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DETECTING DECEPTION IN THE VOICE: AN ANALYSIS OF THE FUNDAMENTAL FREQUENCY, SYLLABIC DURATION AND AMPLITUDE OF THE HUMAN VOICE

By

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ABSTRACT

DETECTING DECEPTION IN THE VOICE:
AN ANALYSIS OF THE FUNDAMENTAL FREQUENCY, SYLLABIC DURATION AND AMPLITUDE OF THE HUMAN VOICE

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The purpose of this study was to determine whether or not changes in the fundamental frequency (voice pitch), amplitude (correlated to intensity measured in dBSPL) and syllabic duration (measured in ms for prolongation of vocal utterances) of the human voice are useful in detecting deception.

Audio tape recordings of actual polygraph examinations recorded by police polygraph examiners were subjected to analysis with a PM Analyzer, an audio-microprocessor that produces an oscillographic envelope display and fundamental frequency of sound, to obtain measurements of the fundamental frequency, amplitude and syllabic duration of the subjects tested. Digital readings of the above mentioned speech parameters from the audio recordings were statistically analyzed and tested for significance.

Malcolm E. Hall

The recordings of 47 confession-verified deceptive subjects, 33 verified truthful subjects, 24 nonverified deceptive subjects and 21 nonverified truthful subjects were analyzed. The vocal data from the primary relevant and primary control questions from the list of test questions in each of two tests were extracted from the list of test questions.

According to the polygraphers control question theorem, when a deceptive person responds to a relevant question, the physiological response is greater than the response to a control question and a truthful persons physiological response to a control question is greater than the response to a relevant question. Therefore one would expect that the fundamental frequency, amplitude and syllabic duration of a deceptive person, when responding to a relevant question would be greater then when responding to a control question and the same speech parameters of a truthful person, when responding to a control question would be greater then when responding to a relevant question.

Analysis of the data supported the interaction effect predicted for the fundamental frequency changes of verified subjects for test one ($P=0.0008$). The predicted interaction effect for the fundamental frequency changes of verified subjects for test two and the combined measurements of tests

one and two, did not prove significant. However the change in the fundamental frequency was in the predicted direction in both instances. The predicted interaction effect for the fundamental frequency changes of nonverified subjects for test one did not prove significant($P=0.755$); however the data supported the predicted interaction of nonverified subjects on test two and the combined measurements of tests one and two($P=0.017$ and $P=0.015$), respectively. Analysis of the data did not support the interaction effect predicted for the amplitude (correlated to intensity measured in dBSPL) and syllabic duration (prolongation of vocal utterances, measured in ms) for either verified or nonverified subjects.

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BACKGROUND

Among even the best of liars, insofar as outwardly observable symptoms are concerned, there are a considerable number who experience certain non-observable internal sensations of uneasiness or fear of detection, and this is particularly true regarding matters of a serious nature, as in the case of a criminal offense (Reid and Inbau, 1966). It is commonly assumed that the fear of detection, or the fear of the consequences of detection, creates stress within an individual and that this stress may be recognized by obtaining recordings of non-visible physiological phenomena, such as changes in blood pressure, pulse and respiration.

Since 1945, the polygraph has been the main scientific tool used for detecting deception. The reliability and validity of polygraph has been historically disputed; however, in the past decade a number of studies indicate a high degree of validity and reliability in analysis of the physiological data obtained during polygraphic examinations (Barland, 1972; Bersh, 1969; Edel and Jacoby, 1975; Horvath and Reid, 1971; Kubis, 1962; Wicklander and Hunter, 1975).

In the field of lie detection, there has been a more recent publicized method of detecting deception, the so-called voice stress analyzer. Voice stress analyzers are described by their marketers as capable of detecting lies with an accuracy that equals or exceeds that of polygraph (Horvath, 1982).

The basis of conventional voice stress technology is a physiological phenomenon called a micro-tremor, which is attenuated when a subject is under stress. This tremor, believed to be caused by the central nervous system, consists of a low intensity periodic frequency wave which can be detected electronically in voluntary muscles of the body, such as the glottis (Horsley, V. and Schaefer, E.A., 1886; Schaefer, E.A., 1886; Bigland, B. and Lippold, O.C.J., 1954; Marshall, J. and Walsh, E.G., 1956; Van Buskirk, C. and Fink, R.A., 1962). This reaction is purported to affect the speech mechanisms, the result being a diminished or complete masking of a constant and predominant frequency (subperturbation of the voluntary muscles of the larynx) of about ten cycles per second. This absence is detected from the normal vibrations present and is portrayed by some voice stress instruments as a graphic pattern, thereby used to detect stress (Dektor Counterintelligence and Security, Inc., 1977). Inbar and Eden (1976) carried out a study to

verify the phenomenon reported by Dektor. They recorded temporal measurements of frequency changes in the human voice and a tremor in the muscles of the vocal area, suggesting that these phenomena are correlated.

Surface electromyographic (EMG) recordings were used to estimate tension changes of the muscles in the vocal area. EMG signals were monitored from various places along the vocal tract. Three male and three female subjects were tested and in all cases, the EMG tremor consistently preceded the voice tremor by a few milliseconds. Inbar and Eden believe that their results indicate the voice tremor is induced by the central nervous system (CNS). This was supported by the evidence that the oscillations are random in nature and that the EMG tremor always leads the voice tremor by approximately the same amount of time for a particular vowel.

Inbar and Eden admit that their methods need refinement, because of the noise present in the recorded EMG, masking tension changes. Kreifeldt and Yao (1974) also reported a major source of difficulty in reading EMG results of a proportional nature and indicated that the difficulty could be traced to the relatively large amount of noise present in the normally processed EMG output.

Olof Lippold, et al., (1957 a and b, 1969 and 1971) examined the physiological tremor described by many of his predecessors (Halliday and Redfearn, 1956; Horsley and Schaefer, 1886; Jasper and Andrews, 1938; Marshall and Walsh, 1956; Schaefer, 1886; VanBuskirk and Fink, 1962). In examining a large number of normal human subjects, most of them had some tremor superimposed on their muscular activity. The tremors varied not only from one person to another, but also in the same individual from time to time. It was deduced by Lippold that the central nervous system apparently brings about variations in tremor from minute to minute. Lippold found that a rhythmical tendency existed at a frequency of about ten cycles per second and this occurred in "most and probably all muscles in normal individuals." Most of Lippold's experimentation dealt with outstretched finger muscles.

Marshall and Walsh (1956) tested different parts of the body and found the tremor to be similar (about ten cycles per second) at the knee, shoulder, biceps, wrist, gastrocnemius and quadriceps. VanBuskirk and Fink (1962), however, believed the tremor to be a Ballistocardiographic effect rather than a central nervous system function, since they found the tremor existed even though the spinal cord was

removed. The tremor amplitude was reduced but the frequency remained the same. These aforementioned studies corroborate the existence of a micro-tremor existing in the voluntary muscles of the human body, at least those muscles of the body examined.

Two studies were performed to find out if the tremor existed within the larynx and musculature of speech mechanisms (Shipp and McGlone, 1973 and 1975). It was determined that there wasn't any EMG evidence to suggest that low frequency tremors occurred in the muscles of the larynx which produced the voiced components of speech. McGlone and Hollien (1976) examined the sub-fundamental frequency range produced in unstressed and stressed speech situations. A fast Fourier Transforms Analysis of the EMG recordings by computer was used to check for low frequency vibrations. The results supported the position that tremors do exist in the extremities of the body when in certain states of contraction, but were not found in fast moving central muscles, like the vocal cords.

If Shipp and McGlone (1973 and 1975), and McGlone and Hollien (1976) are correct in their findings, it presents a problem with the present day theory of a micro-tremor

phenomenon, as the basis of voice stress technology. In addition to this, the effectiveness of voice stress instrumentation in the detection of deception is a matter of scientific controversy (Horvath, 1982). What then, if anything, do we know about the cause and effect of emotional stress and vocal responses of a speaker under emotional stress?

Speech communication scientists have been studying emotional stress and its physiological effects upon the individual and the speech problems derived from this psychological stress. Studies have shown that psychological stress causes a change in the speaker's fundamental frequency (voice pitch), syllabic duration (prolongation of vowel sounds), and the amplitude (intensity) of the voice (Alpert, et al., 1963; Fry, 1958; Hall and Hutchinson, 1976; Inbar, et al., 1977; Lieberman, 1959 and 1961; Lieberman and Michaels, 1962; McGlone and Hollien, 1976; Rubenstein, 1966; Simonov and Frolov, 1973). The change in the fundmental frequency is reported by these researchers as the most dominant and predictable vocal change.

STATEMENT OF THE PROBLEM

Studies related to voice stress analysis, when correlated

with deception, have shown that an increase in the fundamental frequency occurs when one tries to deceive (Ekman, et al., 1976; Streeter, et al., 1977). Other changes occur in the amplitude (Friedhoff, et al., 1962; Alpert, et al., 1963) when this stress is correlated with deception.

The fundamental frequency and the amplitude of the voice is easily determined by vocal analysis and recently a microprocessor controlled device, the PM Analyzer, has been developed that can automatically accomodate sudden and frequent shifts in the fundamental frequency and amplitude of the voice, caused by various emotional or psychological stimuli. The PM Analyzer has been designed for use in a wide range of speech and language applications. This new microprocessor has not yet been tested for the detection of stress and its relationship to deception.

IMPORTANCE OF THE STUDY

The available scientific literature (Friedhoff, et al., 1962; Alpert, et al., 1963; Ekman, et al., 1976; Streeter, et al., 1977) shows not one of them has involved testing subjects under field conditions. This is a concern because there are obvious differences between field and laboratory subjects, for examples, the attitudes toward the examiner,

the testing situation, the purpose of the examination, expectations as to the outcome of the examination, the amount of examiner-subject interaction expected and occurring, different motives for volunteering to take the examination, different modes of compliance, different degrees of resentment toward the test, different levels and types of examiner-subject rapport, may all be affecting the stress levels of the individual and thereby effecting the results of the test data. In addition to the short term stress applied to the subject during the testing procedure, there is a long term stress acting upon the non-experimental subject which is almost always absent in the laboratory situation. The experimental populations are highly homogenous, whereas in field (forensic) populations there are variances in intelligence and educational levels, emotional and mental stability, previous experience with lie detection devices and beliefs regarding the efficacy of the polygraph technique.

The present study is important, because to date, no empirical research involving fundamental frequency, amplitude and syllabic duration of the human voice has been used to detect deception in actual criminal investigations. Examining the high stress or actual field experiences will allow for results applicable to law enforcement.

PURPOSE OF THE STUDY

The purpose of this study was to determine whether or not changes in the fundamental frequency (voice pitch), amplitude (relative intensity) and syllabic duration (measured in millisecond (ms) for prolongation of vocal utterances) of the human voice are useful in detecting deception. As previously indicated, studies have shown that people under stress, other than sorrow, have an increase in fundamental frequency and amplitude and a prolongation in syllabic duration (Alpert, et al., 1963; Fry, 1958; Hall and Hutchinson, 1976; Inbar, et al., 1977; Lieberman, 1959 and 1961; Lieberman and Michaels, 1962; McGlone and Hollien, 1976; Rubenstein, 1966; Simonov and Frolov, 1973). Therefore, in this study, vocal changes of persons under stress, specifically those being questioned during polygraph examinations for alleged involvement in criminal cases, were examined.

DEFINITION OF TERMS

The following definitions are provided to create a common basis for understanding the terms and phrases used in this study:

fundamental frequency- The frequency of the vocal fold vibration directly determines the lowest frequency (fundamental) of the sound which is produced. The human listener perceives the lowest frequency as the speaker's pitch. The pitch of the human voice is the subjective, psychological perception of sound frequency. Pitch can only be measured by asking listeners to make judgements, whereas, frequency is a physical parameter which can be measured by instruments.

amplitude- A waveform is an abstract representation of the displacement from rest of vibrating particles, through time. The amplitude of this displacement is correlated with intensity or power of the sound. Like frequency, the amplitude or correlated intensity of sound is a physical property of the acoustic signal which can be measured by an instrument. The intensity is directly related to its loudness; as the intensity increases, the sound is judged by listeners to be louder. Loudness then, is the subjective, psychological perception of intensity.

decibel- sound pressure or intensity is measured in decibel (dBSPL-sound pressure level and dBSIL-sound intensity level); it is one-tenth of a Bel, so named in honor of Alexander Graham Bell, the U.S.A. inventor of the telephone and educator of the deaf. The Bel is a logarithmic ratio between the sound pressure or the alternative intensity of a sound and a given reference, usually the threshold of hearing of a pure tone of 1 KHz.

syllabic duration- duration of uttered phonemes by an individual, either in isolation or in conjunction with other consonants and syllables, measured in millisecond (ms), thousandth of a second.

PM Analyzer- a microprocessor that analyzes speech sounds at real-time, displaying the fundamental frequency on the upper half of a split screen video monitor (interfaced with the PM Analyzer). The intensity is displayed on the lower half of the split screen with a second tracing representing the envelope of a speech wave (oscillographic display); this display permits the user to segment the speech temporarily on the screen, immediately. The measurement of this envelope of speech -

length, represents the syllabic duration according to a graphic scale.

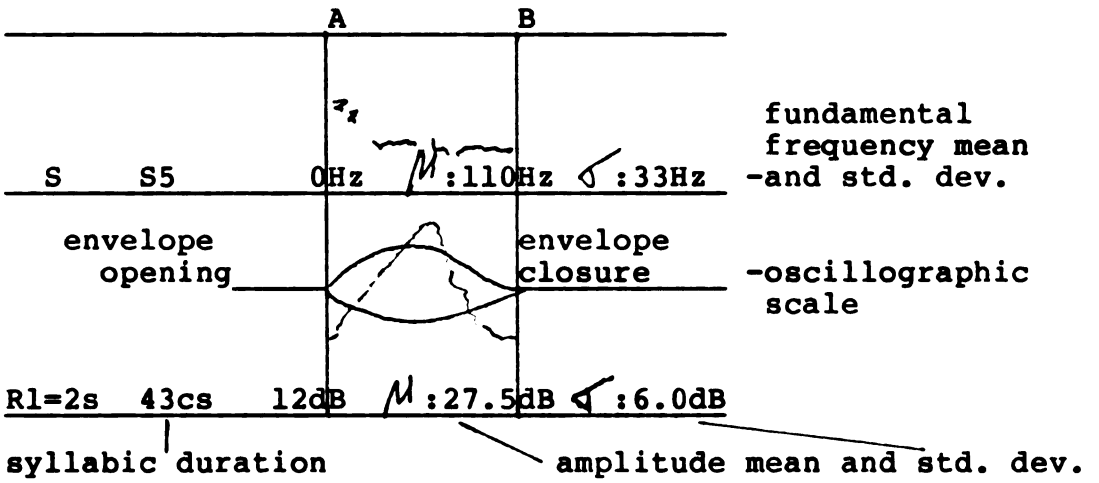

Figure 1. PM Analyzer Graph.

irrelevant questions- are questions asked by the polygrapher of the subject dealing with nonissue matters such as, "are you 21 years of age and did you drive here today?" These questions are asked during the testing in order to establish a so-called normal or baseline pattern.

relevant questions- are questions asked by the polygrapher dealing with the primary issue, such as "did you steal the money?" and "did you use a gun to kill John Doe?"

control questions- are questions asked by the polygrapher to the subject dealing with matters similar to, but of

presumed lesser significance than the offense being investigated, such as, "other than what you told me today, have you ever stolen anything else?

verified truth- a polygrapher, subsequent to testing the truthful subject, verifies his findings by obtaining a confession from another subject, or by receiving information from another criminal justice practitioner that a person has confessed to the crime.

verified deception- a polygrapher verifies his findings by obtaining a confession from the deceptive subject.

nonverified truth- a polygrapher concludes that the subject tested is truthful to the relevant issue; however no confession is obtained from any other subject, thereby not verifying the truthfulness of the subject tested.

nonverified deception- a polygrapher concludes that the subject tested is deceptive to the relevant issue, however, he/she does not confess to the crime or any involvement therein.

polygraphers control question theorem- when a deceptive person responds to a relevant question, the physio-

logical response (e.g.cardiovascular, pneumogastric and galvanic) is greater than the physiological response to a control question of presumed lesser significance; whereas truthful people respond with greater physiological response to a control question than to a relevant question.

Fourier analysis- a mathematical algorithm to analyze (break down) a complex wave into its component simple waves (pure tones of different frequencies and intensities). This analysis was discovered by J.B. Fourier, in France during the first quarter of the 19th century.

MANOVA- a multivariate analysis of variance. It is included in the Statistical Package for Social Sciences (SPSS).

RESEARCH QUESTIONS

The research questions in the present study are adapted from the review of literature related to polygraphy and speech sciences. This study addresses whether or not changes in the vocal parameters of the human voice are useful in detecting deception.

This study will examine whether or not the fundamental

frequency (voice pitch) changes, due to stress related to deception, when interviewed by a polygrapher for an alleged involvement in a crime. Furthermore, this study will examine two other vocal parameters, that of syllabic duration or prolongation of the vocal utterance and that of the vocal amplitude or relative intensity of the voice to determine whether or not these vocal parameters change due to stress related to deception.

HYPOTHESES TO BE TESTED

Based upon the research questions, the following testable hypotheses are hereby presented:

Hypothesis No. 1

Given the polygraphers control question theorem, the fundamental frequency (pitch measured in cycle/s=Hz.) of a deceptive person, when responding to a relevant question, will be greater then when responding to a control question and the fundamental frequency of a truthful person, when responding to a control question, will be greater then when responding to a relevant question.

Hypothesis No. 2

Given the polygraphers control question theorem, the amplitude (correlated to intensity measured in dBSPL) of a deceptive person, when responding to a relevant question, will be greater then when responding to a control question and the amplitude of a truthful person, when responding to a control question, will be greater then when responding to a relevant question.

Hypothesis No. 3

Given the polygraphers control question theorem, the syllabic duration (prolongation of a vocal utterance measured in ms) of a deceptive person, when responding to a relevant question, will be greater then when responding to a control question and the syllabic duration of a truthful person, when responding to a control question, will be greater then when responding to a relevant question.

II. REVIEW OF RELATED LITERATURE

A review of literature provides insight regarding previous methods of detecting deception, present day methods of detecting deception and experimental advances toward increasing ones knowledge of the present state of the art. This review further presents an outlook to future methods of detecting deception by using physiological responses of the human voice.

The review of related literature is organized under three major headings: Polygraph, Acoustics of Speech Production and Psychological Emotion.

POLYGRAPH

The first attempt to use a scientific instrument in an effort to detect deception occurred about 1895, when Cesare Lombroso published an account of several experiments. Encouraged by the reported successes of his predecessors, John A. Larson, in 1921, constructed an instrument capable of continuously recording all three phenomena: blood pressure, pulse and respiration. In 1926, Leonarde Keeler constructed a more satisfactory instrument than the one used by Larson and is generally credited with developing the prototype of

the polygraph instrument now used in most field settings. In 1949, Keeler made some additional changes, adding a galvanometer for recording what is known as the galvanic skin reflex or electrodermal response (G.S.R.).

Horvath (1976, p.109) has indicated that there has been success at detecting deception by other measurements of physiological activity:

> "such as hand tremors, electroencephalic activity, pupil dilation, oculomotor activity, voice modulation and oxygenation of the vascular system. What is now agreed upon by field examiners is that any attempt at detecting deception must be made with an instrument that records both cardiovascular and respiratory activity. It is in fact illegal in some states for a detection of deception examiner to use an instrument not capable of recording these two parameters, although others, particularly electrodermal activity, are also commonly recorded in conjunction with them."

The measure which has shown the greatest success in discriminating between truthfulness and deception in laboratory studies has been electrodermal activity, including the skin resistance response (SRR), (Ellson, et al., 1952; Thackray and Orne, 1968) and the skin potential response (SPR), (Lindsley, 1955; Thackray and Orne, 1968). Yet the most influential field examiners consider electrodermal activity

to be the least effective of the measures used in the field (Arthur, 1971; Lee, 1953; Marston, 1938; Reid and Inbau, 1966).

Field Procedures in Polygraph Testing

The polygraph examination consists of three stages: the pre-test interview, the testing stage and the post-test interrogation, when appropriate. However, no test should ever be conducted without an interview with the investigators. Unless a polygrapher is fully informed about the case, he/she will not be in a position to conduct an adequate pre-test interview with the subject.

Pretest Interview

While there are differences between pre-test interviews from one polygrapher to another, the differences lie in the nature of the objectives formulated during the interview with the investigators and the knowledge the polygrapher gains by learning the case facts and background of the subject. There are irrelevant questions, those used for establishing a normal or truth-telling response dealing with such matters as: are you 21 years of age and did you drive here today? There are relevant questions, those which

pertain to the matter under investigation: such as, did you shoot Mary Smith and did you use a gun to kill Mary Smith? Control questions, are those resulting from past behavior of the subject and what was learned about the subject during the pre-test interview. In general, they deal with matters similar to, but of presumed lesser significance than the offense being investigated. An example might be: did you ever steal anything else, other than what you told me today, or other than what you told me today, have you ever lied to another to avoid getting caught? The polygrapher develops these questions in such a way that the subject will answer no, but will, in all probability be lying or at least will have some doubt or concern about the truthfulness or accuracy of his answer (Horvath, 1976). The control questions work to the advantage of the innocent subject by diverting him/her from the relevant questions and focusing his/her concerns on the control questions. On the other hand, the guilty subject will be more concerned about the relevant questions than the lies that he makes about inconsequential or irrelevant issues.

The irrelevant, relevant and control questions are established during this pretest interview. With the completion of the review of all questions, the pre-test interview draws

to a close and the transition is made to the data acquisition phase of the examination.

Actual Testing

In polygraphic testing, the polygrapher asks the subject the previously reviewed irrelevant, relevant and control questions in a series of polygraph tests. Each test generally consists of about ten or eleven questions: four irrelevant, two control and four or five relevant questions and will usually last about three minutes. A complete examination consists of several of these tests administered before a determination of deception is made. It is often claimed that response data contained in the first two tests are sufficient to indicate the subject's truthfulness or deception.

Post Test

If the testing reveals no indication of deception, the subject is thanked for his/her cooperation and released. Depending upon the polygrapher and the situation, the subject may be told that the results will be given to the investigators when they become available. The latter maneuver permits more control over the subsequent investigation. If the

examination indicates that the subject was lying to one or more of the relevant questions, he/she is usually interrogated in order to seek an admission of involvement in the issue under investigation.

ACOUSTICS OF SPEECH PRODUCTION

Speech sounds are produced by resonance of glottal vibrations and/or friction noise in the vocal tract and nasal cavities. The vocal cords vibrate medially and the vibratory cycle of being forced apart and then returning to the medial position creates a complex wave.

The frequency vibration of a simple wave is measured in Hertz (Hz) in honor of Dr. Heinrich R. Hertz, the physicist who investigated electromagnetic vibrations. The lowest frequency (fundamental) as well as the frequency of a periodic speech wave uttered by a speaker is perceived as the "pitch" of the speaker's voice.

The fundamental frequency of a speaker's voice is easily determined by voice analysis equipment (e.g. sound spectrograph, pitch meters and the PM Analyzer), it is measured in Hz. Since Frequency is perceived as pitch, the higher the frequency of a sound the higher the perceived pitch.

The frequency range of speech sounds (complex waves) goes from approximately 100 to 7000 Hz. Most spectral information regarding speech, including talker-dependent features, is found within a range of 100 to 4000 Hz. A human ear in optimal conditions can perceive vibration from 20 to 20,000 Hz. as sound, providing that the amplitude (intensity) is above threshold.

Amplitude is the maximum displacement of equilibrium within the elastic medium. Amplitude (intensity) is perceived as loudness, usually measured in decibel (dB), which is a logarithmic ratio between the intensity (or alternative pressure) of the sound being measured and a given reference, usually the threshold of hearing at 1000 Hz.

When speaking, an individual tends to establish his/her own intensity level of response and when an emotional stimuli is introduced, there arises a tendency to depart from a pre-set level of response and the stress responses tend to be less like each other. Some individuals respond by increasing the intensity of the voice, while others decrease their intensity (Friedhoff, et al., 1962). Even when a lie was condoned by an experimenter, the emotional stimuli was still sufficient to produce measureable changes; however, "these cues may be more relevant for the trained clinician in

evaluating the emotional state of his patient than the usually measured silent systems such as skin resistance and blood pressure." (Alpert, et al., 1963, p.365).

PSYCHOLOGICAL EMOTION

The third area of study involves emotional or psychological stimuli. It has been found that the effects of emotion on acoustic characteristics of speech show that average values and ranges of fundamental frequency differ from one emotion to another. In a study by Williams and Stevens (1972), they reported that the lowest fundamental frequency was obtained for the emotion of sorrow (usually lower than that for neutral situations), and the highest was for anger. Lehiste and Peterson (1959) found that fundamental frequency and syllabic duration were among the most commonly cited parameters that influence a listener's judgement about stress. Coker, et al.,(1973, p.440) reported that:

> "Newly introduced improbable words (ambiguous speech or that which is indistinct) that are difficult to guess from context, produce high stress within the speaker. The first occurrence of an unlikely noun, verb or other substantive is pronounced slowly and distinctively with almost emphatic pitch values.. subsequent repetitions of the word, showed pitch and other attributes of stress were diminished."

Malcolm Brenner (1974) reported that stress does occur within an individual and is ever increasing as a power function of audience size. In other words, as the number of listening people increases, a speaker's psychological stress increases. In another study performed by Hall and Hutchinson (1976) there was found an increase in fundamental frequency and a prolongation of syllabic utterances for each speaker tested, when they read a slurvian passage (phonetic sequences involving improbable word combinations).

Simonov and Frolov (1973) investigated voice frequency as related to physical and emotional well-being of pilots and cosmonauts, as well as actors. Their method of study using a one-third octave spectral analyzer permitted them to differentiate adequately the degree of emotional stress in 85 percent of all the cases, without singling out separate sounds, which is very important in real conditions, especially in the presence of ambient distortions in EMG output.

Body movements and voice pitch were studied by Ekman, et al., (1976) using sixteen student nurses in an interview process, where each subject watched a short film and then was asked questions concerning her feelings about it. One film was a pleasant feeling nature film and the other was a

film showing amputations and burns that intended to elicit a strong unpleasant effect. However, they were instructed to conceal their negative feelings and convince the interviewer they had seen another pleasant film. In deception regarding the second film being a pleasant effect, there was a significant decrease in illustrators ($p < 0.05$), a trend for an increase in shrugs ($p < 0.10$), an increase in pitch ($p < 0.05$), and no change in adaptors or total hand activity. Low pitch was associated with observers' judgements that a person was sociable, calm and relaxed, whereas, negatively correlated with illustrators (Rho = -0.61, $p < 0.01$), pitch became higher in deceptions.

A study of pitch changes during attempted deceptions was conducted by Streeter, et al., (1977) using 32 pairs of male college undergraduates. The students were paired as interviewer and interviewee unknown to each other. The interviewee was told to lie to certain questions asked. The interviewer did not know which questions the interviewee lied about. On the average, fundamental frequency was 3.3 Hz. higher when the subjects lied than when they told the truth.

III. RESEARCH METHODS AND PROCEDURES

This chapter is divided into four categories: population and sample, instrumentation and data collection, types of questions for analysis and data analysis.

POPULATION AND SAMPLE

The population for this study consisted of general American mid-western speaking individuals from southern-lower Michigan. The individuals recorded were male and female subjects being tested by ten licensed polygraph examiners of the Michigan State Police Forensic Science Division. The individuals were tested for their alleged involvement in crimes of the State and each individual volunteered to be audio tape recorded during their polygraph examination.

After the initial introduction of the goals and objectives of the study, it was explained to each polygrapher the importance of the subjects being tested, for them to give their complete cooperation and for the polygrapher to keep the identity of the subject tested in strict confidence by omitting his/her identity from the audio tape recordings. The "Permission to Tape Record Polygraph Sessions" form was explained and provided to the polygraphers to present before each individual for their perusal and signing.

Table 1. Permission to Tape Record Polygraph Session

I hereby give the Michigan State Police permission to tape record the pre-test interview and actual polygraph examination. All tape recordings are to be used for research purposes and will be identified by number with names being kept in strict confidence. Participation is strictly voluntary.

The tape recordings will have no bearing on the polygraph examination being conducted, but will be used only for testing present and future voice analyzers for detecting deception.

Signed and Date_____

Witness:_____

The objective was to obtain a minimum of 25 verified truthful and 25 verified deceitful audio tape recordings of polygraph subjects being tested. Many more recordings were obtained initially by the polygraphers and submitted to the researcher because some verifications could only be made after other tests were run by the examiner or after time had passed in the investigation. Therefore, non-verified audio tape recorded polygraph examinations were also received by the researcher for analysis.

For the purpose of this study, verified deceptive audio tape recorded polygraph examinations are only those examinations where, subsequent to polygraph testing, the subject being tested confesses to the polygrapher or confesses to another

criminal justice practitioner, as having committed or being involved in the crime that he initially denied. A verified deceitful examination would not exist , if a judge or jury found the subject guilty, while the individual maintained his/her innocence, or if some plea bargaining was accomplished by the prosecutor. A verified truthful subject is one being verified by the polygrapher after receiving a confession from another subject, or by the polygrapher receiving information from another criminal justice practitioner that another person had confessed to the crime subsequent to the first subject being tested as truthful.

INSTRUMENTATION AND DATA COLLECTION

Pearlcorder, Model ME5 remote condenser microphones (Lavaliere type) were placed two to three inches from each individual's mouth during the polygraph examination in order to assure quality voice recordings. The microphones were ultra light and compact so that they could easily be attached to the upper pneumographic tube placed around the individuals' upper chest. With the subjects eyes closed and head slightly bent downward during the testing period, the sensitive microphones had no difficulty transducing the subjects' voice to the tape recorder.

The tape recorders used were Sony brand, portables, using standard size cassettes (Sony LNC 90) at a taping speed of 1-7/8 ips. This size tape provided 45 minutes recording time per side, which was sufficient to record both control question tests, which usually lasts less than ten minutes.

A preliminary analysis was performed in order to ascertain whether or not the recordings were of sufficient quality to be used on the PM Analyzer. Some recordings were found to be of insufficient quality due to ambient noise (e.g. air conditioner/heat duct noise and/or motor traffic noise outside the building bleeding through the windows and doors) and recording techniques (e.g. improper grounding causing a 60 cycle hum masking the speech signal, or the polygrapher forgetting to turn the microphone on, and/or putting the recorder into play mode instead of the record mode).

A total of 125 subjects (47 confession-verified deceptive, 33 verified truthful, 24 nonverified deceptive and 21 non-verified truthful) were utilized for analysis, as to their truthfulness or deception. The reason for having more subjects than proposed was that verifications came in slowly and voice analysis was performed on all quality audio tape recordings as they were received from the polygraphers, contemplating subsequent verification. The audio tape

recordings that were determined to be of sufficient quality were transfered to the PM Analyzer by hardwire for proper transfer of the speech signal without ambient noise interfering.

The PM Analyzer displays (Figure 1, page 15) simultaneously the fundamental frequency on the upper half of a split-screen video monitor (interfaced with the PM Analyzer) and the intensity on the lower half of the split-screen video monitor, along with a second tracing representing the envelope of speech (oscillographic display) that permits the user to segment the speech on the screen immediately. Two cursors move from point A (opening of the envelope of speech) to point B (closing of the envelope of speech). The analyzer instantly reads on-screen the mean values of the fundamental frequency and the amplitude (intensity) of the utterance. There is also a digital display of the standard deviation of both frequency and amplitude. The slow sweep of the screen display allows for measurement of phonemic sounds (e.g. syllables and consonants) over-time in milliseconds (msec.) and depict a speakers' prolongation of speech sounds.

Since the PM Analyzer analyzes at real-time, it was decided to interface the video output with a thermal printer, for

reasons of efficiency and expediency. A Mitsubishi P50U Video Printer was used for this study because it produces hard copies within 15 seconds. The reproduction is an exact image of the video screen. These reproductions are on a continuous roll of paper, so that many polygraph test question responses can be examined and the records kept on each test with little difficulty.

QUESTIONS FOR ANALYSES

Prior to statistical analysis, contact was made with each polygrapher to ascertain which relevant question was the primary question covering the issue. The primary relevant question was the question that the verified deceitful subject confessed to and/or the verified truthful subject was found to have no knowledge about or to have committed. A primary relevant question on a crime of auto theft would be, "did you steal the auto?" or a primary knowledge relevant question for the same test would be, "do you know who stole the auto?"

The primary control question that was compared to the primary relevant question was also determined from each polygrapher. The primary control question would be similar to the primary relevant question, only with lesser

significance. In the above example of an auto theft, a primary control question might be: "other than what you told me today about your past behavior, have you ever stolen anything else in your life?" This question for a deceptive person, theoretically would have lesser significance than the actual auto theft issue, thereby providing less stress in his/her voice; whereas the truthful subject, theoretically will have enough concern about his/her past behavior, so that his/her answer will provide greater stress in their voice for the less significant question.

Michigan law requires at least two control question tests be given each individual examined by polygraph. Other tests may be given during the polygraph examination. However the number of tests given will depend upon the factors mentioned in the first chapter, where the differences between field and laboratory examinations were discussed. The individuals interaction with the examiner, modes of compliance, resentment towards being tested and/or polygraph technique in general.

For the purpose of analysis, two control tests per individual were used with one primary relevant question response compared to one primary control question response.

Each individual tested was asked by the polygrapher to respond with a one word "yes" or a one word "no." They were asked not to nod their head, repeat "uh, uh," "no I didn't," "yes I did," or any like response. Each subjects' verbal response to the primary relevant, primary control and relevant knowledge questions asked in test numbers one and two, produced individual data for each of the three vocal parameters (fundamental frequency, amplitude and syllabic duration).

The knowledge-relevant type question responses by the individuals were determined to be predominantly located in the category of verified deceptive and nonverified truthful subjects tested; however not enough of these type questions were asked each subject in order to provide sufficient data for testing. The knowledge-relevant question means and standard deviations are located in Appendix G.

DATA ANALYSIS

The fundamental frequency of the individuals' voice was considered the measurement recorded in cycles per second, commonly called Hertz (Hz). The Amplitude of the individuals' voice likewise was considered the measurement recorded in decibel (dB), a logarithmic ratio between the

intensity of the sound uttered and a given reference, usually the threshold of hearing. Syllabic duration of the individuals' voice, the third parameter measured was considered the individuals' prolonged voiced sound as a result of the response to the questions asked by the polygrapher and was measured in milliseconds (ms), thousandth of a second.

These measurements of the human voice for each primary relevant, primary control and relevant knowledge question became the raw data used for the statistical analysis. A computer Statistical Package for Social Sciences (SPSS) was used to analyze the raw data collected.

Arithmetic means and the standard deviations were calculated for each vocal parameter for each relevant question and each control question response on each of two control question tests for all verified and nonverified subjects. A multivariate analysis of variance (MANOVA) with repeated measures of a proportional design was computed on each of the vocal parameters for each of the two tests and the combined measurements of both tests. The level of significance established for this study is 0.05.

IV. FINDINGS

The data analyses are presented in this chapter and analyzed according to the procedures described in Chapter III. The analyses are organized into two categories: verified and nonverified subjects. Each of the hypotheses presented in Chapter I is examined, using each vocal parameter (fundamental frequency, amplitude and syllabic duration) for each test.

The polygraphers control question theorem, states that a deceptive person's physiological response to a relevant question is greater than his/her response to a control question and a truthful persons physiological response to a control question is greater than his/her response to a relevant question. Therefore, it would be expected that the fundamental frequency, the amplitude and the syllabic duration of deceptive persons should show an increase when responding to relevant questions, greater then when responding to control questions. The same vocal parameters of truthful persons should show an increase when responding to control questions, greater then when responding to relevant questions.

FUNDAMENTAL FREQUENCY

The first hypothesis is that the fundamental frequency

(pitch measured in cycle/s=Hz) of a deceptive person, when responding to a relevant question, will be greater then when responding to a control question and the fundamental frequency of a truthful person, when responding to a control question, will be greater then when responding to a relevant question.

The rationale for this hypothesis is that studies show that a person under emotional stress has an increase in his/her fundamental frequency; therefore, a deceptive person lying to a relevant question under emotional stress due to a fear of losing his/her freedom, will have an increase in his/her fundamental frequency.

Verified Subjects

The first hypothesis was tested by using the fundamental frequency means of 33 verified truthful and 47 verified deceptive subjects' vocal responses to relevant and control questions. If the hypothesis is true, it would be expected that the interaction between the types of questions (control and relevant) and the types of subjects (truthful and deceptive) would prove statistically significant, thus supporting the hypothesis. The statistical results are shown in tables two through four with the complete MANOVA

tables located in appendices A, B and E.

Table two shows the fundamental frequency means and standard deviations for verified subjects on test one, with the results of the interaction effect proving significant [F(1,77)= 11.16, P=0.0008]; therefore as predicted, deceptive subjects responding to relevant questions showed a greater fundamental frequency then when responding to control questions and truthful subjects responding to control questions showed a greater fundamental frequency then when responding to relevant questions.

Table 2. Fundamental Frequency Means and Standard Deviations for Verified Subjects on Test One.

Type of Examination	Type of Question	
	Relevant	Control
Truthful		
Mean	123.8	134.9
s.d	37.7	39.6
Deceptive		
Mean	112.8	111.5
s.d.	27.9	25.7

Question Type: F(1,77)= 4.44425,P=0.038
Exam Type: F(1,77)= 5.82127,P=0.018
Quest Type/Exam Type: F(1,77)= 11.16292, P= 0.0008

Table three shows the fundamental frequency means and standard deviations for verified subjects on test two with the results of the interaction effect [F(1,77)= 2.135,

0.148], not proving significant. Although the interaction effect was not statistically significant, the subjects' responses were in the predicted direction.

Table 3. Fundamental Frequency Means and Standard Deviations for Verified Subjects on Test Two.

Type of Examination	Type of Question: Relevant	Control
Truthful		
Mean	126.4	128.3
s.d.	39.7	39.6
Deceptive		
Mean	113.5	112.8
s.d.	27.2	27.0

Question Type: F(1,77)= 0.23353, P=0.630
Examination Type: F(1,77)= 3.65488, P=0.060
Quest. Type/Exam Type: F(1,77)= 2.13548, P= 0.148

Table four shows the fundamental frequency means and standard deviations for verified subjects on the combined tests, one and two, with the results of the interaction effect [F(1,78)= 3.065, P= 0.084], not proving significant. However, the results were in the predicted direction and approached statistical significance.

Table 4. Fundamental Frequency Means and Standard Deviations for Verified Subjects on Combined Tests, One and Two.

Type of Examination	Type of Question	
	Relevant	Control
Truthful		
Mean	125.1	132.0
s.d.	39.0	40.0
Deceptive		
Mean	113.1	113.0
s.d.	28.0	27.3

Question Type: F(1,78)= 4.45956, P= 0.038
Examination Type: F(1,78)= 5.51173, P= 0.021
Quest. Type/Exam Type: F(1,78)= 3.06490, P= 0.084

Nonverified Subjects

The first hypothesis was also tested by using the fundamental frequency of 21 nonverified truthful and 24 nonverified deceptive subjects vocal responses to relevant and control questions. If the hypothesis is true, it would be expected that the interaction between the types of questions and the types of examined subjects would prove statistically significant. The statistical results are shown in tables five through seven, with the complete MANOVA tables located in appendices C,D and F.

Table five shows the fundamental frequency means and standard deviations for nonverified subjects on test one,

with the results of the interaction effect [F(1,43)= 0.09887, P= 0.755], not proving significant, although they were in the predicted direction.

Table 5. Fundamental Frequency Means and Standard Deviations for Nonverified Subjects, Test One.

Type of Examination	Type of Question: Relevant	Control
Truthful		
Mean	134.8	135.8
s.d.	34.3	29.8
Deceptive		
Mean	133.9	133.5
s.d.	35.3	39.7
Question Type: F(1,43)= 0.01347, P= 0.908		
Examination Type: F(1,43)= 0.02292, P= 0.880		
Quest. Type/Exam Type: F(1,43)= 0.09887, P= 0.755		

Table six shows the fundamental frequency means and standard deviations for nonverified subjects on test two, with the results of the interaction effect [F(1,43)= 6.13, P= 0.017], proving significant. The interaction effect supported the control question theory providing evidence that truthful subjects showed a greater fundamental frequency when responding to control rather than relevant questions and deceptive subjects showed a greater fundamental frequency when responding to relevant rather than control questions.

Table 6. Fundamental Frequency Means and Standard Deviations for Nonverified Subjects, Test Two.

Type of Examination	Type of Question: Relevant	Control
Truthful		
Mean	132.6	138.3
s.d.	35.9	33.5
Deceptive		
Mean	132.2	126.0
s.d.	39.9	36.8

Question Type: F(1,43)= 0.07201, P= 0.790
Examination Type: F(1,43)= 0.35496, P= 0.554
Quest. Type/Exam Type: F(1,43)= 6.13417, P= 0.017

Table seven shows the fundamental frequency means and standard deviations for nonverified subjects on the combined tests, one and two, with the results of the interaction effect [F(1,43)= 6.447, P= 0.015], proving significant.

Table 7. Fundamental Frequency Means and Standard Deviations for Nonverified Subjects, Combined Tests, One and Two.

Type of Examination	Type of Question: Relevant	Control
Truthful		
Mean	134.0	137.1
s.d.	35.1	31.6
Deceptive		
Mean	133.1	130.0
s.d.	38.0	38.2

Question Type: F(1,43)= 0.02361, P= 0.879
Examination Type: F(1,43)= 0.14914, P= 0.701
Quest. Type/Exam Type: F(1,43)= 6.44713, P= 0.015

AMPLITUDE

The second hypothesis states that the amplitude (correlated to intensity measured in dBSPL) of a deceptive person, when responding to a relevant question, will be greater then when responding to a control question and the amplitude of a truthful person, when responding to a control question, will be greater then when responding to a relevant question.

The rationale for this hypothesis is that studies show that people under emotional stress have an increase in their amplitude; therefore, a deceptive person lying to a relevant question under emotional stress due to a fear of losing his/her freedom, will have an increase in his/her amplitude on the relevant question as opposed to a control question.

Verified Subjects

The second hypothesis was tested by using the amplitude means of 33 verified truthful and 47 verified deceptive subjects' vocal responses to relevant and control questions. If the hypothesis is true, it would be expected that the interaction between the types of questions (control and relevant) and the types of examined subjects (truthful and deceptive) would prove statistically significant, thus

supporting the hypothesis; however, the interaction effect, though in the predicted direction, did not prove significant for the verified subjects. Since the amplitude did not prove significant the statistical results will not be described in detail, but are shown in tables eight through ten, with the complete MANOVA tables located in appendices A, B and E.

Table 8. Amplitude Means and Standard Deviations for Verified Subjects on Test One.

Type of Examination	Type of Question: Relevant	Type of Question: Control
Truthful		
Mean	24.4	24.5
s.d.	3.5	3.4
Deceptive		
Mean	25.8	25.7
s.d.	3.3	3.0

Question Type: F(1,77)= 0.04261, P=0.837
Examination Type: F(1,77)= 3.15684, P=0.080
Question Type/Exam Type: F(1,77)= 0.08427,P= 0.772

Table 9. Amplitude Means and Standard Deviations for Verified Subjects on Test Two.

Type of Examination	Type of Question: Relevant	Type of Question: Control
Truthful		
Mean	24.4	24.5
s.d.	3.8	3.6
Deceptive		
Mean	25.6	25.5
s.d.	3.5	3.2

Question Type: F(1,77)= 0.00023, P=0.988
Examination Type: F(1,77)= 1.92493, P=0.169
Quest. Type/Exam Type: F(1,77)= 0.21716, P= 0.643

Table 10. Amplitude Means and Standard Deviations for Verified Subjects on Combined Tests, One and Two.

Type of Examination	Type of Questions Relevant	Control
Truthful		
Mean	24.4	25.0
s.d.	3.6	3.5
Deceptive		
Mean	25.7	25.6
s.d.	3.4	3.1

Question Type: F(1,78)= 0.49790, P= 0.483
Examination Type: F(1,78)= 0.80540, P=0.372
Quest. Type/Exam Type: F(1,78)= 0.13048, P= 0.719

Nonverified Subjects

The second hypothesis was also tested by using the amplitude of 21 nonverified truthful and 24 nonverified deceptive subjects vocal responses to relevant and control questions. If the hypothesis is true, it would be expected that the interaction between the types of questions and the types of examined subjects would prove statistically significant. However, the interaction effect though in the predicted direction with the exception of the nonverified truthful subjects on test two (Table 12), did not prove significant for the nonverified subjects; statistical results will not be described in detail, but are shown in tables eleven through thirteen, with the complete MANOVA tables located in appendices C, D and F.

Table 11. Amplitude Means and Standard Deviations for Nonverified Subjects, Test One.

Type of Examination	Type of Question	
	Relevant	Control
Truthful		
Mean	24.7	25.1
s.d.	4.9	4.3
Deceptive		
Mean	25.3	24.7
s.d.	3.3	3.5

Question Type: F(1,43)= 0.20700, P= 0.651
Examination Type: F(1,43)= 0.00579, P= 0.940
Quest. Type/Exam Type: F(1,43)= 2.26013, P= 0.140

Table 12. Amplitude Means and Standard Deviations for Nonverified Subjects, Test Two.

Type of Examination	Type of Question	
	Relevant	Control
Truthful		
Mean	24.1	23.9
s.d.	5.3	4.8
Deceptive		
Mean	25.3	24.9
s.d.	3.8	3.9

Question Type: F(1,43)= 0.84899, P= 0.362
Examination Type: F(1,43)= 0.64366, P= 0.427
Quest. Type/Exam Type: F(1,43)= 0.07964, P= 0.779

Table 13. Amplitude Means and Standard Deviations for Non-Verified Subjects on Combined Tests, One and Two.

Type of Examination	Type of Questions Relevant	Control
Truthful		
Mean	24.4	25.0
s.d.	5.1	5.0
Deceptive		
Mean	25.3	25.0
s.d.	4.0	4.0

Question Type: $F(1,43)= 1.08196$, $P= 0.304$
Examination Type: $F(1,43)= 0.22005$, $P= 0.641$
Quest. Type/Exam Type: $F(1,43)= 1.77549$, $P= 0.190$

SYLLABIC DURATION

The third hypothesis states that the syllabic duration (prolongation of a vocal utterance measured in ms) of a deceptive person, when responding to a relevant question, will be greater then when responding to a control question and the syllabic duration of a truthful person, when responding to a control question, will be greater then when responding to a relevant question.

The rationale for this hypothesis is that studies show that people under emotional stress have an increase in their syllabic duration; therefore, a deceptive person lying to a relevant question under emotional stress due to fear of

losing his/her freedom, will have an increase in his/her syllabic duration on the relevant question as opposed to a control question.

Verified Subjects

This hypothesis was tested by using the syllabic duration means of 33 verified truthful and 47 verified deceptive subjects' vocal responses to relevant and control questions. If the hypothesis is true, it would be expected that the interaction between the types of questions (control and relevant) and the types of examined subjects (truthful and deceptive) would prove statistically significant. The interaction effect did not prove significant for the verified subjects. However, the main effect for the type of examined subjects (truthful and deceptive) on tests one, two and the combined measurements of tests one and two showed that the verified deceptive subjects had a significantly greater syllabic duration than the verified truthful subjects. This does not reflect the control question theory and no predictions were made relative to the main effects.

Statistical results of the sample means and the effects of the interaction between the types of questions and the types of examinations will not be described in further detail, but

are shown in tables fourteen through sixteen, with the complete MANOVA tables located in appendices A, B and E.

Table 14. Duration Means and Standard Deviations for Verified Subjects on Test One.

Type of Examination	Type of Question: Relevant	Control
Truthful		
Mean	37.9	36.7
s.d.	8.3	7.8
Deceptive		
Mean	42.7	42.0
s.d.	10.7	9.2

Question Type: F(1,77)= 1.23721, P=0.270
Examination Type: F(1,77)= 6.88489, P=0.011
Quest. Type/Exam Type: F(1,77)= 0.02038, P= 0.887

Table 15. Duration Means and Standard Deviations for Verified Subjects, Test Two.

Type of Examination	Type of Question: Relevant	Control
Truthful		
Mean	37.1	38.1
s.d.	8.5	9.6
Deceptive		
Mean	42.7	42.4
s.d.	11.3	10.3

Question Type: F(1,77)= 0.09594, P=0.758
Examination Type: F(1,77)= 5.34759, P=0.023
Quest. Type/Exam Type: F(1,77)= 0.55133, P= 0.460

Table 16. Duration Means and Standard Deviation for Verified Subjects on Combined Tests, One and Two.

Type of Examination	Type of Questions Relevant	Control
Truthful		
Mean	38.0	37.4
s.d.	8.4	8.7
Deceptive		
Mean	43.0	42.2
s.d.	11.0	9.8

Question Type: F(1,78)= 0.00884, P= 0.925
Examination Type: F(1,78)= 4.39024, P= 0.039
Quest. Type/Exam Type: F(1,78)= 0.00065, P= 0.980

Nonverified Subjects

The third hypothesis was also tested by using the syllabic duration of 21 nonverified truthful and 24 nonverified deceptive subjects vocal responses to relevant and control questions. If the hypothesis is true, it would be expected that the interaction between the types of questions and the types of examined subjects would prove statistically significant. The interaction effect did not prove significant for nonverified subjects; therefore, the statistical results will not be described in detail, but are shown in tables seventeen through nineteen, with the complete MANOVA tables located in appendices C, D and F.

Table 17. Duration Means and Standard Deviations for Nonverified Subjects, Test One.

Type of Examination	Type of Question: Relevant	Type of Question: Control
Truthful		
Mean	37.1	36.4
s.d.	8.1	8.4
Deceptive		
Mean	39.5	38.0
s.d.	7.8	8.1

Question Type: F(1,43)= 1.95654, P= 0.169
Examination Type: F(1,43)= 0.77840, P= 0.383
Quest. Type/Exam Type: F(1,43)= 0.25740, P= 0.615

Table 18. Duration Means and Standard Deviations for Nonverified Subjects, Test Two.

Type of Examination	Type of Question: Relevant	Type of Question: Control
Truthful		
Mean	37.3	36.7
s.d.	7.8	8.8
Deceptive		
Mean	40.8	39.0
s.d.	9.0	7.5

Question Type: F(1,43)= 1.41385, P= 0.241
Examination Type: F(1,43)= 1.71324, P= 0.198
Quest. Type/Exam Type: F(1,43)= 0.33414, P= 0.566

Table 19. Duration Means and Standard Deviations for Non-Verified Subjects on Combined Tests, One and Two.

Type of Examination	Type of Questions Relevant	Control
Truthful		
Mean	37.2	37.0
s.d.	8.0	9.0
Deceptive		
Mean	40.2	39.0
s.d.	8.4	8.0

Question Type: F(1,43)= 2.82427, P= 0.100
Examination Type: F(1,43)= 1.34568, P= 0.252
Quest. Type/Exam Type: F(1,43)= 0.52128, P= 0.474

V. DISCUSSION AND IMPLICATIONS

The purpose of this study was to determine whether or not changes in the fundamental frequency (pitch measured in cycle/s=Hz), amplitude (correlated to intensity measured in dBSPL) and syllabic duration (prolongation of vocal utterances) of the human voice are useful in detecting deception. More specifically, this study examined vocal changes of subjects being questioned during polygraph examinations for alleged involvement in criminal cases. The changes resulting from vocalized responses to relevant questions were compared to those resulting from responses to control questions to determine if the changes were useful in discriminating between truthful and deceptive persons as set forth in the control question theory of polygraph testing.

In this chapter the research findings as they relate to previously mentioned research will be discussed. What these findings imply for future research and for educating and training present-day polygraphers, also will be discussed.

Earlier studies involving human speech under emotional stress depicted changes in the vocal parameters (i.e. fundamental frequency, amplitude and syllabic duration) based upon listener perceived judgements and muscular and acoustical measurements involving stress caused by

electrical shock, actors portraying emotional trauma and a few real-life stressful situations. Studies performed by Coker, et al., 1973; McGlone and Hollien, 1976; Simonov and Frolov, 1973; and Williams and Stevens, 1972 concerned themselves with the changes in fundamental frequency of the human voice due to psychological stress. Changes in amplitude along with the fundamental frequency was examined by Rubenstein in 1966 and changes in the syllabic duration along with the fundamental frequency was examined by Lehiste and Peterson in 1959 and by Hall and Hutchinson in 1976. Changes in all three vocal parameters (fundamental frequency, amplitude and syllabic duration) were studied by Fry, 1958; Lieberman, 1959 and 1961 and Lieberman and Michaels in 1962. Though all studies related changes in the vocal parameters to psychological stress, none of these studies related changes in the human voice to stress due to deception.

Relatively few studies to date involve changes in the fundamental frequency and amplitude of the human voice in detecting deception. Syllabic duration, until now, has never been used in studies for measuring stress related to deception. Studies to date (Alpert, et al., 1963; Ekman, et al., 1976; Friedhoff, et al., 1962 and Streeter, et al., 1977) have chosen a single vocal parameter, either the

fundamental frequency or amplitude to test for stress related to deception.

Ekman, et al.,(1976) and Streeter, et al.,(1977) examined the fundamental frequency (pitch measured in cycle/s=Hz) and found that when subjects were deceptive there was an increase in their fundamental frequency. For example, the subjects tested in both of these studies were instructed to lie to some questions and to tell the truth to other questions; the vocal responses of these individuals were measured and an increase of their fundamental frequency occurred when the individual's lied as opposed to telling the truth. The present study differed from these two studies in that the subjects tested chose of their own volition to be truthful or deceptive as opposed to being given instructions to lie or to tell the truth. Secondly, the subjects in the present study were suspected of committing or being involved in committing a crime, therefore, they were under a presumed higher motivation to be truthful or deceptive as opposed to a presumed lower level of stress from less consequential laboratory situations. Finally, this present study differed from Ekman, et al., (1976) and Streeter, et al.,(1977) studies by measuring the changes in the fundamental frequency as a result of the control question theory.

Given these circumstances in which the present study was conducted the findings confirm and extend the knowledge gained through the Ekman, et al.,(1976) and Streeter, et al.,(1977) studies. That is, the fundamental frequency of the human voice is not only useful in detecting deception within the laboratory, but also in actual field situations using the control question theory.

Like the present study, Alpert, et al.,(1963) and Friedhoff, et al.,(1962) examined the vocal intensity (amplitude, correlated to intensity and measured in dBSPL) of the human voice. In their studies, they found that even when a lie was condoned by the experimenter the vocal stress was sufficient to produce measureable changes. In the present study, the changes in amplitude did not reliably distinguish between people who lied or told the truth. Perhaps the use of control question testing prevented significant changes in amplitude for depicting truth and deception. This blending of relevant question-amplitude response and control question-amplitude response perhaps dampened any significant measurable changes. Using criminal suspects in real-life circumstances may lead to very minute changes in vocal amplitude (intensity) between truthful and deceptive utterances because the amplitude may become static or establish its own equilibrium; whereas in laboratory subjects the changes in

amplitude (intensity) may be more pronounced due to less consequential laboratory situations.

The Streeter, et al.,(1977) study employing listeners to detect deception, indicated that the listeners perceptual judgements were based upon more than just pitch changes and the other acoustic cues may have been articulation rates (e.g. syllabic duration, prolongation of a vocal utterance, measured in ms). Lehiste and Peterson (1959) and Hall and Hutchinson (1976) both found increases in syllabic duration due to psychological stress. Therefore, this third vocal parameter (syllabic duration) was examined to determine its usefulness in detecting deception. The findings of the present study do not support the use of the syllabic duration as a means of detecting deception using the control question theory. However, the findings did show that the syllabic duration for deceptive subjects was significantly greater than the syllabic duration for truthful subjects, irrespective of the type of questions (control-relevant). This main effect was not anticipated, however the consistency suggests that this vocal parameter (syllabic duration) may hold promise in future research in detecting deception.

Using confession-verified test subjects and the control question theory provided an objective means for testing the

validity of the human voice as an indicator of deception. Although it was expected to find the same results for non-verified subjects, the inconsistency between the findings of confession-verified subjects and the findings of nonverified subjects is hard to explain. This difference should be an avenue explored in future research.

IMPLICATIONS

Continued research is needed to establish the validity of the fundamental frequency as an indicator of truth and deception. If future research confirms these findings, fundamental frequency changes may become an added dimension for improving efforts for detecting deception.

Forensic science administrators of present-day polygraphers anticipate the reliability of their science increasing with new technology. Current studies in polygraph are under-way with heat response scaling of the GSR and its adaptation to color change; a digital readout from cardiographic responses and speculation towards blood pressure readings to further advance the polygraph technique. Fundamental frequency of the human voice could become another measurement for testing truth and deception in the criminal justice system.

APPENDICES

APPENDIX A

MULTIVARIATE ANALYSIS OF VARIANCE TABLES

VERIFIED SUBJECTS ON TEST ONE

APPENDIX A

Table 20. Multivariate Analysis of Variance for Fundamental Frequency on Verified Subjects, Test One.

SOURCE OF VARIATION	df	MS	F RATIO	SIG. OF F
Main Effect				
Within Cells	77	1949.74726		
Type of Exam	1	11350.00511	5.82127	0.018
Within Cells	77	133.34821		
Type of Quest.	1	592.63291	4.44425	0.038
Interaction				
Type Exam and Type Question	1	1488.55517	11.16292	0.0008

Table 21. Multivariate Analysis of Variance for Amplitude on Verified Subjects, Test One.

SOURCE OF VARIATION	df	MS	F RATIO	SIG. OF F
Main Effect				
Within Cells	77	20.02570		
Type of Exam	1	63.21800	3.15684	0.080
Within Cells	77	1.24931		
Type of Quest.	1	.05323	0.04261	0.837
Interaction				
Type Exam and Type Question	1	.10527	0.08427	0.772

Table 28. Multivariate Analysis of Variance for Duration on Nonverified Subjects, Test One.

SOURCE OF VARIATION	df	MS	F RATIO	SIG. OF F
Main Effect				
Within Cells	43	116.82676		
Type of Exam	1	90.93829	0.77840	0.383
Within Cells	43	13.63517		
Type of Quest.	1	26.67778	1.95654	0.169
Interaction				
Type Exam and Type Question	1	3.50972	0.25740	0.615

APPENDIX B

MULTIVARIATE ANALYSIS OF VARIANCE TABLES

VERIFIED SUBJECTS ON TEST TWO

APPENDIX B

Table 23. Multivariate Analysis of Variance for Fundamental Frequency for Verified Subjects, Test Two.

SOURCE OF VARIATION	df	MS	F RATIO	SIG. OF F
Main Effect				
Within Cells	77	2134.66838		
Type of Exam	1	7801.96529	3.65488	0.060
Within Cells	77	29.51404		
Type of Quest.	1	6.89241	0.23353	0.630
Interaction				
Type Exam and Type Question	1	63.02657	2.13548	0.148

Table 24. Multivariate Analysis of Variance for Amplitude on Verified Subjects, Test Two.

SOURCE OF VARIATION	df	MS	F RATIO	SIG. OF F
Main Effect				
Within Cells	77	23.56048		
Type of Exam	1	45.35224	1.92493	0.169
Within Cells	77	1.09030		
Type of Quest.	1	0.00025	0.00023	0.988
Interaction				
Type Exam and Type Question	1	0.23677	0.21716	0.643

Table 25. Multivariate Analysis of Variance for Duration on Verified Subjects, Test Two.

SOURCE OF VARIATION	df	MS	F RATIO	SIG. OF F
Main Effect				
Within Cells	77	177.34996		
Type of Exam	1	948.39447	5.34759	0.023
Within Cells	77	26.38857		
Type of Quest.	1	2.53165	0.09594	0.758
Interaction				
Type Exam and Type Question	1	14.54872	0.55133	0.460

APPENDIX D

Table 29. Multivariate Analysis of Variance for Fundamental Frequency on Nonverified Subjects, Test Two.

SOURCE OF VARIATION	df	MS	F RATIO	SIG. OF F
Main Effect				
Within Cells	43	2562.26640		
Type of Exam	1	909.50020	0.35496	0.554
Within Cells	43	129.77028		
Type of Quest.	1	9.34444	0.07201	0.790
Interaction				
Type Exam and Type Question	1	796.03353	6.13417	0.017

Table 30. Multivariate Analysis of Variance for Amplitude on Nonverified Subjects, Test Two.

SOURCE OF VARIATION	df	MS	F RATIO	SIG. OF F
Main Effect				
Within Cells	43	37.33143		
Type of Exam	1	24.02857	0.64366	0.427
Within Cells	43	2.45637		
Type of Quest.	1	2.08544	0.84899	0.362
Interaction				
Type Exam and Type Question	1	0.19563	0.07964	0.779

Table 31. Multivariate Analysis of Variance for Duration on Nonverified Subjects, Test Two.

SOURCE OF VARIATION	df	MS	F RATIO	SIG. OF F
Main Effect				
Within Cells	43	111.45245		
Type of Exam	1	190.94464	1.71324	0.198
Within Cells	43	26.43695		
Type of Quest.	1	37.37778	1.41385	0.241
Interaction				
Type Exam and Type Question	1	8.83353	0.33414	0.566

APPENDIX E

MULTIVARIATE ANALYSIS OF VARIANCE TABLES

VERIFIED SUBJECTS ON COMBINED TESTS ONE AND TWO

APPENDIX E

Table 32. Multivariate Analysis of Variance for Fundamental Frequency on Verified Subjects, Combined Tests One and Two.

SOURCE OF VARIATION	df	MS	F RATIO	SIG. OF F
Main Effect				
Within Cells	78	2064.22915		
Type of Exam	1	11377.47621	5.51173	0.021
Within Cells	78	96.20348		
Type of Quest.	1	429.02500	4.45956	0.038
Interaction				
Type Exam and Type Question	1	294.85379	3.06490	0.084

Table 33. Multivariate Analysis of Variance for Amplitude on Verified Subjects, Combined Tests One and Two.

SOURCE OF VARIATION	df	MS	F RATIO	SIG. OF F
Main Effect				
Within Cells	78	29.49158		
Type of Exam	1	23.75264	0.80540	0.372
Within Cells	78	1.85307		
Type of Quest.	1	0.92264	0.49790	0.483
Interaction				
Type Exam and Type Question	1	0.24178	0.13048	0.719

Table 34. Multivariate Analysis of Variance for Duration on Verified Subjects, Combined Tests One and Two.

SOURCE OF VARIATION	df	MS	F RATIO	SIG. OF F
Main Effect				
Within Cells	78	166.08155		
Type of Exam	1	729.13786	4.39024	0.039
Within Cells	78	21.37721		
Type of Quest.	1	0.18906	0.00884	0.925
Interaction				
Type Exam and Type Question	1	0.01379	0.00065	0.980

APPENDIX F

MULTIVARIATE ANALYSIS OF VARIANCE TABLES

NONVERIFIED SUBJECTS ON COMBINED TESTS ONE AND TWO

APPENDIX F

Table 35. Multivariate Analysis of Variance for Fundamental Frequency on Nonverified Subjects, Combined Tests One and Two.

SOURCE OF VARIATION	df	MS	F RATIO	SIG. OF F
Main Effect				
Within Cells	43	2360.39701		
Type of Exam	1	352.02857	0.14914	0.701
Within Cells	43	38.12355		
Type of Quest.	1	0.90000	0.02361	0.879
Interaction				
Type Exam and Type Question	1	245.78750	6.44713	0.015

Table 36. Multivariate Analysis of Variance for Amplitude on Nonverified Subjects, Combined Tests One and Two.

SOURCE OF VARIATION	df	MS	F RATIO	SIG. OF F
Main Effect				
Within Cells	43	32.13978		
Type of Exam	1	7.07251	0.22005	0.641
Within Cells	43	1.05798		
Type of Quest.	1	1.14469	1.08196	0.304
Interaction				
Type Exam and Type Question	1	1.87843	1.77549	0.190

Table 37. Multivariate Analysis of Variance for Duration on Nonverified Subjects, Combined Tests One and Two.

SOURCE OF VARIATION	df	MS	F RATIO	SIG. OF F
Main Effect				
Within Cells	43	101.32980		
Type of Exam	1	136.35734	1.34568	0.252
Within Cells	43	11.26052		
Type of Quest.	1	31.80278	2.82427	0.100
Interaction				
Type Exam and Type Question	1	5.86984	0.52128	0.474

APPENDIX G

MEANS AND STANDARD DEVIATIONS TABLES

VERIFIED AND NONVERIFIED SUBJECTS ON TESTS ONE AND TWO

KNOWLEDGE-RELEVANT-CONTROL TYPE QUESTION

APPENDIX G

Table 38. Fundamental Frequency Means and Standard Deviations for Verified Subjects on Test One/ Knowledge-Relevant Type Question.

Type of Examination	Type of Question: Knowledge-Relevant	Control
Truthful		
Mean	---	---
s.d.	---	---
Deceptive		
Mean	115.1	119.7
s.d.	33.3	27.6

Table 39. Fundamental Frequency Means and Standard Deviations for Verified Subjects on Test Two/ Knowledge-Relevant Type Question.

Type of Examination	Type of Question: Knowledge-Relevant	Control
Truthful		
Mean	---	---
s.d.	---	---
Deceptive		
Mean	123.8	124.3
s.d.	38.5	37.3

Table 40. Fundamental Frequency Means and Standard Deviations for Nonverified Subjects on Test Two/ Knowledge-Relevant Type Question.

Type of Examination	Type of Question: Knowledge-Relevant	Control
Truthful		
Mean	175.0	191.0
s.d.	0.0	0.0
Deceptive		
Mean	---	---
s.d.	---	---

Table 41. Amplitude Means and Standard Deviations for Verified Subjects on Test One/Knowledge-Relevant Type Question.

Type of Examination	Type of Question: Knowledge-Relevant	Control
Truthful		
Mean	---	---
s.d.	---	---
Deceptive		
Mean	25.2	25.7
s.d.	2.5	3.0

Table 42. Amplitude Means and Standard Deviations for Verified Subjects on Test Two/Knowledge-Relevant Type Question.

Type of Examination	Type of Question: Knowledge-Relevant	Control
Truthful		
Mean	---	---
s.d.	---	---
Deceptive		
Mean	25.6	25.4
s.d.	3.1	3.1

Table 43. Amplitude Means and Standard Deviations for Nonverified Subjects on Test Two/Knowledge-Relevant Type Question.

Type of Examination	Type of Question: Knowledge-Relevant	Control
Truthful		
Mean	15.3	20.6
s.d.	0.0	0.0
Deceptive		
Mean	---	---
s.d.	---	---

Table 44. Syllabic Duration Means and Standard Deviations for Verified Subjects, on Test One/Knowledge-Relevant Type Question.

Type of Examination	Type of Question: Knowledge-Relevant	Control
Truthful		
Mean	---	---
s.d.	---	---
Deceptive		
Mean	44.1	42.0
s.d.	7.2	9.2

Table 45. Syllabic Duration Means and Standard Deviations for Verified Subjects, on Test Two/Knowledge-Relevant Type Question.

Type of Examination	Type of Question: Knowledge-Relevant	Control
Truthful		
Mean	---	---
s.d.	---	---
Deceptive		
Mean	41.8	40.0
s.d.	5.2	3.9

Table 46. Syllabic Duration Means and Standard Deviations for Nonverified Subjects, on Test Two/Knowledge-Relevant Type Question.

Type of Examination	Type of Question: Knowledge-Relevant	Control
Truthful		
Mean	32.0	38.0
s.d.	0.0	0.0
Deceptive		
Mean	---	---
s.d.	---	---

REFERENCES

REFERENCES

Alpert, M., Kurtzberg, R.L. and Friedhoff, A.J., "Transient Voice Changes Associated with Emotional Stimuli", Archives of General Psychiatry, Vol.8, No. 4, p.365, April, 1963.

Arthur, R.O.,"The G.S.R. Unit", Journal of Polygraph Studies,Vol. V, No. 6, May-June 1971.

Barland, G.H., "The Reliability of Polygraph Chart Evaluations", Paper presented at the American Polygraph Association Seminar, Chicago, IL, August 15, 1972.

Bersh, P., "A Validation Study of Polygraph Examiner Judgements", Journal of Applied Psychology, Vol. 53, pp. 399-403, 1969.

Bigland, B., and Lippold, O.C.J., "Motor Unit Activity in the Voluntary Contractions of Human Muscle", Journal Physiology, Vol. 125, pp. 322-335, 1954.

Brenner, Malcolm, "Stagefright and Steven's Law", Paper presented at Eastern Psychological Association Convention, April 1974.

Coker, C.H., Umeda, N. and Bowman, C.P., "Automatic Synthesis from Ordinary English Text," Speech Synthesis, edited by James L. Flanagan and Lawrence R. Rabiner, Stroudsburg, PA., Dowden, Hutchinson and Ross, Inc., pp. 440-441, 1973.

Dektor Counterintelligence and Security, Inc., 5508 Port Royal Road, Springfield, VA., 1977.

Edel, E. and Jacoby, J., "Examiner Reliability in Polygraph Chart Analysis: Identification of Physiological Responses", Journal of Applied Psychology, Vol. 60, pp.632-634, 1975.

Ekman, Paul, Friesen, Wallace V. and Scherer, Klaus R., "Body Movement and Voice Pitch in Deceptive Interaction", Semiotica, Vol. 16, No. 1, pp.23-27, 1976.

Ellson, D.G., Davis, R.C., Saltzman, I.J. and Burke, C.J., "A Report of Research on Detection of Deception", (Contract N6 onr-18011 with the Office of Naval Research) Available from the University of Indiana, Bloomington, IN, 1952.

Friedhoff, Arnold J., Alpert, Murray and Kurtzberg, Richard L., "An Effect of Emotion on Voice", Nature, Vol. 193, No. 4813, pp.357-358, January 27, 1962.

Fry, D.B., "Experiments in the Perception of Stress", Language and Speech, Vol. 1, 1958.

Hall, M.E. and Hutchinson, J., "Spectrographic Analysis of Interspeaker and Intraspeaker Variabilities of Speakers Under Stress", Human Communication, Vol. 1, Spring, 1976.

Horvath, F. and Reid, J., "The Reliability of Polygraph Examiner Diagnosis of Truth and Deception", The Journal of Criminal Law, Criminology and Police Science, Vol. 62, No. 2, 1971.

Horvath, Frank, "Detection of Deception: A Review of Field and Laboratory Procedures and Research", Polygraph, Vol.5, No. 2, pp. 107-145, June 1976.

Horvath, Frank, "Detecting Deception: The Promise and the Reality of Voice Stress Analysis", Journal of Forensic Science, JFSCA, Vol.27, No.2, April 1982. pp. 340-351.

Horsley, V. and Schafer, E.A., "Experiments on the Character of the Muscular Contractions which are Evoked by Excitation of the Various Parts of the Motor Tract", Journal Physiology, Vol. 7, pp.96-110, 1886.

Jaspar, H.H. and Andrews, H.L., "Brain Potentials and Voluntary Muscle Activity in Man", Journal Neurophysiology, Vol. 1, pp. 87-100, 1938.

Keeler, L., "A Method for Detecting Deception", American Journal of Police Science, Vol. 1 (1): 38, 1930.

Kreifeldt, J.G. and Yao, S., "A Signal to Noise Investigation of Nonlinear Electromyographic Processors", IEEE Trans. Bio. Eng., Vol. 21, 1974.

Kubis, J., Studies in Lie Detection: Computer Feasibility Considerations. Technical Report 62-305, Arlington, VA, Armed Services Technical Information Agency, June 1962, prepared for Air Force Systems Command, Contract No. AF20 (602) - 2270, project no. 5534, Fordham University, 1962.

Larson, J., "Modification of the Marston Deception Test", Journal of the American Institute of Criminal Law, Criminology and Police Science, Vol. 12, pp.390-399, 1921.

Lee, C.D., "The Instrumental Detection of Deception", Springfield, IL, Thomas, 1953.

Lehiste, I. and Peterson, G., "Vowel Amplitude and Phonemic Stress in American English", Journal of Acoustical Society of America, Vol. 31, pp.428-435, 1959.

Lieberman, Philip, "Some Acoustic Correlates of Word Stress in American English", Journal of the Acoustical Society of America, Vol. 32, No. 4, April, 1959.

Lieberman, Philip, "Perturbations in Vocal Pitch", Journal of the Acoustical Society of America, Vol. 33, No.5, May, 1961.

Lieberman, Philip and Michaels, Sheldon B., "Some Aspects of Fundamental Frequency and Envelope Amplitude as Related to the Emotional Content of Speech", Journal of the Acoustical Society of America, Vol.34, No. 7, July, 1962.

Lindsley, D.S., "The Psychology of Lie Detection", In G.J. Dudycha (ed.) Psychology for Law Enforcement Officers, Springfield, IL, Thomas, pp. 89-125, 1955.

Lippold, O.C.J., Redfearn, J.W.T. and Vuco, J., "The Relation Between the Stretch Reflex and the Electrical and Mechanical Rhythmicity in Human Voluntary Muscle", Journal Physiology, Vol. 138, pp. 14-15, 1957.

Lippold, O.C.J., Redfearn, J.W.T. and Vuco, J., "The Rhythmical Activity of Groups of Motor Units in the Voluntary Contraction of Muscle", Journal Physiology, Vol. 137, pp.473-487, 1957.

Lippold, O.C.J., "Tremor and Oscillation in the Stretch Reflex Arc", Journal Physiology, Vol. 202, pp. 55-57, 1969.

Lippold, O.C.J., "Physiological Tremor", Scientific American, March, 1971.

Marshall, J. and Walsh, E.G., "Physiological Tremor", Journal Neurology, Neurosurgery and Psychiatry, Vol. 19, pp. 260-267, 1956.

Marston, W.M., "The Lie Detector Test", New York, Smith, 1938.

McGlone, Robert E. and Hollien, Harry, "Partial Analysis of Acoustic Signal of Stressed and Unstressed Speech", Carnahan Crime Countermeasure Conference Proceedings, pp. 19-21, 1976.

Reid, J.E. and Inbau, F.E., Truth and Deception: The Polygraph ("Lie Detector") Technique, Baltimore, MD., William and Wilkins, 1966.

Rubenstein, Leonard, "Electro-Acoustical Measurement of Vocal Responses to Limited Stress", Behavioral Research and Therapy, Vol. 4, pp. 135-138, 1966.

Schafer, E.A., "On the Rhythm of Muscular Response to Volitional Impulses in Man", Journal Physiology, Vol. 7, pp. 111-117, 1886.

Shipp, T. and McGlone, R., "Physiologic Correlates of Acoustic Correlates of Psychological Stress", Acoustical Society of America Convention, Los Angeles, 1973. (Also reported in 1975 Carnahan Crime Countermeasure Conference by McGlone, R., "Tests of the Psychological Stress Evaluator (PSE) as a Lie and Stress Detector").

Simonov, P.V. and Frolov, M.V., "Utilization of Human Voice for Estimation of Man's Emotional Stress and State of Attention", Aerospace Medicine, Vol. 44, March, 1973.

Streeter, Lynn A., Krause, Robert M., Geller, Vallerie, Olson, Christopher and Apple, William "Pitch Changes During Attempted Deception", Journal of Personality and Social Psychology, Vol. 35, No. 5, pp. 345-350, 1977.

Thackray, R.T. and Orne, M.T., "A Comparison of Physiological Indices in Detection of Deception", Psychophysiology, Vol. 4, pp. 329-339, 1968.

VanBuskirk, C. and Fink, R.A., "Physiologic Tremor, An Experimental Study", Neurology, Vol. 12, pp. 361-370, Minneapolis, 1962.

Voice Identification, Inc., P.O. Box 714, Somerville, N.J. 08876, publication on PM Analyzer, "Speech Processing with the PM Pitch Analyzer".

Welch, B.L., "On the Comparison of Several Mean Values: An Alternative approach," Biometrika, Vol. 38, pp.330-336, 1951.

Wicklander, D. and Hunter, F., "The Influence of Auxilliary Sources of Information in Polygraph Diagnosis", Journal of Police Science and Administration, Vol. 3, pp. 405-409, 1975.

Williams, Carl E. and Stevens, Kenneth N., "Emotion and Speech: Some Acoustical Correlates", Journal of the Acoustical Society of America, Vol.52, No.4, (Part 2), pp.1238-1250, 1972.