A Galvanic Skin Response Interface for People with Severe Motor Disabilities

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ABSTRACT

Biometric input devices can provide assistive technology access to people who have little or no motor control. We explore a biometric control interface based on the Galvanic Skin Response, to determine its effectiveness as a non-muscular channel of input. This paper presents data from several online studies over a six-month period of a locked-in subject using a Galvanic Skin Response system for communication and control. We present issues with GSR control, and approaches that may improve accuracy and information transfer rate.

Categories & Subject Descriptors: Computer Applications: Life and Medical Sciences: Health

General Terms: Human Factors

Keywords

Locked-in syndrome, Galvanic Skin Response, Biometric Control, Assistive Technology

INTRODUCTION

Over a half-million people worldwide suffer from *locked-in syndrome*, a disorder characterized by complete paralysis and inability to speak [1]. Locked-in syndrome may result from a variety of causes, including traumatic brain injury, vascular diseases such as stroke, neurological diseases such as ALS, or medication overdose. Individuals with locked-in syndrome are typically conscious and fully cognitively intact, but are unable to speak or move. With little or no ability to communicate or control their environment, these people are essentially prisoners in their own bodies.

Assistive technology (AT) offers many avenues for people with motor disabilities [2]. However, these solutions are not available to people with locked-in syndrome because most AT input devices depend on such as brain signals, to provide non-muscular channels for control. Brain-Computer Interfaces (BCIs) are biometric input technologies that have been demonstrated to be effective in many people [7]. However, some diseases such as late-stage ALS can attenuate the brain signals that can be recorded from scalp electrodes, preventing BCI usage.

Our alternate biometric approach is based on the Galvanic Skin Response (GSR), which measures electrical conductivity on the skin. GSR levels are affected by emotional responses such as fear, excitement, or anxiety. This paper details a study examining to what extent the GSR can be controlled by a person with locked-in syndrome, to determine the efficacy of GSR as an input device for assistive technology. We worked with a (now completely) locked-in subject whose disease progressed beyond the ability to operate a BCI [8]. We have collected data over the course of a year in which our subject used a GSR system to communicate. This paper presents data from our initial intensive week-long study with our subject. We also performed an offline analysis on the data to determine which signal processing algorithms provide the best accuracy and information transfer rate.

BACKGROUND AND RELATED WORK

The *Galvanic Skin Response* is a type of *electrodermal response*, which is a change in the electric conductivity of the skin caused by an increase in activity of sweat glands. The GSR is affected when the sympathetic nervous system is active, in particular when a person is anxious [4]. The electrical conductivity of the skin can be measured by placing two electrodes on the skin, usually on the fingers, although other sites such as feet and armpits have been tested. A GSR device sends an imperceptibly small current through the electrodes, measuring the momentary conductivity of the skin. This produces a continuous signal that varies with the emotional state of the subject.

The Galvanic Skin Response was first documented over one hundred years ago. Carl Jung explored the GSR for psychiatric evaluation and therapy in the early 1900's [3]. Most of the applications for GSR since then have been focused on psychiatry [4], utilizing it to gauge emotional states such as agitation or anxiety. More recently, GSR has been used as a biofeedback mechanism [6],[11] in order to teach meditation or emotional control, and to treat anxiety disorder.

The GSR is commonly known today as a component of a polygraph, or lie-detection device [10]. Along with blood pressure, pulse, and respiration monitors, an elevated GSR can indicate nervousness or anxiety when questions are asked. A trained polygrapher can compare GSR levels during questioning to baseline GSR to indicate when a subject might be lying.

To a far lesser extent, GSR has also been explored for control. Several game programs have been adapted for GSR [5]. In the *AffQuake* game [12], the MIT Affective Computing group utilizes GSR to detect emotional responses to game events. These responses are then reflected in the game's avatar, for example if the user is startled by a game event, the avatar may withdraw from the current situation. The same group has also adapted GSR for applications such as detecting driving stress and for gauging frustration.

METHODS

Subject

The study involved one male subject, 42 years of age, who had been diagnosed with ALS in 1997. He progressively lost the ability to move or speak, becoming "locked-in" approximately one year prior to our study. Initially our subject could move his eyes very slightly to indicate "yes" and "no", but he lost that ability during the course of the study. He also lost the ability to hold his eyes open, but his ophthalmologist crafted a special pair of glasses that could brace his eyelid, allowing him to see for short periods. His vision was limited to a central focus due to the absence of eye saccades. As soon as our subject lost all muscle movement, he began learning to control his GSR in order to continue communicating, observing the GSR graph projected on a 72" diagonal screen at the foot of his bed. He had fourteen months of experience with the GSR detection device at the start of this study.

Apparatus

We used an unmodified police-grade commercial polygraph system [10] as the signal collection mechanism for this study. Although this system has the capability to record blood pressure, respiration, and pulse, we only used the GSR component (a ventilator prevents the other components from being controllable).

The GSR was recorded with two steel electrodes attached to the fingers, usually the index and middle fingers of either hand. Electrodes were cleaned and moved periodically to improve signal fidelity (typically from one hand to the other, but sometimes to different finger pairs). The polygraph system provided an adjustment for sensitivity level, which we raised from the default level of 20 to 250-300. We calibrated the sensitivity by asking our subject to raise his GSR and then adjusting the sensitivity to allow him to reach a threshold set at 50% of the GSR range.

On top of the polygraph system, we implemented an experimental engine that provided our subject with targets and guided task prompts, and collected performance data. We implemented auditory versions of each interface so that our subject could operate the system without having to prop his eyes open. Because the values emitted directly from the polygraph were encrypted, we obtained the GSR values from the polygraph display. We also implemented several applications, including a binary (yes/no) answering system, a binary speller, a number program to select phrases from a chart, and a chess game. The control displays for these applications were superimposed transparently over the standard display of the GSR system. We generated an auditory representation of the GSR level by emitting a short tone for each GSR value, rising and falling in pitch corresponding to the relative amplitude of the GSR signal. Figure 1 below shows the control display of the polygraph system, with a threshold target (red line) generated by our experimental system.

Figure 1 - Control display for GSR trainer showing subject crossing threshold target.

Protocols

In order to measure the accuracy and the reliability of the GSR system as a communication device, we conducted a series of studies that tested our subject's control with the binary (yes/no) guided task. We visited the subject's home for one week at the start of the project, recording two sessions a day for four days. We then set up a remote data collection mechanism that allowed us to receive data from subsequent sessions conducted by the subject's family and caregivers. The data presented here were recorded in 30 independent sessions over a 6-month period.

Sessions were conducted in the subject's home with distractions at a minimum (no TV or extraneous noise initially). At the start of each recording session, we calibrated the GSR device, adjusting the sensitivity so that our subject could easily attain a 50% threshold. A baseline GSR of 1-2 minutes was measured before each trial.

During the baseline period, the subject did not try to influence the graph in any respect.

For each trial, the experimental system produced auditory prompts that requested "please generate a yes" or "please generate a no", in random order. Initially, the subject was instructed to raise his GSR level on the "yes" prompts and keep it low (stable) on the "no" prompts. The subject was given a time period for controlling his GSR, ranging from 15 seconds to 60 seconds, with an inter-task interval (ITI) of 10 seconds. If the subject raised his GSR to cross the threshold during the time period, the experimental system produced auditory feedback indicating "yes detected". If the subject kept the GSR low (did not cross the threshold) during the time period, the feedback indicated "no detected". Each run consisted of ten trials, and sessions typically consisted of 3-4 runs, depending on the fatigue level of our subject. Our subject was allowed to rest 5-15 minutes between runs.

RESULTS AND DISCUSSION

To determine the subject's degree of control, we examine data from a run during our initial week with our subject. Table 1 shows baseline recording data from a representative session.

Trial #	% Yes Correct	% No Correct
1	50	100
2	0	66
3	0	0
4	0	100
5	0	75
6	0	100
7	0	100
8	50	100
9	0	100
10	0	100
11	0	100
Average	10%	94.1%

Table 1. Baseline GSR recordings

The results presented for the baseline essentially indicate randomness, with a bias towards low GSR (indicating "no"). From these data we imply that when the subject does not intend to raise his GSR level, the level remains stable. Table 2 presents data from the same session in which our subject was attempting to influence the graph. For these trials we employed a manual ITI, allowing us to observe when the GSR signal "settled" after activation before starting the next trial. The ITI was chosen manually because once the subject generated a "yes" by moving the GSR above the threshold it took a certain amount of time for the GSR to stabilize again. The stabilization time varied between subsequent requests and with the fatigue of the subject. Once the GSR stabilized, the subject was requested to generate another "yes" or "no" randomly.

Trial #	%Yes Correct	%No Correct
1	50	100
2	40	100
3	43	33
4	0	66
5	25	66
6	0	100
7	33	88
8	25	100
9	75	83
10	40	80
Average	33.1%	81.6%

Table 2. GSR accuracy during trials

Table 3 shows the averages of our subject's ability to activate his GSR (TP - true positives), ability to keep his GSR low (TN - true negatives) inability to activate when desired (FP - false negatives), and activations when not desired (FP - false positives). The overall correctness average is 57.35% for this run, calculated by the formula (TP + TN) / 2. The overall error rate is the inverse, calculated by (FP + FN) / 2, which in this case is 42.65%.

State	*TP*	*FP*	*TN*	*FN*
Baseline	10	5.9	94.1	90
Control	33.1	18.4	81.6	66.9

Table 3. Accuracy data summary

Table 4 shows average accuracies for all sessions conducted during the week, calculated for each session as illustrated above:

Run	***Overall Accuracy***
Day 1-1	40%
Day 1-2	60%
Day 1-3	50%
Day 1 average	***50%***
Day 2-1	75%
Day 2-2	70%
Day 2-3	50%
Day 2-4	70%
Day 2 average	***66.25%***
Day 3-1	60%
Day 3-2	60%
Day 3-3	30%
Day 3 average	***50%***
Day 4-1	90%
Day 4-2	70%
Day 4-3	80%
Day 4-4	60%
Day 4 average	***75%***

Table 4. Average accuracies for all runs

Analysis

The statistics present evidence that there is a significant difference in accuracy between baseline and control states when the subject attempts to raise his GSR past a 50% threshold. His accuracy varied from run to run and day to day, but the overall (unbiased) accuracy was 61.78%. The Yes responses (activations) are almost always zero for the baseline, while they are almost never zero when the subject is actually trying to influence his GSR. The accuracy of the "no" responses (keeping GSR stable) decreased when the subject tried to control his GSR level. This may be due to the effect of raising his GSR for a "yes" in a previous request carrying over to the next. We did note in initial pilot sessions that it was difficult for the subject to generate two consecutive "yes" responses with our automated ITI of 10 seconds, which is why we opted for the manual ITI. In an assistive technology system, the GSR system could detect when the signal stabilized enough to continue.

Our subject's performance varied from day to day although there was an overall trend toward improvement. His accuracy increased between the first and second days, and on the third day his first two runs were 60%, but then in the third run he achieved only 30%, which we attribute to fatigue. However, his performance on the fourth and last day was consistently superb – he achieved a 90% accuracy rate during the first run. This increased accuracy may be attributed to practice, learning effect, or simply feeling less tired on that day. His performance declined slightly after that, which we attribute to fatigue. We asked our subject if he felt a large sense of effort in raising his GSR, and he indicated "yes" (using the GSR, asking the question three times for confirmation).

Issues with artifacts

Aside from the issues of accuracy and fatigue, there are other considerations for GSR control. During our study we occasionally noticed large peaks in the data where no activation was requested or observed. One data set contained a peak strength of 5329, which did not correspond with the remainder of the data. A closer look at peak reveals that it was probably an artifact caused by bed movement or someone touching the subject. The peak is shown in Figure 2 below.

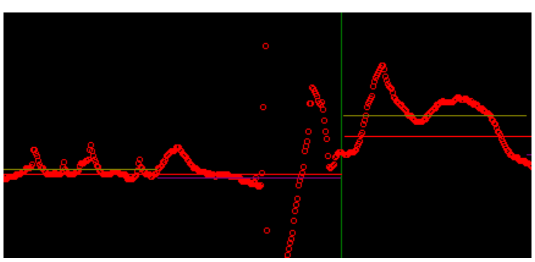

Figure 2 - Artifact peak

As shown above, the peak randomly fluctuates and causes a false detection in the peak finding algorithm. This peak pattern is representative of a movement in the subject's electrodes during the trial. In another instance, we observed a pattern in the GSR signal, as shown in Figure 3.

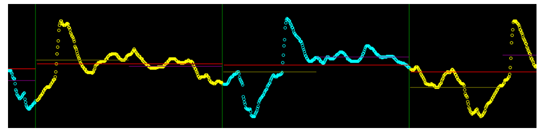

Figure 3 - The graph showing periodic patterns

There was little or no deviation from the pattern when the subject was trying to say "yes" or "no". The patterns occurred at intervals of approximately 45 seconds. We also noticed that at the beginning of this trial the pattern did not exist. We eventually discovered that a component of the subject's automated bed had activated to shift his position. These occurrences indicate that artifact detection is an important component of any AT device based on GSR.

Methods to Improve Accuracy

The data clearly show that our subject can control his GSR level with a simple thresholding paradigm, sufficient enough for rudimentary "yes/no" communication. For a person with no other means of communicating, this is extremely significant. However, the 61.78% accuracy is clearly unsatisfactory for controlling other applications, such as spelling, in which the high error rate would undoubtedly cause immense frustration. We discovered that environmental factors such as the temperature in the room had an effect on performance, correlating GSR control with a warmer temperature (73 degrees as opposed to our subject's usual 69 degrees). However, even with optimal conditions and more practice, we cannot expect accuracy to improve by such a huge margin with this approach. Therefore, we performed some preliminary pilot studies to examine alternative approaches to collecting and analyzing the GSR signal in order to increase accuracy. Our goal was to perform tests on a limited basis to gauge the merits of pursuing further study with these approaches.

Sudden Changes in Visual Input

Visual stimulation can have a very significant impact on a person's GSR levels. The type of visual stimulus provided is also significant. Different visual stimuli produce vastly different results, and we may be able to take advantage of this difference for control if selective attention can influence the GSR. To test this hypothesis, we performed a limited study to gather evidence.

The objective of this experiment was to determine if a sudden change in visual input affected the GSR of our locked-in subject. We recorded our subject's GSR while he attended to a game of golf on a big screen located at the foot of his bed.

Results

During the golf game, our experimental system recorded the subject's GSR level for a total of 270 seconds. Of the 270 seconds, the GSR graph appeared flat for approximately 265 seconds as shown in Figure 4 below.

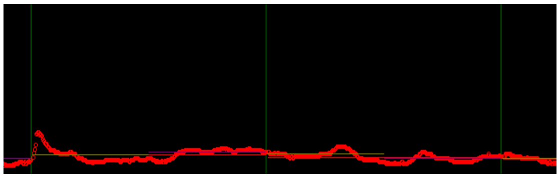

Figure 4 - Stable GSR graph during a golf game.

As shown above, the graph appeared flat for 98% of the trial time. However, for a very short period of time, the graph suddenly spiked as shown in Figure 5 below.

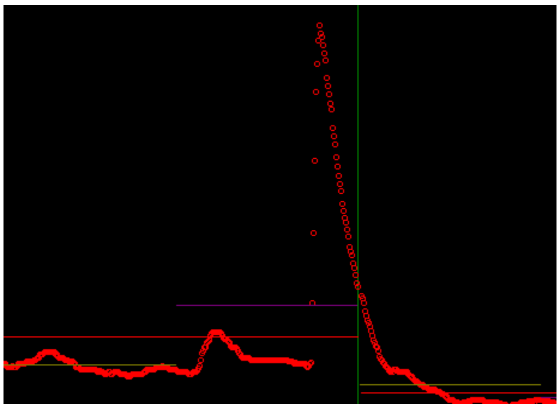

Figure 5 - Sharp Increase due to visual stimulus.

The sharp increase in GSR response was only encountered once during the trial. The graph reached its peak very quickly and then stabilized slowly. The time to return back to normal from the peak was approximately 7 times as long as the time to reach the peak from a stable baseline.

Analysis

We believe the spike in the graph was caused due to a sudden change in visual input. This can be attributed to the nature of the visual stimulus. During a golf game the camera focuses on the player conducting various activities, which includes shooting the golf ball. The sudden spike occurred when the player shot the golf ball through the air. As a result, the camera suddenly pointed skywards in an attempt to follow the ball. When this occurred, the subject's GSR spiked. This demonstrates the effect of a sudden change in visual input on the GSR. Whether this effect occurs every time visual stimulation suddenly changes is yet to be determined. If so, it would provide a reliable method to measure the GSR response capabilities of a subject and could facilitate more reliable calibration and tuning.

Comparative Changes in Visual Input

In a related limited experiment, we measured the difference in GSR response when our subject was watching a game of golf, which has sudden changes in visual input, compared to another show that does not. The alternate show used in this experiment was "Judge Judy" because it has an indoor environment, which tends to have consistent visual input.

Results

The following are the GSR amplitudes (peak strengths) found when the subject was watching the golf channel. The first column indicates the trial number. A trial with only "-" implies no peaks were found during the trial interval.

Trial #							
1	8584	-	-	-	-	-	-
2	129	69	-	-	-	-	-
3	770	390	160	225	-	-	-
4	-	-	-	-	-	-	-
5	1346	96	56	142	2000	120	645
6	-	-	-	-	-	-	-
7	1488	480	53	262	-	-	-
8	211	131	79	-	-	-	-

Table 5. Peak strengths with changing visual input

Table 6 shows the peak strengths when the subject was watching "Judge Judy" on TV.

Trial #			
1	106	206	242
2	5329	184	
3	62	186	71
4	41	42	42
5	-	-	-
6	-	-	-
7	371	-	-
8	61	105	-
9	1529	51	-
10	219	-	-
11	229	265	-

Table 6 – Peak strengths with consistent visual input

Analysis

The data representing the golf game shows a higher tendency of peaks than the one representing the "Judge Judy" show. On average, there were 2.6 peaks for every trial during the golf game as compared to only 1.7 peaks on average for "Judge Judy". We believe this can be attributed to a greater change in visual input during the golf game. The results of this experiment encourage us to study the possibility that multiple visual stimuli could be presented to a subject, who could use selective attention to raise or lower his GSR level with less effort and fatigue.

Auditory Input

Another type of stimulus that we tested was sound. In our studies, we found that although sound has little direct influence on the GSR, it can be used as a distraction to keep the GSR more stable. Unlike visual input, which can cause random spikes in the GSR, auditory input has no such influence. Therefore, it may be useful as stimulus for control.

The objective of this experiment was to measure the influence of auditory input on the GSR. The subject was asked to focus on a book being read on tape. The subject was also allowed to watch his GSR graph on a big flat screen TV located in front of him during the experiment and was also asked not to influence the GSR response in any respect with the exception of listening to the book on tape.

Results

The average peak strengths recorded for every trial are depicted graphically in Figure 7.

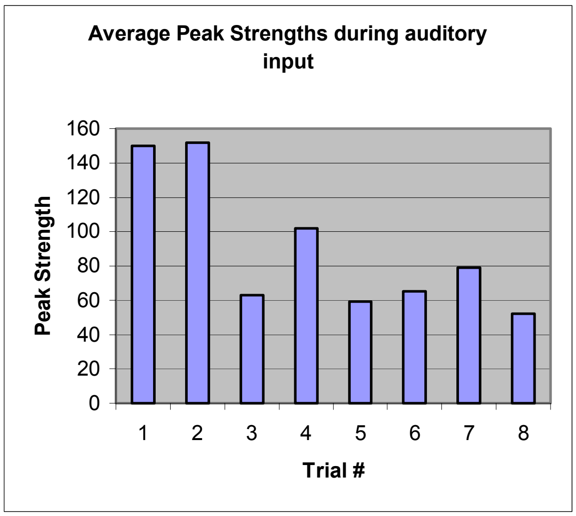

Figure 7 - Auditory input

Analysis

Auditory input provided a focus for our subject's thoughts, which resulted in a lower and more stable GSR graph. The peak strengths on average were quite low and no sudden spikes were encountered during any of the trials. The greatest spike encountered once the subject was involved with the auditory input was only 309. Therefore, the auditory input provided for a lower and more stable GSR.

When compared to the visual input, we noticed a sharp decrease in peak strengths. The lowest average value during the visual input was 223 for the "Judge Judy" show, while it was only 90 for the auditory input. The visual stimuli had higher values because sudden changes in visual input were encountered. Auditory input provided no such effect. This result might again be useful in a selective attention control interface, where a user could attend to either a visual or an auditory stimulus.

Choice Anticipation

Another important factor that influences a person's ability to control the GSR is knowledge of an upcoming event. Predictability can cause desirable as well as undesirable effects. To test these effects, we performed another limited experiment to measure the effect of choice anticipation on the GSR of the subject. The experiment consisted of two protocols.

The first protocol required the subject to generate yes's and no's randomly, using the 50% threshold paradigm. The second protocol requested the subject to generate yes's and no's in a predetermined pattern. There were 4 no's followed by a yes and this pattern repeated twice, allowing the subject to predict what the next choice would be.

Results

Figure 8 shows GSR accuracy results for protocol 1, when the subject was unable to predict the upcoming option.

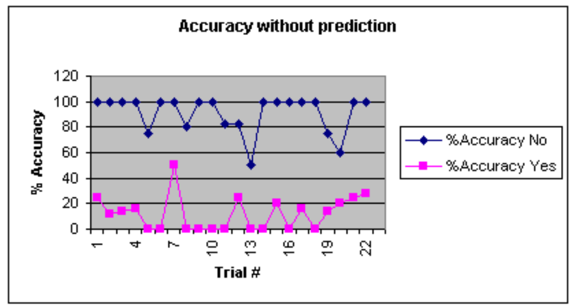

Figure 8 - Accuracy without prediction

In comparison, the accuracy for protocol 2, with a predictable pattern, is shown in Figure 9.

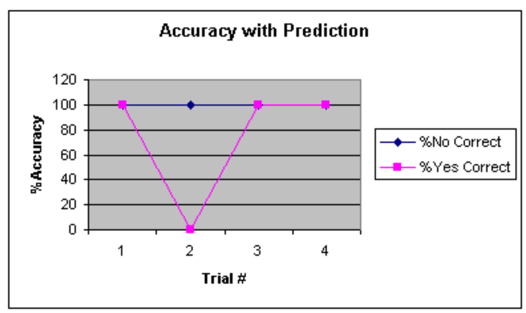

Figure 9 - Accuracy with prediction

Most of the yes's that were recorded during this component had peaks occurring in the first 7 seconds of the request.

Analysis

The accuracy of the subject improved significantly when he was able to predict the next request. As shown in Figure 8, the accuracy remained primarily between 20-30% for the yes's and between 80-100% for the no's when it was not possible to predict the next option. On the other hand, when it was possible to predict the next option the subject had an accuracy of 100% for the no's and yes's for most of the trials. Therefore, the ability to predict the next choice has a significant impact on accuracy.

Choice anticipation also results in false detections sometimes because the subject can begin to influence the graph before a question is asked. This is shown in Figure 10 below.

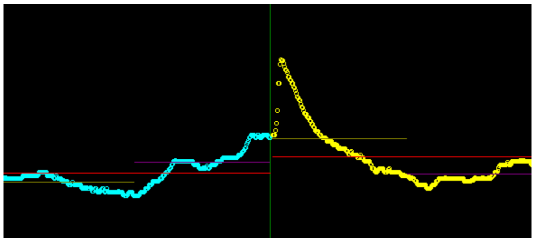

Figure 10 - Anticipatory GSR

Although the above results are undesirable, they are rare. The advantages and improvement in accuracy provided by this method easily outweigh its flaws. During a real spelling program, the subject may anticipate which letter to select and therefore predictability will be an advantage if the letters are presented in order.

CONCLUSIONS AND FUTURE WORK

The results from this study demonstrate that the GSR can be used as a control interface and has provided us with many ideas for improving its performance. We are currently conducting this same series of GSR studies with three more people who have locked-in syndrome and also with more than twenty able-bodied subjects. Our goal is to more completely characterize GSR controllability and to determine optimal techniques for training, imagery, and user interfaces. We are also experimenting with real-time analysis algorithms that provide the best accuracy, and heuristics for tuning a GSR system for an individual's abilities. Other promising avenues for the future include new, possibly customized GSR hardware with greatly increased sensitivity to reduce usage fatigue. In addition, we are in the process of adapting our existing assistive technology applications [9] to accept GSR input, with the aim of significantly improving the quality of life for people with locked-in syndrome.

ACKNOWLEDENTS

This article is dedicated to the memory of Timothy A. Tinius, our longtime friend, collaborator, and inspiration. We are grateful for the unflagging support of the Brourman family, and our collaborator Dr. Peter Cornell. We express our sincere thanks to Mr. Chuck Slupski of Quality Polygraph Services for his advice and equipment used for this project, and to Mr. Elias Museris for generously donating a polygraph machine to the GSU BrainLab.

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