Voice Stress Analysis and Evaluation

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ABSTRACT

Voice Stress Analysis (VSA) systems are marketed as computer-based systems capable of measuring stress in a person’s voice as an indicator of deception. They are advertised as being less expensive, easier to use, less invasive in use, and less constrained in their operation than polygraph technology. The National Institute of Justice (NIJ) have asked the Air Force Research Laboratory (AFRL/IFEC) for assistance in evaluating voice stress analysis technology. Law enforcement officials have also been asking questions about this technology. If VSA technology proves to be effective, its value for military and law enforcement application is tremendous.

Keywords: Voice Stress

1.0 INTRODUCTION

Police departments everywhere are bombarded with offers of advanced technologies by commercial enterprises that promise to reduce their officers’ workload, improve law enforcement effectiveness, and/or save lives. With increasingly limited budgets, police departments must turn a critical eye to every purchase. One interest by law enforcement and military organizations are the commercial VSA systems, which are used to detect deception or to detect when a person under interrogation is lying. If voice stress can be detected, and effectively analyzed, perhaps it can be used as a viable investigative tool as well as an adjunct to speech recognition technology in order to improve speech recognition capabilities.

Numerous police officers and agencies have been approached in recent years by vendors touting computer-based systems capable of measuring stress in a person’s voice as an indicator of deception. These systems are advertised as being cheaper, easier to use, less invasive in use, and less constrained in their operation than polygraph technology. Table 1 is a replication of the table of comparisons made by one vendor contrasting their VSA system with a computerized polygraph. Besides costing less to purchase the equipment and train users, the table indicates that a VSA examiner can conduct seven (7) exams per day while a polygraph examiner can conduct only two (2) per day. This vendor claims to have a 0% average percent of inconclusive results and the ability to analyze audio-recorded as well as live speakers. They claim that use of their system is not affected by a speaker’s medical condition, age, or consumption of drugs. Voice stress analysis does not require physical attachment of the system to the speaker’s body and does not require that answers be restricted to “yes” and “no”. Purportedly, according to some vendors, any spoken word or even a groan, whether recorded, videotaped, or spoken in person, with or without the speaker’s knowledge, are acceptable inputs to voice stress analysis systems.

The value of voice stress analysis technology for military application is extensive. During military field interrogations of potential informants, it could be applied in a manner similar to its application for law enforcement: as a lie detector. Also, it is not known if stressed speech has any effects on the accuracy of speech technology, such as speaker identification and language identification. If voice stress can be detected, perhaps it can be taken into account in applying speech recognition technology and be used to...
improve these recognition capabilities. Therefore, this effort is to determine the scientific value and utility of existing, commercial voice stress analysis technology for law enforcement and military requirements.

<table>
<thead>
<tr>
<th></th>
<th>Computer Voice Stress Analyzer</th>
<th>Computerized Polygraph</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial cost of system</td>
<td>$9,250.00</td>
<td>$13,000.00</td>
</tr>
<tr>
<td>Tuition for 1 student</td>
<td>$1,215.00</td>
<td>$3,000.00</td>
</tr>
<tr>
<td>Length of training</td>
<td>6 days</td>
<td>8 weeks</td>
</tr>
<tr>
<td>Cost of room and board factored at $70 per day</td>
<td>$420.00</td>
<td>$3,920.00</td>
</tr>
<tr>
<td>Salary for student while in training (U.S. average)</td>
<td>$769.23</td>
<td>$6,153.84</td>
</tr>
<tr>
<td>Number of exams that an examiner can conduct per day</td>
<td>7 exams</td>
<td>2 exams</td>
</tr>
<tr>
<td>Average percent of inconclusive results on exams</td>
<td>0%</td>
<td>20%</td>
</tr>
<tr>
<td>Can unit analyze audio tapes for truth verification?</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Do drugs, medical condition, or age affect testing?</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Total cost to purchase 1 unit and train 1 agent</td>
<td>$11,654</td>
<td>$26,073.84</td>
</tr>
</tbody>
</table>

Table 1. Cost comparisons made by a VSA vendor*

VSA literature [1] points to a descriptor of the physiological basis for the micro muscle tremor or microtremor. This paper describes "a slight oscillation at approximately 10 cycles per second" (i.e. physiological tremors) during the normal contraction of voluntary muscle. All muscles in the body, including the vocal chords, vibrate in the 8 to 12 Hz range. It is these microtremors that the VSA vendors claim to be the sole source of detecting if an individual is lying. This human system is a feedback loop, similar to a thermostat/heater that will maintain an average temperature. By raising the temperature a little above the setting, it will switch off, and not come back on until the temp is a little below it. Just as the temperature swings up and down over time, so too does the muscles tighten and loosen as they seek to maintain a constant tension. In moments of stress, as when you tell a lie and that you dare not to get caught, the body prepares for fight or flight by increasing the readiness of its muscles to spring into action. The muscle vibration increases. This muscle tremor is usually evident in a hand tremor, as when one holds their arm out in an extended position. This indicates that restricting the blood supply to the muscle can reduce the tremor. Physiological tremor is "the ripple that is superimposed on the voluntary contraction of a particular muscle and arises solely from this activity." Most people exhibit a fine, rapid tremor of their hands when their arms are outstretched. According to the Merck Manual [2], "enhanced physiologic tremor maybe produced by anxiety, stress, fatigue, or metabolic derangements (ex. alcohol withdrawal, thyrotoxicosis) or by certain drugs (eg, caffeine and other phosphodiesterase inhibitors, beta-adrenergic agonists, and adrenal corticosteroids beta-blocker: propranolol)."

* The National Institute of Truth Verification distributes this chart.
2.0 TESTING

The goal of these tests is to determine how effective these VSA units can detect stress. It has touted by these VSA vendors that this technology is scientific and takes advantage of the human micromuscle tremor in the vocal tract. These tests attempt to prove or disapprove these theories.

2.1 Test Objective

The objective of these tests is to measure the output response of several VSA given several controlled input signals. This will verify the manufacturer’s claims of operation for each analyzer. The degree of source consistency of results for each analyzer will then be determined. This will determine the correct process to use when recording audio for evaluation. Finally the VSA systems will be laboratory tested and field tested, by evaluating them with trained laboratory analyzers and law enforcement investigators.

2.2 Scope/Approach

This effort will test and evaluate two (2) commercially available voice stress analyzers. Tests will be accomplished using a series of test signals that contain information distributed over the frequency spectrum, generally covered by the spectrum of normal speech. Analysis of the VSA test results will be conducted to determine
- VSA response characteristics
- Degree of accuracy compared to the manufacturers theory of operation and technical specifications
- Accuracy of result repeatability
- Evaluate under audio with stressed ground truth

2.3 Test And Analysis Procedures

The procedures are developed to three areas - procedures for the development of test tapes containing artificial signals, source consistence test, and analysis and evaluation of audio data with stress ground truth.

2.4 Systems Tested

Lantern
The Diogenes Group, Inc.

The Diogenes Group Inc., established in 1995, produces a system called the Lantern. The Lantern instrumentation consists of an analog-type magnetic tape recorder with integral microphone, a powerful laptop computer serving as a high-speed processor, and an extensive program of copyrighted proprietary processing software designed specifically for ease of operation. The Windows based software is also responsible for control of all processing operations, display format and presentation, and the printing of hard copies of the waveforms representing the behavior of the microtremor. The tape recorder is operated throughout an interview, to create the primary record, which includes both questions and answers in the context in which they occurred. The monitor output of the recorder provides the real-time input to the digital processor. The examiner is able to control, with a single finger, high-sample rate digital capture of the sound of each answer.

Vericator
Trustech Ltd.
Integratek Systems, Inc.,

Trustech Ltd. was founded in 1997, and produces a system called Vericator, formally known as the Truster Pro. This system allows the user to use their own personal computer with the following requirements: WIN95 / WIN98 /NT 4.0, Pentium II or III, 32 MB RAM to 128 MB RAM, a highly sensitive microphone,
CD ROM Drive (double speed), and a 16 Bit Soundcard (full duplex). The package includes a Vericator CD, Stereo T-Connector (for connecting your PC and telephone), Vericator User Manual. It features automatic calibration process; analysis of deception in real-time; analysis of pre-recorded online conversations/interviews and TV or radio segments. The summary and technical reports can be viewed, saved and printed. There are graph displays for advanced diagnosis; four built-in psychological lie detection patterns; filtering system for reducing background noise.

2.5 Technical Testing

Trained analyzers in a laboratory setting completed the technical testing. These analyzers were each trained through the VSA vendor training programs.

2.5.1 Artificial Signal Test (Test 1)

2.5.1.1 Objective (Test 1)

Test 1 of the VSA Evaluation was to determine if the VSA units detect the frequency modulation of a signal. These signals are similar to the microtremor, which the manufacturer’s state is their theory of operation. For the purposes of this test we utilized the Vericator system and the Diogenes Lantern system. A generically generated signal database of FM frequencies, occurring at different rates and depths of modulation, was processed repeatedly through the systems.

2.5.1.2 Test 1 Set-Up

The test was performed on laptop computers that housed the Vericator and Diogenes Lantern software. The signals were fed to the laptops from a desktop PC. The desktop PC dispatched the artificial signals using the commercial off-the-shelf (COTS) application Cool Edit. Cool Edit is a digital audio editor for a Windows base system. It is used to record and play files in a wide variety of audio formats, edit files and mix them together, and convert audio files from one format to another. Cool Edit also gives the ability to create sounds from scratch with generated tones, and generated noise signals.

The FM test signals that comprise the signal database for Test 1 were generated using Cool Edit. These FM signals were generated at the carrier frequencies of 80 Hz and 160 Hz (these frequencies represented the fundamental frequency on a speech signal), with varying modulation rates and depth of modulation rates (Figure 1). Modulating rates measures how fast the signal modulates, and depth represents how much the signal modulates from the carrier frequency.

<table>
<thead>
<tr>
<th>MODULATION RATE (Hz)</th>
<th>1</th>
<th>2</th>
<th>4</th>
<th>6</th>
<th>10</th>
<th>15</th>
<th>20</th>
<th>25</th>
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<tbody>
<tr>
<td>1</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<td>X</td>
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<td>8</td>
<td>X</td>
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<td>X</td>
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<td>X</td>
</tr>
</tbody>
</table>

*Figure 1: FM Recorder Test Signals @ 80 Hz & 160 Hz*
The test signals were recorded in 15 second utterances. Each signal was passed through each VSA system. The test results were recorded on data spreadsheets, and the wave analysis was labeled and printed. Once the test waves were all analyzed the documentation was compared to determine consistency.

2.5.1.3 Vericator

For the purposes of this test we utilized the “Online Mode” of the Vericator application. The “Online” mode allows the detection of stress with a live audio signal. The signals were processed through the Vericator in short utterances. A few signals were attempted with a consistent result of “No indication of voice segments” or “Not enough voice samples.”

To overcome the inability to analyze the bare FM tones, we added a voice to the signal to the tone. After recording a female voice, analyzing it and determining the most consistent signal, the FM frequency was added. The signals listed in figure 1 were the signals processed through the Vericator system. The system was able to identified these signals and process them. The system responded with a spike in the analysis wave every time the FM frequency was introduced to the signal. These results were recorded in the test log for the Vericator analysis.

2.5.1.4 Diogenes Lantern

The test waves were re-sampled to an 11025-sampling rate, 8-bit mono to facilitate the acceptance of the signal by the Diogenes Lantern system. The FM signals, were 3-4 second long. The signals were processed through the Lantern system. The graphs were labeled according to frequency, depth of modulation, and modulation rate. The signals listed in figure 1 were the signals processed through the Diogenes Lantern:

The above test waves for both systems were analyzed and documented. The results were found to be consistent across the board with little variation in the results in response to the adjustments/changes in the modulation or depth of modulation rates. For example, the analysis of the 80Hz FM test wave with a depth of modulation rate of 1 Hz and a modulation rate of 1 Hz; differed very little from an 80 Hz FM test wave with a depth of modulation of 4 Hz and a modulation rate of 25 Hz. Since there was no variation of indicated stress from different input signals, it can be assumed that the systems tested do not use microtremors as indicated in their claims.

2.5.1.5 Summary (Test 1)

The tests were performed, the data was documented, and the results were compared. The Vericator and Diogenes Lantern Systems were utilized in this evaluation and their technology was tested. For the purposes of this test the nature of the results, stress or no stress indicated, were not taken into account. The primary goal of this phase of the VSA evaluation was to determine if the microtremor claim is the VSA’s true theory of operation. It was determine, late in the testing phase of this project, that the VSA units measure the energy change of the spectrum envelope between 20 Hz and 40 Hz. This is what the vendors are claiming to be microtremors. It is the change of energy in the speech envelope. If an individual is under stress, their vocal tract muscles are likely to tighten up, when this occurs the energy of their voice signal becomes abrupt when they start and finish talking, and has less variation while they are talking. When an individual is not stressed, their voice energy slowly leads to a peak when they start to speak, then the energy varies until the individual stops speaking where the energy slowly tails off. This algorithm was coded in the laboratory with the same audio signal inputted. As seen in the waveforms in figure 2a and 2b, the results were identical when compared to the Diogenes Lantern system. The waveform comparison could also be seen in figure 2c and 2d. This discovery makes the artificial signal test obsolete and the results invalid.
Figure 2a Diogenes Lantern System Output (No Stress Indicated)

Figure 2b Matlab Output (No Stress Indicated)

Figure 2c Diogenes Lantern System Output (Stress Indicated)
2.5.2 Source Consistency Tests (Test 2)

One of the major questions presented to the engineers testing the voice stress systems, “is there a difference in the analysis of an audio file utilizing different media’s.” The different media’s could be a Digital Audio Tape system (DAT); a cassette recorder or telephone input device. Each recording device has their own different properties, which could effect the overall analysis by the examiners.

2.5.2.1 Objective (Test 2)

This experiment is designed to compare the analysis of identical signals utilizing the different media’s.

2.5.2.2 Scope

We will feed these signals in several times to evaluate consistency of results from the two systems that were available for evaluation. The analysis of the output was then compared to the analysis of the output of the same signal from a different type of media. This will give indications of whether or not different types of media play an important role in the evaluation and analysis of the voiced responses.

2.5.2.3 Test

A collection of 60 voiced utterances from different males and females were recorded on digital audio tape (DAT), a computer and cassette tapes. These utterances were collected simultaneously by the computer (.wav format), analog cassette format, and digital via a 48KHz DAT recorder (see figure 3). The audio was analyzed separately from each of the three media’s (cassette, computer, and DAT). The live feed was connected directly into the computer, the output was analyzed and the results were printed. At the same time, the utterance was recorded on the DAT, this signal was inputted into the computer for reanalysis and the results were printed. Again at the same time, the utterance was recorded on a cassette tape and was inputted into the computer to be re-analyzed, and again the results were printed.
2.5.2.4 Examination Results

Voiced analysis reported consistent results utilizing DAT and live voice. Each utterance was examined and found that all the waveforms and analysis was consistently identical. When using a cassette recorder similar results were obtained as in the live data. One must be very careful, when recording with a cassette player, to adjust the recording gain accurately, or use the automatic gain control (AGC). If the recording volume is not set accurately, the recorded utterances changes the waveforms and results drastically. This could result in an analysis which is completely different from the truth, therefore providing an incorrect result by the examiner. These discrepancies can be seen in figures 4a - 4d, when using the Diogenes Lantern system.

Reviewing the charts in figure 4 shows how much the waveform will change when recorded on the cassette recorder without the AGC set. The input file (top waveform) is consistent for figure 4a, 4b, and 4c. It is clipped for figure 4d. This corrupts the output signal (bottom waveform), as seen when comparing figure 4d with the others.

Figure 4a: Data recorded live
2.5.2.5 Summary (Test 2)

From the results in test 2 it is recommended to perform all analysis, when possible, in live mode. This eliminates any media effects on the audio signal and provides consistent results. It is also absolutely necessary to use a quality microphone, such as the Shure microphone model SM58, or one with equivalent specifications. When data needs to be recorded, it is recommended to use a DAT player as a media source. This will reduce any possible human error when analyzing data.

2.5.3 DATA EVALUATION (TEST 3)

Data: Audio statements from 2 sets of polygraph tests performed by a certified polygraphist
Evaluators: By engineers who were certified by Diogenes and Vericator manufacturers.

2.5.3.1 Data Collection And Down Sampling
Six videotapes were obtained from Department of Defense Polygraph Institute (DODPI), of two suspects in two separate murder cases. The audio portion of the video tape was extracted and digitized into .wav files. These digital audio files were inserted into the VSA computers. The audio files were then downsampled from 48kHz down to 11.025kHz to accommodate the manufacturer's requirements.

2.5.3.2 Segmentation

Once the audio data was entered and stored in the computer systems we then proceeded to segment the audio. For the Lantern system we had to create individual .wav file for each utterance that the defendant made, in these cases usually answered by a yes or no. This was done to allow short utterances to be processed by the Lantern as suggested by the manufacturer. There were a total of 45 questions ranging from relevant to non-relevant questions.

The Vericator performs its own unique segmentation, this task was completed utilizing their own process. This was done through the off-line mode.

2.5.3.3 Testing

Each audio segment was processed through the Lantern system and performed a separate analysis of each wave pattern. Each waveform was compared to the other to verify any distinct changes due to stress. Each file that gave indication of stress were marked and compared to the baseline.

Each audio file was processed through the off-line mode of the Vericator. Results were automatically recorded by the system.

2.5.3.4 Results

The stress ground truth was obtained through the polygraph examiner and court proceedings via the outcomes of each of the interviews. Both suspects confessed and were subsequently convicted of murder. All of the deceptive stress sentences were verified. Each of the 48 utterance was analyzed and compared to the ground truth. Each system gave indications of high levels of stress where deception was verified. The Vericator system scored 100% in its indication of some form of stress, such as deceitful, high stress, probably lying. The Lantern system also scored 100% in its indication of stress through the waveform analysis. Both systems gave the examiner conclusively areas of deception indicated.

7.6 Field Testing

In the field testing portion of this study, two local police investigators obtained a VSA system, Mike Addist of the Canastota, New York Police Department and James F. Masucci of the Rome, New York Police Department. Mike Addist used the Vericator, and James Masucci used the Diogenes Lantern. The goal of this phase of testing was to determine the feasibility of these systems in the law enforcement environment. It also provided the unbiased opinion of an experienced investigator. The following are their reports:

I have been in Law Enforcement for the past twenty years, and during this time I have had the opportunity to see all facets of crimes and investigations. I have been involved in crimes dealing with the least punishable to the severest of them all. Also, I have had the opportunity to attend schools that taught me how to detect when a suspect is being deceptive during questioning. In some cases it was difficult to sometimes determine if a suspect was deceptive, and that made my job harder until the summer of 1997 when I came to your facility for help.

My first contact was with Ms. Sharon Walters who advised me that the U.S. Government (Military) and a group of Research Technicians (Private Contractors) at Rome Laboratory were about to take on the task of evaluating some technology dealing with truth verification. I was
I was asked to join this task force to assist the government in this evaluation, but first I was to learn what truth verification was. This also required me to learn and study what a microtremor was, and how algorithms mathematically calculated the stress in a human voice. I reviewed the technology and was given a voice stress program called Truster-Pro, now known as Vericator. By using this system I was able to interview a subject whom may have been involved in a crime. First an interview is performed to determine the facts, as he/she knew them. Then, I was able to give the subject one or two tests to determine the truth or deception. Finally, a post interrogation would be conducted in an attempt to get a confession.

I have found by using this technique, while observing body movement, I have had great success with this system. I have had the opportunity to use the system on crimes from petit larcenies to rapes, and have been able to determine either from the victim or the suspect, the deception or truth. Not all of the tests were positive, but on the majority of them I was able to get a true confession to the crime. This, I believe, verifies the system's capability of being a valuable investigative tool for the law enforcement officer.

In conclusion, I keep in mind that by use of this system by itself cannot determine the guilt of the suspect. The continuous training that I receive and other facets of my duties must be used to determine the guilt. I believe that this system is a valuable tool, and that further research is needed to be able to offer this technology to the Police Officer on the streets of our cities, towns and villages across this nation.

Respectfully,

Michael G. Adsit
Criminal Investigator

I have been using the Lantern Voice Stress Analyzer from Diogenes since October of 1997. I have had many rewarding experiences with the Lantern. I have successfully used it in homicide, arson, robbery, burglary, assault and sexual abuse cases. I do all of the testing for the Oneida County Child Advocacy Center, formerly known as the Oneida County Sexual Abuse Task Force. I point this out to show that I have tried the Lantern on just about every type of crime. Although I did not keep statistics, I feel that I can safely say that with the aid of the Lantern, I have been able to eliminate about as many suspects as I have found reason to "dig into" a little more.

I am not much of a technical expert, but I have made the following observations. I do believe the theory of the micro-muscle tremor and the need for "jeopardy." I have found that without jeopardy, or a fear of some consequence to lying, you do not get accurate charts. I have seen a tremendous difference in the voice stress patterns when there is jeopardy - vs - no jeopardy. For example, I have told suspects to intentionally lie on certain questions during the test. I have found that when they do lie over something that means nothing, you don't get a clear-cut stress pattern. I have seen a small amount of "stress" in those answers, but nothing comparable to a stress pattern when the suspect lies on a relevant question.

As far as recorded material being analyzed by the Lantern, I personally am not a big proponent. I have had some success in analyzing audiotapes, but I find the charts much more difficult to analyze. I have used both cassette and DAT and I really don't see much of a difference between the two. They are both just as difficult for me to interpret. The patterns seem to appear much different that when a "live" test is administered. I do not feel that I can say that the taped material gives inaccurate readings, it may be just a personal preference on my part.
One final and perhaps most important point I would make regarding the Lantern is the fact that you should not rely solely on the charts to make a determination if someone is "lying." I am not saying that Diogenes professes that this is a "lie detector," actually they profess the opposite. I am just saying that this should never be looked at as a "lie detector." I have truly found that it CANNOT detect lies. As you know, it DOES detect stress. Stress, however, does not always equate to a "lie." I have found in several cases that a person "fails", if you will, on all relevant/crime questions, but has been found to have not committed the crime.

I will close by saying that my experiences with the Lantern have been very positive, however, it cannot be looked upon as a "magic bullet." It is simply an investigative tool. Interrogation and the manner in which questions are formulated are very important. I truly believe that a person that is not strong in the interrogation area, will not be as successful with it, as the person that possess strong interrogation skills. There is much open to interpretation on the charts as far as I can see. It is very situational and again, can NEVER be determined a "lie detector."

James F. Masucci
Rome P.D.

These two reports reinforce the results of the technical testing, in that these systems do indicate stress. Caution should be taken when using these systems. They should only be used as investigator tool, and not total rely on these systems for a case conclusion.

3.0 SUMMARY

After reviewing the three technical tests performed, it could be stated that these two VSA units do recognize stress. Although these systems state they detect deception, this was not proven. This study does shows, from a number of speech under stress studies, that linear and non-linear features are useful for stress classification [2]. Due to the lack of deceptive stress data available, classification of deceptive stress versus emotional stress or physical stress was not been tested. This is a vital role in the detection and classification of stress. Many suspects are under an extreme amount of stress under being interrogated. Do these VSA systems actually differentiate between the different types of stress? This still needs to be proven.

It was proven that the Diogenes Lantern system detects stress via the amount of energy in the speech envelope. Even though this system performed well under the technical and the field tests, it seems from an engineering point of view, that one feature is insufficient to detect and classify deceptive stress. In the study under Dr. Hansen [2], it was shown that fusion of features help to increase the accuracy of your stress classification.

It was proven that the systems tested will and do give the same response when the inputted audio is recorded as opposed to live. The only criterion is when recording using a cassette player it is the up most importance to set the AGC. To eliminate any possibility of errors, recording with a DAT is the safest way to go.

REFERENCES
