Conscious Control of Electrodermal Activity: The Potential of Mental Exercises

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Abstract — **Few practical methods of communicating with people who are locked-in currently exist. This study investigates conscious control of physiological signals, specifically electrodermal activity, to generate two distinguishable and reproducible states. These states can be translated into a binary signal to control a communication device for people who are locked in. Breathing rates, mental arithmetic and mental music were investigated as means of controlling electrodermal activity. Features extracted from the signals included mean, range and number of electrodermal reactions. For three of four subjects, at least one mental technique caused a reproducible, statistically significant change in one of these signal features. This study demonstrates the potential of using mental exercises to develop volitional control of electrodermal activity.**

Index Terms—**Augmentative communication, electrodermal activity, locked-in syndrome**

I. INTRODUCTION

Locked-in syndrome, a disorder characterized by complete paralysis and inability to speak, affects over half a million people worldwide [1]. Individuals who suffer from this condition are typically cognitively aware and conscious, but lack the means of interacting with their environment. Health economics has created a prevalent nonchalant attitude towards treating individuals who are locked-in, in spite of recent research that has shown that many of these individuals exhibit residual voluntary functions such as yawning, tearing or drooling [2] and are cognitively alert [3]. In local hospitals such as Bloorview Kids Rehab, devices such as alphabet boards and simple switches are used to communicate with the locked-in who have residual movements, but technology is not available to communicate with those who are fully locked-in.

Recent trends in research on communicating with locked-in patients have tended toward creating a brain-computer interface (BCI) using technologies such as electroencephalography and brain-implanted electrodes [4]. Current brain-computer interfaces have a maximum information transfer rate of between 10-25 bits/min. However, issues such as constantly having to wear an electrode cap, constantly looking at a given visual display [5], expense, and the ability to do real-time analysis to integrate brain-computer interfaces into other activities encourage research into alternate access paths for communication.

One alternate approach to communicating with subjects who are locked-in involves monitoring their autonomic physiological changes in order to differentiate their mental state. This approach has been popular in the field of polygraphy [6]. Physiological signals that have been correlated with a subject's mental state include electrodermal activity, heart rate, blood pressure, peripheral vasoconstriction, pupil dialation, skin temperature and respiration rate [7] [8]. Electrodermal activity (EDA), the changes in the electrical properties of the skin due to sympathetic stimulation of sweat glands, is of particular interest. Electrodermal activity has been recorded in patients where sweating was completely absent [9], and in two conditions that can lead to locked-in syndrome - multiple sclerosis and amyotropic lateral sclerosis [10] [11]. This technique has been used by Tsukahara et al to develop a pilot device that determines with 47% accuracy which letter a subject is thinking of by monitoring their unconscious skin potential reactions [12].

Another approach to communicating with subjects who are locked-in involves monitoring consciously controlled physiological signals to determine a subject's intent. In the field of polygraphy, recent attention has been focused on the effect of mental countermeasures that consciously change physiological reactions such as electrodermal activity [8]. Studies have also demonstrated that electrodermal activity can be consciously controlled through meditation [13]. Recently, this ability was exploited to build a pilot interface for a subject with ALS whose controlled changes in electrodermal activity were displayed on a police-grade commercial polygraph system. He was able to reproduce the required yes or no response with an accuracy of 60.3% [14]. There remains an opportunity for significant improvement, both by training subjects in using different techniques of developing conscious control of their electrodermal activity, and in using a combination of features from electrodermal signals to detect a subject's conscious intent.

The purpose of this study is to determine whether untrained subjects can develop conscious control of their electrodermal activity (EDA) through different mental exercises. As the effects of an activity on each individual are unique to that person's physiology, results will not be generalized across individuals to determine the best exercise for developing control in the population. Instead, this study looks at each subject individually, recognizing that each subject may have a different technique that is best to control their EDA, and that the patterns of changes in EDA may be unique to the individual. If the subject can develop two reproducible controlled states, computers programmed to recognize the distinguishing features of each state can translate these states into a binary signal, which is a potential access point for communication with those who are locked-in.

II. METHODS

A. Overview

Subjects performed three different exercises involving modulating breathing rates, mental arithmetic and mental music. In each exercise, a relaxing activity was alternated each minute with a stimulating activity. Electrodermal activity was recorded continuously throughout each session. Ethical approval of the research was obtained from Bloorview Kids Rehab and the University of Toronto.

B. Subjects

For this pilot study, four able-body subjects (mean age = 22) were recruited from the University of Toronto. Subjects were healthy, and instructed not to exercise or to drink caffeine an hour prior to the recording.

C. Measures

Electrodermal activity was recorded using a ProComp Infiniti multi-modality encoder and an HP laptop to enable the investigator to observe real-time feedback of the signals. Two Ag-AgCl, 10 mm diameter electrodes were attached with adhesive collars on the medial phalanges of the index and middle fingers of the subject's non-dominant hand. Subjects washed their hands with antibacterial soap before the attachment of the electrodes. Skin conductance was measured using a constant voltage (0.5 V) applied between the two electrodes, sampled at a frequency of 256 Hz and displayed in real-time on the computer screen.

D. Procedure

Following electrode attachment, subjects were instructed to sit quietly to enable their electrodermal activity to stabilize, while several brief trial recordings were conducted to test and adjust the equipment. Subjects were given instructions for each task before it began. Each task consisted of alternating three times between two states that lasted for one minute each, for a total recording time of 6 minutes per task. The first task consisted of alternating between breathing at a slower-than-normal and a faster-than-normal frequency [15]; the second, alternating between mental relaxation and mental arithmetic (continuously subtracting 7 from an initial value of 1000) [16]; the third, alternating between mental relaxation and mentally recalling a piece of enjoyable music (Table 1) [13].

Table 1: Exercises to Control EDA

Exercise	Details	Pattern
Breathing	1 breath / 3 s, 1 breath / 8 s	Slow breathing / fast breathing
Mental Arithmetic	Subtract in patterns of 7	Rest / math
Mental Music	Imagine favourite song	Rest / music

III. RESULTS

A. Data Reduction and Scoring

Each subject's electrodermal activity was plotted against time for each phase of each trial. Three features were chosen to characterize the data: the number of electrodermal reactions (defined as increases > 0.05 uS), the mean EDA and the range of the EDA signal over the minute. Each feature in the simulating trials was compared by a paired t-test to the corresponding feature in the relaxation trials to determine whether they were significantly different (significant at $\alpha = 0.05$). An exercise was classified as having the potential to control EDA if one of the above measures caused a consistent change in a given direction away from the resting level, and if the subsequent resting activity was able to reverse this change. This manifested as a sawtooth-shaped plot of that feature over the course of the 6 trials.

B. Subject 1

Subject 1 did not demonstrate significant changes in any feature of electrodermal activity during the two breathing patterns. However, as seen in Figure 1, the number of electrodermal reactions (EDRs) was significantly higher during the mental arithmetic exercises than during the relaxation trials ($p = 0.003$). The increase in the number of EDRs ($p=0.076$) and the range of EDA during mental arithmetic ($p = 0.051$) in relation to the relaxed state also resulted in a sawtooth-shaped plot, but were not statistically significant.

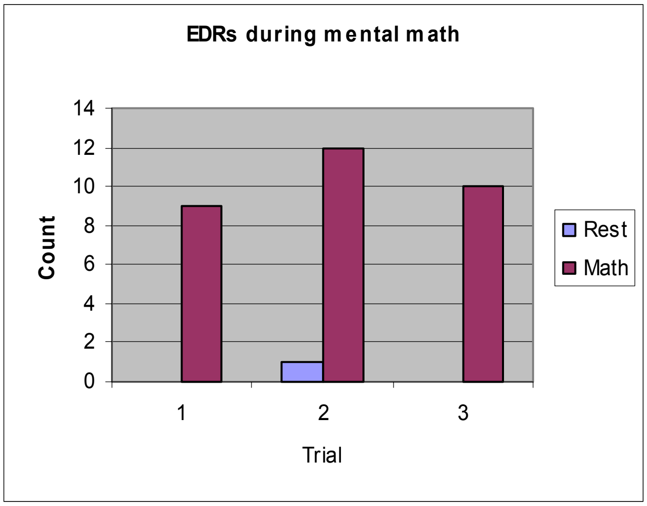

Figure 1: Significant change in electrodermal reaction counts (Subject 1): mental arithmetic vs. relaxed state

C. Subject 2

Subject 2 also did not demonstrate any consistent EDA changes between the two breathing states. However, as demonstrated in Figure 2, there was a reproducible, significant increase in the number of EDRs each time mental arithmetic was performed ($p = 0.015$). Other EDA features resulting in a sawtooth, but statistically not significant pattern, include a reproducible increase in the mean EDA during mental arithmetic ($p = 0.063$) and during mental music ($p = 0.066$).

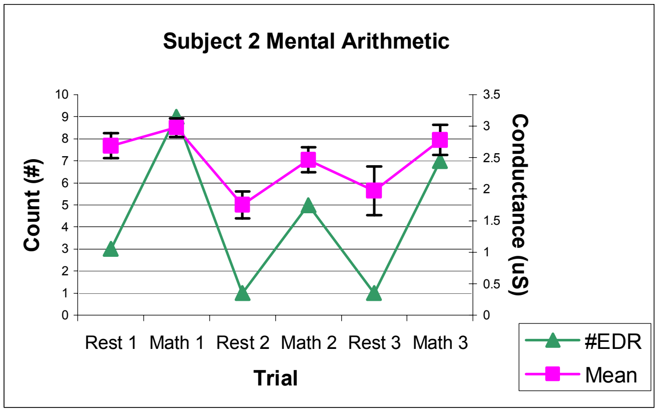

Figure 2: Significant EDA changes (Subject 2): mental arithmetic vs. relaxed state

D. Subject 3

Subject 3 demonstrated electrodermal reactions and changes in electrodermal levels in response to all three mental exercises. However, the changes in signal characteristics during stimulating exercises were not consistently reproduced for all 3 trials for any of the mental exercises.

E. Subject 4

Consistent changes in electrodermal characteristics did not occur during the breathing or mental arithmetic exercises. However, as demonstrated in figure 3, the mean of the subject's electrodermal activity during mental music was consistently and significantly lower than EDA during the rest periods (p = 0.029). The EDA range did not change significantly from the relaxed state (p = 0.107) during the mental music exercises, though it produced a sawtooth-shaped plot.

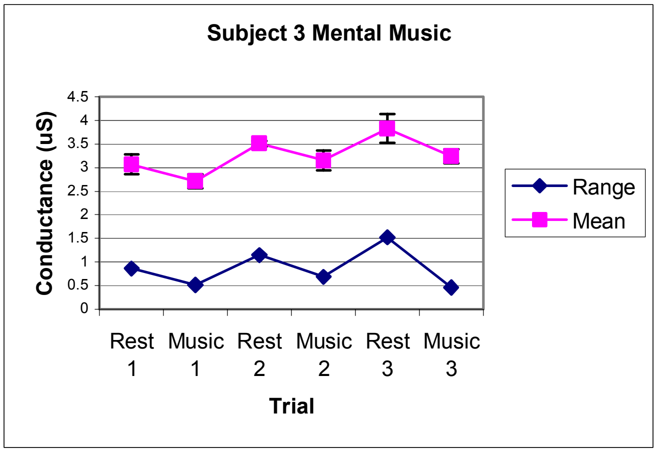

Figure 3: Significant changes in mean EDA (Subject 3): mental music vs. relaxed state.

IV. DISCUSSION

This study examined the effect of three exercises on different characteristics of electrodermal activity to determine whether there is potential to use one of these mental techniques to facilitate the creation of distinct, volitional changes in electrodermal activity. To be successful as a means of communication, it is important that two states can be created and controlled; therefore, only characteristics that reproducibly changed in the same direction away from the resting state during stimulating periods and reversed their direction of change during rest periods were considered controllable. With these criteria, 3 of 4 previously untrained subjects had at least one mental technique that produced a distinct, consistent change in one characteristic of EDA.

These results suggest that EDA can be consciously controlled, especially given the relative simplicity of the EDA feature space used to characterize the signal. The top graph of Figure 4 depicts the raw EDA signal of a subject relaxing, while the bottom graph of the figure is a representation of the EDA of that subject performing mental math.

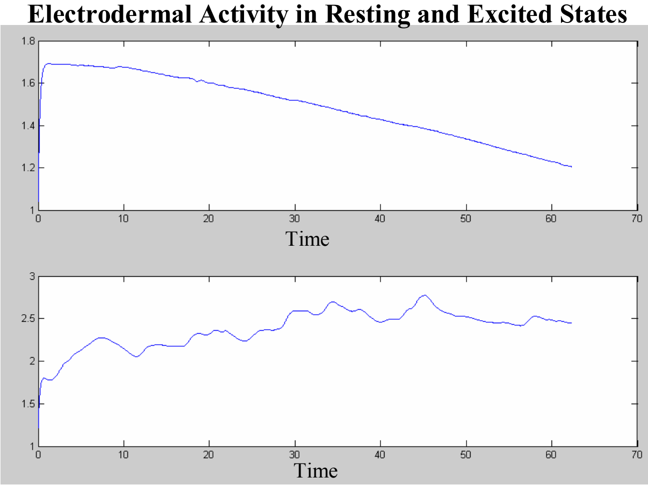

Figure 4: Raw EDA signal of rest vs. mental arithmetic.

These two states are distinguishable simply by visual inspection. The signal's mean, range and number of EDRs provided simple summary values. Further study of EDA signals may reveal more discriminatory features between relaxation and stimulation. Candidate features may include dominant spectral components or spread of the detrended signal. In addition, each individual's EDA patterns are unique. In this preliminary study, the same three features were used to characterize each subject's EDA signal, in spite of obvious differences in signal characteristics between individuals. In future studies, more accurate differentiation between signals generated during mental relaxation and stimulation may be achieved by choosing a feature space that is optimized for each individual.

While this study has predominantly focused on mental techniques designed to stimulate the subject, the importance of being able to reverse this change during the relaxation phases is crucial to developing volitional EDA control. Subject 3, who was unable to develop consistent changes in EDA during any mental exercises, commented after the recording that it was difficult to relax and to stop thinking during the required relaxation phases, and easier to relax while focusing on music and numbers. As a result, the signal characteristics of the relaxation phase were indistinguishable from, or changed inconsistently from the mental activity phase. Training subjects to relax will be just as important as training them to stimulate themselves in learning to control their EDA.

V. CONCLUSIONS

In summary, three of four subjects had at least one feature of their EDA that could be used to distinguish between relaxation and mental activity states. The fact that these changes were produced solely by mental activity without any physical, muscular control makes EDA a potential controllable signal for people who are locked-in. Different mental exercises must be attempted to determine which signal feature the locked-in subject is best able to control, and each subject’s signals need to be analyzed individually to determine the unique feature space that optimally classifies the binary signal they are generating. These results have implications for the development of a communication device for people who are locked in that is accessed through a binary switch controlled by volitional changes in their electrodermal activity.

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