INTERIM REPORT OF THE

DEPARTMENT OF COMMERCE

TO

THE GOVERNOR

AND

THE GENERAL ASSEMBLY OF VIRGNIA

Response to House Resolution No. 45 Requesting the Department of Commerce to Study the Feasibility and Desirability of Licensure of Audio Stress Examiners

House Document No. 34

COMMONWEALTH OF VIRGINIA
Richmond, Virginia
1980

AUDIO STRESS REPORT TO THE GENERAL ASSEMBLY

APPENDIX

COMMONWEALTH of VIRGINIA

Department of Commerce

[illegible]

January 28, 1980

TO: The Honorable John N. Dalton
Governor of Virginia

and

The General Assembly of Virginia

I herein transmit to you the report of the Department and Board of Commerce on the desirability and feasibility of licensure of Audio Stress examiners. This study was authorized by HR 45 of the 1979 session of the General Assembly.

The report concludes that, based on the study conducted to date, no action be taken to license in this area, but that further study be conducted.

Sincerely,

Ruth J. Herrink

Ruth J. Herrink

Attachments

RECOMMENDATIONS AND FURTHER ACTION

The Board of Commerce recommends that no legislative action be taken this year to license Audio Stress Examiners under Chapter 27, Title 54 of the Code of Virginia. The investigation to date concerning voice stress analysis has not found it to be clearly an effective method for the determination of deception. Upon completion of the field evaluation, the Department of Commerce will make further recommendations and a final report prior to the 1981 session of the General Assembly.

The use of such machines can have profound consequences for the individuals examined. Truth detection devices have been used to screen prospective applicants for jobs, conduct criminal investigations, terminate employees suspected of theft. These devices can also be used covertly and final recommendations on their use, should the method prove to be valid, will likely include certain restrictions on their use if licensure is recommended.

The Board of Commerce will continue to study this matter under its general mandate to evaluate professions and occupations in Virginia in order to fulfill the intent of House Resolution 45.

HOUSE RESOLUTION NO. 45

Requesting the Department of Commerce to conduct a study of the desirability and feasibility of licensure of audio stress examiners.

Patron—Callahan

WHEREAS, the practice of certain professions and occupations is regulated by State law for the protection of the health, safety, and welfare of the public; and

WHEREAS, current State law, and regulation promulgated under such law, regulates the activities of polygraph examiners; and

WHEREAS, through the operation of an audio stress evaluator it has been alleged that an audio stress examiner can perform much the same tasks as are presently being carried out by polygraph examiners; and

WHEREAS, it is highly desirable that an unbiased and informed study of audio stress examiners be conducted prior to a decision as to the need for State regulation of their profession; now, therefore, be it

RESOLVED by the House of Delegates, That the Department of Commerce is requested to study the desirability and feasibility of State licensure, certification or regulation of audio stress examiners. The Department is requested to lay its findings, together with any legislative recommendations, before the nineteen hundred eighty Session of the General Assembly.

BACKGROUND

This issue of audio stress examiners revolves around two problems: (1) The ability of the devices to indeed record voice characteristics that result in detection of deception (2) The needed training and/or examination of individuals to operate devices, assuming such are valid.

At the present time audio stress machines are not permitted for use in Virginia. Such activities are restricted to polygraph examiners who may only use a machine measuring at least two physiological reactions which relate to deception. An individual cannot be examined without his knowledge by use of the polygraph.

Unlike the polygraph, however, audio stress devices purport to detect deception by measurement of the presence or absence of "microtremors" which are reflected in the voice. Responses to questions may be tape recorded and then charted or converted by the actual devices to a pattern. Patterns are then "read" by trained individuals. Some devices bypass the taping procedure and produce an indication of truth or deception immediately. The devices could be used without the subject of the examination being aware that such examination is being conducted.

Pursuant to House Resolution 45, the Department of Commerce, through the Board of Commerce, spent the last year in study of an audio stress device manufactured in Virginia, has surveyed the literature and is conducting an evaluation in conjunction with the State Police to compare this device to the polygraph.

The issues involved are substantial. If the device is approved for use, it will be used for criminal investigations, employment purposes, and may, upon stipulation, be introduced as evidence in legal proceedings. Since a review of the literature offers no conclusive evidence as to its validity, completion of the formal evaluation should be a prerequisite to its licensure.

While the evaluation began in August 1979, after a period of planning, a number of technical difficulties were encountered. It is apparent that the device may require controlled procedures to work effectively.

DESCRIPTION OF STUDY AND FINDINGS

Pursuant to House Resolution No. 45, the Department of Commerce is studying the feasibility and desirability of licensure of audio stress examiners.

In March of 1979 a subcommittee of the Board of Commerce was appointed to conduct the study. The appointees to the study are Mrs. Polly Y. Campbell, Mr. Zack T. Perdue, and Mr. Alan McCullough, Jr., as Chairman. The Department assigned three staff members to assist in the study.

The staff began the study by gathering all available information and literature on the subject of audio stress analysis. Those persons recognized in the field of detection of deception were notified of the study and were requested to make all information available. The studies and reports received were reviewed for all pertinent information concerning the use of the audio stress machines.

Voice stress analizers are widely used in the private sector, and by law enforcement agencies; however, their use remains controversial. Investigation of research literature indicates conflicting opinions of the reliability and validity of coice stress analyzers. The accuracy rate of the machines and the operators to detect deception range from 32 percent to one of 100 percent.

Michael P. Kradz, now an employee of Dektor Counterintelligence and Security, Inc., the manufacturer of the Psychological Stress Evaluator, conducted a study in 1972 to determine the validity of the machine. At that time he was a police polygraph examiner with Howard County, Maryland. Of the 43 subjects tested, he had a correlation of 100 percent between the polygraph and the PSE instrument.

In 1973 the Army Land Warfare Laboratory contracted with Joseph H. Kubis to conduct a study comparing the polygraph with the PSE and the Mark II. The conclusion of the study was that neither of the presently existing voice analysis devices were accepted as valid within the constraints of the experimental design. However, it should be noted that the experimental design of the study has been highly critized. The weakness in the experimental design is often cited as a factor which caused the PSE to rate a 32 percent accuracy.

In 1975 Dr. John W. Heissee, Jr., M.D., conducted a study using the alternate criteria supplied by the Army Land Warfare Laboratory for the Kubis Study. The PSE was tested for the validity and examiner-interevaluator reliability against known-solution criminal cases. The results of the study indicate that the PSE is a very useful instrument in the hands of competent, well trained examiners who adhere to a prescribed format in determining truth and deception.

Dr. Malcolm Brenner, Research Associate with the University of Oregon, and Harvie Branscomb, Graduate Studies with the Massachusetts Institute of Technology, conducted research on the PSE. Based on their research they found the PSE not to be of a technical quality to be used in the detection of deception.

In 1975 Gordon Barland, Ph.D, conducted a study to determine the validity of the polygraph and the PSE in detecting deception in suspects involved in criminal investigations. Barland found that the accuracy of each physiological measure recorded with the polygraph instrument exceeded chance level, whereas the accuracy of the PSE did not exceed chance level.

Frank Horvath, Ph.D, conducted a study in which he compared the validity of the polygraph to that obtained with an audio stress evaluator. His research does not support the contention that audio stress analysis is useful in detecting deception. The PSE yielded an accuracy rate at only chance level.

From the literature available on the subject of voice stress analysis, it is reasonable to conclude that the effectiveness of the method in accurately detecting deception has not been resolved.

At the present time, of the twenty-five states that license polygraph examiners, only one, North Carolina, issues licenses to voice stress operators. Four states, Alabama, Mississippi, Oklahoma and Oregon, have opinions from their attorneys general to the effect that the PSE and similar devices may not be used. In Illinois a circuit court has issued an injunction against their use. New York has passed a statute specifically prohibiting the use of the PSE and similar devices in the employment context. In Pennsylvania it is illegal to use these devices surreptitiously. In Texas voice stress operators have been jailed and fined for using their equipment within the state. In Virginia recently a voice stress operator was fined for illegal use of the machine within the state. The state of Florida held public hearings in 1974 concerning the Psychological Stress Evaluator. The hearing officer concluded that the PSE in the hands of a competently trained operator is equally as credible as the polygraph. At this time, however, audio stress examiners are not required to be licensed.

The Department of Commerce is presently conducting a field evaluation to assess the reliability of voice stress analysis procedures and instrumentation using the Psychological Stress Evaluator marketed by Dektor Counterintelligence and Security, Inc., Springfield, Virginia. Because of the inconsistency of conclusions reported in previous studies, the Department determined that conducting this field evaluation would best fulfill the intention of House Resolution 45.

Initial contacts for the study were made in March, April and May to Dektor and the Virginia State Police seeking their assistance in the study. Dektor agreed to allow department investigators to attend an 80-hour course in the use of the PSE. The Virginia State Police agreed to tape record actual polygraph examinations for the purpose of charting through the PSE instrument. Investigators attended the two-week training course May 14 - 25, 1979.

There are two courses offered by Dektor, 40 hours and 80 hours. The 80 hour course is offered for those persons who desire additional training and wish to apply for an audio stress examiner's license to operate the PSE in North Carolina. Upon conclusion of the course, one investigator provided the Department with a descriptive analysis of the PSE instrument (Appendix). In June a representative from Dektor appeared before the Board of Commerce. Mr. Michael Kradz, instructor, demonstrated the instrument and spoke to the Board concerning its operation.

A meeting was held at the Department of Commerce on August 9th to formally establish the field study and to delineate the areas of responsibility to those participating in the field evaluation. Representatives of the Department of Commerce, the Virginia State Police and Dektor were present and agreed substantially to the design of the evaluation.

In accordance with the study, two assumptions were made by the Department: (1) that the General Assembly licensed polygraph examiners and the use of the polygraph machine in Virginia;

therefore, the polygraph process is assumed to be reliable in detecting deception; (2) that both the PSE operator from Dektor and the State Police polygraphers were competent in their field.

It was decided that the Virginia State Police polygraph examiners, using their equipment, would tape record polygraph examinations. The results of the examinations and the tapes would be sent to the Department. The tapes would then be distributed to a PSE examiner of Dektor Counterintelligence and Security, Inc. and the investigators of the Department to be charted through the PSE process. The results obtained by the PSE examiners and the polygraph examiners would then be correlated by an independent statistician from Psychological Consultants, Inc. for comparisons of the voice stress analysis method for the polygraph.

On August 23, August 28 and September 12 meetings were held at the State Police Headquarters. There were repeated technical problems with the equipment which was being used by the polygraph examiners to record the examinations. On September 27 arrangements were made to take an examination tape to Dektor to have it charted on a PSE instrument. The results were of an acceptable quality which could be charted on the PSE.

It was decided that a total of forty tapes would be charted through the PSE process. The Department has received these forty tapes and is now evaluating them. The Department had hoped to have the tapes completed sometime ago; however, technical problems repeatedly set the study back in the schedule. It is expected that the report will be completed within three to four months.

LIST OF PARTICIPANTS

ALAN McCULLOUGH, JR. - Chairman of the Subcommittee and member of Board of Commerce

POLLY Y. CAMPBELL - Board of Commerce

ZACK T. PERDUE Board of Commerce

BARBARA L. WOODSON - Department of Commerce

S. SUZANNE FALLS - Department of Commerce

ROBERT L. HARP - Department of Commerce

RODNEY D. GRIMES - Virginia State Police

PATRICK B. GURGANUS - Virginia State Police

LARRY W. BARDEN Virginia State Police

THOMAS A. SNEAD - Virginia State Police

GILBERT W. GRAY - Dektor Counterintelligence & Security

EDWARD W. KUPEC - Dektor Counterintelligence & Security

DAVID PURDY - Psychological Consultants, Inc.

ABSTRACT OF RESEARCH

Kubis, Joseph F. "Comparison of Voice Analysis and Polygraph as Lie DEtection Procedures." Final Report, Contract No. DAAD05-72-0217, Technical Report No. LWL-CR-03B70, August 1973, U. S. Army Land Warfare Laboratory, Aberdeen Proving Ground, Maryland 21005. Research conducted at Fordham University. Reprinted in Polygraph 3 (1)(March 1974): 1-47.

Two voice analysis techniques were evaluated as lie detection devices in a simulated theft experiment which utilized 174 subjects. One group of subjects (n=137) were examined with the polygraph at the same time as voice recordings were taken. A smaller group (n=37) was tested only with voice recordings. The results failed to demonstrate that either of the voice analysis techniques (Psychological Stress Evaluator and Voice Stress Analyzer) was effective above chance.

ABSTRACT OF RESEARCH

Brenner, Malcolm and Branscomb, Harvie "The Psychological Stress Evaluator: Technical Limitations Affecting Lie Detection." Paper delivered at the Hearing on S. 1845, Sub-Committee on the Consitution, Committee on the Judiciary, United States Senate, Washington, D. C., September 19, 1978. Reprinted in Polygraph 8 (2)(June 1979).

The authors conducted research on the PSE at Harvard University and the University of Oregon. They found five basic shortcomings of the PSE. First, they found that the scoring is highly subjective. Considering an inter-judge reliability coefficient of R = .80 as a minimum for psychological tests to be acceptable; they reported that four independent studies of the PSE reported coefficient values of R = .56, R = .54, R = .39, and R = .38. Second, they found that the scoring of words spoken changed according to the linguistic properties of the word. For example, the number nine gave a high stress response over the low response of the number eight, on the order of two to one. Third, they found that the scores depended on the quality of the tape recording, with a poor tape showing less stress. PSE analysis from tapes sent over the telephone, a routine PSE procedure, would characteristically show low stress. Fourth, the transcription speed of the tape varied the PSE scores. Using the two most common speeds, 1 7/8 ips and 15/16 ips, and comparing the results, inter-judge reliability ranged from R = .43 to R = .47 for each subject. In 8% of the cases, one speed showed high stress, and the other speed showed low stress. Last, they found that subjects may be able to control their voice stress. Duplicating a study by Dr. David Lykken in which he obtained 100% accuracy with the GSR, detecting 20 out of 20 when subjects attempted to control their responses; the authors using PSE and the same testing method were wrong in 19 out of 20.

ABSTRACT OF RESEARCH

Horvath, Frank "An Experimental Comparison of the Psychological Stress Evaluator and the Galvanic Skin Response in Detection of Deception," Journal of Applied Psychology 63 (3)(1978): 338-344.

A Psychological Stress Evaluator (PSE) and the GSR unit of a field polygraph were used to detect lies about numbered cards with 30 male and 30 female college students. The detection rates for the PSE were at chance rates.

The inter-rater agreement between two examiners who had formal PSE and polygraph training was R = .38 for PSE analysis and R = .92 for GSR evaluation.

ABSTRACT OF RESEARCH

"Detection of Deception in Criminal Suspects:
"A Field Validation Study"
Gordon H. Barland, Ph.D. University of Utah,
1975

This study examined the accuracy of the polygraph technique for the detection of deception by criminal suspects. Seventy-seven suspects involved in 67 different cases were examined by a private polygraph examiner using the federal modification of the zone comparison control question technique Standard field polygraphs were used to record respiration, the skin conductance response (SRR), and cardiovascular activity by means of occlusion plethysmography. A minimum of three polygraph charts were obtained from each suspect. Additionally, the suspects' answers to the test questions were tape recorded for voice stress analysis with the Psychological Stress Evaluator, Model PSE-1. During the pretest interview, the MMPI L-scale, K-scale, Psychopathic Deviancy (Pd) scale, Depression (D) scale, and Hypocondriasis (Hs) scale were orally administered. The polygraph and PSE charts were numerically evaluated using standard field scoring practices. The significance level for all tests in the study was .05, two-tailed.

The examiner concluded that 55 (71.4%) of the 77 suspects were deceptive (DI) when they denied having committed the act of which they were accused, 10 (13.0%) of the subjects had no deception indicated (NDI), and the remaining 12 examinations (15.6%) were inconclusive. Excluding the inconclusives, 84.6% of the decisions were DI. When the charts were rescored about six months later, the scores were significantly more conservative. Sixty-five (84.4%) of the decisions remained the same upon rescoring. In no case was a decision reversed: the main changes were from a decision to inconclusive. The mean absolute value of the scores of the NDI subjects (M= 3.8) was significantly smaller than that of the DI subjects (M= -10.5).

In 17 of 19 cases (89.5%), the examiner correctly predicted the polygraph outcome by observing the suspect's pretest behavior. In 27 examinations confirmed by the confession or guilty plea of the suspect, the skin resistance response was the single most accurate physiological measure, being correct in 25 of 26 decisions (96.2%).

The sign of the PSE Mode III score agreed with the sign of the polygraph score in 34 of 52 cases, which was significant.

The accuracy of the examiner's decisions was assessed by comparing the decision to the consensus of a panel consisting of 5 attorneys and judges who had been presented with all available evidence concerning each case with the exception of the polygraph examination result. The examiner's decisions agreed with the direction of the panel's decision in 37 of 47 cases (78.7%), which was significant. When higher levels of agreement within the panel were required for a panel decision, the agreement between the panel and the polygraph examiner's decisions was generally about 85%. When unanimity of the panel was required for a panel decision, the rate of agreement between the panel and the polygraph outcome was 83.3%. The three disagreements occurred on suspects considered innocent by the panel. When the examiner's decisions were compared against the judicial outcome in those cases in which the judiciary was uninformed of the polygraph outcome, the rate of agreement was 26 out of 29 cases (89.7%). Again, the disagreements occurred on suspects acquitted by the judicial process.

None of the following biographical variables was related to autonomic responsivity as recorded by the polygraph: age, sex, education, number of previous arrests, number of previous polygraph examinations, depth of religious convictions, and type of crime committed. No practical effect upon autonomic responsivity of the suspects' scores on the MMPI scales was found, including the psychopathic deviancy scale.

It was concluded that, within the limitations inherent in any attempt to validate the polygraph technique outside of the laboratory setting, the results of this study support the proposition that carefully administered control question polygraph examinations are highly accurate in assessing the credibility of criminal suspects.

Order No. 75-28,874, 72 pages.

THE PSYCHOLOGICAL STRESS EVALUATOR

by

S. Suzanne Falls

June 20, 1979

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INTRODUCTION

It is the intent of this report to provide a concise descriptive analysis of the Psychological Stress Evaluator marketed by Dektor Counterintelligence and Security, Incorporated, 5508 Port Royal Road, Springfield, Virginia 22151. In this description the electronic, psychological, and physiological terminology which describes those aspects of this machine has been reduced to terms which may more readily be understood by persons who are not electronics engineers, psychologists, or physicians by profession. The sources of information for this report which are not cited in either the reference section of the report or the bibliography include the following:

a. A two-week instructional course in the use of the Psychological Stress Evaluator provided by Dektor,
b. Dr. Glen L. Bull, Assistant Professor of Speech Pathology at the University of Virginia, Charlottesville, Virginia, and
c. Mr. Wes McDonald, a Research Engineer at the University of Virginia.

The Psychological Stress Evaluator will hereinafter be referred to by its initials (PSE).

The PSE was invented by Allan D. Bell, Jr., Wilson H. Ford, and Charles R. McQuiston. A patent was granted these men for the PSE by the United States Patent and Trademark Office on July 20, 1976. A copy of this patent is included in the reference section of this report. According to this patent the PSE provides a method of detecting psychological stress by the conversion of vocal utterances into electrical signals. These signals are processed to emphasize specific inaudible characteristics of the voice. These inaudible characteristics are said to change with various psycho-physiological changes.

The PSE as described above is used in the detection of deception as well as in the field of Behavioral Science for psychological testing. One of the current uses cited by Dektor is the testing of air traffic controllers to determine the stress levels associated with various types of air traffic handled by the controllers.

MICROTREMOR AS DEFINED BY DEKTOR

The muscle microtremor is the physiological basis for the development of the Psychological Stress Evaluator by Dektor. Dektor defines this microtremor as an inaudible wave form resulting from the physiological tremor described by Lippold as occurring in the voluntary muscles. This wave form is an infrasonic (inaudible) frequency modulation which modulates the carrier wave (the audible portions of the voice).

The muscles associated with the vocal folds and the cavity walls of the larynx are subject to mild muscular tension when an individual is under slight to moderate stress. This tension is sufficient to lessen or to dissipate the physiological tremor of the voluntary muscles of the larynx.

In the muscles of a relaxed or unstressed person the extent of the microtremor is at a maximum of eight to fourteen Hertz. The amplitude of this tremor diminishes or ceases entirely when the amount of stress experienced by an individual increases.

WHAT IS A PHYSIOLOGICAL TREMOR?

The source for the definition of a physiological tremor is an article entitled 'Physiological Tremor' by Olof Lippold, which was published in the <u>Scientific American</u>, March, 1971. A copy of this article is included in the reference section of this report.

The phenomenon identified by Lippold's article as a physiological tremor consists of minute oscillations varying between eight and twelve cycles per second which accompany the contraction of a voluntary muscle. This tremor varies from one individual to another, and in the same individual from time to time. The amplitude of a normal tremor can be reduced by resting the muscle or increased by strong contraction of the muscle. The frequency of a normal tremor can be altered by warming or cooling the muscle.

HOW SOUND IS PRODUCED IN HUMANS

In the larynx are two folds or bands of tissue called the vocal folds. When not in use in the production of speech these vocal folds are laid back with a wide opening to allow for respiration. They are connected to the interior of the larynx by muscles: the Cricothyroidei muscles, which cause tension and elongation of the vocal folds; and the Thyroarytenoidei muscles, which shorten and relax the vocal folds.

In normal speech air in the lungs is at first contained by the closing of these vocal folds. The vocal folds then open slightly to emit short puffs of air. This air resonates through the remainder of the larynx, the pharynx, and the sinusoidal cavities, is modified by the teeth, tongue, and lips, and results in the production of a sound wave.

During the course of normal speech in the average human male the vocal folds open and close approximately one hundred times per second. Each time the vocal folds open and close constitutes one complete cycle. In normal speech the period, (the amount of time required to complete one cycle of the vocal fold opening and closing), varies from cycle to cycle. Thus a low pitch is produced by longer periods.

The number of complete cycles per second is referred to as the frequency of the sound wave or the fundamental voice frequency. One cycle per second is equivalent to one hertz. The length of the vocal folds, their degree of tension, and their mass can all affect frequency.

THE MECHANICAL USE OF THE PSE

The PSE-101 which is currently in use is an updated version of the original PSE-1 for which the patent was obtained. The PSE-101 is utilized in the following manner. First a recording of the PSE examination is made on either a cassette recorder or a reel-to-reel recorder. Conventional cassette recorders record at one and seven-eights inches per second. Recordings made on a reel-to-reel recorder should be made at the speed of seven and one-half inches per second to allow them to be run through the PSE at either one quarter or one eighth of their original speed. Dektor has developed a cassette deck called the Dek which allows cassettes recorded at the standard one and seven-eights inches per second to be reduced to one-half, one-quarter, or one-eighth of their original speed for processing through the PSE.

The PSE is attached to a tape recorder by a patch cord and a power cord for charting. Tape recorders recommended by Dektor include the Dek for cassettes and the Uher for reel-to-reel tapes. Power for the tape recorder is provided through the PSE, and the PSE is powered from a standard one hundred-fifteen volt supply outlet. The recording speed of the tape recorder is reduced by either one-quarter or one-eighth, and the recording is processed through the PSE. This recording may be either selectively or wholly reproduced by the chart recorder of the PSE, which contains heat-sensitive chart paper and a heated stylus. The chart drive speed may either be set at twenty-five or fifty millimeters per second, depending on the Mode chosen for charting the responses.

The PSE has four Modes which can be used to change the size of the pattern and the distribution of the pattern on the chart paper. Mode I displays amplitude, with the least discernible pattern to the responses. Mode II has a more discernible pattern than Mode I, and is useful for identifying diction blocks and charting unstructured conversation. Mode III causes the wave form pattern to increase vertically and horizontally so that changes in the pattern are more readily identifiable. Mode IV eliminates amplitude and centers the pattern activity on the chart paper. Of the four Modes available for charting, Mode III is the most commonly used in charting structured test responses.

CORRECT PROCEDURE FOR USE OF THE PSE IN DETECTION OF DECEPTION

According to Dektor, proper detection of deception cannot be done covertly with one set of questions. Anything short of an overt face-to-face testing situation results in a process of elimination of probable stressful responses. Therefore, Dektor teaches the following method of using the PSE in the detection of deception.

Prior to testing an individual, a personal history is completed by the subject. This form ideally should include questions about the subject's present physical condition, background, education, and medical history. The subject is then introduced to the examiner, who advises the subject that the entire proceedings are being taped. The examiner then reviews release forms and/or Advice of Rights to the Accused forms with the subject, which are subsequently signed by all present.

In the pre-test interview the personal history form is reviewed with the subject. Relevant, irrelevant, and control questions are established and reviewed with the subject. The subject is assured that no question which has not been discussed thoroughly with him will be asked during the examination. The PSE is explained to the subject so that the subject's fears about the tests and the instrument may be allayed.

The following structured tests are taught by Dektor: the Peak of Tension test, the Irrelevant-Relevant Technique, the General Question test, the Zone Comparison Test, the Truth Versus Lie test, the Stimulation test, and the Pre-employment test. Any of these tests or adaptations of them are used by PSE examiners.

The first test given is generally the Modified Zone Comparison Test. The resultant chart of the subject's responses is used by the examiner to establish the subject's normal level of stress. Examples of distressed responses are pointed out to the subject on the chart, and his help in determining the cause or causes for these responses is solicited. After the subject has verbalized his reasons for the distressed responses in his chart, another test is made using the same set of questions. If the subject has correctly identified the reasons for his distressed responses, there should be no indications of distress in the second chart. If indications of distress are still evident on the subject's chart, the examiner undertakes further discussion with the subject to determine the reasons for this distress. Questions are again formulated and discussed with the subject relative to the content of the questions and their meaning to the subject. If the subject admits his guilt or complicity in a specific act in the discussion with the examiner, a final test is used in the same manner to establish the veracity of the subject's statements. During the testing situation various forms of the aforementioned structured tests may be used which have been modified to the individual situation at the discretion of the examiner.

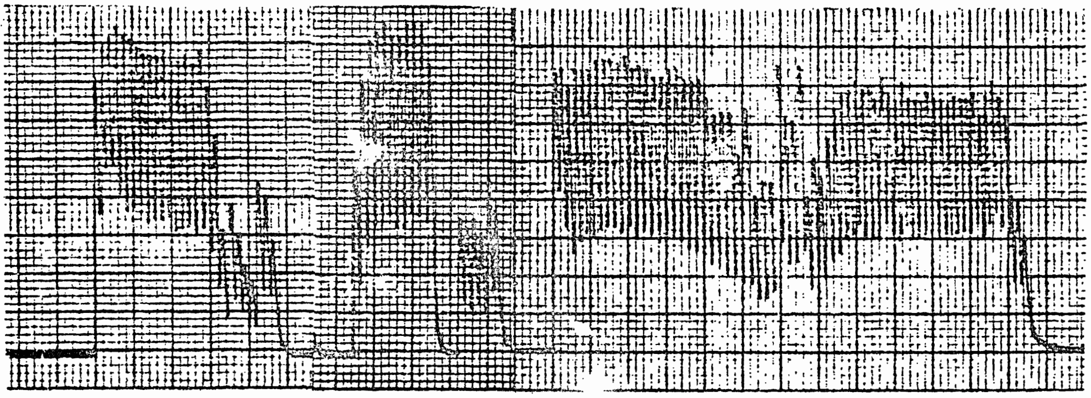
IDENTIFICATION OF RESPONSES IN PSE CHARTS

In the normal speech of persons who are not experiencing excessive stress the cycles charted by the PSE are irregular, with the entire pattern resembling a wave form. Some degree of uniformity in these cycles may be present in the chart of a person who is experiencing a high level of stress. For this individual the normal level of stress displayed in his charted responses would necessarily involve a consistent degree of uniformity. It is necessary to identify this consistent level of uniformity so that it may be differentiated from very highly stressed, or distressed, responses.

Distressed responses are interpreted from the chart display of the subject's responses as being either those which exhibit a high degree of uniformity in comparison with those displaying an irregular wave form, or those showing a deviation from the normal stress level which has previously been established for the subject. Patterns which exhibit a high degree of uniformity are said to lack frequency modulation, thereby causing uniformity exhibited in square blocking, diagonal blocking, a doming formation, or a tendency to produce a block, diagonal or dome. Patterns which exhibit a deviation from the normal stress level include cyclic rate changes, diction blocks, and gross changes. The cyclic rate change becomes meaningful in interpreting distress only when it is part of a response which exhibits uniformity as in a block, diagonal, or dome. In a diction block all of the words in a multiple word answer occupy or attain the same height on the PSE chart without any adjustments having been made to the equipment. The diction block becomes meaningful in the interpretation of distress when it is involuntarily produced by the subject. A gross change is said to occur when all of the other charted responses are multi-cycled, and a specific response appears on the chart as only one cycle.

Responses which exhibit a higher degree of uniformity are compared with other responses in each chart to determine the deviation from the normal level of stress of the subject. Responses to the same question should not be compared between two charts which are made from separate tests because the subject's interaction with the examiner has caused the subject's implicit set to change. Any comparison of these two answers would produce invalid assumption.

Displayed below are examples from the Dektor Manual which exemplify distressed responses.



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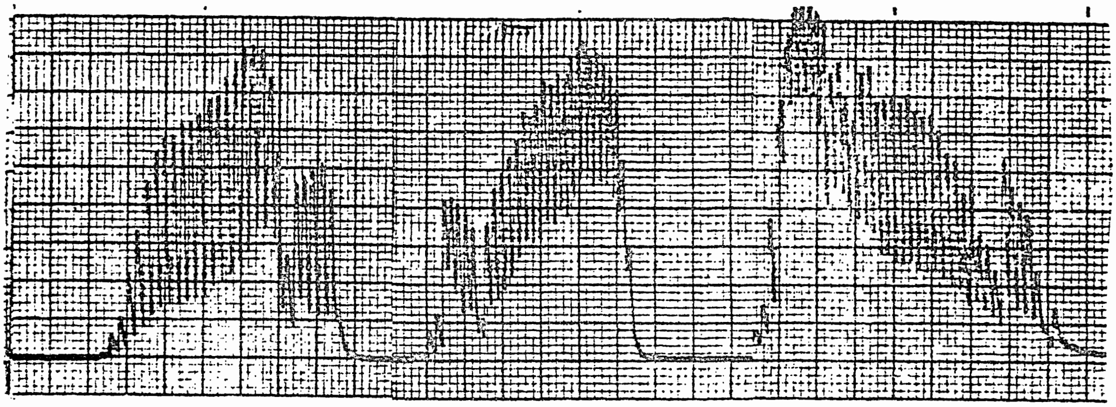
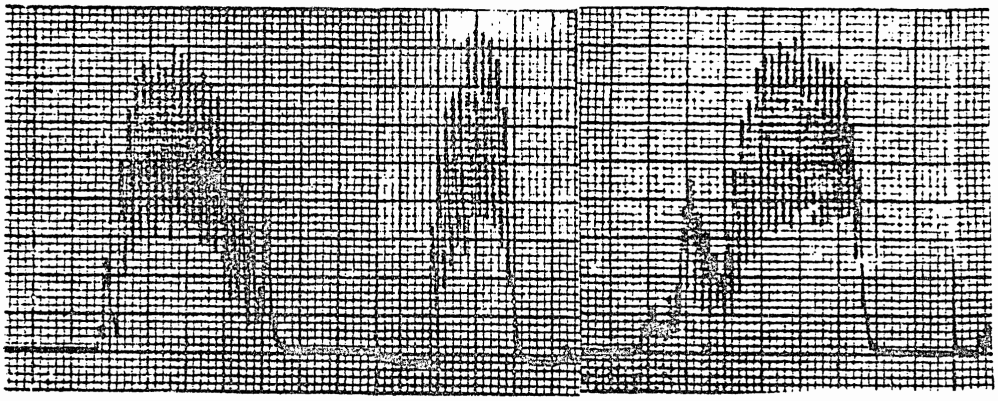
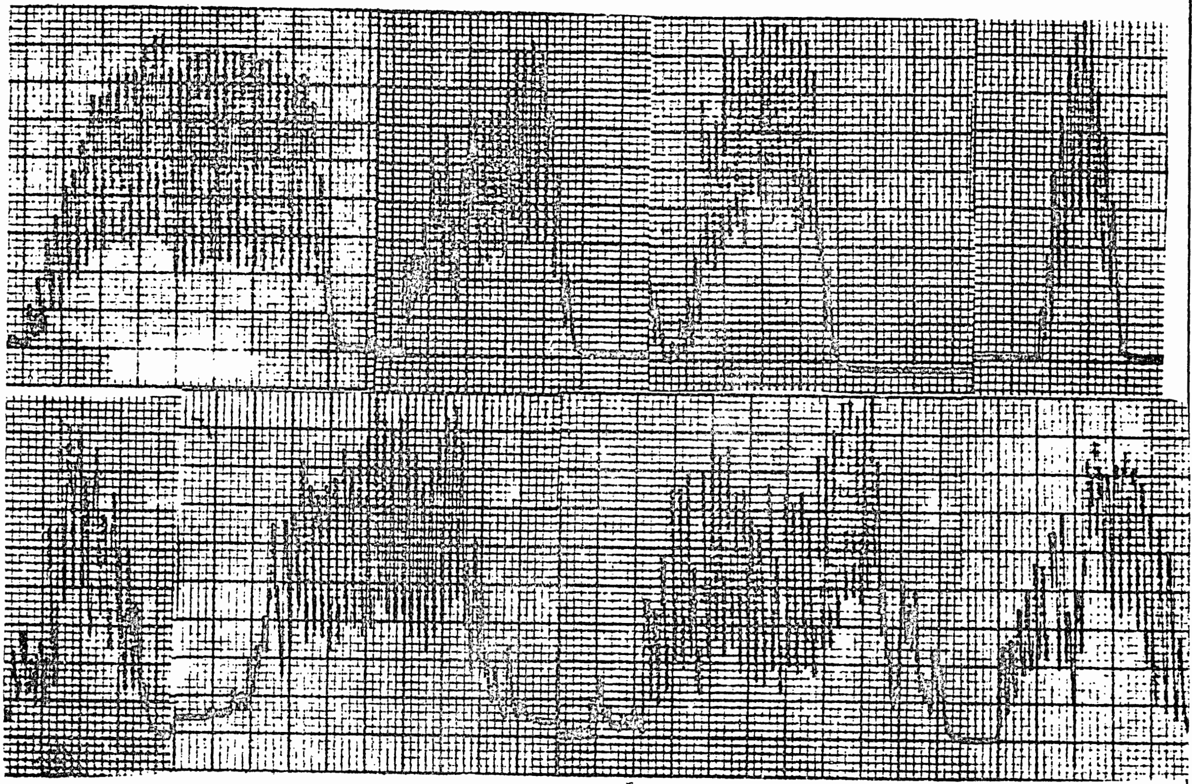


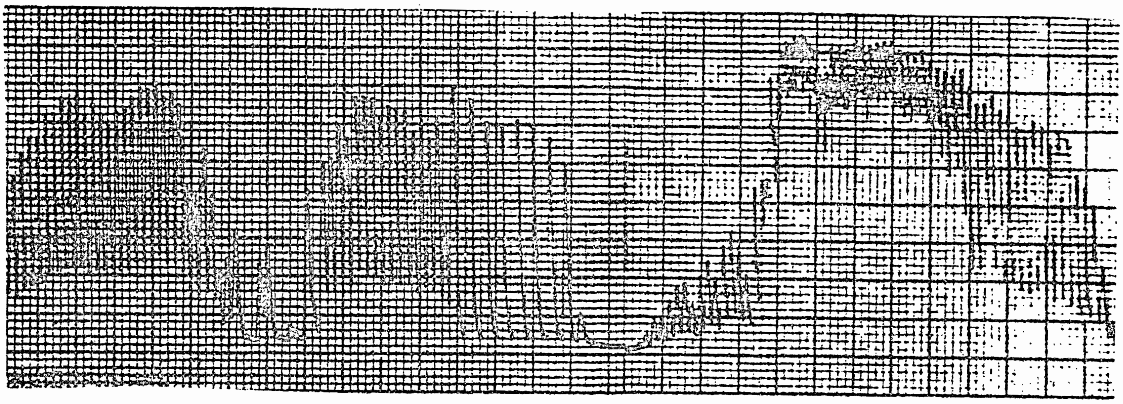
Diagonal Blocking



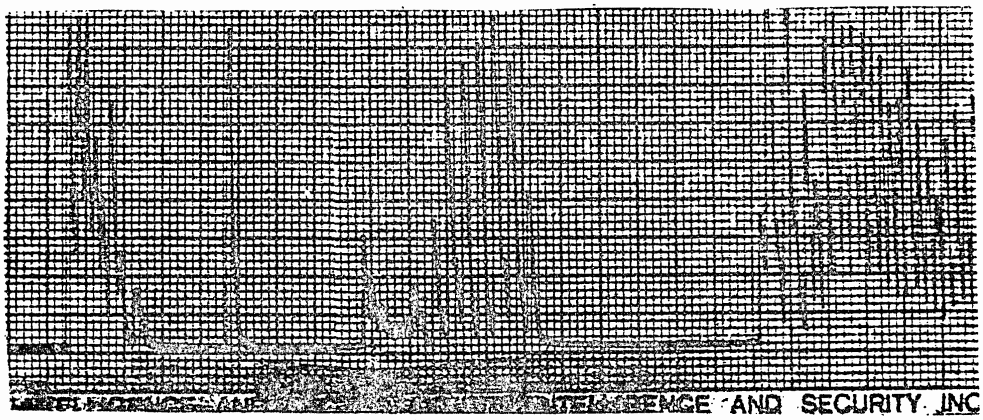
Doming Formation



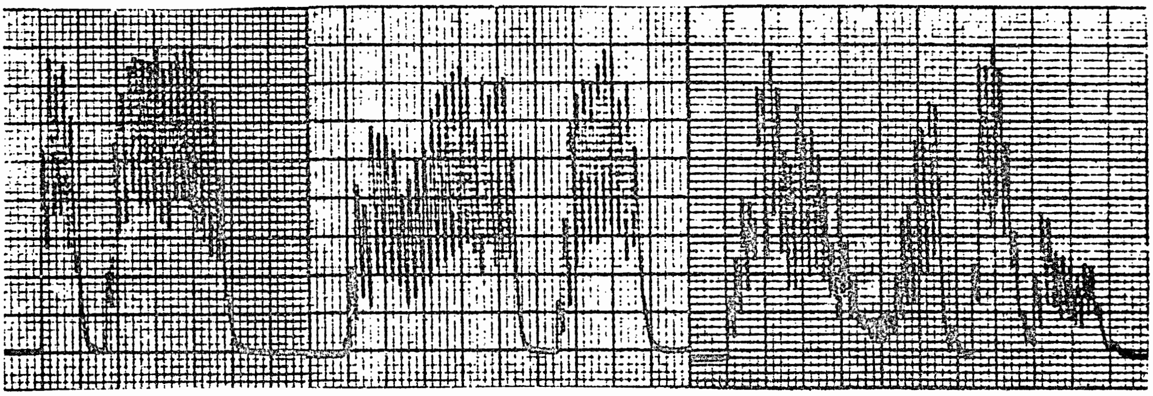
Tendency to form Block, Diagonal or Dome



Cyclic Rate Change



Gross Change



Diction Blocks

VARIABLES IN A TESTING SITUATION WHICH CAN INFLUENCE RESPONSES

There are a multitude of variables in the testing situation which can and do influence the responses made by subjects while they are undergoing a PSE examination. Many of these external stimuli can be eliminated or adjusted so that the situational anxiety manifested by the subject is minimal.

The relationship of the examiner to the subject should be totally objective. An examiner should never test coworkers, family, or friends, because the examiner's personal involvement with the subject can and will influence the examiner's interpretation of the results of the PSE examination. The room in which testing takes place should be large, light, and well-ventilated.

Since vocal responses from the subject are necessary, it is desirable to establish a rapport with the subject prior to administering any tests. In order to establish this rapport it is necessary for the examiner to determine from observation and discussion with the subject certain basic attitudes held by that subject. Communication with the subject must be in the language the subject uses to communicate in order to avoid the possibility of misunderstanding of word usage, meaning, or application by either the examiner or the subject.

The manner in which the examiner conducts the examination can also produce misleading anxiety responses from the subject. Many persons feel threatened by authoritarian figures; thus an examiner who presents an image of authority to the subject introduces unnecessary anxiety into the testing situation. Some subjects tend to feel more comfortable without direct eye contact with the examiner. All subjects perceive themselves as having a territorial space surrounding them. Violation of this territorial space by the examiner can produce anxiety. Some subjects may evidence misleading anxiety when requested to answer questions with a simple affirmative or negative response. In this instance anxiety lessens if the subject is allowed to qualify his responses during the examination.

The proper use of a personal history form prior to the testing of an individual should eliminate the following persons who would evidence distress throughout their PSE charts, and who should not be tested:

a. Epileptics,
b. Diabetics,
c. Persons suffering from or undergoing treatment for hypertension,
d. Hypoglycemics,
e. Individuals with a dependency, (i. e. drugs or alcohol),
f. Females who are experiencing pre-menstrual anxiety or menstrual stress, or who are taking mood elevators after a hysterectomy,
g. Females who have ceased taking birth control pills and are experiencing withdrawal symptoms,
h. Individuals who have not had the proper amount of sleep, food, etc.,
i. Individuals who are suffering from any type of disease which impairs or affects the muscles, and
j. Persons who have recently experienced sensory deprivation, (i. e. persons who have been in solitary confinement).

Another category of subjects who cannot successfully be tested includes persons who are referred to as 'Guilt Complex Reactors'. These persons evidence a high level of anxiety to all relevant and irrelevant questions in an examination.

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REFERENCE

The reference section includes the following copies of documents or articles:

a. The patent for the PSE,

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c. 'Physiological Tremor' by Olof Lippold, from the Scientific American, March, 1971, Published by W. H. Freeman and Company, San Francisco, California.

3971034

THE UNITED STATES OF AMERICA

TO ALL TO WHOM THESE PRESENTS SHALL COME:

WHEREAS THERE HAS BEEN PRESENTED TO THE

COMMISSIONER OF PATENTS AND TRADEMARKS

A PETITION PRAYING FOR THE GRANT OF LETTERS PATENT FOR AN ALLEGED NEW AND USEFUL INVENTION THE TITLE AND DESCRIPTION OF WHICH ARE CONTAINED IN THE SPECIFICATIONS OF WHICH A COPY IS HEREUNTO ANNEXED AND MADE A PART HEREOF, AND THE VARIOUS REQUIREMENTS OF LAW IN SUCH CASES MADE AND PROVIDED HAVE BEEN COMPLIED WITH, AND THE TITLE THERETO IS, FROM THE RECORDS OF THE PATENT AND TRADEMARK OFFICE IN THE CLAIMANT(S) INDICATED IN THE SAID COPY, AND WHEREAS, UPON DUE EXAMINATION MADE, THE SAID CLAIMANT(S) IS (ARE) ADJUDGED TO BE ENTITLED TO A PATENT UNDER THE LAW.

NOW, THEREFORE, THESE LETTERS PATENT ARE TO GRANT UNTO THE SAID CLAIMANT(S) AND THE SUCCESSORS, HEIRS OR ASSIGNS OF THE SAID CLAIMANT(S) FOR THE TERM OF SEVENTEEN YEARS FROM THE DATE OF THIS GRANT, SUBJECT TO THE PAYMENT OF ISSUE FEES AS PROVIDED BY LAW, THE RIGHT TO EXCLUDE OTHERS FROM MAKING, USING OR SELLING THE SAID INVENTION THROUGHOUT THE UNITED STATES.

IN TESTIMONY WHEREOF *I have hereunto set my hand and caused the seal of the* **PATENT AND TRADEMARK OFFICE** *to be affixed at the City of Washington this* twentieth *day of* July *in the year of our Lord one thousand nine hundred and seventy-six, and of the Independence of the United States of America the two hundredth and first.*

Attest:

Ruth C. Mason
Attesting Officer

C. Marshall Dann
Commissioner of Patents and Trademarks

United States Patent [19]

Bell, Jr. et al.

[11] **3,971,034**

[45] **July 20, 1976**

[54] **PHYSIOLOGICAL RESPONSE ANALYSIS METHOD AND APPARATUS**

[75] Inventors: **Allan D. Bell, Jr.**, Annandale; **Wilson H. Ford**, Arlington; **Charles R. McQuiston**, Falls Church, all of Va.

[73] Assignee: **Dektor Counterintelligence and Security, Inc.**, Springfield, Va.

[22] Filed: **Sept. 5, 1972**

[21] Appl. No.: **286,426**

Related U.S. Application Data

[63] Continuation of Ser. No. 113,949, Feb. 9, 1971, abandoned.

[52] **U.S. Cl.** .... **346/1; 128/21 R; 179/1 SP; 324/77 A; 346/13; 346/33 R**

[51] **Int. Cl.²** **G01D 1/04**

[58] **Field of Search** .... 346/33 R, 33 ME, 13; 179/1 VS, 1 SA; 128/2 R, 2.1 R; 324/77 A

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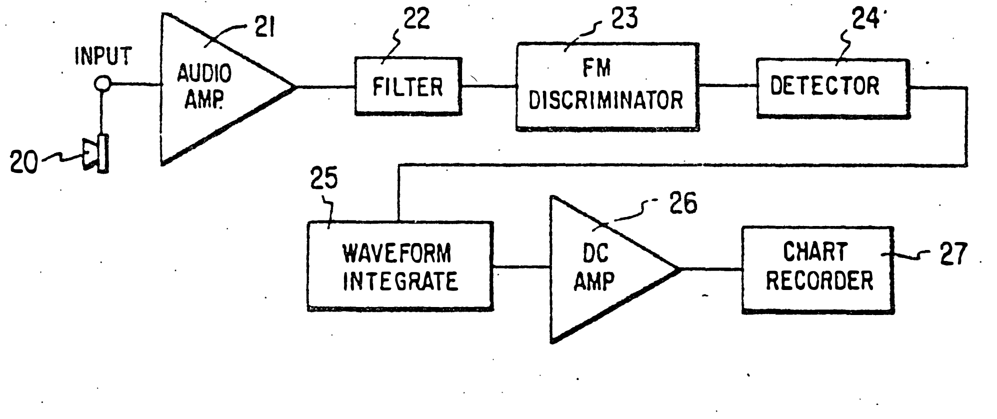
Primary Examiner—Joseph W. Hartary
Attorney, Agent, or Firm—Roylance, Abrams, Berdo & Kaul

[57] ABSTRACT

A method of detecting psychological stress by evaluating manifestations of physiological change in the human voice wherein the utterances of a subject under examination are transduced to electrical signals and processed to emphasize selected characteristics which have been found to change with psycho-physiological state changes. The processed signals are then displayed, as on a strip chart recorder, for observation, comparison and analysis. An especially useful characteristic is an infrasonic modulation in the voice. Apparatus for performing detection of this type includes a transducer, a magnetic recorder, a series diode, a plurality of integrating capacitors, an amplifier and a chart recorder. A second apparatus includes filter means, an FM discriminator and a detector, a waveform integrator, an amplifier and a recorder for producing a visible record.

9 Claims, 10 Drawing Figures



PHYSIOLOGICAL RESPONSE ANALYSIS METHOD AND APPARATUS

This is a continuation of application Ser. No. 113,949, filed Feb. 9, 1971, now abandoned.

This invention relates to a method of detecting and measuring psychological stress and to an apparatus for accomplishing the method.

Throughout history, various societies have recognized the fact that there is a relationship between psychological stress and changes in physiological states. One manner in which this relationship has been employed is in the causation of programmed response to psychological stimuli, a technique which has most notably been documented by Pavlov in his experiments with conditioned responses. Essentially the same characteristics have provided some basis for the development of techniques in such diverse fields as applied psychology, advertising and hypnotism. Although the existence of this aspect of the psycho-physiological relationship is well recognized, it is only indirectly involved with the present invention.

The second general type or category of the psychophysiological relationship, which is of more direct interest to the present invention, involves the recognition and identification of physiological changes which occur when the psychological changes take place. This approach is used more often in medical and psychological research and diagnosis, and in lie detection.

If the physiological manifestations of a change in psychological state are sufficiently great, it is possible for some subjective evaluations to be made by visual, unaided observation by a trained observer. However, far more accurate evaluation can be made by instrumentation designed to detect and measure relatively small degrees of physiological change. Those physiological changes most usually considered are brain wave patterns, heart activity, skin conductivity and breathing activity. One example of such a technique is found in U.S. Pat. No. 1,788,434 to Leonarde Keeler.

While the measurement of these activities does provide a far more accurate evaluation of physiological response than does direct unaided observation, it introduces several disadvantages. The most functionally serious of these problems is the artificiality of the testing situation caused largely by the previous requirement that sensors be attached to the person who is the subject of the examination. In addition, techniques heretofore used have generally required a controlled environment with resultant restrictions on the normal activity of the subject. These requirements can be expected to induce a psychological "set" in the subject which, in some cases, may be as strong as, or stronger than, the psychological set which is to be evaluated, thereby substantially reducing the validity of the evaluation.

An object of the present invention is to provide a method of evaluating psychological stress by detecting and measuring manifestations of physiological changes wherein the traditional restraints are minimized or eliminated to the extent that, in some cases, the subject under examination need not know that he is being examined.

A further object of the invention is to utilize the human voice as the medium by which changes in physiological state in response to psychological stress are detected.

A further object is to provide an apparatus for providing a visible record of those characteristics of the human voice by which physiological changes can be detected and from which the existence of psychological stress can be determined.

Briefly described, the method of the invention includes the steps of recording oral utterances of a subject on a visually observable medium and identifying frequency components of the recorded utterances which indicate physiological manifestations of the psychological stress. More specifically, the frequency components which can be identified as indicating the physiological state changes involve, in part, the infrasonic variations between utterances of a subject, changes in the infrasonic frequency variations being indicative of stress.

The apparatus of the invention includes transducer means for converting oral utterances of a subject into electrical signals, means for converting the frequency modulations in those electrical signals to amplitude modulations, and then recording the amplitude modulations thus produced on a visible record which can then be observed to detect indications of psychological stress.

In order that the manner in which the foregoing and other objects are attained in accordance with the invention can be understood in detail, particularly advantageous embodiments thereof will be described with reference to the accompanying drawings, which form a part of this specification, and wherein:

FIGS. 1 and 2 are reproductions of records drawn in accordance with the invention and illustrating one aspect thereof;

FIGS. 3*a–c* are reproductions of a record drawn in a test of the method of the invention and using the apparatus of the invention;

FIGS. 4*a–c* are reproductions of portions of a record drawn in a test of the method of the invention and using the apparatus of the invention;

FIG. 5 is a schematic diagram, in block form, of an apparatus in accordance with the invention; and

FIG. 6 is a schematic diagram of a further apparatus in accordance with the invention.

The so-called voice vibrato has been established as a semi-voluntary response which might be of value in studying deception along with certain other reactions; such as respiration volume; inspiration-expiration ratios; metabolic rate; regularity and rate of respiration; association of words and ideas; facial expressions; motor reactions; and reactions to certain narcotics; (TROVILLO, PAUL V. "A History of Lie Detection," The Journal of Criminal Law and Criminology, Mar-April May-June 1939.) however, no useable technique has been developed previously which permits a valid and reliable analysis of voice changes in the clinical determination of a subject's emotional state, opinions, or attempts to deceive.

Early experiments involving attempts to correlate voice quality changes with emotional stimuli (see SEASHORE, C. E., "Phonophotography in the Measurement of the Expression of Emotion in Music and Speech," Sci. Mo. 24:463–471 (1927); and METFESSEL, MILTON, "What is the Voice Vibrato?" Psychol. Monog. 39 (2) : 126–134 (1928) have established that human speech is affected by strong emotion. It has not yet been established that these changes are directly related to the functioning of the autonomic nervous system. In fact, the results of recent experiments by the inventors have established that detectable changes in the voice occur much more rapidly, following stress stimulation, than do the classic indications of physiological manifestations resulting from the functioning of the autonomic nervous system.

These experiments have further established two types of voice change as a result of stress. The first of these is referred to as the gross change which usually occurs only as a result of a substantially stressful situation. This change manifests itself in audible perceptible changes in speaking rate, volume, voice tremor, change in spacing between syllables, and a change in the fundamental pitch or frequency of the voice. This gross change is subject to conscious control, at least in some subjects, when the stress level is below that of a total loss of control.

The second type of voice change established was that of voice quality. This type of change is not discernible to the human ear, but is an apparently unconscious manifestation of the slight tensing of the vocal cords under even minor stress, resulting in a dampening of selected frequency variations. When graphically portrayed, the difference is readily discernible between unstressed or normal vocalization and vocalization under mild stress, attempts to deceive, or adverse attitudes. These patterns have held true over a wide range of human voices of both sexes, various ages, and under various situational conditions. This second type of change is not subject to conscious control.

As previously understood, there are two types of sound produced by the human vocal anatomy. The first type of sound is a product of the vibration of the vocal cords, which, in turn, is a product of partially closing the glottis and forcing air through the glottis by contraction of the lung cavity and the lungs. The frequencies of these vibrations can vary generally between 100 and 300 Hertz, depending upon the sex and age of the speaker and upon the intonations the speaker applies. This sound has a rapid decay time.

The second type of sound involves the formant frequencies. This constitutes sound which results from the resonance of the cavities in the head, including the throat, the mouth, the nose and the sinus cavities. This sound is created by excitation of the resonant cavities by a sound source of lower frequencies, in the case of the vocalized sound produced by the vocal cords, or by the partial restriction of the passage of air from the lungs, as in the case of unvoiced fricatives. Whichever the excitation source, the frequency of the formant is determined by the resonant frequency of the cavity involved. The formant frequencies appear generally about 800 Hertz and appear in distinct frequency bands which correspond to the resonant frequency of the individual cavities. The first, or lowest, formant is that created by the mouth and throat cavities and is notable for its frequency shift as the mouth changes its dimensions and volume in the formation of various sounds, particularly vowel sounds. The highest formant frequencies are more constant because of the more constant volume of the cavities. The formant wave forms are ringing signals, as opposed to the rapid decay signals of the vocal cords. When voiced sounds are uttered, the voice wave forms are imposed upon the formant wave forms as amplitude modulations.

It has been discovered that a third signal category exists in the human voice and that this third signal category is related to the second type of voice change discussed above. This is an infrasonic, or subsonic, frequency modulation which is present, in some degree, in both the vocal cord sounds and in the formant sounds. This signal is typically between 8 and 12 Hertz. Accordingly, it is not audible to the human ear. Because of the fact that this characteristic constitutes frequency modulation, as distinguished from amplitude modulation, it is not directly discernible on time-base/amplitude chart recordings. Because of the fact that this infrasonic signal is one of the more significant voice indicators of psychological stress, it will be dealt with in greater detail.

There are in existence several analogies which are used to provide schematic representations of the entire voice process. Both mechanical and electronic analogies are successfully employed, for example, in the design of computer voices. These analogies, however, consider the voiced sound source (vocal cords) and the walls of the cavities as hard and constant features. However, both the vocal cords and the walls of the major formant-producing cavities constitute, in reality, flexible tissue which is immediately responsive to the complex array of muscles which provide control of the tissue. Those muscles which control the vocal cords through the mechanical linkage of bone and cartilage allow both the purposeful and automatic production of voice sound and variation of voice pitch by an individual. Similarly, those muscles which control the tongue, lips and throat allow both the purposeful and the automatic control of the first formant frequencies. Other formants can be affected similarly to a more limited degree.

It is worthy of note that, during normal speech, these muscles are performing at a small percentage of their total work capability. For this reason, in spite of their being employed to change the position of the vocal cords and the positions of the lips, tongue, and inner throat walls, the muscles remain in a relatively relaxed state. It has been determined that during this relatively relaxed state a natural muscular undulation occurs typically at the 8–12 Hertz frequency previously mentioned. This undulation causes a slight variation in the tension of the vocal cords and causes shifts in the basic pitch frequency of the voice. Also, the undulation varies slightly the volume of the resonant cavity (particularly that associated with the first formant) and the elasticity of the cavity walls to cause shifts in the formant frequencies. These shifts about a central frequency constitute a frequency modulation of the central or carrier frequency.

It is important to note that neither of the shifts in the basic pitch frequency of the voice or in the formant frequencies is detectable directly by a listener, partly because the shifts are very small and partly because they exist primarily in the inaudible frequency range previously mentioned.

In order to observe this frequency modulation any one of several existing techniques for the demodulation of frequency modulation can be employed, bearing in mind, of course, that the modulation frequency is the nominal 8–12 Hertz and the carrier is one of the bands within the voice spectrum.

An example of the infrasonic variations discussed above can be observed in FIG. 1 which shows a recording made from the electrical signal resulting from a transduced voice of a normal unstressed subject. The figure depicts the pulses of the amplitude modulation of formants by a voiced signal of approximately 190 Hertz, the variations which appear as amplitude variations in FIG. 1 being amplitude representations of frequency modulation, the conversion being made by simple slope detection.

In order to more fully understand the representation of FIG. 1, the concept of a "center of mass" of this wave form must be understood. It is possible to approximately determine the midpoint between the two extremes of any single excursion of the recording pen as the wave form of FIG. 1 was drawn. If the midpoints between extremes of all excursions are marked and if those midpoints are then approximately joined by a continuous curve, it will be seen that a line approximating an average or "center of mass" of the entire wave form will result. For example, the midpoint of the excursion between the peaks identified as 10 and 11 in FIG. 1 is marked at 12. Joining all such marks, with some smoothing, results in the smooth curved line 13 in FIG. 1. The line 13 represents the infrasonic frequency modulation resulting from the undulations previously described.

As mentioned above, it has been determined that the array of muscles associated with the vocal cords and cavity walls is subject to mild muscular tension when slight to moderate psychological stress is created in the individual examination. This tension, indiscernible to the subject and similarly indiscernible by normal unaided observation techniques to the examiner, is sufficient to decrease or virtually eliminate the muscular undulations present in the unstressed subject, thereby removing the basis for the carrier frequency variations which produce the infrasonic frequency modulations.

FIG. 2 depicts an utterance similar to that of FIG. 1 but at a time of induced psychological stress. In this case, the center of mass wave form can be seen to be essentially devoid of the infrasonic variations observed in the unstressed utterance in FIG. 1, even though all other test factors and the demodulation procedures were held constant. For convenience, the center of mass is approximately indicated in FIG. 2 by line 14.

While the use of the infrasonic wave form is unique to the technique of employing voice as the physiological medium for psychological stress evaluation, the voice does provide for additional instrumented indications of aurally indiscernible physiological changes as a result of psychological stress, which physiological changes are similarly detectable by techniques and devices in current use. Of the four most often used physiological changes previously mentioned (brain wave patterns, heart activity, skin conductivity and breathing activity) two of these, breathing activity and heart activity, directly and indirectly affect the amplitude and the detail of an oral utterance wave form and provide the basis for a more gross evaluation of psychological stress, particularly when the testing involves sequential vocal responses.

FIG. 3 is a recording made during a test in which a psychological stress was induced in a female subject by having her utter a hypothetical lie in a Peak-of-Tension test. In the test the subject was asked to select one letter from a specified series of twelve letters, and to remember, but maintain in confidence, which letter she had selected. She was then asked if she had selected each of the letters in sequence. Further, she was told to respond, "I did not choose that letter" for each of the letters asked despite the fact that she had selected one. FIGS. 3*a*, 3*b* and 3*c*, which are a continuation of the same chart showing recordings of the oral responses by the subject when asked about each of the letters, displays an aggregate of pneumographic, cardiographic and, to a lesser degree, infrasonic influence. The signal for this display has been rather highly integrated to show more clearly the gross aggregate effect. The technique demonstrated by this chart is particularly useful in determining stress zones in tests wherein the answers constitute longer statements, wherein the statements include different words, or wherein the tests are very long requiring large numbers of statements. The evaluation is made simpler in these longer statement runs because wave form complexity is significantly reduced as compared with the wave forms shown in FIGS. 1 and 2.

The charts showing the responses on the twelve letter series from K to V show the following significant features which are indicative of physiological changes caused by the attempted deception. A marked constriction in the response to the letter K reflects the beginning-of-test tension which is normal in most overt testing situations. Generally, this initial tension would dissipate at L unless the set (the psychological predisposition) of the individual were such that the initial tension is reinforced by the tension of anticipating the approaching lie. Such is the case in this test, and tension is seen to continue at M, N and O, O being the point of deception. In addition to the observable effects of the infrasonic signal (which is normally present in relaxed speech but attenuated or absent in stressed statements) there are specific more usual physiological indicators also present which portray the changing emotional pattern of the individual. These are suppression/hyperventilation, diction stress, and significant delays in response time. The pneumographic influence gives the greatest indication of relief after the point of deception in that a noticable increase of amplitude is indicated at the point where the individual passed the point of deception and began to compensate for the decrease in oxygen/carbon dioxide exchange occurring at K through O.

Beginning at P, the relief which is experienced by the subject is evident through the remainder of the chart with the partial exception of Q, which can be expected as a momentary fear on the part of the subject that relief at P may have been audibly evident to the examiner.

Additionally, there are certain diction stresses which may be evident as a progressive change in an individual pattern. This may or may not be audible as the subject exercises abnormal control over his diction in an attempt to maintain a static speech pattern. These indications include minor changes in individual syllable stress and changes in the concatenation patterns in the separate responses. These indicators are largely responsible for the wave form pattern (as distinguished from amplitude) of the individual response displays: they follow a slightly different progression to O, the point of deception, in that they are not as much involved with the beginning-of-test stress demonstrated by the lower amplitude at K, but cause an increasingly less complex display up to N and O, and suddenly return to their complexity with the marked psychological relief at P. With the exception of Q (for the reason previously discussed) this non-stressed pattern continues throughout the remainder of the test.

It should be noted that the opposite configuration may occur; that is, the stress may be indicated by high amplitude and a multi-form trace while relief may be shown by a drop in amplitude and more simple pattern.

This, of course, depends upon whether a given individual responds to a given psychological stimulus with excitation or depression. While the general indicators of stress and relief may differ from test to test, they are relatively stable within any individual test and, of course, the infrasonic indicator remains constant from test to test and from individual to individual.

FIGS. 4*a*, 4*b* and 4*c* show recordings of portions of the responses in the test discussed with reference to FIGS. 3 *a–c*. FIG. 4*a* shows the individual characteristics of the words "not" and "letter" in the response to the letter N; FIG. 4*b* shows recordings of the same two words for the letter O; and FIG. 4*c* shows these same words for the letter P. The recordings in FIGS. 4 *a–c* were made at a somewhat higher chart speed than were the diagrams of FIGS. 3 *a–c* so that each horizontal division represents a much smaller increment of time than in FIGS. 3 *a–c*. Additionally, the electrical signals driving the recording mechanism are integrated or filtered to a substantially lesser degree in FIGS. 4 *a–c* than in FIGS. 3 *a–c*. Thus, it is possible in FIGS. 4 *a–c* to observe characteristics in the individual words and, in particular, the vowel sounds in each word. The diagrams are thus "expanded" and exhibit more clearly the infrasonic characteristics of the speech which were discussed previously. In FIG. 4*a*, the words show relatively little of the infrasonic undulation of the type shown in FIG. 1. Similarly, in FIG. 4*b* (the lie) practically no infrasonic undulation appears. However, in FIG. 4*c* the undulation again reappears, illustrating the relief from the stress approached at the point of the lie, illustrating again the phenomenon of muscular relaxation which permits the acyclic undulations to recur. Thus, as has been indicated in the previous examples, the infrasonic wave form is obvious in the unstressed utterance and is greatly attenuated in the stressed utterance.

Some general comments about the foregoing graphical representation should be made. While the above descriptions deal with psycho-physiological relationships from some of the more significant points of view, those who are knowledgable in these areas will readily recognize the functions of the endocrine glands and sympathetic and parasympathetic nervous systems in completing the interrelationships between the psychological stimulus and the several physiological responses involved in the present invention. Similarly, while the details of the physiology of the larynx and the resonant cavities of the throat and head have been described only to the point deemed necessary to support the techniques described herein, those persons versed in human physiology will be aware of the well known physical features involved in these areas.

It should also be recognized that, while some training and experience is highly desirable in becoming adept at recognizing certain characteristics which appear in the graphical representations discussed above, it will be appreciated that considerably less training and experience is necessary to interpret charts of this nature than is necessary for the more traditionally used physiological response indicators which, in addition, have the other disadvantages hereinbefore discussed. With a minimum of training and experience one with reasonable intelligence can frequently absorb and put to use the principles and methods disclosed herein. Further, one who is already trained in the fields of polygraphic analysis and lie detector use employing the more traditional physiological manifestation indicators, can adapt to this present technique in an extremely short time.

As to the graphs themselves, the visual presentations and the manner in which they are produced can more fully be understood by a discussion of some apparatus which can be used to produce the charts previously discussed.

One embodiment of an apparatus is shown in FIG. 5 wherein a transducer 20 converts the sound waves of the oral utterances of the subject into electrical signals wherefrom they are connected to the input of an audio amplifier 21 which is simply for the purpose of increasng the power of electrical signals to a more stable, usable level. The output of amplifier 21 is connected to a filter 22 which is primarily for the purpose of eliminating some undesired low frequency components and noise components.

After filtering, the signal is connected to an FM discriminator 23 wherein the frequency deviations from the center frequency are converted into signals which vary in amplitude. The amplitude varying signals are then detected in a detector circuit 24 for the purpose of rectifying the signal and producing a signal which constitutes a series of half wave pulses. After detection, the signal is connected to an integrator circuit 25 wherein the signal is integrated to the desired degree. In circuit 25, the signal is either integrated to a very small extent, producing a wave form which is similar in configuration to that seen in FIGS. 1 and 2, or is integrated to a greater degree, producing a signal which more nearly resembles those in FIGS. 3 *a–c*. After integration, the signal is amplified in an amplifier 26 and connected to a chart recorder 27 which produces the visible record.

A somewhat simpler embodiment of an apparatus for producing visible records in accordance with the invention is shown in FIG. 6 wherein the acoustic signals are transduced by a microphone 30 into electrical signals which are magnetically recorded in a tape recording device 31. The signals can then be processed through the remaining equipment at various speeds and at any time, the play-back being connected to a conventional semiconductor diode 32 which rectifies the signals. The rectified signals are connected to the input of a conventional amplifier 33 and also to the movable contact of a selector switch indicated generally at 34. The movable contact of switch 34 can be moved to any one of a plurality of fixed contacts, each of which is connected to a capacitor. In FIG. 6 is shown a selection of four capacitors 35, 36, 37 and 38, each having one terminal connected to a fixed contact of the switch and the other terminal connected to ground. The output of amplifier 33 is connected to a chart recorder indicated generally at 39.

An apparatus substantially identical to that shown in FIG. 6 was used to produce the chart records shown in FIGS. 1–4, the differences between the appearances of various charts being determined by the difference in play-back speed used with tape recorder 31 and the degree of integration accomplished by the selection of capacitors with switch 34. The tape recorder used in this particular assembly of equipment was a Uher model 4000 four-speed tape unit having its own internal amplifier. The values of capacitors 35–38 were 0.5, 3, 10 and 50 microfarads, respectively, and the input impedance of amplifier 33 was approximately 10,000 ohms. The strip chart recorders used had sufficient inductance to provide a desirable amount of high frequency filtering and slope detection. Two recorders were used, one being a model O-601 Esterline-Angus recorder (FIGS. 3 *a–c* and 4 *a–c*) and the other being a galvanomic pen motor from a Keeler lie detector. As will be recognized, various other components could be, or could have been, used in this apparatus.

In the operation of the circuit of FIG. 6, the rectified wave form emerging through diode 32 is integrated to the desired degree, the time constant being selected so that the effect of the frequency modulated infrasonic wave appears as a slowly varying DC level which, as shown in FIG. 1, approximately follows the line identified by numeral 13. The excursions shown in that particular diagram are relatively rapid, indicating that the switch was connected to one of the lower value capacitors. For the diagrams of FIGS. 3 *a–c*, switch 34 would be set to connect capacitor 38 to the input of amplifier 33.

In this embodiment composite filtering is accomplished by the capacitor 35, 36, 37 or 38, the chart recorder, the chart-recorder amplifier, and, in the case of the playback speed reduction, the tape recorder. Frequency modulation discrimination is accomplished by the frequency-sensitive filtering at the input of the chart-recorder amplifier and by the electrical and mechanical inertia of the chart-recorder pen motor.

It will be recognized that the above described method and apparatus provides a relatively simple technique for evaluating psychological stress in a subject under examination and can be useful in detecting efforts at deception. It will also be recognized that the complete absence of connections to the subject under examination permits the apparatus to be used with a subject who does not know that he is being examined and also permits examination of subjects at a remote distance, such as over telephone lines or other communications networks. An example of this technique is the recording of the oral utterances of a person, or several individuals, appearing on a television program, notably one program in which each of three parties claimed to be a specific individual but only one of the parties was telling the truth. Recordings of the statements by each party, processed in accordance with the method of the present invention on an apparatus such as that shown in FIG. 6, provided recordings from which the individual telling the truth could be readily identified. Thus, the apparatus is much less limited than any previously known stress analyzing device.

While certain advantageous embodiments have been chosen to illustrate the invention it will be understood by those skilled in the art that various changes and modifications can be made therein without departing from the scope of the invention as defined in the appended claims.

What is claimed is:

1. A method of identifying physiological manifestations of psychological stress in a human subject comprising the steps of
   converting an oral utterance by the subject from sound energy into electrical signals;
   emphasizing those portions of the electrical signals which represent inaudible variations in the infrasonic frequency modulation of the voice of the subject;
   recording signals representative of the emphasized portions of the electrical signals on a visually observable medium; and
   observing the visual record of the utterance to determine increases and decreases in modulation variations, the degree of presence of the modulation constituting an inverse measure of the stress.

2. An apparatus for producing a display of characteristics of oral utterances of a subject, which display can be observed for indications of involuntary physiological manifestations of psychological stress, the apparatus comprising the combination of
   transducer means for converting the oral utterances into electrical signals,
   said transducer means including means for producing a magnetic recording of the oral utterances to permit repeated processing of said utterances to emphasize different characteristics;
   signal processing means for receiving the electrical signals and for emphasizing preselected inaudible involuntary stress indicating characteristics thereof; and
   means for displaying the emphasized characteristics.

3. An apparatus according to claim 2 wherein said signal processing means includes
   means for detecting infrasonic frequency variations in said electrical signals and for providing to said means for displaying an amplitude-varying signal representative of said variations.

4. An apparatus for producing a display of characteristics of oral utterances of a subject, which display can be observed for indications of involuntary physiological manifestations of psychological stress, the apparatus comprising the combination of
   transducer means for converting the oral utterances into electrical signals;
   signal processing means for receiving the electrical signals and for emphasizing preselected inaudible involuntary stress indicating characteristics thereof; and
   means for displaying the emphasized characteristics,
   said signal processing means including means for detecting infrasonic frequency variations in said electrical signals and for providing to said means for displaying an amplitude-varying signal representative of said variations, and means for integrating said electrical signals.

5. An apparatus for producing a display of characteristics of oral utterances of a subject, which display can be observed for indications of involuntary physiological manifestations of psychological stress, the apparatus comprising the combination of
   transducer means for converting the oral utterances into electrical signals;
   signal processing means for receiving the electrical signals and for emphasizing preselected inaudible involuntary stress indicating characteristics thereof,
   said signal processing means including means for integrating said electrical signals; and
   means for displaying the emphasized characteristics.

6. An apparatus according to claim 5 wherein said signal processing means includes means for emphasizing composite characteristics resulting from aggregate physiological changes.

7. An apparatus according to claim 5 wherein
   said signal processing means includes demodulator means for converting the inaudible infrasonic frequency modulations representative of the characteristics to be analyzed in said electrical signals to amplitude modulations; and
   said means for displaying includes means for recording the amplitude modulations on a visible record.

8. An apparatus for producing a visible indication of involuntary stress manifestations comprising the combination of

means for converting the oral utterances of a subject into electrical signals;

discriminator means for converting frequency deviations in said electrical signals into amplitude variations;

detector means for rectifying said electrical signals to produce signals having unidirectional pulses;

means for partially integrating said signals with respect to time; and

means for accepting the integrated signals and for producing a visible indication of the degree of presence of an inaudible infrasonic component in said deviations,

the degree of presence of said component constituting a measure of psychological stress in the subject.

9. An apparatus for producing a visible record of characteristics of oral utterances of a human subject, which characteristics are not discernible by the unaided human ear, for analysis of involuntary psychological stress manifestations, the apparatus comprising the combination of

transducer means for converting the oral utterances into electrical signals;

demodulator means for converting the inaudible infrasonic frequency modulations representative of the characteristics to be analyzed in said electrical signals to amplitude modulations;

means for recording the amplitude modulations on a visible record; and

integrator circuit means for partially integrating the electrical signal output from said demodulator means to emphasize the amplitude modulation in the signals representative of inaudible infrasonic frequency modulation components present in the voice of the subject before recording,

the absence and degree of presence of said modulations being observable as indications of the presence and degree of presence of psychological

* * * * *

FIG. 1

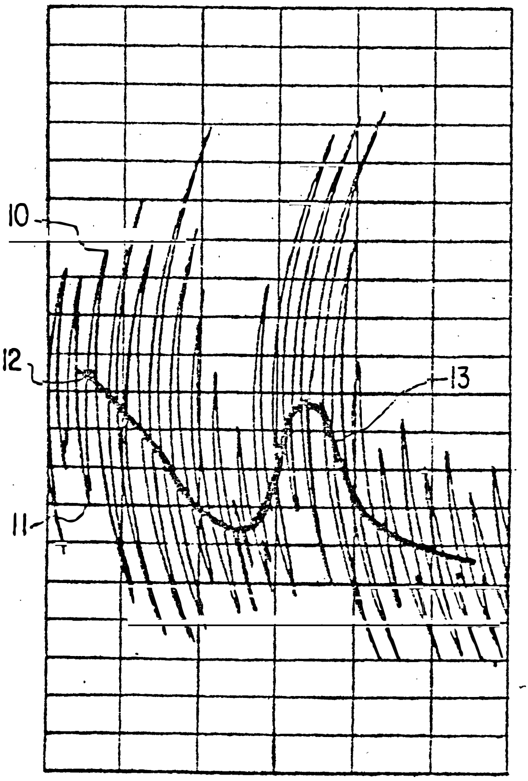
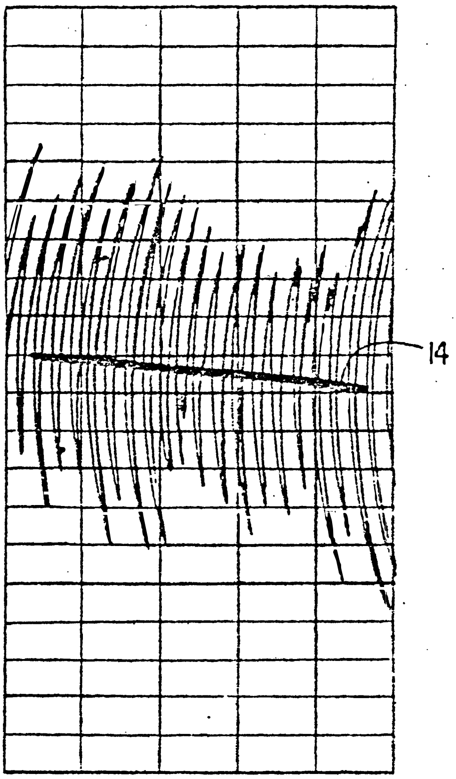


FIG. 2



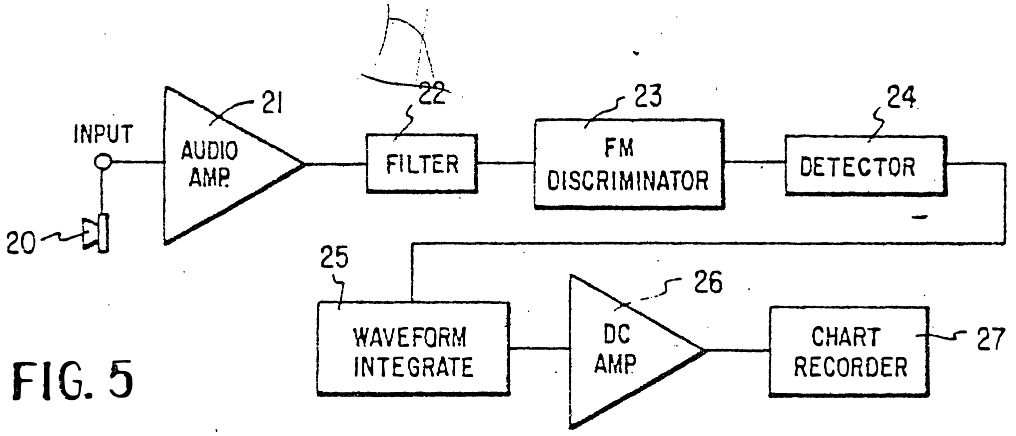


FIG. 5

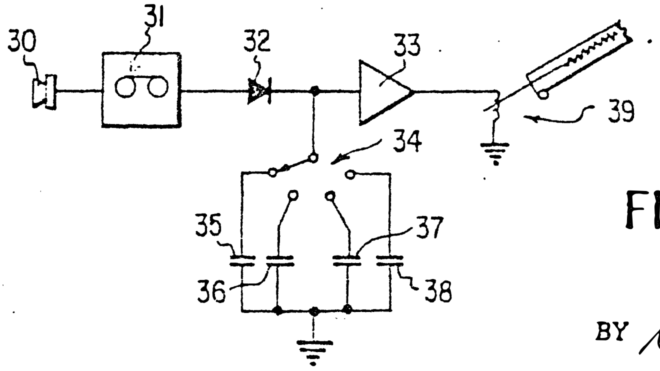


FIG. 6

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FIG. 3b

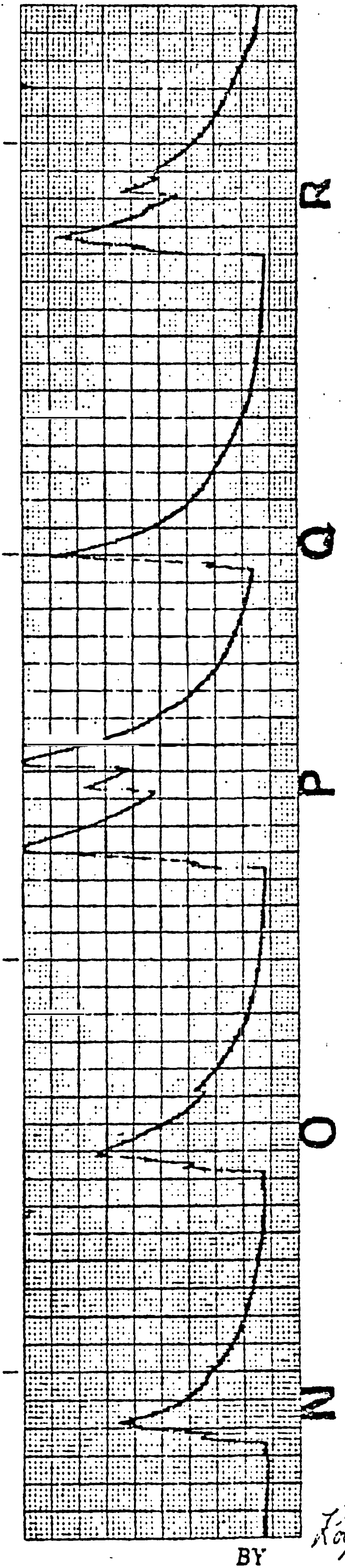
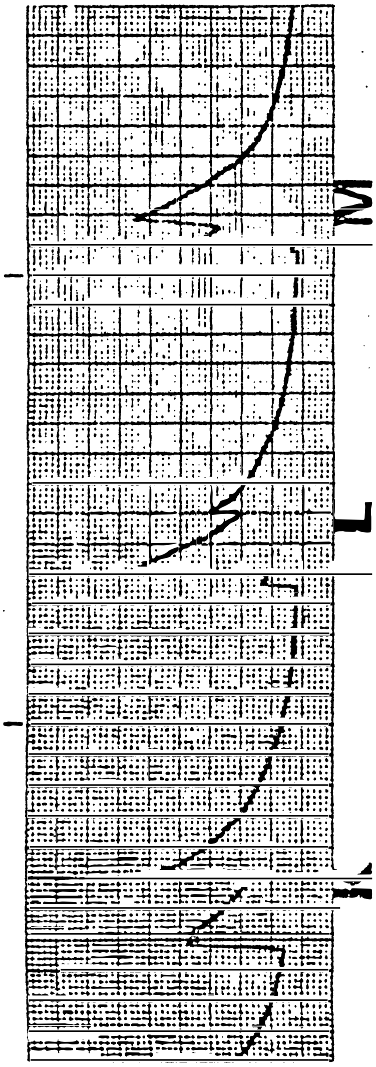


FIG. 3a



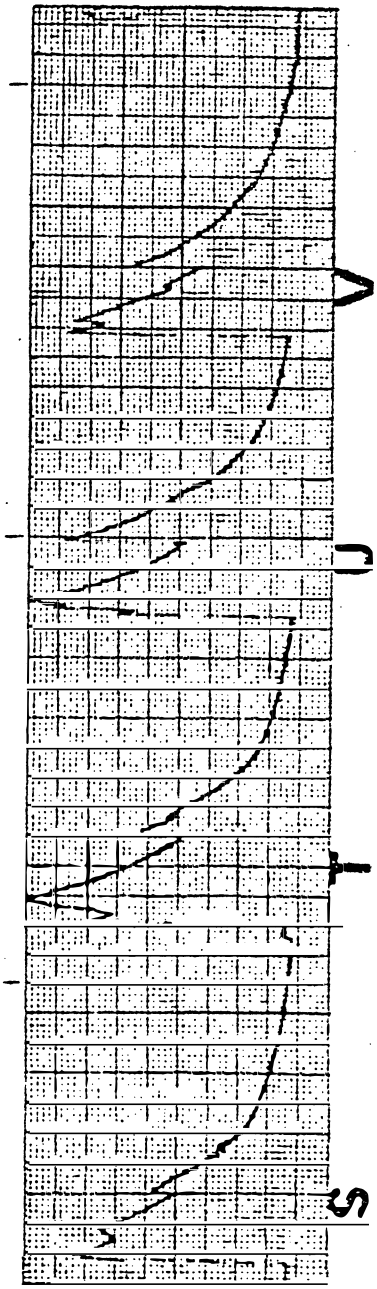


FIG. 3c

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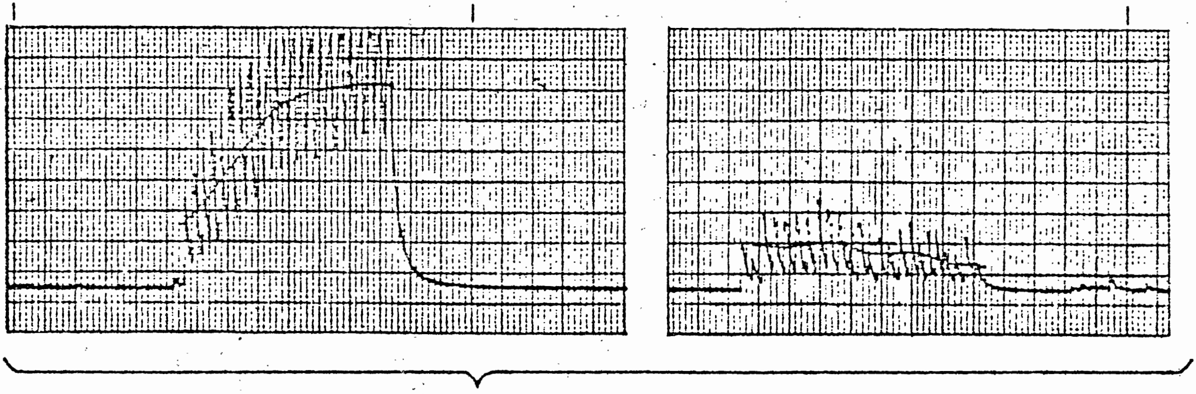

FIG. 4a

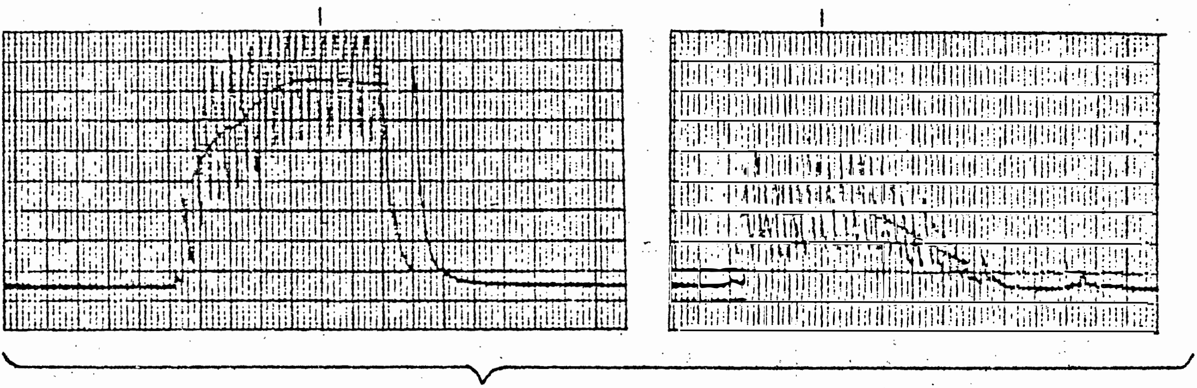

FIG. 4b

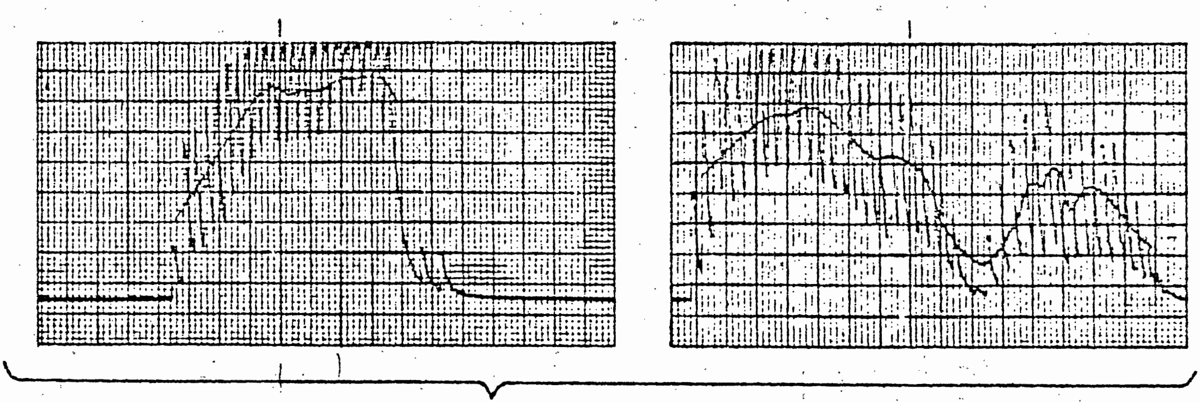

FIG. 4c

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PSYCHOLOGICAL STRESS EVALUATOR

This invention relates to the detection and measurement of psychological stress and, more particularly, to the measurement of psychological stress at levels below those discernible without instrumentation and the measurement of psychological stress without the use of applied or visible sensors.

The existence of the relationships between psychological states and physiological responses to such states has long been recognized. Two general types of exploitation of these relationships have developed. The first of these is the causation of programmed response to psychological stimuli, which has been most notably documented by Pavlov in his experiments with conditioned responses, and has provided some basis for such divergent fields. as applied psychology, advertising, and hypnotism. This type of exploitation of the psycho-physiological relationships is only supplementally involved with the present invention.

The second general type of exploitation of the psycho-physiological relationships involves the identification and measurement of psychological changes by identifying and measuring resultant physiological changes. This approach is used largely in medical and psychological research and diagnosis, and in lie detection. Two methods of evaluation are used. When the responses are sufficiently great, some subjective evaluations can be made by a trained observer; however, far more accurate evaluations can be made by instrumentation designed to detect and measure relatively small degrees of physiological change. Those physiological changes most usually considered are brainwave patterns, heart activity, skin conductivity, and the breathing activity. While the measurement of these activities does provide a far more accurate evaluation of physiological response than does direct observation, it introduces several disadvantageous features. The most functionally serious of these problems is the artificiality of the testing situation caused by the requirement for sensors to be attached to the subject of the examination, the controlled environment usually required, and resultant restrictions on the normal activity of the subject. These requirements can be expected to induce a psychological set in the subject which, in some cases, may be as strong as or stronger than the psychological set which is to be evaluated, thereby substantially reducing the validity of the evaluation.

It has been an objective of this invention to achieve a method for psychological stress evaluation which avoids the testing and evaluation constraints imposed by the existing requirements for obvious and attached sensors.

It has been a specific objective of this invention to use the human voice as the medium which provides the physiological response to psychological change — inasmuch as the use of this medium resolves the existing problems of attached sensors, elaborate equipment, and highly controlled environment in association with the subject; inasmuch as this is the one physiological medium which can be transmitted over distances by existing and readily available techniques (telephone and radio); and inasmuch as this is the one physiological medium which can be recorded simply as a completely valid and comprehensive analog of the medium (e.g., by tape recording).

The basic physiology of the human voice, as heretofore understood, produces two types of sound. The first of these is a product of the vibration of the vocal chords, which, in turn, is a product of partially closing the glottis and forcing air through the glottis by contraction of the lung cavity and the lungs. The frequency of these vibrations may vary generally between 100 and 300 Hertz, depending upon the sex and age of the speaker and upon the intonations the speaker applies. This sound has a rapid decay time.

The second type of sound involves the formant frequencies. This is sound which results from the resonance of the cavities in the head (throat, mouth, nose, and sinus cavities). This sound is created by excitation of the resonant cavities by a sound source of lower frequencies, in the case of the vocalized sound produced by the vocal chords, or b y the partial restriction of the passage of air from the lungs, as in the case of unvoiced fricatives. Whichever the excitation source, the frequency of the formant is determined by the resonant frequency of the cavity involved. The formant frequencies appear generally above 800 Hertz and appear in distinct frequency bands which correspond to the resonant frequency of the individual cavities. The first, or lowest, formant is that created by the mouth and throat cavities and is notable for its frequency shift as the mouth changes its dimensions and volume in the formation of various sounds, particularly vowel sounds. The higher formant frequencies are more constant, because of the more constant physical volume of the cavities. The formant waveforms are ringing signals, as opposed to the rapid decay signals of the vocal chords. When voiced sounds are uttered, the voiced waveforms are imposed upon the formant waveforms as amplitude modulation.

A third signal category in the human voice has been uncovered during the research leading to this invention. This is an infrasonic frequency modulation, present, in some degree, in both the vocal chord sounds and in the formant sounds. This signal is typically between 8 and 12 Hertz; therefore, it is inaudible to the human ear. As frequency modulation, as opposed to amplitude modulation, it is not directly discernible on time base/amplitude chart recordings. Because this infrasonic signal is one of the more significant voice indicators of psychological stress, it will be dealt with in greater detail.

There are several analogies which are used to provide schematic representations of the entire voice process. Both mechanical and electronic analogies are successfully employed, for example, in the design of computer voices. These analogies, however, consider the voiced sound source (vocal chords) and the walls of the cavities as hard and constant features. As opposed to these analogies, both the vocal chords and the walls of the major formant-producing cavities are soft flexible tissue immediately responsive to the complex array of muscles which control them. Those muscles which control the vocal chords thru the mechanical linkage of bone and cartilage allow both the purposeful and automatic production of voiced sound and variation of voice pitch. Similarly, those muscles which control the tongue, lips, and throat allow both the purposful and the automatic control of the first formant frequencies. Other formants can be affected similarly to a more limited degree. It is worthy of note that, during normal speech, these muscles are performing at a small percentage of their work capability. For this reason, in spite of their being employed to change the position of the vocal chords and the position of the lips, tongue, and inner throat walls, the muscles remain in a relatively relaxed state. As a result of research conducted for this invention, it has been determined that during this relatively relaxed state a natural muscular undulation occurs at the typically 8 to 12 Hertz frequency previously mentioned. This undulation slightly varies the tension of the vocal chords and causes audibly indiscernible shifts in the basic pitch frequency of the voice and it slightly varies the volume of the resonant cavity (particularly that associated with the first formant) and the elasticity of the cavity walls to cause audibly indiscernible shifts in the formant frequencies. These shifts about a central frequency constitute a frequency modulation of the central or carrier frequency. In order to observe this frequency modulation, any of the several existing techniques for the demodulation of frequency modulation may be employed, bearing in mind, of course, that the modulation frequency is the nominal 8 to 12 Hertz and the carrier is one of the bands within the voice spectrum. Figure 1 depicts pulses of the amplitude modulation of formants by a voiced signal of 190 Hertz, resulting from 2.5 Kilohertz high-pass filtering of the voice of an unstressed subject and the contained infrasonic frequency modulation observable in the center-of-mass waveform. A simple slope detection was made of the unlimited infrasonic waveform of a syllable utterance.

It has been determined, further, that the array of muscles associated with the vocal chords and the cavity walls are subject to mild muscular tension when slight to moderate psychological stress is created in the subject. This tension, indiscernible to the subject, is sufficient to decrease or virtually eliminate the muscular undulations present in the unstressed subject, thereby removing the basis for the carrier frequency variations which produce the infrasonic frequency modulation. Figure 2 depicts a similar utterance as that of Figure 1, but at a time of induced psychological stress. In this case the center-of-mass waveform can be seen to be essentially devoid of the infrasonic variations observed in the unstressed utterance in Figure 1, even though all other test factors and the demodulation procedures were held constant.

While the use of the infrasonic waveform is unique to the use of voice as the physiological medium for psychological stress evaluation, the voice provides for additional instrumented indications of aurally indiscernible physiological changes as a result of psychological stress, which physiological changes are detectable also by current means. Of the four most usually considered physiological changes previously mentioned (brainwave patterns, heart activity, skin conductivity, and breathing activity), two – breathing activity and heart activity – directly and indirectly affect the amplitude and the detail of an utterance waveform and provide the basis for a more gross evaluation of psychological stress, particularly when the testing situation involves sequential vocal responses. Figure 3 depicts a test in which psychological stress was induced in a female subject by having her utter a hypothetical lie in a Peak of Tension test, in which she responded, "I did not choose that letter" for each of a series of 12 letters, one of which, in fact, she had selected. The chart displays an aggregate of pneumographic, cardiographic, and, to a lesser degree, infrasonic influence. The signal for this display has been highly integrated to show more clearly the gross aggregate effect. This technique is particularly useful in determining stress zones in longer statement runs, by avoiding waveform complexity. This chart, the 12 letter series from K to V, shows the following significant features which are indicative of physiological changes caused by the attempted deception.

There is a marked constriction at K which reflects the beginning-of-test tension normal in most overt testing situations. Normally, this initial tension would dissipate at L unless the set of the individual were such that the initial tension is reinforced by the tension of anticipating the approaching lie. Such is the case in this test, and tension is seen to continue at M, N, and O, the point of deception. In addition to the observable effects of the infrasonic signal (which is normally present in relaxed speech but attenuated or absent in stressed statements) there are certain more usual physiological indicators also present which portray the changing emotional pattern of the individual; these are supression/hyperventilation, diction stress, and significant delays in response time. The pneumographic influence gives the greatest indication of relief after the point of deception in that a noticeable increase of amplitude is indicated at the point where the individual passed the point of deception and began to compensate for the decrease in oxygen/carbon dioxide exchange occuring at K through O. Beginning at P the relief experienced by subject is evident through the remainder of the chart with the partial exception of Q, which can be expected as a momentary fear on the part of the subject that relief at P may have been evident audibly to the examiner.

Additionally, there are certain diction stresses which may be evident as a progressive change in an individual pattern. This may or may not be audible as subject exercises abnormal control over his diction in an attempt to maintain a static speech pattern. These indications include minor changes in individual syllable stress and changes in the concatenation patterns in the separate responses. These indicators are largely responsible for the waveform pattern (as distinguished from amplitude) of the individual response displays; they follow a slightly different progression to O, the point of deception, in that they are not as much involved with the beginning-of-test stress demonstrated by the lower amplitude at K, but cause an increasingly less complex display up to N and O, and suddenly return to their complexity with the marked psychological relief at P. With the exception of Q (for the reason previously discussed) this non-stressed pattern continues throughout the remainder of the test.

It should be noted that the opposite configuration may occur; that is, the stress may be indicated by high amplitude and a multi-form trace while relief may be shown by a drop in amplitude and a more simple pattern. This, of course, depends upon whether a given individual responds to a given psychological stimulus with excitation or depression. While the general indicators of stress and relief may differ from test to test, they are relatively stable within any individual test and, of course, the infrasonic indicator remains constant from test to test and from individual to individual.

Figure 4 depicts an expansion of the N-O-P portion of this Peak of Tension test to show the somewhat constrained infrasonic waveform at N, as the tension is increasing, the more greatly constrained infrasonic waveform at O (the "lie") and the presence of the infrasonic waveform at P, as a result of psychological relief.

Figure 5 depicts similar portions of two narrative-type utterances made by a subject under unstressed conditions (5a) and under conditions of induced mild anxiety (5b). As has been indicated in the previous examples, the infrasonic waveform is obvious in the unstressed utterance and is greatly attenuated in the stressed utterance.

While the above descriptions and examples deal with the psycho-physiological relationships from the standpoint of an overview, those who are knowledgeable in these areas will readily recognize the functions of the endocrine glands, and the sympathetic and parasympathetic nervous systems in completing the course between the psychological stimulus and the several physiological responses involved in this invention. Similarly, while the details of the physiology of the larynx and the resonant cavities of the throat and head have been described only to the point deemed necessary to support the techniques and findings, those persons versed in human physiology will be aware of the well-known physical features involved in these areas.

FIG. I

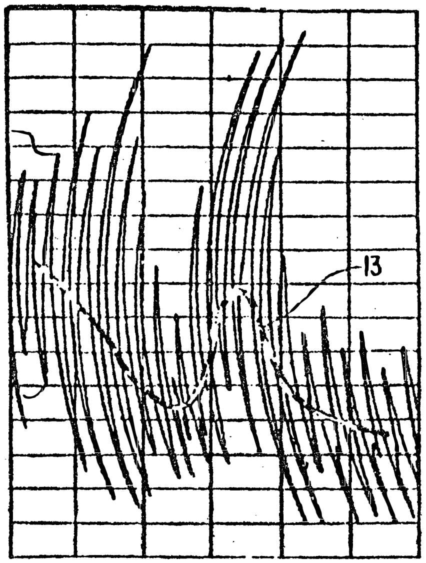


FIG. 2

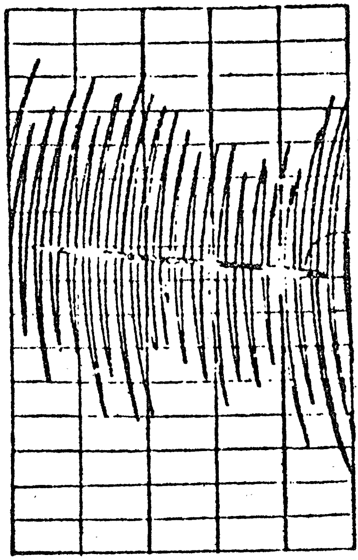



FIGURE 3

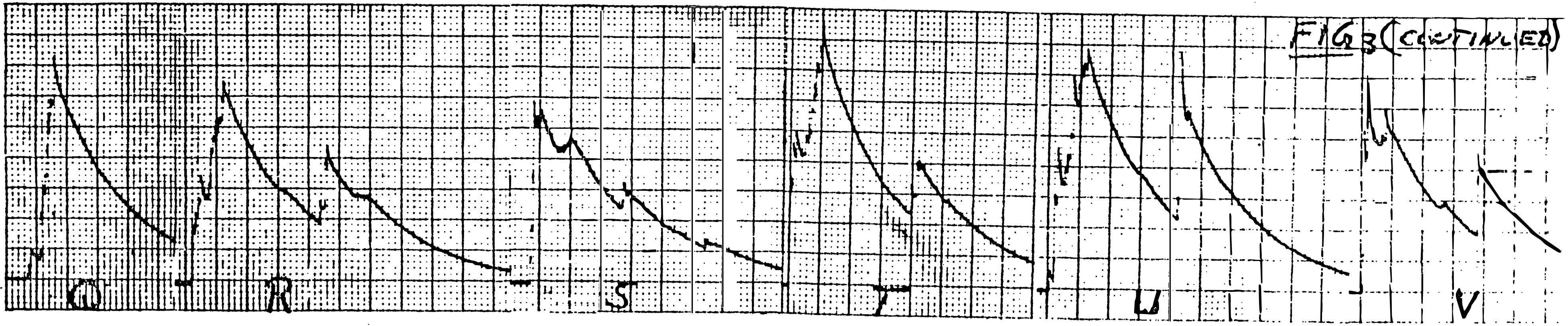


FIG 3 (CONTINUED)

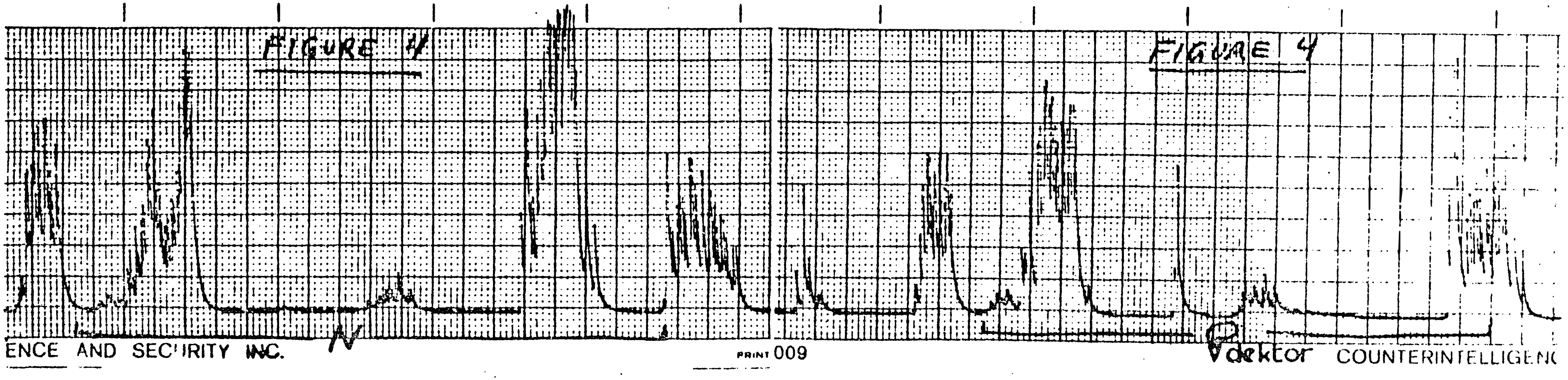


FIGURE 4

FIGURE 4

FIGURE 4

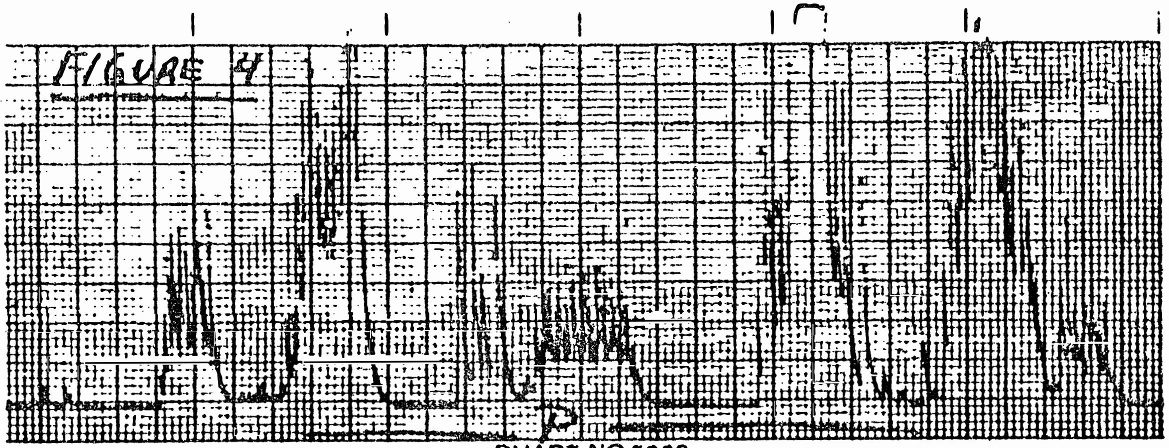
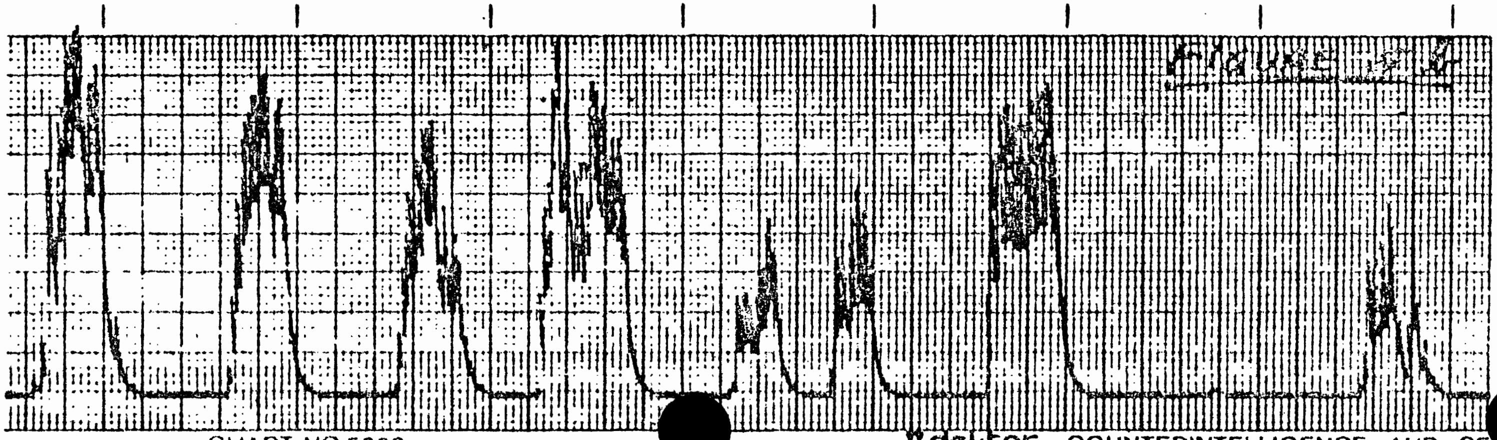


Figure [illegible]

Figure [illegible]



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PHYSIOLOGICAL TREMOR

by Olof Lippold

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PHYSIOLOGICAL TREMOR

A slight oscillation at approximately 10 cycles per second accompanies the normal contraction of voluntary muscle. It appears to be caused by a "hunting" mechanism in the reflex arc that controls the muscle

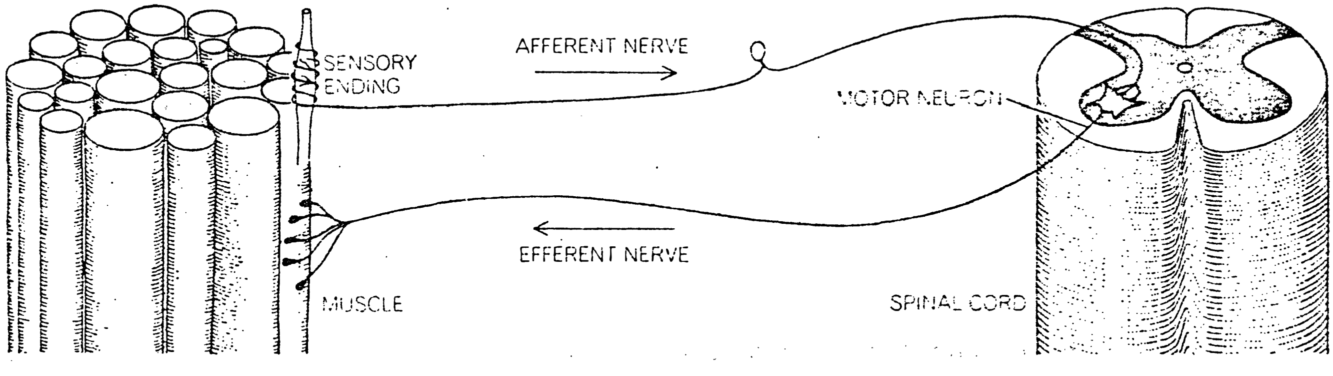
by Olof Lippold

The contraction of a voluntary muscle is accompanied by tremors of the muscle in the form of minute oscillations. In an electrical recording of the muscle's activity the tremor can be seen as a trace of very fine rhythmic movements superimposed on the record of the contraction itself. The amplitude of the oscillations is about a hundredth or a fiftieth as large as that of the total movement produced by the contraction, and the predominant frequency, in man, is about 10 cycles per second. This rippling of the muscle, known as physiological tremor, was discovered many years ago to be a normal accompaniment of the voluntary muscles' activity. Various explanations were proposed. There were theories that the factor generating the tremor might be the heartbeat or the alpha waves of the brain or synchronized activity of a group of motor neurons—motor nerve cells—in the spinal cord or some form of local activity involving only the contracting muscle or its neural junction. All these theories fail to account for the actual behavior of the tremor, as we shall see. It remained for a modern insight in technology, arising from the investigation of servomechanisms and the role of feedback, to suggest what now seems to be the correct explanation of physiological tremor.

The first clue leading to this explanation came from a study of muscle tremor made a little more than a decade ago by Martin Halliday and Joe Redfearn at the National Hospitals for Nervous Diseases in London. Applying the techniques of Fourier analysis to the frequency spectrum of physiological tremor, they found that the major part of the tremor consisted of an oscillation of the reflex mechanism that controls the length and tension of a stretched muscle. The fact that the tremor's spectrum peaks sharply in the narrow range between eight and 12 cycles per second then pointed to a likelihood that physiological tremor is an oscillation like the "hunting" behavior of mechanical servomechanisms, because characteristically in such systems the energy tends to be concentrated in a rather narrow bandwidth.

Consider the simple thermostat, a servomechanism designed to maintain temperature at a constant level. In this feedback control system there is an unavoidable delay in the response to a change in the temperature of the regulated space or object, so that the system overcorrects and the temperature keeps oscillating slightly above and below the desired value. In short, the temperature is continuously in a state of slow "tremor."

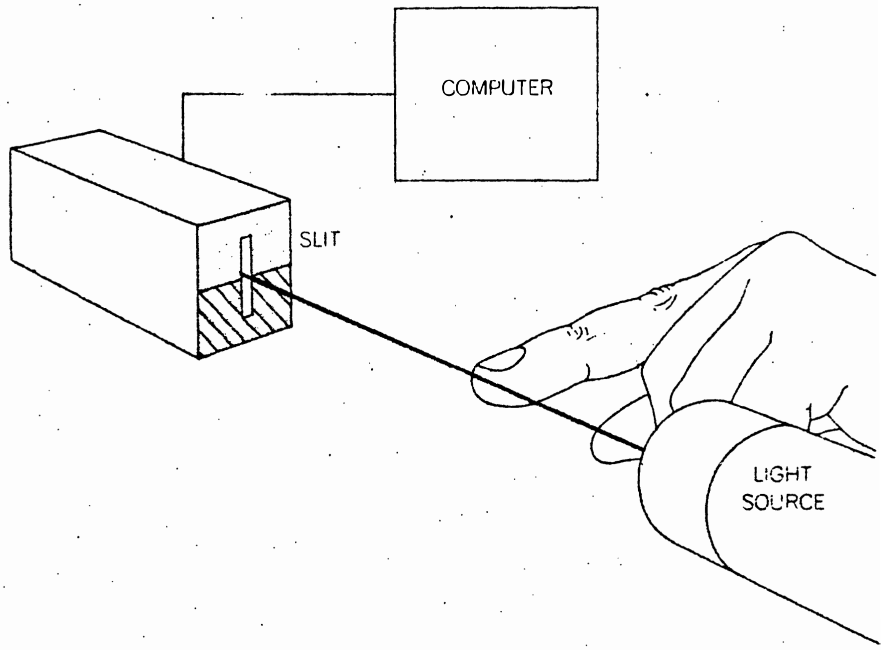
Built into the body of every mammal is an entire complex of biological servomechanisms, analogous to the thermostat, that operate to maintain the body's internal stability. Many of these homeostatic mechanisms are nervous reflexes. For instance, there are reflexes that adjust the diameter of the eye pupil to control the amount of light impinging on the retina, there are nerve pathways



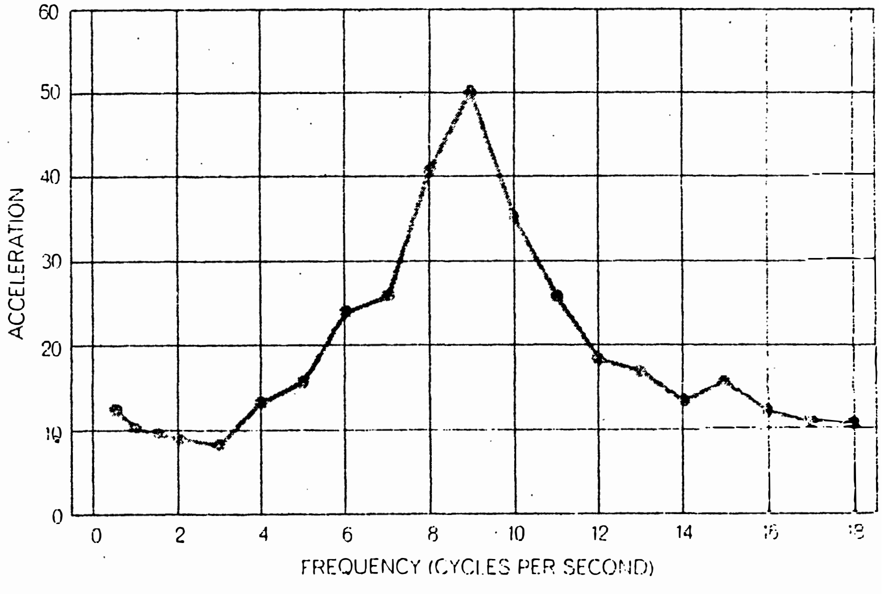
REFLEX ARC that senses and controls the stretching of a voluntary muscle consists of three main components: a sensory ending within the muscle that signals the amount by which it is stretched, an afferent nerve fiber that conveys the signal to the spinal cord and a motor neuron in the cord that in response sends a contraction-activating signal to the muscle by way of the efferent nerve. Physiological tremor has been investigated in the author's laboratory at University College London by interrupting this feedback loop at a suitable point, by modifying the properties of the loop and by introducing various inputs into the opened or intact loop.

that keep the blood pressure constant and there are the stretch reflexes of muscle.

In the case of the stretch mechanism the control system is a reflex arc consisting of three main components: a sensory ending within the muscle that signals the amount by which it is stretched, an afferent nerve fiber that conveys the signal to the spinal cord and a motor neuron in the cord that in response sends an activating signal to the muscle by way of the efferent nerve. A simple example of the operation of such an arc in maintaining stability is the reaction to a slight push tending to tilt a standing person forward and thus move him off balance. The slight stretching of the extensor muscles in the back of the legs resulting from the push generates trains of nerve impulses that go to the spinal cord and there activate the appropriate motor neurons, which in turn incite a small strengthening of the contraction of the leg muscles, thus correcting the posture. All muscles are supplied with this kind of control system, usually operating in a more complex way than I have just described. The control generally is concerned either with damping the muscle's movements or with ensuring that for the given action of the operated limb there is an appropriate relation between the muscle's tension and its length.



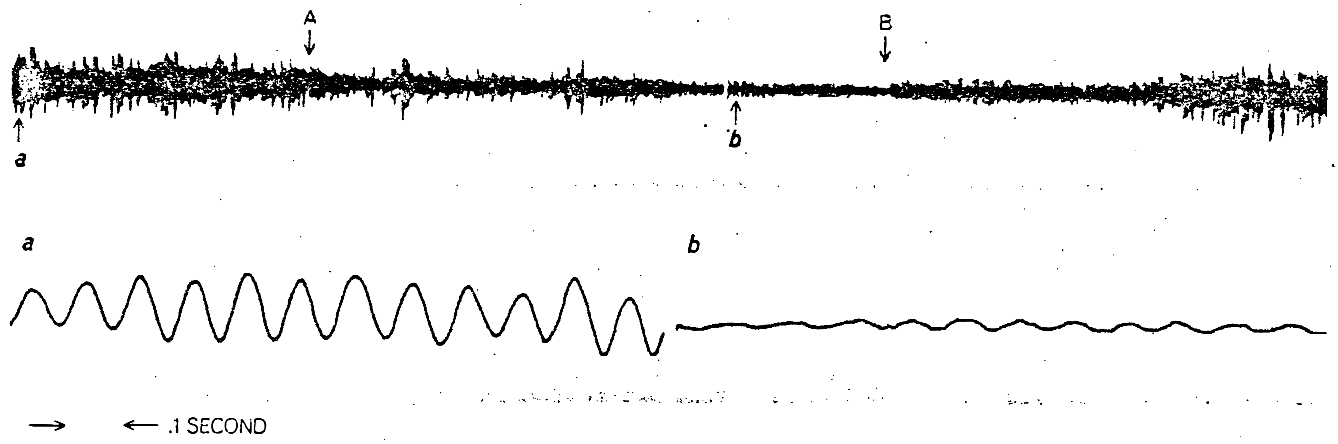
EXPERIMENTAL APPARATUS used by the author and his colleagues for recording physiological tremor in humans is shown in this illustration. The subject's forefinger interrupts a beam of parallel light falling on a ground-glass slit. Behind the slit is a photodetector, the output of which is amplified and fed into a small fixed-program averaging computer.



TYPICAL FREQUENCY SPECTRUM for finger tremor was measured using the apparatus depicted at the top of the page. The curve shows the acceleration of the finger plotted against the frequency of the oscillation in order to bring out the fact that finger tremor takes place in a clear-cut frequency band extending roughly from six to 12 cycles per second, superposed on a more or less flat base line. Since acceleration is proportional to the displacement of the finger times the frequency squared, the points on the ordinate were obtained by multiplying the first differential of the output of the photodetector by the frequency.

Once it was realized that physiological tremor in muscle had much the same character as the oscillations of a mechanical control system, physiological tremor became accessible to the kind of detailed investigation in mathematical terms that engineers employ in studying the parameters of a servomechanism. The problem can be attacked experimentally by three devices: (1) opening, or interrupting, the feedback loop at a suitable point, (2) modifying the properties of the loop, (3) introducing various inputs, such as step functions (variables that change value in steps), into the opened or the intact loop. In our laboratory at University College London we have applied these methods to look into the causation, properties and behavior of tremor in muscles.

We began by examining the effects of interruption of the loop. Since cutting the loop on the efferent side would simply abolish all activity of the muscle under study, it was obvious that significant information could be obtained only by interrupting the afferent side. This could be done at the muscle spindle generating the sensory message, in the fiber conveying the message to the spinal cord or at the fiber's synapse with the motor neuron in the cord. It happens that certain patients are afflicted with an afferent interruption: tertiary syphilis of the central nervous system sometimes abolishes the conduction of impulses by the afferent nerve. We found that these patients generally showed no sign of the oscillation peak around 10 cycles per second, the mark of physiological tremor, when a muscle was stretched. Similarly, the tremor peak disappeared in cats when the afferent nerve was cut experimentally. The same result was obtained when we interfered with the normal ac-



TREMOR CAN BE REDUCED by cutting off the blood supply to the muscle. The top trace represents a forefinger tremor that gradually disappears after a blood-pressure cuff is inflated at the time indicated by arrow *A*. After the cuff is deflated at arrow *B*, some two minutes later, the tremor gradually returns. The two bottom traces, made on faster-moving recording paper at the times indicated by arrows *a* and *b*, show the detailed wave form of the tremor before and after the blood supply has been cut off.

tion of muscle spindles in signaling the stretching of the muscle. Cutting off the blood supply to a muscle causes profound disturbance of these spindles; they fire impulses spontaneously at a high rate and become almost completely unresponsive to stretching. When we cut down the blood supply to a muscle with an inflated cuff applying pressure to the artery, we found that physiological tremor in the muscle disappeared within 30 to 60 seconds. All in all, these observations and experiments tended to support the hypothesis that physiological tremor is associated with muscular contraction and signifies an oscillatory process taking place in the stretch-reflex loop.

Turning to the second device for experimental investigation—modification of a property of the loop—we selected first a treatment that might affect the oscillation frequency. In the stretch-reflex cycle there is a certain major period of delay: it consists in the time the muscle takes to contract after receiving the activating signal from the spinal cord and then to stretch again (either as a result of its elasticity or in response to a load on the muscle). Obviously if tremor is an oscillatory process, the frequency of the oscillations will be affected by any change in the duration of the delay. On this premise we performed the experiment of cooling or warming the muscle, which would be expected to lengthen or shorten the delay interval. The experiment in human subjects consisted in immersing a leg in water at a given temperature and recording the tremor frequency with a transducer [*see illustration on next page*]. Most subjects were able to stand temperatures up to about 113 degrees Fahrenheit and down to the freezing temperature of 32 degrees, but we must admit that one of our best subjects fainted when he put his leg in really cold water!

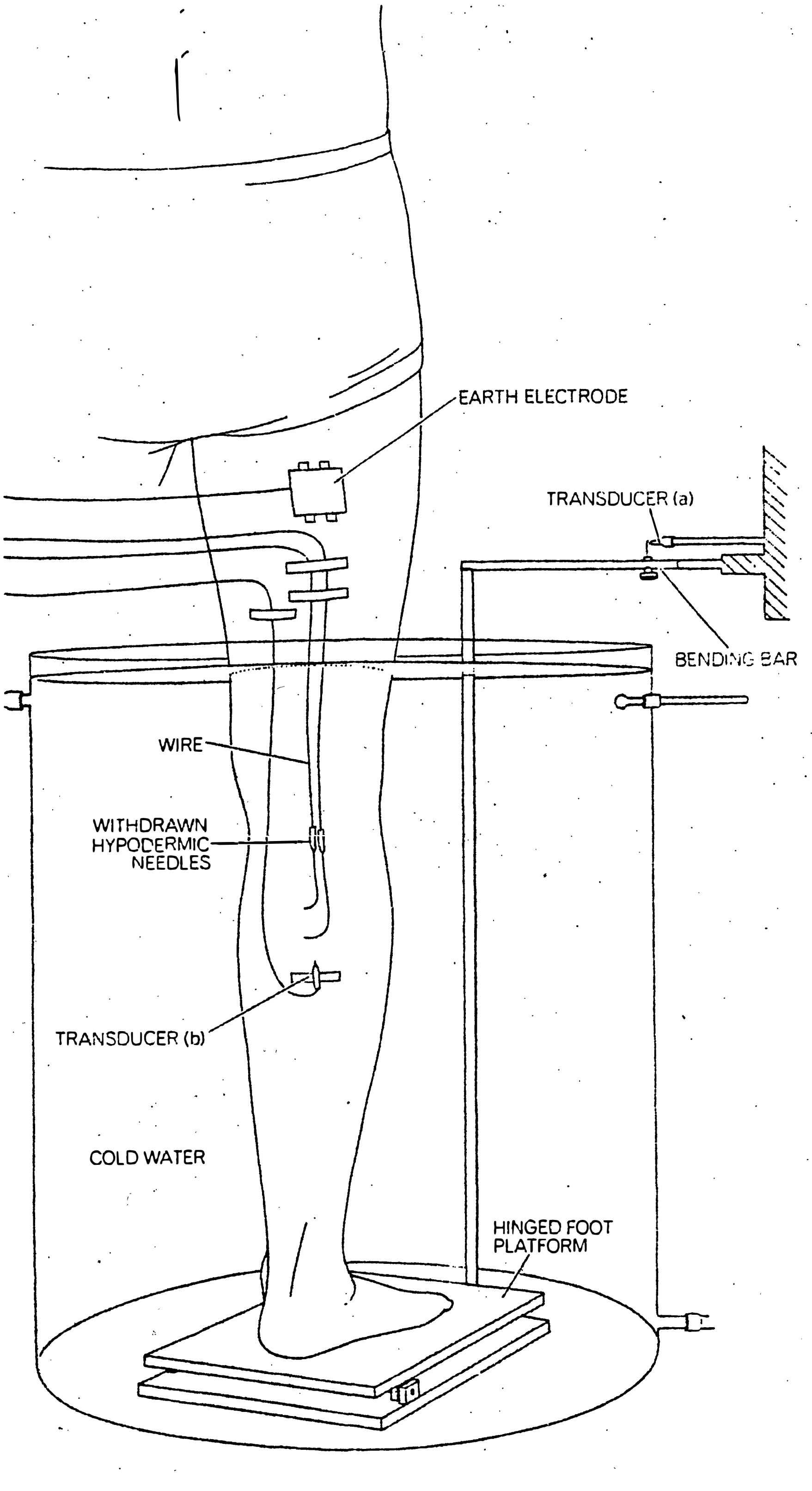
We found that cooling could slow the tremor from the normal rate of about 10 cycles per second to as low as five cycles, and rewarming could speed it up to nearly 15 cycles per second. It seems safe to conclude that the only reasonable interpretation of these results is that the tremor is indeed the kind of oscillation that takes place in a servo loop. We found also that in trembling muscle groups of action potentials accompanied the tremor and remained in phase with it as the oscillations slowed down or speeded up. The presence of the action potentials strongly indicates that the oscillations actually represent nerve-generated, synchronized muscle activity rather than, say, dying mechanical reverberations of the trembling limb.

Just as the tremor *frequency* could be changed by altering the delay interval, it might be expected that the tremor *amplitude* could be changed by modifying the system's sensitivity, or what engineers call the "loop gain." The signal-generating spindles of muscle offered an opportunity for such modification. These spindles have a complex structure, typically consisting of a central bag that contains the stretch-sensitive nerve endings and muscle fibers that contract and pull on the nuclear bag when they are activated. The fibers have their own activating nerve supply, provided by small motor fibers called "gamma" nerves because of their small diameter. Consequently some experimental intervention that activated the gamma nerves should increase the firing rate of the muscle spindles for a given stretch of the main muscle, thus enhancing the sensitivity of the entire reflex arc.

A simple maneuver called "Jendrassik's reinforcement" is known to produce a general enhancement of reflex action by way of activation of the muscle spindles' motor fibers. The maneuver consists in gripping one hand with the other and holding on while attempting to pull them apart. Applying this test, we obtained a most gratifying increase in the overall amplitude of physiological tremor. This again supported the oscillation theory.

For the third test of the theory—introducing inputs into the loop—we injected perturbations, by means of a mechanical prod, into the loop in an intact condition. As the prod we used a moving-coil transducer (driven by a power amplifier) that vibrated with a constant amplitude of two millimeters and prodded a human subject's extended middle finger. In order to record the tremors induced in the finger, it was placed in the path of a parallel beam of light directed at a photodetector mounted behind a vertical slit of ground glass; any oscillations of the finger were thus focused and measured [*see top illustration on page 8*].

It turned out that a prod of the freely extended finger lasting 30 milliseconds usually generated a series of five or more roughly sinusoidal waves. The frequency of the waves was the same as that of nor-



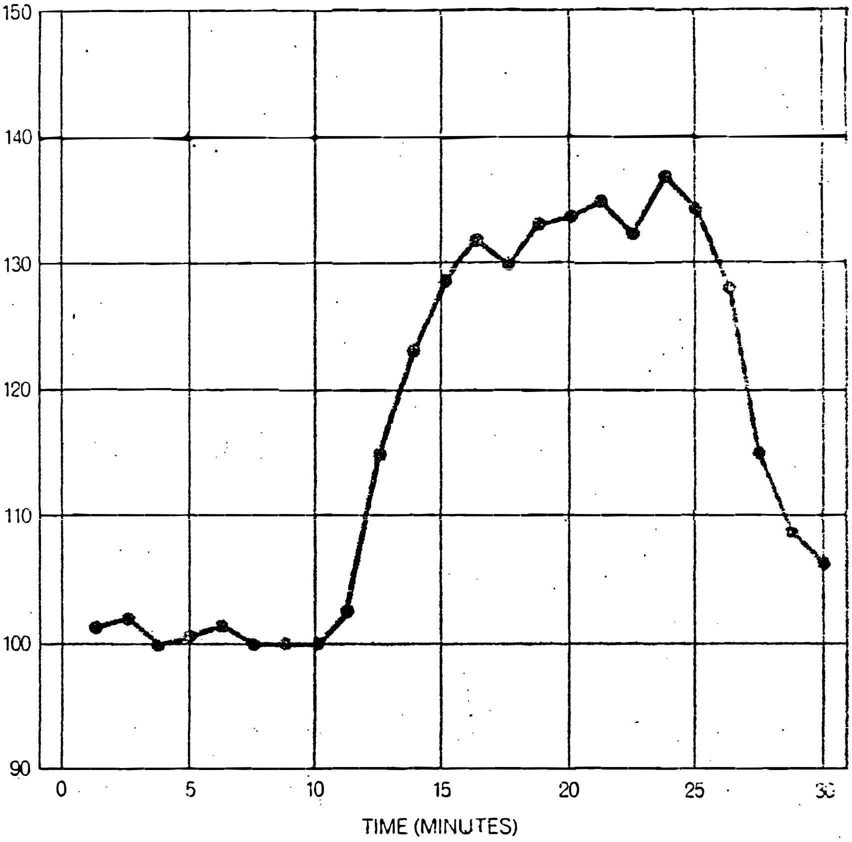
LEG MUSCLES WERE COOLED in this experimental apparatus designed to measure the effect of temperature on the frequency of a muscle's tremor. Copper electrodes were inserted into the muscle through hypodermic needles, which were subsequently withdrawn as shown. A transducer was employed in two alternative positions to measure the muscle's "twitch" time. In position *a* the transducer was attached to a bending bar connected to a hinged foot platform; in position *b* it was strapped to the calf and connected to a needle inserted through the skin with its tip in the muscle. Water at the desired temperature flowed through the tank, while the subject stood upright in as normal a posture as possible. Reflexes were elicited by means of sudden blows on a steel strip attached to the foot platform, raising the platform abruptly. The tension in the strip was recorded during maneuver.

mal tremor (generally about 10 cycles per second), and the amplitude was roughly uniform in a given subject. This could be taken as evidence that the waves were phase-locked to the mechanical input and hence represented oscillations such as would be expected in an underdamped (that is, flexible) servomechanism. Superimposed on the 10-cycles-per-second waves we often found, in the early part of the record, vibrations of about 25 to 30 cycles per second. These waves proved to be due to the mechanical, die-away resonance of the finger, as was shown by the fact that they were retarded when a load was placed on the finger.

Was the 10-cycles-per-second oscillation purely mechanical in nature or did it have the same neurological origin as physiological tremor? Several items of evidence indicated that it was in fact nerve-generated. Its frequency was always the same as that of the customary physiological tremor in any given individual. Warming or cooling the muscle or cutting off the blood supply produced the same results as when these treatments were applied to physiological tremor. Bursts of action potentials, phase-locked with the oscillations, took place in the prodded finger as they do in normal tremor, and the amplitude of the oscillations and the size of the action potentials tended to increase rather than to die away, indicating that energy was somehow being fed into the system and thus giving further support to the idea that the prod had initiated a process involving nerve activity.

With the prodding technique we obtained new evidence that the waves of normal tremor represent oscillations in a self-sustaining feedback loop. It would be expected that in such a system the injection of an input of the same amplitude as that of the tremor would either enhance or suppress the tremor waves, depending on whether it was applied in phase or out of phase with those waves. A prod less than half a millimeter in amplitude could serve as such an input. We carried out this experiment in various ways. In one version we applied the prod at random intervals while the muscle was in continuous tremor. Then, examining the record, we could see what happened to the oscillation when the input occurred at various phases of the wave form. This experiment showed that the tremor was indeed enhanced when the prod occurred in phase and was suppressed for several cycles when the prod came in antiphase [*see bottom illustration on page 8*].

In interpreting the results of all these studies we must first be clear about exactly what we mean by physiological tremor. Tremor in a muscle can be produced by a great variety of stimuli: the beating of the pulse, general movements involving a number of other muscles, even vibrations created by passing traffic. In identifying and examining normal physiological tremor, however, we are concerned specifically with the ripple that is superimposed on the voluntary contraction of a particular muscle and arises solely from this activity. Consequently in order to investigate physiological tremor in a finger, say, we must fixate the limb as a whole so that extraneous movements are excluded and we can focus on the indigenous oscillations of the finger muscle itself. One must also distinguish between normal physiological tremor and pathological tremor such as that of Parkinson's disease. The Parkinson tremor has a different frequency, peaking at about five cycles per second. Apparently, like normal physiological tremor, it is characterized by oscillating loops, but its origin is different, it probably involves the brain stem, and the experimental findings in the normal case do not necessarily have any application to the pathological one or vice versa.



EFFECT OF COOLING on tremor in leg muscle is indicated by this graph, which shows a large increase in the mean interval between bursts of action potentials in the calf muscle plotted during the course of the immersion of the leg in cold water. At the 10th minute the leg was cooled by filling the tank with water at a temperature of about zero degrees Celsius; the tank was emptied again at the 26th minute. Mechanical tremor waves recorded during this experiment bore a constant phase relationship with the action-potential bursts.

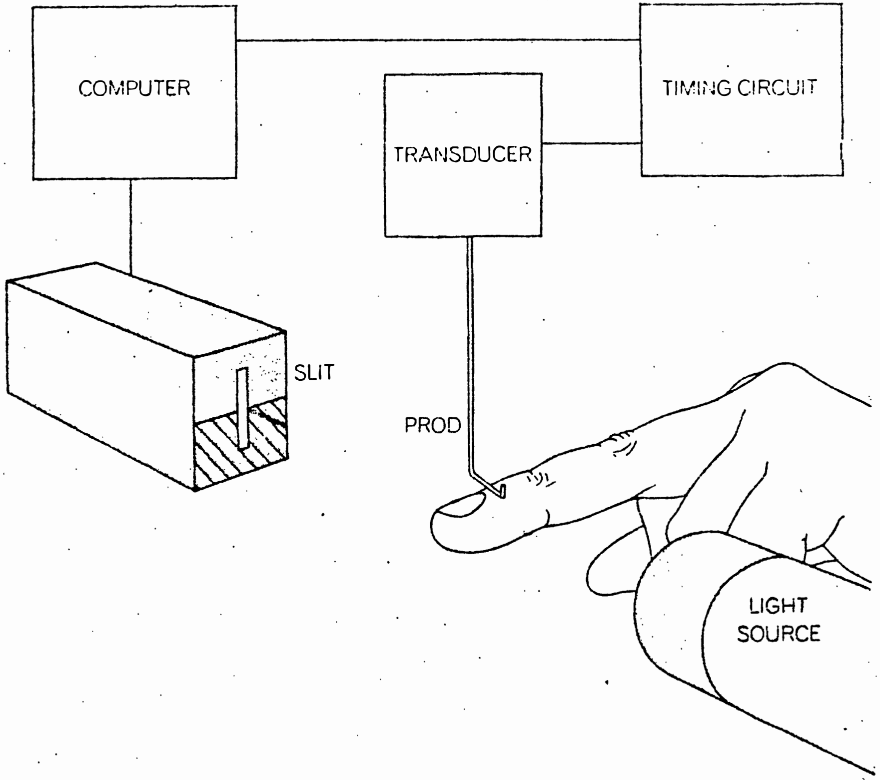
In the light of the new experimental information, how do the old theories about physiological tremor stand up? Let us consider first the theory of an origin in the brain. After the discovery by encephalography of the brain's alpha waves there were several reasons to suppose tremor might well be connected with those waves. The alpha rhythm is very similar to tremor oscillations in wave form and in frequency (ranging from eight to 13 cycles per second for alpha). In both cases the development of the frequency follows the same course, starting at five cycles per second in young children and accelerating to about 10 cycles in adults. Both alpha waves and tremor respond in much the same way to a sudden stimulus (such as a loud sound), to anesthesia, to sleep and to general alerting of the system. Yet the many attempts to find a causal connection between the two phenomena were fruitless. It became evident that the rhythms do not quite match each other, either in frequency or in phase. When the tremor frequency is changed drastically (for example by cooling the muscle), there is no change whatever in the brain's alpha rhythm. No delay interval such as exists in the tremor loop has been found in the brain's motor systems. Another finding arguing against the brain's involvement is the fact that when the spinal cord is severed from the brain, tremor at about 10 cycles per second can still be induced in muscle by stimulating the cord electrically.

Although the search for a connection between physiological tremor and electrical activity in the brain was unsuccessful, it might profitably have been pursued further than it was. It now appears that the alpha waves may be generated by the extraocular muscles (voluntary muscles that control movements of the eyeball).

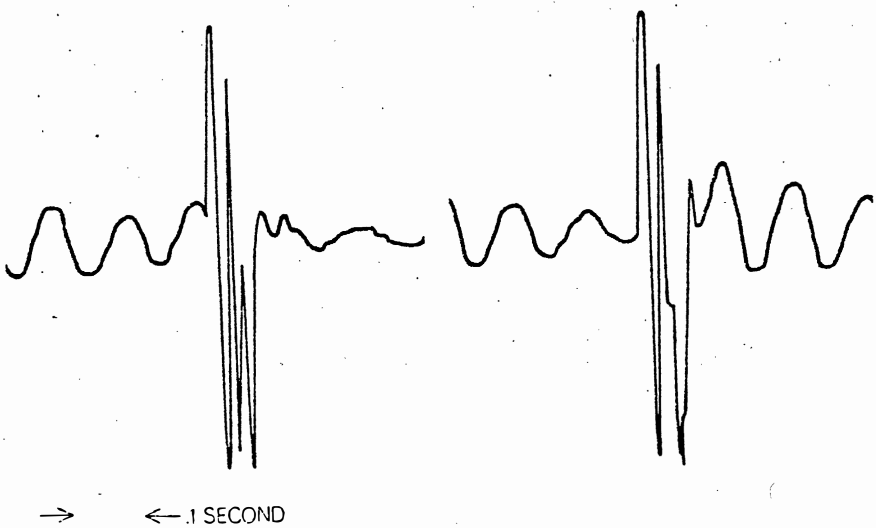
Then there is the simple and attractive theory that tremor may be originated by the spinal cord. This hypothesis has gone through several versions. One suggests that the group of motor neurons activating a muscle may somehow synchronize their discharge of impulses in a rhythmic fashion. The main problem with this theory is that it cannot explain how the cooling or warming of a muscle would alter the frequency of discharges in the cord, or how prodding a finger would generate tremor or bring about a change in the amplitude of the oscillations. Another version of the theory argues that the rhythmic waves may be produced by a pacemaker of some kind in the cord, causing bursts of action potentials at about 10 cycles per second. Such systems have been found in the thalamus of the brain, but no evidence for the existence of such a center in the spinal cord has been established.

Finally, there is the hypothesis that tremor may be strictly a local phenomenon within the muscle (perhaps with participation by the neuromuscular junction), not involving the spinal cord or the brain at all. One ingenious and plausible idea imagines the muscle to be acting as a low-pass filter that screens out all impulses except those at about 10 cycles per second. We know that during a voluntary contraction motor units composed of functionally identical muscle fibers start discharging at about seven cycles per second and then accelerate up to 30 or 40 cycles per second as the strength of the contraction increases.

Experiments in stimulating an isolated nerve-muscle preparation at various rates show that when the rate of stimulation is raised to above 10 cycles per second, the individual twitches fuse, or merge, into a more or less smooth tetanus. Similar experiments in stimulating a human muscle through the skin with brief electric shocks produce the same result. It is also known that the motor units in muscle do not often fire at much below the 10-cycles-per-second frequency. Thus, assuming that the units fire more or less at random, the result of the filtering effect would be that only the action potentials with a frequency in the neighborhood of 10 cycles per second (in a normal human subject) would be effective in producing the small discrete contractions that account for the major part of tremor.



FINGER-PRODDING APPARATUS employs a moving-coil transducer driven by a power amplifier that is fed with step-function signals from a crystal-controlled timing circuit. The timing circuit also triggers the averaging computer, which then derives the algebraical sum of the wave form of the finger displacements for a given number of consecutive prods.

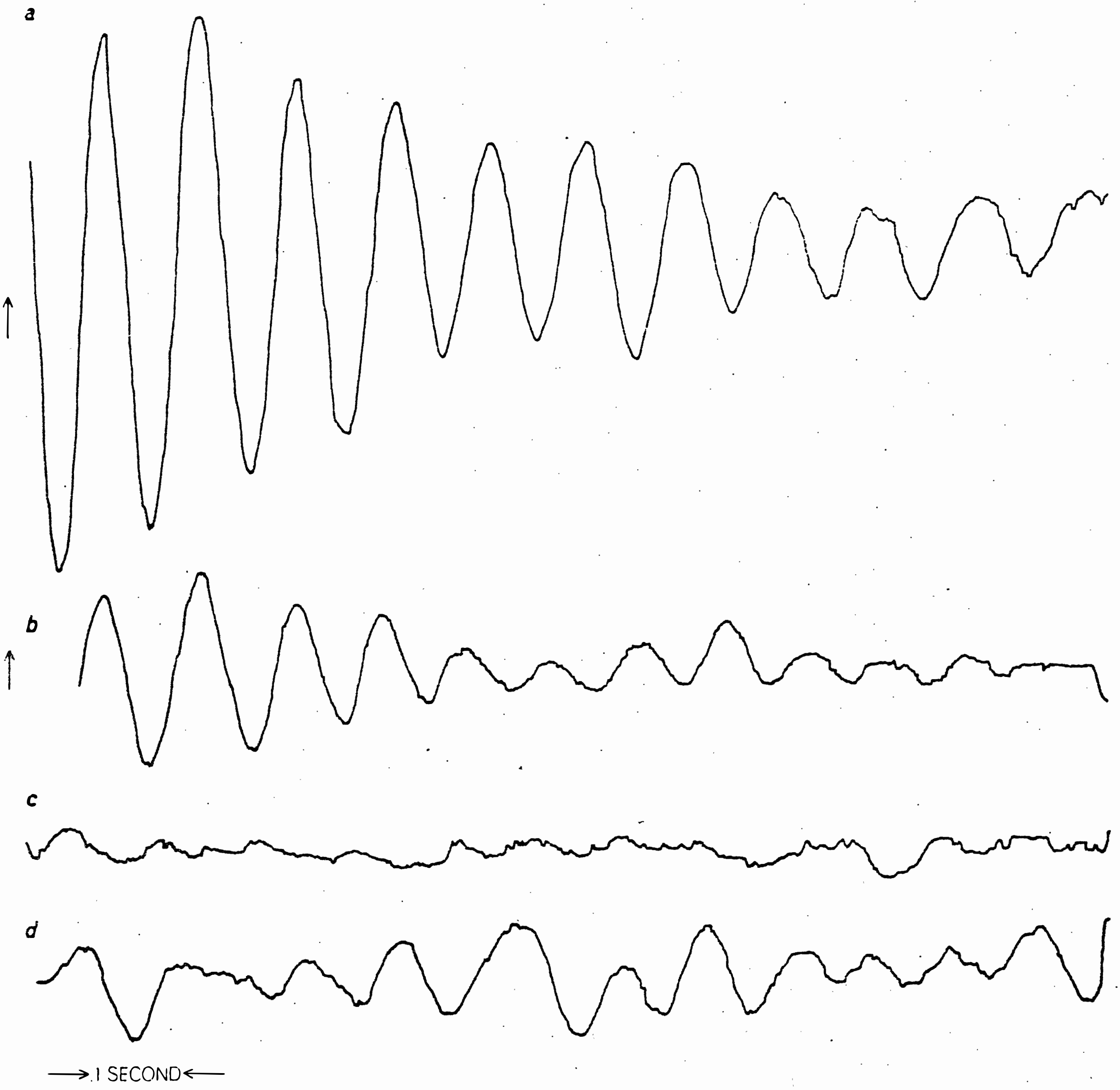


TREMOR IS SUPPRESSED OR ENHANCED depending on the instant at which the prod is administered. When the prod is given out of phase with the ongoing tremor (*left*), the tremor is suppressed. When the prod is in phase (*right*), subsequent waves are enhanced.

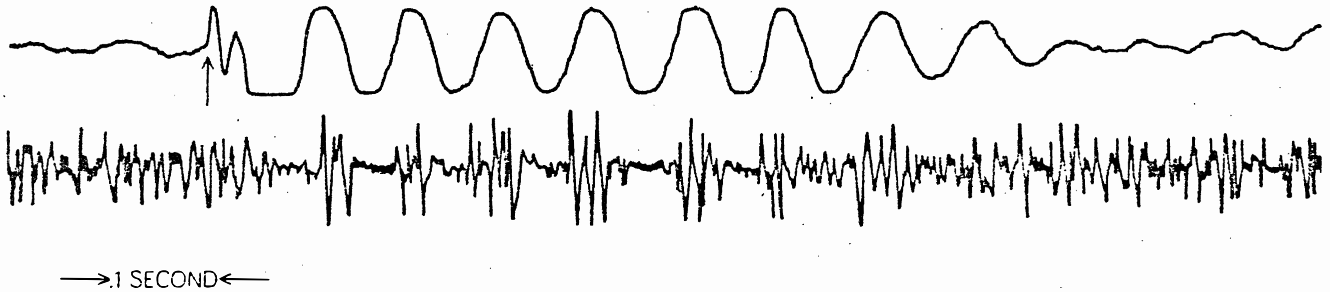
There are a number of powerful objections to this theory, however. In the first place, if the motor units fire randomly, there will be no discernible tremor, even if all the units are firing at the rate of about 10 cycles per second, unless there is a synchronizing mechanism that causes them to fire in phase. Secondly, the theory implies that a factor such as fatigue, which considerably lowers the threshold frequency at which individual twitches merge, should slow the tremor frequency to much below 10 cycles per second; actually it is found that during and after fatiguing contractions a muscle always shows a slight rise in the tremor frequency and a marked increase in its amplitude.

The results of some of the experiments I have mentioned are also not compatible with the filter theory. It cannot explain the clear correspondence between the grouping of action potentials and the tremor waves, nor the fact that a brief displacement of a stretched finger by a prod produces a train of waves phase-locked to this perturbation. Moreover, when an isolated muscle is stimulated through its motor nerve with repeated shocks at rising frequency, the muscle's contraction shows no increase in tremor at about 10 cycles per second, as would be expected if there were a filtering effect.

If we accept the hypothesis that the physiological tremor at from eight to 12 cycles per second arises as a hunting phenomenon in the stretch reflex arc, in the final analysis we must ask why this biological servomechanism is so "inefficient" as to allow tremor. Most man-made control mechanisms are provided with devices that automatically suppress oscillation and thus ensure stability. Analyzing the control system in the reflex arc, however, we can see that excessive damping in this system would inevitably slow the response to stimulation. Reflex action therefore must involve a necessary compromise between speed of response on the one hand and a certain degree of overshooting, or inaccuracy, on the other. We have found in examining a large number of normal human subjects that most of them have some tremor superimposed on their muscular activity. The amplitude of the tremor usually does not exceed 2 percent of the physiological range of movement of a



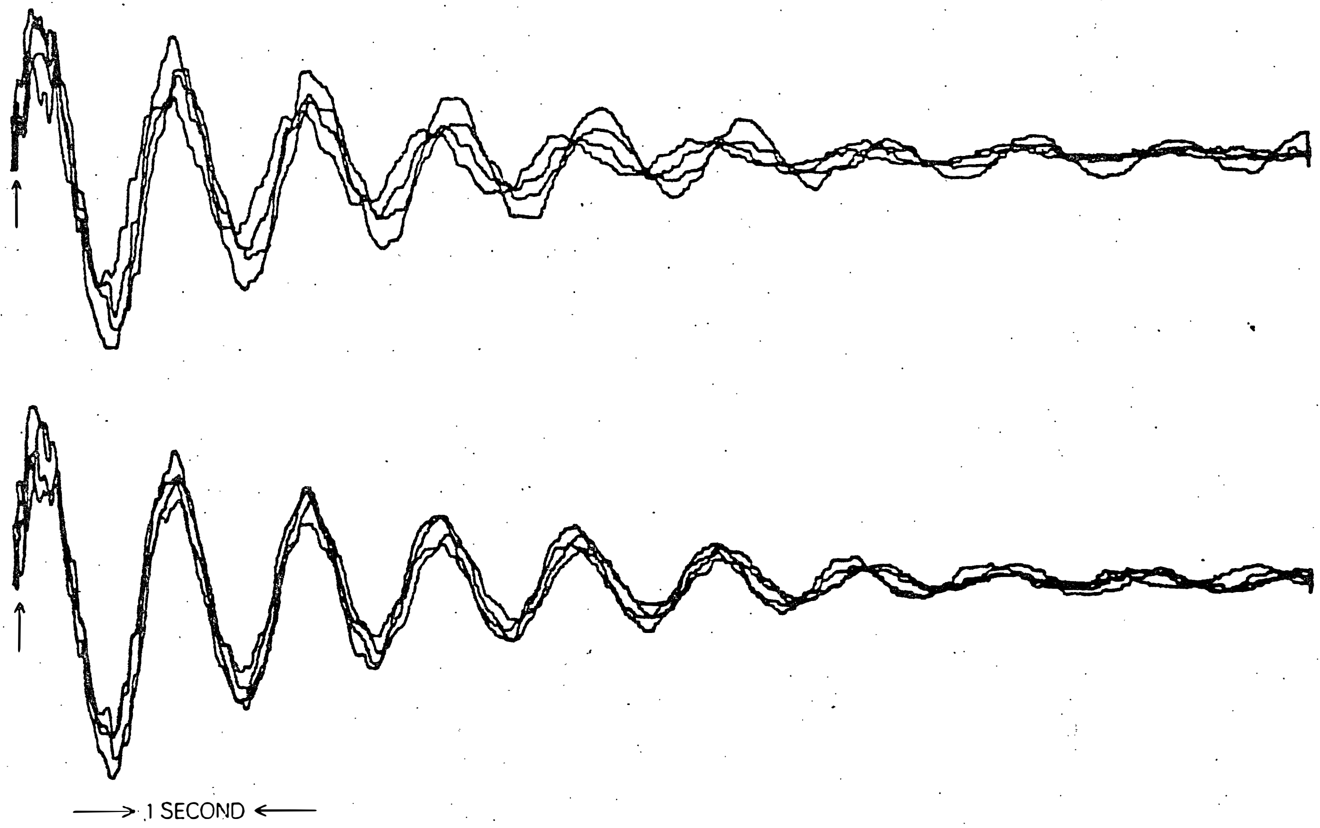
SERIES OF DAMPED OSCILLATIONS can be induced in a trembling finger by means of a single prod. A brief prod delivered just before the arrows was responsible for the two upper traces. Trace *a* is an average of 16 consecutive sweeps; trace *b* is one sweep recorded at four times the gain. The two lower traces are records of normal tremor in the finger. Trace *c* is a control run with 16 sweeps with no prodding at the same gain as trace *a*; trace *d* is a single sweep, again without prodding, at four times the gain.



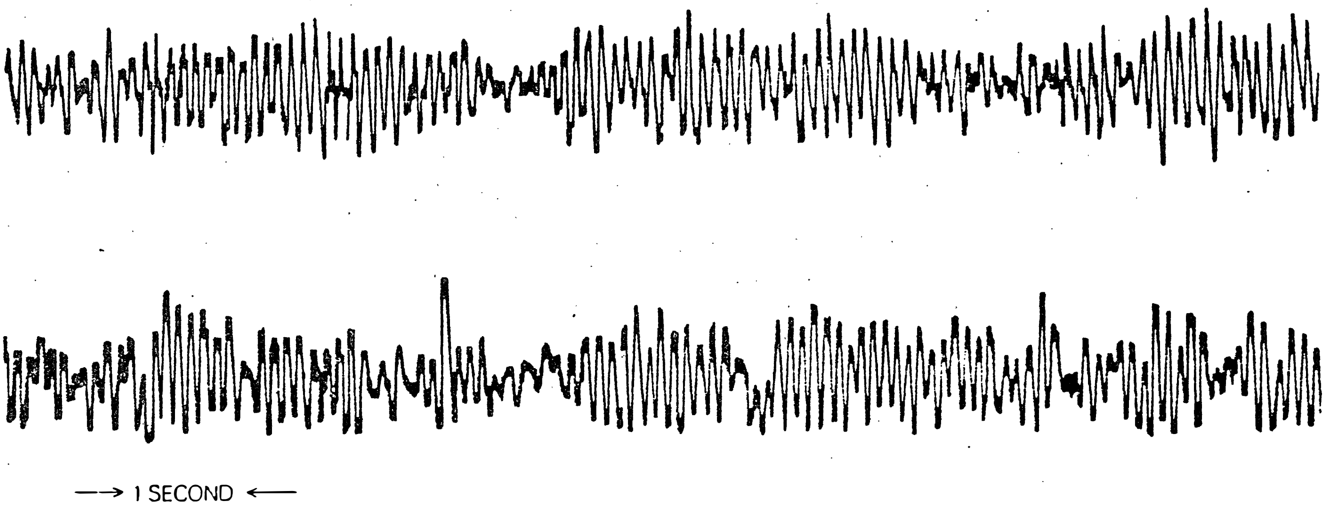
ELECTRICAL SIGNALS from a prodded finger muscle were recorded by means of surface electrodes applied to the skin over the muscle. The bursts of action potentials recorded in this way (*bottom trace*) turned out to be very nearly in phase with the oscillating displacement of the finger (*top trace*) that resulted from a single prod administered at the time indicated by the arrow.

limb. It would appear that this amount of oscillation can be tolerated in the interest of maintaining a fast response.

Why do some normal people have more tremor than others? We find that tremor varies not only from one person to another but also in the same individual from time to time. Apparently the central nervous system normally brings about variations in tremor from minute to minute (leaving aside the changes that may be produced by factors such as fatigue, circulating adrenalin or pathological conditions such as hyperthyroidism). We have already noted that Jendrassik's maneuver can increase tremor, presumably because the strong contraction of a muscle results in a spreading "irradiation" of nerve action speeding up the frequency of motor impulses generally. Some recent experiments show that



VISUAL FEEDBACK LOOPS appear to have little influence on either normal tremor or prod-initiated tremor. The superposed traces in both cases represent four sets of averaged responses to a forefinger prod given just before the arrow. The top traces were recorded with the eyes open, the bottom traces with the eyes closed. The recordings were made alternately with the same subject.



DECEPTIVE SIMILARITY is evident in these two traces, which were recorded simultaneously using the same subject. The top trace represents physiological tremor recorded in the forefinger. The bottom trace represents the "alpha" rhythm recorded from the scalp using a conventional electroencephalograph. Hypotheses relating these two types of oscillation have had to be abandoned.

normal tremor can also be reduced. Resting a limb for some hours (for example by putting an arm in a splint) will reduce the amplitude of tremor in all the muscles of the arm. This may involve the same mechanism that is affected by a strong contraction; inactivity may result in a decrease of activity in the fusimotor system (the system of gamma motor nerves in muscle that cause the muscle spindles to contract), whereas strong contraction stimulates increased activity in the system.

Quite by chance, while we were screening a large group of students for visual defects, we came on a surprising and fascinating discovery. It turned out that people with poor eyesight tended to show an unusually large amount of finger tremor! This was particularly true of farsighted individuals: the amplitude of their finger tremor was much larger than normal. Tentatively we postulate that the explanation may be essentially the same as in the case of Jendrassik's maneuver. In farsighted people there is a conflict between the acts of accommodation (focusing the eyes on a near object, for example) and convergence (directing the optical axes of the eyes toward the object). Anatomically these two acts are joined, so that they cannot be performed separately; hence in a farsighted person any effort exerted to accommodate the lens to bring an object into focus also will tend to make the eyes converge on too close a point and thus produce double vision. A possible action to correct this might bring into play the rectus muscles of the eyeball that rotate the eyes outward horizontally. We can suppose, then, that the activity of these muscles may be intense enough to bring about stimulation of the fusimotor systems and hence tremor in all the other muscles of the body while the individual is actively observing his environment. We have one piece of concrete evidence that this theory represents something close to the actual state of affairs. It is found experimentally that if a person with normal vision wears special glasses that make him functionally farsighted, after a day or so the amplitude of his finger tremor increases considerably.

Clearly physiological tremor is introducing us to a fascinating field of study. With the sophisticated techniques of investigation and analysis now available, there is reason to hope that we shall be able to find answers to some puzzles about normal muscle activity and also to learn something about how pathological tremors arise, thereby making them more useful as a diagnostic and prognostic tool in psychiatry.

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