through the filter at the various settings and measuring output at the receivers.

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Replacement was made by adjusting the attenuator on channel one of the audiometer.

Measurements.--Sound pressure level, duration and fundamental frequency measures were made on a sample of vocal output for each subject and condition. In each instance the sample consisted of each subject's reading of the fourth sentence in the first paragraph of the Rainbow Passage. The sentence reads as follows: There is, according to legend, a boiling pot of gold at one end.

The sound pressure level measure consisted of the mean sound pressure level for the total sample of vocal output. This measure was obtained by playing the recorded samples of vocal output and feeding the signal through a graphic level recorder. The amplitude of deflection of the tracing needle was adjusted using the calibration signal previously described (page 30). The writing speed was set at eighty millimeters per second and the paper speed at thirty millimeters per second.

In the resultant tracings variations in tracing needle deflections directly relate to variations in the relative sound pressure level of vocal output. The greater the intensity of the signal the greater the amplitude of deflection made by the tracing needles away from the baseline.

In each instance the tracings intersect with the baseline (which represents time) at two points. The first point of intersection is associated with the onset of uttering the fi

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first word in the sentence. The second point of intersection occurs with the termination of the utterance associated with the final word in the sentence. When the tracings are viewed in combination with the baseline, an enclosed area is formed (see Figure 2).

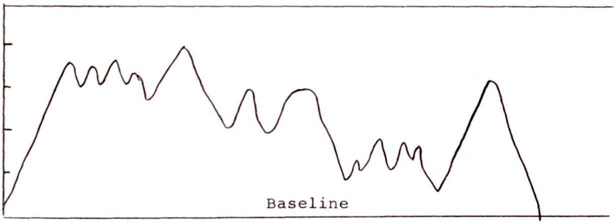

Figure 2. Illustration of tracing obtained from graphic level recorder.

These graphed areas were measured using a compensating polar planimeter. This instrument has the capacity for measuring the area circumscribed by bounded lines. The pole arm setting was 30.15 and the tracer arm setting was 12.9. These settings resulted in values which were translated into square millimeters. By dividing the length of the baseline into the total area, the mean amplitude of needle deflections in millimeters for the whole sample of vocal output was determined.

Using the tracing for the calibration tone, it was possible to determine the decibel value per millimeter of am

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amplitude in tracing needle excursions. The mean amplitude of tracing needle excursions was then converted into decibel equivalents. In their final form the data related to the sound pressure level of vocal output consisted of the mean sound pressure level of each sample of vocal output expressed in decibels (see Appendix C).

The duration of each subject's reading was determined by measuring the length of the baseline on the graphic level recorder tracings used to assess vocal sound pressure level. These values were then divided into the scale of time of the paper speed used, which was thirty millimeters per second. The resultant quotients expressed the elapsed time for each sample of vocal output in seconds. These latter values represented the duration data in final form (see Appendix D).

The fundamental frequency measure was derived from spectrographic analysis. Narrow-band spectrograms were made of each subject's reading of the sample sentence. The spectrograms were studied visually to determine representative points reflecting changes in the fundamental frequency. Eleven such points distributed throughout the sample were selected as referents. These points were identified for all subjects in each sample of vocal output. Figure 3 illustrates points where estimates of fundamental frequency were made.

At each point of reference, measurements were made of the fundamental frequency. This was accomplished by first counting the number of harmonics between the baseline and frequency calibration points on the ordinate axis of the spectrograms.

The number of harmonics observed were then divided into the calibration reference frequency at 1000, 2000, or 3000 Hz. The reference frequency used was dictated by the spectrogram. The highest reference was used based on clarity of displayed harmonics. The resultant quotient was taken as an estimation of the fundamental frequency at that point.

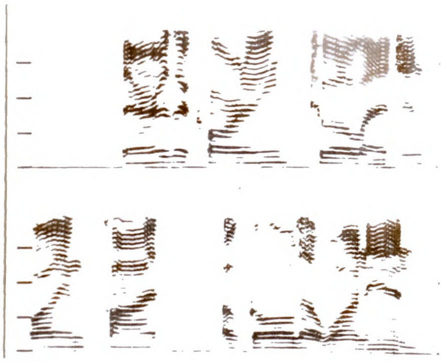

Figure 3. Illustration of narrow band spectrogram used in fundamental frequency measurement. Horizontal lines represent frequency calibration references. Vertical lines represent points of fundamental frequency measurement.

The median value of the eleven quotients for each sample of vocal output was used to represent the fundamental frequency for that entire sample. These values represent the data for fundamental frequency in their final form (see Appendix E).

CHAPTER IV

ANALYSIS AND DISCUSSION

Introduction

For each subject and condition the sample of vocal output selected for analysis consisted of the fourth sentence in the first paragraph of the Rainbow Passage. The sentence reads as follows: There is, according to legend, a boiling pot of gold at one end.

The three measures discussed in Chapter III were as follows: 1) Vocal sound pressure level, a measure of the mean vocal sound pressure level represented by the mean amplitude of tracing needle excursions on graphic level recorder tracings; 2) Duration, a measure of the total time represented by the baseline length between onset and termination of reading indicated on graphic level recorder tracings; and 3) Fundamental frequency, a measure of estimation related to the median fundamental frequency represented by the number of harmonics between the baseline and frequency calibration referents at eleven selected points on narrow band spectrograms.

Analysis of Vocal Sound Pressure Level

In their final form the data for analysis of vocal sound pressure level consisted of the mean sound pressure level of each sample of vocal output. These data were submitted to analysis using the Wilcoxon Matched-Pairs Signed-Ranks Test.[1] In this test each subject serves as his own control; and the magnitude of differences, as well as direction, is taken into account. In this analysis differences in mean sound pressure level for each subject were compared between amplified and low-pass filter conditions. The results of this analysis are summarized in Table I.

Table 1.--Summary of T Values Related to Differences in Mean Vocal SPL Between Amplified and Low-Pass Filter Conditions of Sidetone

Amplified Conditions	Low-Pass Filter Conditions			
	2400HZ	1200Hz	600Hz	300Hz
Amplified - 1	10	10	15	12.5
Amplified - 2	13	7	10	16

The critical value of T, the statistic on which the test is based, is $T \leqq 4$ when $N = 8$ for significance at the .05

[1]Sidney Siegel, Nonparametric Statistics for the Behavioral Sciences (New York: McGraw-Hill, Inc., 1956), pp. 75-82.

level and beyond. The obtained T values in this analysis did not reach significance on any of the comparisons. The differences in vocal sound pressure level between reading with non-filtered and reading with filtered sidetone were not significant.

To assess differences between male and female subject responses the Walsh Test was used.[1] In the present study when $T = 0$ both male and female subjects reflect the same consistency and direction of trend. When $T > 0$ a difference may exist in this regard.

In the Walsh Test each subject serves as his own control also. The only available level of significance when $N = 4$ is .125. To reflect this strength of trend, critical values are $d1 > 0$ or $d4 < 0$. To obtain such values, it is necessary that all differences be in the same direction within the group. The results of this analysis are summarized in Table 2 in the form of the direction and magnitude of the first and fourth ranked differences within each subject group.

The results do not show consistent trends which differed in direction between males and females. The results do show that female subjects demonstrated a consistent trend of greater vocal sound pressure level with low-pass filtering at 1200 Hz compared to the second amplified condition. Male subjects did not demonstrate this consistency of trend, nor did they approximate it sufficiently to provide a significant result with pooled data (see Table 1). This difference

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[1] Ibid., pp. 83-87.

Table 2.--Summary of Walsh Test Analysis Showing Magnitude and Direction of First and Fourth Ranked Differences in Mean Vocal SPL for Each Subject Group Between Amplified and Filtered Sidetone Conditions. Differences are Expressed in Decibels

Compared Conditions	Males		Females	
	d1	d4	d1	d4
Amplified 1 - Low-Pass 2400Hz	- 3.0	9.3	- 8.2	4.1
Amplified 1 - Low-Pass 1200Hz	- 5.4	3.2	-11.1	3.5
Amplified 1 - Low-Pass 600Hz	- 8.8	5.2	-10.8	3.8
Amplified 1 - Low-Pass 300Hz	- 8.9	4.2	-10.1	8.8
Amplified 2 - Low-Pass 2400Hz	- 1.2	12.9	-11.0	2.8
Amplified 2 - Low-Pass 1200Hz	- 3.6	8.6	-13.9	-0.7*
Amplified 2 - Low-Pass 600Hz	- 7.0	10.6	-13.6	2.5
Amplified 2 - Low-Pass 300Hz	-10.7	3.7	-12.9	4.6

*Significant at the .125 level of significance.

between groups was not demonstrated in comparison with the first amplified condition. The remaining results do not show consistent trends for either group.

Another analysis of the data was made comparing differences in mean vocal sound pressure level for each subject between the low-pass filter conditions of sidetone. For this analysis the Wilcoxon Matched-Pairs Signed-Ranks Test was again used. The results of this analysis are shown in Table 3. The critical value of T is $T \leqq 4$.

The $T = 0$ values obtained between low-pass filtering at 2400 and 1200 Hz, and 2400 and 600 Hz are significant at the .01 level of significance. Greater vocal sound pressure level was associated with lowering the cut-off frequency from 2400

Table 3.--Summary of T Values Associated With Differences in Mean Vocal SPL Between Low-Pass Filtering Conditions

Reference Conditions	Compared Conditions		
	Low-Pass 1200 Hz	Low-Pass 600 Hz	Low-Pass 300 Hz
Low-Pass 2400 Hz	0*	0*	7
Low-Pass 1200 Hz		14	14
Low-Pass 600 Hz			16

*Significant at the .01 level of significance.

Hz to either 1200 or 600 Hz. The remaining results are not significant. Lowering the cut-off frequency to 300 Hz from higher levels did not result in significant changes in vocal sound pressure level. The lowering of the cut-off frequency from 1200 to 600 Hz also did not result in significant changes.

It may be recalled that when $T > 0$ differences may exist in consistency of trend between male and female subjects. To assess this factor, the data were analyzed using the Walsh Test. The results of this analysis are shown in Table 4. The critical values are $d1 > 0$ or $d4 < 0$. The consistency of trend associated with such values is significant at the .125 level.

The results show no consistent trends which differ in direction between males and females. The results related to differences in vocal sound pressure level between low-pass

Table 4.--Summary of Walsh Test Analysis Showing Magnitude and Direction of First and Fourth Ranked Differences in Mean Vocal SPL for Each Subject Group Between Filtered Sidetone Conditions. Differences are Expressed in Decibels

Low-Pass Filter Conditions Compared	Males		Females	
	d1	d4	d1	d4
2400 Hz - 1200 Hz	- 8.2	-2.4*	-4.1	- 0.1*
2400 Hz - 600 Hz	- 5.8	-2.3*	-6.0	- 0.3*
2400 Hz - 300 Hz	-12.8	-1.2*	-2.5	5.2
1200 Hz - 600 Hz	- 3.4	2.8	-5.9	3.8
1200 Hz - 300 Hz	-10.1	3.1	1.0*	5.3
600 Hz - 300 Hz	- 8.4	4.6	-2.2	11.3

filtering at 2400 and 1200 Hz and at 2400 and 600 Hz confirm the significant results obtained with pooled data. Both male and female subjects demonstrated greater vocal sound pressure level with low-pass filtering at 1200 and 600 Hz compared to 2400 Hz.

The results show that male subjects also demonstrated a consistent trend of greater vocal sound pressure level with low-pass filtering at 300 Hz compared to 2400 Hz. This consistency of trend is significant at the .125 level. Female subjects did not demonstrate this consistency of trend, nor did they approximate it sufficiently to provide a significant result on this comparison with pooled data (see Table 3).

Another difference in consistency of trend is shown in the results comparing low-pass filtering at 1200 Hz and 300 Hz. Female subjects demonstrated a consistent trend of less

vocal sound pressure level with low-pass filtering at 300 Hz compared to 1200 Hz. This consistency of trend is significant at the .125 level. Male subjects did not demonstrate this consistency of trend, nor did they approximate it sufficiently to provide a significant result on the same comparison with pooled data (see Table 3). The remaining results do not reflect consistent trends for either male or female subjects.

To observe group trends further, the median vocal sound pressure level for each subject group was computed for each sidetone condition. These values are shown in Table 5.

Table 5.--Median Values of Vocal SPL for Male and Female Subject Groups Expressed in Decibels Re: 0.0002 Dyne/cm^2

Subject Group	Conditions					
	Amplified		Low-Pass			
	1	2	2400 Hz	1200 Hz	600 Hz	300 Hz
Males	42.0	44.5	39.5	42.0	44.5	45.5
Females	37.5	34.5	34.5	37.5	37.0	36.0

The median levels for the male group reflect progressive increases with the lowering of the cut-off frequency. Previous analyses revealed a consistent trend for male subjects to demonstrate greater vocal sound pressure level at all lower cut-off frequencies compared to 2400 Hz. The trends between other cut-off frequencies were not consistent. The pattern

displayed by the medians of the male group, however, indicate a tendency toward greater vocal sound pressure level associated with the lower of any two cut-off frequencies and at 300 Hz the median value exceeds that for the non-filtered conditions.

The median levels of vocal sound pressure level for the female group reflect a somewhat different pattern from those of the male group under the filtered conditions. Rather than progressive increases, the medians show progressive decreases with cut-off frequencies below 1200 Hz. Previous analyses showed a consistent trend by female subjects to demonstrate greater vocal sound pressure level with the cut-off frequency at 1200 and 600 Hz compared to 2400 Hz. Unlike the male subjects, however, they did not demonstrate a consistent trend of greater vocal sound pressure level at the 300 Hz cut-off frequency compared to 2400 Hz. The median value is greater at 300 Hz, however, indicating a tendency in that direction.

Previous analyses revealed a consistent trend for female subjects to demonstrate less vocal sound pressure level with low-pass filtering at 300 Hz compared to 1200 Hz. The male subjects did not demonstrate this consistency of trend. The median vocal sound pressure levels for the male group show a tendency toward greater vocal sound pressure level with cut-off frequencies below 1200 Hz. The divergent pattern in direction of tendencies with cut-off frequencies below 1200 Hz may suggest possible differences in effects related to sex. In the present study, however, it is not confirmed.

In summary, the results of the analysis regarding differences in mean vocal sound pressure level show:

1. No significant differences in vocal sound pressure level were found between filtered and non-filtered conditions of sidetone. Attenuation of frequencies above 2400, 1200, 600 and 300 Hz in sidetone did not result in vocal sound pressure level changes which differed from the non-filtered conditions. There were some inconsistent differences in strength of trend (consistency within groups) between subject groups, but there were not significant trends within both groups which differed in direction between groups.

2. Significant differences in mean vocal sound pressure level were found between certain conditions of sidetone. Attenuation of frequencies above 1200 and 600 Hz in the sidetone resulted in greater vocal sound pressure level than attenuation of frequencies above 2400 Hz. This trend was consistently extended to the 300 Hz cut-off frequency by male subjects as well. Female subjects did not show the same consistency of trend; however, the median vocal sound pressure level for the female group was greater at 300 Hz compared to the 2400 Hz cut-off frequency. Female subjects consistently demonstrated less vocal sound pressure level with attenuation of frequencies above 300 Hz compared to 1200 Hz. Male subjects were not consistent; however, the median vocal sound pressure level for the male group was greater, rather than less, with the 300 Hz cut-off frequency compared

to 1200 Hz. There were not, however, significant trends within both groups which differed in direction between groups.

Analysis of Duration

In their final form the data related to duration consisted of the elapsed time for each subject's readings of the sentence used as the sample of vocal output. These data were first analyzed comparing the difference in duration for each subject between amplified and filtered sidetone conditions. In this analysis the Wilcoxon Matched-Pairs Signed-Ranks Test was used. The results of this analysis are summarized in Table 6.

Table 6.--Summary of T Values Associated With Differences In Duration Between Amplified and Low-Pass Filter Conditions of Sidetone

Amplified Conditions	Low-Pass Filter Condition			
	2400 Hz	1200 Hz	600 Hz	300 Hz
Amplified - 1	18	11	9	5.5
Amplified - 2	7.5	16	15	11.5

The critical value of T is $T \leqq 4$. The obtained T values in this analysis did not reach significance on any comparisons. Therefore, the results show that the differences in duration

between amplified and low-pass filtered conditions of side-tone were not significant.

To assess whether male and female subjects differed in consistency or direction of trend, the same comparisons were made using the Walsh Test. The results of the analysis are shown in Table 7. The critical values of the first and fourth ranked differences within each group are $d1 > 0$ or $d4 < 0$. The consistency indicated by such values is significant at the .125 level.

Table 7.--Summary of Walsh Test Analysis Showing Magnitude and Direction of First and Fourth Ranked Differences in Duration for Each Subject Group Between Amplified and Filtered Sidetone Conditions. Differences are Expressed in Seconds

Compared Conditions	Males		Females	
	d1	d4	d1	d4
Amplified 1 - Low-Pass 2400 Hz	-.25	.47	-.20	.13
Amplified 1 - Low-Pass 1200 Hz	-.10	.15	-.04	.00
Amplified 1 - Low-Pass 600 Hz	-.50	.70	-.63	.00
Amplified 1 - Low-Pass 400 Hz	-.20	.20	-.87	.10
Amplified 2 - Low-Pass 2400 Hz	-.23	.24	-.07	.37
Amplified 2 - Low-Pass 1200 Hz	-.20	.28	-.10	.30
Amplified 2 - Low-Pass 600 Hz	-.27	.47	-.50	.07
Amplified 2 - Low-Pass 300 Hz	-.27	.08	-.74	.04

The results of this analysis do not show consistent trends for either group on any of the comparisons. Therefore, the results indicate no difference between subject groups in the consistency of trends related to differences in duration between amplified and low-pass filter conditions of sidetone.

Another analysis of the data was made comparing differences in duration for each subject between low-pass filter conditions of sidetone. The Wilcoxon Matched-Pairs Signed-Ranks Test was again used. The results of this analysis are shown in Table 8. The critical value of T is $\leqq$ 4.

Table 8.--Summary of T Values Associated With Differences in Duration Between Low-Pass Filter Conditions of Sidetone

Reference Conditions	Compared Conditions Low-Pass 1200 Hz	Low-Pass 600 Hz	Low-Pass 300 Hz
Low-Pass 2400 Hz	13	7	3*
Low-Pass 1200 Hz		8	6.5
Low-Pass 600 Hz			8.5

*Significant at the .02 level of significance.

The T = 3 value obtained between low-pass filtering at 2400 Hz and 300 Hz is significant at the .02 level of significance. This result shows a significant trend for an increase in duration under low-pass filtering at 300 Hz compared to 2400 Hz. With this exception, the remaining results indicate the differences in duration between any other two filtered conditions of sidetone were not significant.

To assess differences in consistency of trends between male and female subjects, these data were analyzed again using the Walsh Test. The results of this analysis are shown in

Table 9. The critical values of the first and fourth ranked differences within each group are d1 > 0 or d4 < 0. The consistency of trend indicated by such values is significant at the .125 level.

Table 9.--Summary of Walsh Test Analysis Showing Magnitude and Direction of First and Fourth Ranked Differences in Duration for Each Subject Group Between Filtered Sidetone Conditions. Differences are Expressed in Seconds

Compared Conditions	Males		Females	
	d1	d4	d1	d4
2400 Hz - 1200 Hz	-.44	.15	-.17	-.07*
2400 Hz - 600 Hz	-.28	.23	-.43	-.13*
2400 Hz - 300 Hz	-.27	.05	-.67	-.03*
1200 Hz - 600 Hz	-.43	.67	-.26	.04
1200 Hz - 300 Hz	-.34	.17	-.50	.14
600 Hz - 300 Hz	-.50	.00	-.24	.10

*Significant at the .125 level of significance.

The results show a difference in consistency of trends for male and female subjects between low-pass filtering at 2400 Hz and lower cut-off frequencies. Female subjects demonstrated a consistent trend of increased duration with low-pass filtering at 1200, 600 and 300 Hz compared to 2400 Hz. Male subjects did not demonstrate this consistency of trend. They did, however, approximate it sufficiently at the 300 Hz cut-off frequency to account for the significant result obtained with pooled data on this comparison (see Table 8). The remaining comparisons do not show consistent trends for either group.

To further observe group tendencies the median duration of each group were computed for each condition. These measures of central tendency are displayed in Table 10.

Table 10.--Median Duration for Male and Female Subject Groups Expressed In Seconds for Each Sidetone Condition

Subject Groups	Conditions					
	Amplified		Low-Pass			
	1	2	2400 Hz	1200 Hz	600 Hz	300 Hz
Males	3.76	3.79	3.81	3.62	3.90	3.94
Females	3.52	3.64	3.42	3.55	3.63	3.62

Differences between group median durations are small for both groups. The difference between the shortest and longest median durations is 0.32 seconds for the male group and 0.22 seconds for the female group. Within these ranges of differences the pattern reflected by the group medians differs somewhat between groups. The shortest median duration for the male group was associated with low-pass filtering at 2400 Hz. In both instances, these median durations were less than median durations under the amplified conditions. The median durations show progressive increases for the male group with cut-off frequencies below 1200 Hz. The median duration for the female group shows an increase with cut-off frequencies below 2400 Hz. In this regard, previous analyses showed a consistent trend for female subjects to increase

duration under low-pass filtering at 1200, 600, and 300 Hz compared to 2400 Hz. The overall pattern reflected in the group median durations, however, would not suggest divergent directional tendencies between the two groups.

In summary, the results related to the analysis of differences in duration show:

1. No significant differences in duration existed between filtered and non-filtered sidetone conditions. Attenuation of frequencies above 2400, 1200, 600 and 300 Hz in the sidetone did not result in duration changes which differed significantly from the duration when sidetone was not filtered for either male or female subjects.

2. A significant difference was found between one pair of filtered sidetone conditions. The attenuation of frequencies above 300 Hz resulted in an increase in duration compared to attenuation of frequencies above 2400 Hz. Female subjects consistently demonstrated increased durations with cut-off frequencies below 2400 Hz. Male subjects did not demonstrate the same consistency of trend; however, the median durations for the male group were increased at cut-off frequencies below 2400 Hz with the exception of 1200 Hz. There were not significant trends within groups, however, which differed in direction between groups.

Analysis of Fundamental Frequency

In their final form the data for the analysis of fundamental frequency for each subject consisted of the median value derived from eleven points of reference on a spectrogram under each condition. In the initial analyses these data for male and female subjects were pooled and analyzed by a series of Wilcoxon Matched-Pairs Signed-Ranks Tests. The first series compared the differences in median fundamental frequency for each subject between the amplified and low-pass filter conditions of sidetone. The results of this analysis are summarized in Table 11.

Table 11.--Summary of T Values Related to Differences in Median Fundamental Frequency Between Amplified and Low-Pass Filter Conditions of Sidetone

Amplified Conditions	Low-Pass Filter Conditions			
	2400 Hz	1200 Hz	600 Hz	300 Hz
Amplified - 1	5	7	3*	9
Amplified - 2	8	8.5	16	16

*Not significant due to tie which resulted in N = 7. With N = 7 the critical value of t is $T \leq 2$.

It may be recalled that the critical value of T when $N = 8$ is $T \leq 4$. The results of this analysis indicate that differences in median fundamental frequency between filtered and non-filtered conditions of sidetone were not significant.

The T = 3 value obtained between the first amplified condition and low-pass filtering at 600 Hz was not significant. The absence of a demonstrated difference for one male subject reduced the size of N to N = 7. The critical value of T when N = 7 is $T \leqq 2$.

As noted previously, when $T > 0$ it is possible that male and female subjects differed in the direction of their responses. To assess this factor the Walsh Test was used and the same comparisons made. The results of this analysis are shown in Table 12 with the magnitude and direction of the first and fourth ranked differences for each subject group indicated.

Table 12.--Summary of Walsh Test Analysis Showing Magnitude and Direction of First and Fourth Ranked Differences in Median Fundamental Frequency for Each Subject Group Between Amplified and Filtered Sidetone Conditions. Differences are Expressed in Hertz

Compared Conditions	Males		Females	
	d1	d4	d1	d4
Amplified 1 - Low-Pass 2400 Hz	- 1.0	7.0	- 2.7	10.8
Amplified 1 - Low-Pass 1200 Hz	- 8.0	8.2	0.2	5.8*
Amplified 1 - Low-Pass 600 Hz	- 2.0	10.0	0.5	8.8*
Amplified 1 - Low-Pass 300 Hz	- 7.8	16.2	- 8.0	15.7
Amplified 2 - Low-Pass 2400 Hz	- 5.0	1.5	-16.7	10.8
Amplified 2 - Low-Pass 1200 Hz	-10.8	0.5	-13.5	5.8
Amplified 2 - Low-Pass 600 Hz	- 7.7	4.5	-13.5	8.8
Amplified 2 - Low-Pass 300 Hz	-10.6	8.5	-15.0	16.5

*Significant at the .125 level of significance.

The critical values of d are $d1 > 0$ or $d4 < 0$. The consistency of trend indicated by such values is significant at the .125 level of significance. The results show no consistent trends which differed in direction between males and females. The results do show female subjects demonstrated consistent trends on two comparisons. They had a higher fundamental frequency under the first amplified condition than they did with low-pass filtering at either 1200 or 600 Hz. Male subjects did not demonstrate this consistency of trend, nor did they approximate it sufficiently to provide a significant result with pooled data (see Table 11). This difference in consistency of trends did not exist on the comparisons with the second amplified condition. The remaining results do not show consistent trends for either group.

Another analysis of the data was made comparing differences in median fundamental frequency for each subject between the filtered sidetone conditions. In this analysis the Wilcoxon Matched-Pairs Signed-Ranks Test was again used. The results of this analysis are summarized in Table 13.

The critical value of T is again $T = 4$. The obtained values in this analysis do not reach significance. The results of this analysis show that the differences in median fundamental frequency between the filtered conditions of sidetone were not significant.

To assess whether differences in consistency or direction of trends existed between male and female subjects,

Table 13.--Summary of T Values Associated with Differences in Median Fundamental Frequency Between Low-Pass Filter Conditions

Reference Conditions	Compared Conditions Low-Pass 1200 Hz	Low-Pass 600 Hz	Low-Pass 300 Hz
Low-Pass 2400 Hz	17	8	10
Low-Pass 1200 Hz		8	8.5
Low-Pass 600 Hz			12

these data were analyzed using the Walsh Test. The results of this analysis are summarized in Table 14. The results show no difference in consistency of trend in median fundamental frequency existed between male and female subjects under filtered conditions of sidetone. Neither group demonstrated consistent trends on any comparisons among low-pass filter conditions of sidetone.

To further observe group tendencies the median fundamental frequency for each subject group was computed for each condition. These measures of central tendency are displayed in Table 15.

The over-all pattern displayed by the medians is similar for both groups. The median values for both groups reflect the same tendency under low-pass filter conditions. The median values are greater at 1200 Hz compared with 2400 Hz. Progressive decreases in median values are reflected with

Table 14.--Summary of Walsh Test Analysis Showing Magnitude and Direction of First and Fourth Ranked Differences in Median Fundamental Frequency for Each Subject Group Between Filtered Sidetone Conditions. Differences Expressed in Hertz

Low-Pass Filter Conditions Compared	Males d1	Males d4	Females d1	Females d4
2400 Hz - 1200 Hz	-7.0	3.3	-5.0	3.2
2400 Hz - 600 Hz	-6.0	4.0	-2.0	7.6
2400 Hz - 300 Hz	-6.8	13.2	-8.0	5.7
1200 Hz - 600 Hz	-8.2	6.7	-0.2	7.4
1200 Hz - 300 Hz	-2.2	12.9	-8.2	10.7
600 Hz - 300 Hz	-5.8	6.2	-0.2	7.7

Table 15.--Median Fundamental Frequency for Male and Female Subject Groups for Each Sidetone Condition Expressed in Hertz

Subject Groups	Amplified 1	Amplified 2	Low-Pass 2400 Hz	Low-Pass 1200 Hz	Low-Pass 600 Hz	Low-Pass 300 Hz
Males	118.5	111.5	111.5	115.5	113.0	112.0
Females	222.0	211.5	221.0	222.0	218.5	218.0

cut-off frequencies below 1200 Hz. These indicated tendencies, however, are based on small differences in median values; and they were not strong enough to reach significance when each subject was used as his own control.

In summary, the results regarding the analysis of differences in median fundamental frequency show:

1. No significant differences in fundamental frequency

were found between filtered and non-filtered conditions of sidetone. Attenuation of frequencies above 2400, 1200, 600 and 300 Hz in sidetone did not result in fundamental frequency changes which differed significantly from the non-filtered conditions for either male or female subjects.

2. No significant differences in fundamental frequency were found between filtered conditions of sidetone. Attenuation of frequencies above 2400, 1200, 600 or 300 Hz in the sidetone did not result in fundamental frequency changes which differed among the filtered sidetone conditions for either male or female subjects.

Discussion

Analysis of the data showed no significant differences in mean sound pressure level, duration, or median fundamental frequency of vocal output existed between filtered and non-filtered (amplified) sidetone conditions. The results related to male subjects did not show significant trends on any of the three measures, and the results related to female subjects were not consistent. Therefore, the failure to demonstrate significant differences on the three measures between filtered and non-filtered sidetone conditions does not appear to be accounted for by clear-cut differences in male and female subject responses.

The finding of no difference in vocal sound pressure level between filtered and non-filtered sidetone conditions

is not in agreement with the study by Atkinson reviewed in Chapter II.[1] He found greater sound pressure level associated with low-pass filtering at 1900 Hz compared to non-filtering of sidetone when subjects read long passages. This difference in findings may be due to non-replacement of signal loss from filtering in his study; however, there are other precedural differences as well. Atkinson analyzed a longer sample of vocal output and the level of sidetone amplification was not specified. The median values for the male group in the present study did, however, show progressive increases with lowering of the cut-off frequency. Ultimately, the median vocal sound pressure level associated with low-pass filtering at 300 Hz did exceed the median values under the non-filtered conditions. Female subjects did not reflect this pattern in their group medians. In fact, the tendency of the female group was toward decreased sound pressure level with cut-off frequencies below 1200 Hz. The median values for the female group did not, however, fall below values for both non-filtered conditions.

Peters found that speakers received increased intelligibility scores when reading with low-pass filtering of the sidetone at 600 and 300 Hz compared to non-filtered

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[1]C. J. Atkinson, "Rate and Sound Pressure Level of Speaking as Affected by Spectrum Changes in Amplified Sidetone," Supplementary Report No. 1, Signal Corps Contract No. DA 36-039 Sc-42562, 1953 (State University of Iowa).

sidetone.[1] The underlying assumption seems to be that increased speaker intelligibility resulted from increased sound pressure level of vocal output. The results of the present study would not offer support for this assumption. Again, however, there are procedural differences which may partially account for the differences in findings. The replacement of signal loss from filtering in Peters' study was on the basis of subjective judgments on the part of the subjects. The intensity under the filtered conditions was judged to sound "normal" compared to non-filtered conditions. In the present study insertion loss from filtering was measured and replaced uniformly. Secondly, differences in stimulus material may also be a factor. The uttered units in speaker intelligibility testing do not allow the normal variation in sound pressure level that is reflected in the reading of prose.

The results of the present study did show significant trends in vocal sound pressure level between certain conditions of filtered sidetone. Greater vocal sound pressure level was consistently demonstrated by both male and female subjects when the cut-off frequency was lowered from 2400 to 1200 or 600 Hz. This trend was also manifested by male subjects at 300 Hz as well, and the central tendency of the female group was also in this direction. The difference between male and female subjects was in strength of trend and not direction.

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[1] R. W. Peters, "The Effect of Filtering of Sidetone Upon Speaker Intelligibility," Journal of Speech and Hearing Disorders, 20 (1955), 371-375.

Therefore, within the frequency range imposed on sidetone through low-pass filtering, it would appear that attenuation of frequencies above 1200, 600, or 300 Hz has a tendency to induce a change toward greater vocal sound pressure level.

Some suggestion of possible differential effects related to subject sex is also found among low-pass filter conditions. The median sound pressure level with cut-off frequencies below 1200 Hz reflects differences in direction of group tendencies. The male group median values reflect progressive increases, and the female group median values reflect progressive decreases. Female subjects demonstrated a consistent trend of decreased vocal sound pressure level with low-pass filtering at 300 Hz compared to 1200 Hz. Male subjects did not demonstrate the same degree of within-group consistency in the opposite direction; therefore, the strongest possible suggestion of a differential effect within the limits of the present study was not made.

The results of the present study in regard to duration are not in agreement with Atkinson's finding.[1] Atkinson found a tendency for subjects to reduce rate with low-pass filtering at 1900 Hz compared to non-filtered sidetone conditions. This tendency was related to longer passages and not short, abrupt passages. The present study did not reveal significant differences between amplified and filtered sidetone conditions.

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[1]Atkinson, loc. cit.

The male group in the present study did reflect some tendency toward duration increase with low-pass filtering. Their median durations were increased with low-pass filtering at 2400, 600 and 300 Hz compared to the amplified conditions. The female group, however, did not have median durations which were increased from both non-filtered conditions.

Between filtered sidetone conditions a significant trend was found for increased duration with the 300 Hz cut-off frequency compared to 2400 Hz. Female subjects also consistently demonstrated increased durations at all lower cut-off frequencies when compared to 2400 Hz. Male subjects did not demonstrate the same within group consistency, but their group median values indicate a tendency of increased duration at 600 and 300 Hz compared to 2400 Hz. The over-all pattern tends not to suggest a difference in directional tendencies between groups under low-pass filtering.

As noted, no significant differences in median fundamental frequency were found between filtered and non-filtered conditions of sidetone. The same finding was obtained with differences between filtered conditions as well. The group median values did show a tendency toward decreased fundamental frequency when the cut-off frequency was lowered from 1200 Hz. None of the group median values were lower, however, than both values related to the amplified conditions. The strongest suggestion made by the group medians under low-pass filtering is restriction in the range of difference.

The range of difference in median values under filtered conditions was 4.0 Hz for both groups. The range of difference under the amplified conditions was 7.0 Hz for the male group and 10.5 for the female group.

It is suggested by the results of the present study, for individuals with normal auditory sensitivity, that the attenuation of frequencies above 300 Hz in sidetone may not alter the efficiency of the control system for continuous speech when the ratio between vocal and sidetone levels is retained between non-filtered and filtered conditions of sidetone. It is further suggested that attenuation of frequencies above points between 2400 and 300 Hz may differ in their effects in some respects, but the differences tend to fall within the range of variation with non-filtering.

When questioned regarding their reactions to the different way their voices sounded, the subjects indicated they tried to "ignore" it. This raises the question as to whether they were indeed able to not attend to the distorted sidetone and relied upon other cues. It should also be kept in mind that the sample of vocal output analyzed was selected from near the middle of the passage read. Therefore, it is possible that differences existed initially at the beginning of the passage or nearer the end of the passage.

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

There is little doubt that the auditory sense plays some role in the control of vocal output. Changes observed in the vocal output of some individuals with acquired hearing losses tend to attest to this fact. Various authorities have also emphasized the role of self-hearing in remedial procedures for a variety of speech impairments. The investigative emphasis given to the auditory sense relative to speech, however, has been in terms of the ability to receive and comprehend it, rather than control it. With the exception of investigations into the effects of delayed sidetone signals, other aspects of the sidetone signal and their effect on vocal output have received little, if any, attention. The paucity of information is greater still where direct assessment of continuous vocal output is concerned. Certainly more evidence is needed regarding the nature of the relationship between sidetone and vocal output to provide an understanding of the control function of the auditory sense and permit optimum utilization of it.

The purpose of this study was to investigate and analyze the effect of low-pass filtering of sidetone on three aspects of continuous vocal output. The three aspects of vocal output considered were sound pressure level, duration and fundamental frequency. It was also the purpose of this study to investigate these effects while allowing speakers to vary the sound pressure level of vocal output and thereby control the ultimate level of sidetone, a relationship which is normal.

The review of pertinent literature was divided into three sections. The first section reviewed studies related to the normal perception of one's own voice, the second reviewed studies related to the effects of sidetone intensity and the third reviewed studies related to the effects of spectrum changes in sidetone. Most of the studies related to intensity and spectrum changes in sidetone quantified the effects in terms of speaker intelligibility, rather than in terms of various dimensions of vocal output. There is general agreement among studies that vocal intensity varies inversely with variations in sidetone intensity and that speaker intelligibility varies directionally with vocal intensity. That is, increased speaker intelligibility increases with increased vocal sound pressure level and vice versa. The effects of spectrum changes on vocal sound pressure level and speaker intelligibility are less defined. There are findings which suggest frequency distortion results in a reduction in vocal sound pressure level and also findings which show increased speaker intelligibility with frequency distortion of sidetone.

Many of the studies tended to be related to conditions surrounding aircraft communications as they existed at the time. It was questioned whether results of these studies pertain to more normal conditions. Where frequency distortion was concerned, the associated loss in sidetone level was not always replaced, or replaced on the basis of subjective judgments. It was questioned whether differences resulted from frequency distortion, possible attenuation of sidetone signal, or both. Also previous studies were found to lack in the representation of the female sex as subjects.

The speaker subjects employed in this study consisted of four male and four female undergraduate students selected from the Department of Audiology and Speech Sciences at Michigan State University. Each possessed normal hearing, mature vocal mechanisms free from pathology, General American dialect; and they were void of clinical level speech problems.

The speakers read under six experimental conditions of sidetone. In each instance the sidetone signal was amplified 20 dB above the sound pressure level of vocal output at the microphone. The first two sidetone conditions consisted of the amplification without filtering. The remaining four conditions consisted of low-pass filtering at 2400, 1200, 600 and 300 Hz in addition to the amplification. Four different orders of the filter conditions were rotated among male subjects and female subjects.

The stimulus material consisted of the first paragraph of the Rainbow Passage.[1] Each subject's readings were tape recorded and stored for later analysis. The portion of the vocal output selected for analysis consisted of the reading of the fourth sentence in the paragraph. The tapes were played and graphic level recorder tracings and narrow band spectrograms were obtained for the selected sample of vocal output.

The graphic level recorder tracings provided the bases for measurements of vocal sound pressure level and duration. The variations in tracing needle deflections related to variations in sound pressure level of vocal output. An enclosed area was formed between the point of deflection away from the baseline and return point of intersection with the baseline. These areas were measured in millimeters using a compensating polar planimeter, and the mean amplitude of needle deflections was computed. These values were converted to decibels representing the mean sound pressure level of vocal output for each reading. The duration measure was obtained by measuring the distance between the points of intersection with the baseline noted above. These values were then converted into seconds.

The narrow band spectrograms provided the bases for the measurement of estimation related to fundamental frequency.

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[1]Grant Fairbanks, Voice and Articulation Drillbook (2nd ed.; New York: Harper and Brothers, Publishers, 1960), p. 127.

Eleven different points were selected and the fundamental frequency determined by counting the number of harmonics present between the baseline and frequency calibration referents. The number of harmonics present were divided into the value of the frequency calibration referent. The median value of the fundamental frequency at the eleven different points was taken as the representative value for the sample of vocal output.

The data for each measure were analyzed using each subject as his own control. Comparisons were made between non-filtered and filtered sidetone conditions and between filtered sidetone conditions on each measure. The data were analyzed twice; first with pooled data using the Wilcoxon Matched-Pairs Signed-Ranks Test and again with the data separated for male and female subjects using the Walsh Test. Group medians were also computed for each measure and condition of sidetone.

Conclusions

On the basis of the data within the experimental limitations of this investigation, the following tentative conclusions appear warranted:

1. There are no significant differences in vocal sound pressure level between reading prose with frequencies above 2400, 1200, 600 or 300 Hz attenuated in the sidetone and reading prose without these frequencies attenuated in the sidetone.

2. There is a significant difference in vocal sound pressure level between reading prose with frequencies above 2400 Hz attenuated in the sidetone and reading prose with frequencies above 1200 and 600 Hz attenuated in the sidetone. Increased vocal sound pressure level occurs with attenuation of frequencies above 1200 and 600 Hz in the sidetone.

3. Males and females do not differ significantly in the direction of vocal sound pressure level changes when reading prose with frequencies above 2400, 1200, 600 or 300 Hz attenuated in the sidetone.

4. There is no significant difference in duration between reading prose with frequencies above 2400, 1200, 600 or 300 Hz attenuated in the sidetone and reading prose without these frequencies attenuated in the sidetone.

5. There is a significant difference in duration between reading prose with frequencies above 2400 Hz attenuated in the sidetone and reading prose with frequencies above 300 Hz attenuated in the sidetone. An increased duration is used when frequencies above 300 Hz are attenuated in the sidetone.

6. Males and females do not differ significantly in the direction of duration changes when frequencies above 2400, 1200, 600 or 300 Hz are attenuated in the sidetone.

7. There is no significant difference in fundamental frequency between reading prose with frequencies above 2400, 1200, 600 or 300 Hz attenuated in the sidetone and reading prose without these frequencies attenuated in the sidetone.

8. Males and females do not differ significantly in the direction of fundamental frequency changes when reading prose with frequencies above 2400, 1200, 600 or 300 Hz attenuated in the sidetone.

Implications for Additional Research

The present study was exploratory in nature relative to assessment of continuous vocal output. Investigation of sidetone and its effects on continuous vocal output appears to be a valid area of investigation. The results of the study reflect implications for additional research. Some of the suggestions for future research are as follows:

1. Replication of the present study using a greater number of subjects to further explore trends which were not significant in the present study but which are reflected in the group measures of central tendency.

2. Investigation of differences in various dimensions of continuous vocal output obtained between methods employing non-replacement of sidetone signal loss from filtering, replacement by subjective equal loudness judgments and replacement by physical measurements.

3. Investigation of differences in selected dimensions of continuous vocal output when exposed to low-pass filter sidetone conditions over time.

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APPENDICES

APPENDIX A

Amplifier Passage[1]

People talk with each other by means of acoustic signals. The signals are produced by the speaker and received by the listener. They pass from the one to the other in many different ways. In the most common situation, the speaker and listener are linked directly by the air between them. This air is the natural path that the speech signals follow. Often, however, we can improve upon this arrangement by using equipment between speaker and listener. We convert the speaker's acoustic signals into electrical signals, control them in some way, and then change them back into the acoustic form for the listener to hear. In other words, we give the signals a new path through the equipment.

The fact that we can change the path in this way means we can serve a number of purposes. For one thing, we can amplify the speech signals, or increase their power. As we all know from experience, the power of the human voice is limited. An amplifier can raise the limit. In a harbor, for example, or a football stadium it can be used to make speech audible at a distance. A man who wears a hearing aid carries a small amplifier with him. He needs more power than the average speaker produces, and the hearing aid supplies it.

In their electrical form the speech signals can be sent over very long distances. The radio and the telephone thus allow the speaker to ignore the space that separates him from his listener. If we put a recorder in the system, he can also ignore time. The listener can listen whenever he wants, and repeat the speech as often as he likes. These are only a few of the ways in which equipment can extend speech far beyond the simple, direct situation.

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[1]Grant Fairbanks, Voice and Articulation Drillbook (2nd ed.; New York: Harper and Brothers, Publishers, 1960), p. 114.

APPENDIX B

First Paragraph of the Rainbow Passage[1]

When the sunlight strikes raindrops in the air, they act like a prism and form a rainbow. The rainbow is a division of white light into many beautiful colors. These take the shape of a long round arch, with its path high above, and its two ends apparently beyond the horizon. There is, according to legend, a boiling pot of gold at one end. People look, but no one ever finds it. When a man looks for something beyond his reach, his friends say he is looking for the pot of gold at the end of the rainbow.

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[1]Grant Fairbanks, Voice and Articulation Drillbook (2nd ed.; New York: Harper and Brothers, Publishers, 1960), p. 127.

APPENDIX C

Each Subject's Mean Vocal Intensity Under Amplified and Filtered Sidetone Conditions Expressed in Decibels Re: 0.0002 Dyne/cm^2

Subject	Sidetone Condition					
	Amplified		Low-Pass			
	1	2	2400 Hz	1200 Hz	600 Hz	300 Hz
Male 1	41.2	39.4	37.3	40.0	41.7	50.1
Male 2	39.0	40.8	42.0	44.4	47.8	43.2
Male 3	42.5	47.9	35.0	39.3	37.3	44.2
Male 4	51.2	49.7	41.9	50.1	47.3	47.0
Female 1	41.6	40.3	37.5	41.6	37.8	40.0
Female 2	33.1	28.9	29.5	29.6	35.5	24.3
Female 3	22.3	19.5	30.5	33.4	33.1	32.4
Female 4	42.6	42.9	44.2	46.3	46.3	43.8

APPENDIX D

Each Subject's Duration Under Amplified and Filtered Sidetone Conditions Expressed in Seconds

Subject	Sidetone Conditions					
	Amplified		Low-Pass			
	1	2	2400 Hz	1200 Hz	600 Hz	300 Hz
Male 1	3.30	3.58	3.55	3.40	3.83	3.50
Male 2	3.75	3.88	3.68	3.60	3.60	3.90
Male 3	3.77	3.70	3.93	3.63	3.97	3.97
Male 4	4.70	4.47	4.23	4.67	4.00	4.50
Female 1	3.43	3.33	3.33	3.43	3.50	3.57
Female 2	3.63	3.57	3.50	3.67	3.63	3.53
Female 3	3.40	3.70	3.33	3.40	3.63	3.67
Female 4	4.20	4.33	4.40	4.57	4.83	5.07

APPENDIX E

Each Subject's Median Fundamental Frequency Under Amplified and Filtered Sidetone Conditions Expressed in Hertz

Subjects	Sidetone Conditions					
	Amplified		Low-Pass			
	1	2	2400 Hz	1200 Hz	600 Hz	300 Hz
Male 1	111.0	103.3	105.0	102.8	111.0	105.0
Male 2	103.0	100.2	104.2	111.0	105.0	110.8
Male 3	125.0	119.5	118.0	120.0	115.0	111.0
Male 4	146.0	138.0	143.0	142.7	136.0	129.8
Female 1	230.8	230.8	220.0	225.0	222.0	214.3
Female 2	222.3	208.3	225.0	221.8	221.8	222.0
Female 3	200.3	200.0	200.0	199.8	200.0	199.8
Female 4	222.0	215.0	222.0	221.8	214.4	230.0