

EYEBROW ACCELEROMETER SWITCH AS AN ALTERNATIVE ACCESS PATHWAY FOR AN INDIVIDUAL WITH SEVERE MOTOR IMPAIRMENTS

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INTRODUCTION

Spinal cord disability (SCD) is becoming increasingly prevalent in North America. According to the most recent estimate by the National Spinal Cord Injury Statistical Center, 225,000 to 296,000 persons in the United States have a spinal cord injury [1]. Patients with spinal cord disabilities often have a major loss of function and are unable to control their environment by conventional means; they involuntarily place a large burden on health care because of their need for constant care. To address these concerns of activity restrictions, there is a growing field in the research and development of assistive technology devices. The use of assistive technologies can increase the patient's independence by permitting him or her to control his or her immediate environment by operating light switches and the television, as well as aiding in other activities of daily living [2].

Simple switch devices are commonly used to assist people by providing a method of access. Switches can be applied as communication devices to control surroundings. Despite the development of many different commercial products, most switches are not universal. Therefore, it remains difficult to find a device that reliably suits an individual patient's requirements.

The level of impairment in SCD ranges widely; even those with high spinal cord lesions may still retain the ability to control some muscle movement [3]. A tilt switch has been developed for quadraplegic patients, with a high C1-C4 injury, who are able to retain some head nodding ability [4]. However in many cases where patients lack this degree of motor function, use of this head-operated switch is not feasible. An alternative solution is to use the much more commonly remaining contractile ability of the facial muscles. The frontalis muscles on the frontal lobe of the head direct eyebrow movement and present a potential control site that can be used as a switch actuation. The activation produced from this movement can then be extended into transmission of an infrared signal to the television, thus enabling control of the television set. A simple

raise of the eyebrow would enable the patient to operate this switch. Ideal considerations for a switch access can be ranked by importance [5]. The top choice is the reliability and consistency with which the person is able to complete the task and perform the action volitionally and comfortably. These are followed by safety concerns, ease of use and endurance, daily activities of the patient, efficiency, and the ability to perform the activation within a time frame. Therefore, an ideal eyebrow switch would be one that takes into account all of the above considerations.

We seek to describe a new alternative access pathway for a patient with an SCD resulting in quadriplegia. After an evaluation of some current commercially available mechanical switches based on the recommended criteria listed above, the design of a new switch is proposed in anticipation of achieving more single-switch access considerations. First and foremost, the design has been optimized to promote reliability and consistency. In addition, it has been designed to be ultra low-power and small-sized so that no bed-mounting device is needed. The device is mounted onto a headband, which is then placed on the forehead of the user. This allows the device to be easily cleaned and used, with no impediment to vision.

In this paper, data was first collected to analyze the accelerometer signal quality from eyebrow movement. The data provided evidence that distinct eyebrow movement can be used to transmit a signal, ultimately leading to television channel control. Based on these results, a preliminary device was developed in order to further investigate this access pathway. The ultimate goal is to implement a simple accelerometer coupled with a single microchip eyebrow switch that will enable the patient to control the surrounding environment and to complete the predefined task of changing the channel on the television. The eyebrow movement during lift and relaxation will subsequently activate an infra-red signal to be sent to the television in a manner similar to a person pressing a button on a television remote control.

METHODOLOGY

Participants

This study is focused on a 20-year old female quadriplegic with a high level C1-C4 spinal cord disability requiring mechanical ventilatory support. She has no cognitive impairment and is verbally communicable. She has minimal voluntary movement in her thumb that is often masked by involuntary activity. She has complete facial control with no evidence of ptosis. Preliminary testing of the system was also conducted on a 22-year old able-bodied male. Consent was obtained from both participants and approval to conduct the study was granted by the Institutional Review Board of Bloorview Kids Rehab and the University of Toronto.

Evaluation of Commercial Mechanical Switches

There are various commercial mechanical switches that are available for use. However, many are not universally suitable. Three commonly used, commercially available mechanical switches were evaluated for their performance level: the Tash Big Buddy Button, Tash Leaf Switch and a Touch Switch. Performance and high efficiency were examined based on three criteria:

1. Reliability and Accuracy
2. Repeatability and Fatigue
3. Ease of use

In her hospital room, the participant was asked to attempt to activate each of the different switches using her thumb and then her chin. The test was repeated 10 times for each switch and location.



Figure 1: The participant wearing the headband with four accelerometers on the forehead for initial detection of eyebrow movements.

Device Design

Our eyebrow switch device design combines a simple accelerometer with a single, ultra low-power microchip. The high precision analog ADXL203 dual-axis accelerometer (dimensions 5mm x 5mm x 2mm) was used to detect the eyebrow movement. The accelerometer contains extremely sensitive accuracy, having a range of $\pm 1.7g$ (gravitational acceleration). It acts as a transducer that measures its own change in mechanical motion and converts this into an analog output.

Four accelerometers were initially used to determine the sensitivity of the eyebrow movement. The accelerometers, with the x-axis oriented perpendicular to the eyebrow, were secured at evenly spaced intervals along a hard plastic headband which was subsequently placed on the forehead of the patient (Figure 1). It must be noted that although the accelerometer is dual-axis, only one axis was required and the resulting signals from the x-axis were recorded using the Valitec ReadyDAQ Data Acquisition System at a sampling rate of 512Hz.

Different types of analyses were conducted to assess the analog signal output obtained by the accelerometer (Table 1). To ensure that the voluntary eyebrow motion is unambiguous, the values for each assessment were compared to the baseline value using the Student t-test, with a significance level of $p = 0.001$.

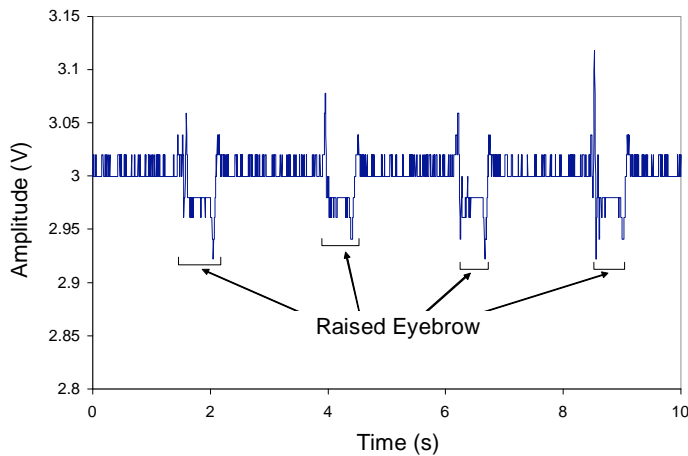
Table 1: Eyebrow Signal Evaluation

Assessment	Action
Baseline Detection	1) A limited amount of movement
Facial Movements	2) Encouraged to speak, laugh, smile to create natural facial movement
Fan and Facial Movements	3) Introduction of an electric fan blowing directly at the face
Voluntary Eyebrow Motion	4) Queued intervals for lifting and relaxing of the eyebrows

A sample of the raw data collected is displayed in Figure 2. A visible signal can be seen when the eyebrow is contracted and relaxed. The onset of the lift can be seen in the sudden peak to the maximum due to the initial acceleration of the eyebrow which is followed by an instantaneous minimum plateau that indicates the eyebrow has lifted. The signal then returns to baseline position when the eyebrow has relaxed.

Only one accelerometer is used in the final system setup. The analog output signal from one accelerometer is passed through buffer filters before entering the analog-to-digital converter on the MSP430 microcontroller. It is also smoothed using a moving average to remove any unwanted signals such as noise and small vibrations or movements. The processed signal is then compared to a variable threshold voltage value which will in consequence activate the switch if this threshold has been reached. Preliminary testing of the system on an able-bodied person was performed to examine the ability for the eyebrow movement.

Figure 2: Raw data collected from one accelerometer



from four eyebrow lifts. There is a sharp peak on the onset of the eyebrow lift followed by a plateau signifying when the eyebrows are raised.

RESULTS

Evaluation of Mechanical Switches

All the mechanical switches used in this evaluation posed great difficulties. Due to the limited amount of movement and strength in the client's fingers, switches used at this location were unsuccessful. As a result of fatigue and frustration felt by the participant, and the lack of any activation of the switches, the thumb trials were reduced to four repetitions instead of the projected ten. The two greatest problems encountered in these trials were the switch position and the amount of force required to successfully activate the switch. The position was crucial as the Button and Leaf switches involved a specific direction of the force to be exerted. Though small, the Touch switch was unreliable because the participant was unable to lift her thumb away from the contact surface.

Results from the chin activation of switches were more successful. However, this location impaired the

patient's ability to speak and restricted access to her tracheostomy site. The placement of the switches required an opposing or resistive force that would allow her to push down on the button.

Eyebrow Signal

Since the accelerometer operates with respect to the earth's gravitational field, the DC component of the signal is a result of the axis orientation and position on the forehead. Four conditions (Table 1) were assessed to determine whether a distinct voluntary eyebrow signal could be distinguished. Datasets obtained with baseline detection were statistically different ($p < 0.001$) compared to the data collected with additional environmental disturbance (fan blowing at the face and other facial movements). In comparison to both baseline detection and situations with environmental disturbance, datasets collected during voluntary movement were statistically different ($p < 0.001$).

System

Various factors were used to test the efficiency of the system. The results of the reliability testing on the able-bodied participant are displayed in Table 2. The speed of the user is limited due to the 0.8s debounce time required by the system. Taking into account this debounce time, as well as the lift and relaxation period at a comfortable pace ($0.55s \pm 0.01s$), the participant is allowed to successfully activate the system at a maximum rate of 45 activations per minute. The user was able to activate the switch at a rate of 26 activations per minute.

Table 2: Result of Preliminary Experiment

Feature	Average Percentage of Activations (%)	Standard Deviation (σ)
On Cue	83.33	3.57
Rest	27.33	3.31
Smiling	23.33	15.27
Laughing	41.67	7.22
Talking	22.22	4.81
Squinting Eyes	96.67	5.77

DISCUSSION AND FUTURE WORK

Although a debounce time is required by the system, it is important to note that it is advantageous to have a delay in between activations in order to allow time for the participant to make a decision to stay at the channel or to continue to advance.

Preliminary experiments demonstrated inadvertent activation of the system whenever there was detection of two separate activations during a single eyebrow lift or whenever there were unintentional movements. Additional delay time could be used to decrease these occurrences; however, this would compromise the rate of activation.

The high percentage of activation during laughing is likely a result of the ability of an able-bodied person to exert other motor activity. Further testing on the quadriplegic participant, where these movements would be absent, is required to determine if laughing could cause substantial error to the system.

The participant was also asked to close his eyes tightly. Although this resulted in a large percentage of activation, the likelihood of this particular motion impacting switch activation is rare because it is not a common movement. However, if desired, correction of this motion may be accomplished by an additional sensor located on the cheek to counteract the inadvertent activations.

CONCLUSION

In this paper, we have shown that there are distinguishable accelerometer signals from eyebrow movement. As well, based on the data acquired from the preliminary study on the able-bodied person, the rate and percentage of successful activation is promising. Further studies are being carried out on this system to assess its performance in disabled individuals. Therefore, the design of an accelerometer coupled with a single microchip device has the ability to be an effective switch for a user to control his or her environment.

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