# Contribution of Biosensors to Enhancing Performance for Users with Special Needs

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**Abstract.** This paper describes two lines of research addressing the use of biosensors for populations with disabilities. The first line of research focused on deriving changing cognitive state information from the patterns of data acquired from users with the goal of improving presentation of multimedia computer information. Detecting individual differences via performance and psychometric tools can be supplemented by using real-time physiological sensors such as eye tracking and pressure applied to a computer mouse. We describe a computer task that demonstrates how to identify cognitive state and discuss types of physiological and cognitive state measures and associated advantages and disadvantages. Adaptive information filtering is discussed as a model for using the physiological information to improve individual performance. In the second line of research we interviewed participants with disabilities in an engineering vocational training program about their needs and suggestions for assistive devices that incorporate biosensors.

**Keywords:** biosensors, special needs, cognition, physiological sensors, adaptive information filtering.

## 1 Introduction

Biosensors are analytical devices for measuring or monitoring physiological states. The simplest analogy one can make to a biosensor is the canary in a cage used by miners to warn of dangerous gas or low oxygen levels. In modern times, biosensors can detect an array of biological states by using a transducer or detection element combined with a biological component. Thus, biometrics have been employed for a range of uses including user identification, medical monitoring of condition status and medication levels such as for diabetes. In many ways such research is at its early stages, as materials development affects range of potential applications.

In this paper we examine research involving the use and application of biosensors at the University of Hawaii, with a focus on proposing future directions of research

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and development for people with disabilities. We first describe basic research in computer science aimed at using biometrics to monitor users' cognitive states in response to tasks requiring varying degrees of cognitive resources or cognitive load. Although this research has focused on an experimental population without disabilities, we propose applications for users with disabilities, a next step.

Secondly, we explore applied research and training done at the University of Hawaii at Manoa College of Education's Curriculum Research & Development Group that focuses on developing applications and training for people with disabilities to improve their employment prospects. Specifically, we interviewed participants with disabilities in the Archimedes Hawaii Project's Technology for Untapped Talent (TUT) Program. We were interested in their input and suggestions for devices that incorporate biosensors and can facilitate their completion of job-related tasks. One participant was a technological innovator who described his unique perspective on biosensing applications. Another interviewee was an engineer who has interest in robotics, programming, electronics and mechanical engineering.

## 2 Cognitive State and Cognitive Load

The way that humans interact and absorb information delivered through technology is of interest to researchers in many fields. For the last several years, we have designed and executed experiments about individual differences in the way people perceive, search, and understand information presented in multimedia environments. Our research focuses on deriving changing cognitive state information from the patterns of data acquired from the user with the goal of making effective multimedia computer systems for users with special needs. A cognitive state is a subjective experience which cannot always be explicitly expressed or accurately evaluated based on performance. It is affected by level of mental attention and affective relationship users have with tasks. Our goal is to unobtrusively monitor humans performing tasks using multimedia systems with several levels of complexity to determine their current cognitive state. With the ability to identify a person's cognitive state, we can dynamically adapt models of their interactions with multimedia systems to produce learning improvements. Ideally, such a system could increase comprehension while maintaining user satisfaction.

### 2.1 Assessing Cognitive Load

There are three methods to assess the cognitive load of a user doing a multimedia activity [1]. The first method is by using performance measures. Measures of task performance can be used to assess the cognitive load (e.g., percent correct or time taken), but because tasks often differ, every performance measure needs to be customized to the task. The second method is by using rating scales. These are subjective measures usually taken after the activity is completed, although if interruptions do not degrade task performance, ratings can be taken between or during the tasks of an activity. Subjective measures are essential to assessing the user's perceptions of the task and can provide information of the cognitive state of the user, but since most rating scales are taken after the activity, real-time cognitive state assessment is not possible. The third method is by using physiological measures. Unobtrusive physiological measures are measured in the same way regardless of task, are objectively analyzed and can be taken in real-time without impacting user performance or user ratings. Sensors can also be used to measure perceptual-motor changes during a task and by inference perceptual-motor changes can be related to cognitive performance [2].

Each of the three methods of cognitive assessment adds in overlapping and different ways to the understanding of the user's cognitive state. For real-time measures of cognitive state, only performance and physiological measures are reasonable. The purpose of the following summary is to provide an overview of our research from finding significant positive correlations between users personality types, experience and performance across many tasks to using physiological monitoring to assess an individual's cognitive state in real time.

## 3 Detecting Individual Difference via Performance and Psychometric Tools

Individual differences in people usually account for more variability in performance than variations in system design or training procedures. Using news stories, Dumais and Wright [3] studied how people searched for information with various combinations of names and screen locations as the search variables. They found a ratio of 7:1 to 10:1 between individual's slowest to fastest search performance. People also vary greatly in their performance using multimedia systems. Research shows that visual thinking is particularly relevant to how humans interact with multimedia systems. Two findings from the literature on visual thinking research are persistent. First, the ability to think visually (visual ability) differs from person to person. Second, the degree to which people rely on visual thinking also varies [4]. Spatial memory may be an important component of multimedia searching tasks. In addition, several studies in human-computer interaction suggest a strong connection between visual ability and the use of computer interfaces [5]. For example, Egan and Gomez [6] found that variation in computer interaction performance due to age and spatial memory of subjects with similar experience was 20 times greater than variation in performance due to design of an editor. Questionnaires and psychometric tests can assess individual characteristics. For example, Egan and Gomez found that the Building Memory Test [7] that measures the ability to remember the spatial arrangement of objects, correlated significantly with the subjects ability to learn text editing. Vincente, Hayes, and Williges [8] found two measures of spatial visualization were the best predictive measures for the time subjects took to locate target texts in a hierarchical retrieval system. Studies of text editors [9] indicate novice users with high visual ability perform significantly better than those with low ability. Mayer and Sims [10] found that high spatial ability students were better able than low spatial ability students to transfer what they learned about a scientific system when verbal and visual explanations were presented contiguously, that is coordinated animation and narration are most useful for high spatial ability students. Sein and Bostrom [11] studied the differences in performance of undergraduate students in learning an electronic mail system and found that both learning styles (KLSI) and visual ability (VZ-2) [7] predicted their performance.

### 3.1 Characteristics of the User and Multimedia Interface

We performed a series of experiments that examined the relationships between characteristics of the user and multimedia interfaces. Along with various presentation materials as independent variables, we used individual differences as co-variates. These individual difference measures included demographics and results obtained from psychological tests such as a visual ability test (VZ-2) and the Myers-Briggs Type Indicator (MBTI). The four-scale MBTI rating instrument contained preferences scales for measuring features such as introvert vs. extrovert and sensing vs. intuitive that we found to be related to student performance using multimedia courseware [12-13]. For dependent variables we used combinations of performance measures such as comprehension task, time on task, keystroke or mouse-click protocols and eye-fixations (12-14). For several experiments we used a variety of subjects that included such diverse populations as eighth grade students in Hawaii, tenth grade pre-engineering science students, undergraduate and graduate university computer science students and faculty.

Most of our early experiments examined different aspects of multimedia systems [15-17]. As a general method, we presented data on a video screen and asked the participants to solve simple problems. Specific examples of the task domains we used included programs [18-19], maps [20-21] and graphical representations of data models [22-23].

Results from those studies, helped us determine which visual cues and cognitive strategies people used to extract information, how individual differences influenced the way people get information from a video display and how people used the information they found. In particular, we recorded eye movements to gather detailed information on viewing patterns and strategies for a range of typical computer screen types during the performance of different types of tasks. Eye scanning patterns provided a particularly rich collection of data about how an individual searches or views specific multimedia interfaces [24]. Data from the eye-movement monitor helped us determine that, in addition to task variables, individual differences are related to the way students read and understand computer programs [18-19]. Crosby and Peterson [25] also used eye-movements to study how students searched lists.

We found positive correlations between the participants' personality types, experience and performance. Although previous research on individual differences informed multimedia designers that what is good for one individual at one time is not necessarily good for other individuals or even the same individual in all situations, better
multimedia system and interface designs did not necessarily follow. A potential reason for this is that evaluating results from psychological tests is not feasible if the goal is to build real-time adaptable software. As a result, our research focused on

creating a methodology to improve learning and task performance by optimizing the human-computer interface based on the user's cognitive state or cognitive load inferred from a suite of passive physiological measures.

## 4 Archimedes Hawaii Project's Technology for Untapped Talent

The Archimedes Hawaii Project's Technology for Untapped Talent (TUT) Program is an unconventional vocational training program that imparts job skills to individuals with disabilities where they learn to design and build a range of valuable products using computer-based design and fabrication software.

The TUT program is, at its heart, an engineering education program. The Archimedes Hawaii Project goal is to provide education and training opportunities in engineering and hands-on design and crafting using computer aided design (CAD) software, computer assisted manufacturing (CAM) software, and computer-numerically-controlled (CNC) devices and technology. The focus is on instruction in computer design, fabrication/manufacturing of products (wood, metal, plastic) and developing business skills. This includes curriculum development, professional development, program evaluation, dissemination, and implementation. A special capability of the Archimedes Hawaii Project is extensive knowledge and experience with designing and implementing universal access to information and computers for individuals with disabilities. Following, we describe the story of two TUT participants for whom biosensors could potentially enable adaptation to a their cognition in real time and facilitate real world tasks.

### 4.1 A Craftsman's Story

Joseph has been participating in the TUT program for a year. He learned of the TUT program through a friend who was a counseling education student. His interest in TUT was to learn more about fabrication techniques to enable refinement of the various prosthetics he had created for himself through the years. He feels that the designs on the market are not suited to his needs for farming, construction, and efficiency of fine-motor manipulation. Moreover, they are not affordable for him. Joseph lost his right forearm in the mid 1980s in a shark attack. Because it was not during a work accident, or during any military service, he is not eligible for insurance monies for his prosthetics. His health insurance has limitations because a shark attack is considered an "act of nature," and is therefore not considered coverable.

Prior to sailing to the islands, Joseph was an avid sportsman and spent time working with youth in computer science classes as an assistant. He designs kinesthetically because he has difficulties with numbers because of his dyslexia. Being able to see the visualizations were important for him in the TUT program because they were three-dimensional designs that he could manipulate on screen and refine.

Over the years, Joseph has designed what he calls the "other side" of biosensors, namely physical tension reaction from his muscle contractions. One of his hands he designed in the TUT program. From a drawing in Corel that was then transferred to a three-dimensional visual in ArtCAM, he took a sheet of aluminum and fabricated his split hook hand and 3D printed the supporting pieces that he would have formerly made out of plywood. The entire hand is held together with one hook and one bolt. Some bungee cord is then applied by Joseph in a very creative manner, perhaps never done before. He uses three feet of bungee cord seized around the fingers and thumb to allow the hand to flex, grip, and self adjust as necessary. Joseph is able to feel the amount of grip that he applies by the harness across his back that indicates how much pressure is being exerted to close the hand. The hand works as a voluntary closing terminal device. He states that because it does not have myoelectric feedback that a biosensor would, he has to constantly watch his invention because the only feedback he receives right now is vibration.

With a biosensing hand, he could receive additional feedback that would give him more awareness of his hand placement and the fine motor skills he wants to attain. Though Joseph shared that he does have advanced fine-motor skills with his self-designed hand where he can pick up a dime on a carpet, manipulating individual digits could be an improvement.

## 4.2 An Engineer's Story

David has been participating in the TUT program for two years. A fully-trained mechanical engineer, he was referred to the program by a vocational rehabilitation counselor because of his interests in robotics, programming, electronics and mechanical engineering. David suffered a bicycle accident in 2010 that fractured his neck. He is a incomplete quadriplegic (tetraplegia), and his injury affects all of his body functions from the top of his chest downwards across his entire body including his arms. He has some voluntary movement of his body below the injury site, able to move his arms and legs a small amount, not with sufficient strength to perform the general activities of daily living.

In the TUT program, David appreciated the TUT team's suggestions and implementation of ideas that improved his ability to function at a more productive level with the CAD-CAM-CNC work. For example, there were components on his wheelchair that he designed and made at TUT. Also, he borrowed an idea from a table he saw in New Zealand and made modifications to the table top; the modifications allowed him to provide more inputs from his tablet device. He felt the program helped him leverage his knowledge of mechanics and opened doors to possibilities for future work opportunities. More importantly for him, the TUT program gave David the confidence to try new things, and he was actively exploring the possibility of starting his own business using the technologies he learned during his two years in the program. He considers the solutions he devises as very simple, simple enough for other people to devise on their own and not have to rely on more expensive solutions.

With more time and resources, however, he believed that there were other innovations that could have been realized with biosensors. From an engineer's perspective, he described seven ideas for improving his TUT experience as well as daily living needs. First, he illustrated pressure sensors such as in a glove remotely attached to tools to provide feedback either tactile or by reading it on a dial. This idea was in response to his not being able to feel pressure or touch in the areas below his injury site. Next, David explained that he cannot feel temperature differences. A biosensor that provides visual feedback can protect him from burning himself since hot water out of the faucet could scald him or simply inform him if his coffee is hot. Third, he expressed an interest in an exoskeleton that would provide him with mobility--strength to his legs so he could walk, or strength and dexterity to his arms and fingers so that he could be more productive. He described examples of exoskeletons currently in use and under study in rehabilitation centers all over the world. Fourth, David talked about robotics and simpler devices like microcontroller where inputs and outputs can provide assistance. Fifth, he pointed out the interface with computers. Part of his interview was dictated to us via email with voice recognition software. He described tablet devices as being an important intermediary step if direct biofeedback was not possible. He has been exploring how his phone can control simple everyday devices, not just the TV and a computer but also the refrigerator, the range, a hospital bed, the washing machine and any other device that we may interface with in our daily lives. Sixth, David has been considering simple robotic devices that can assist his mobility, perhaps to pick something up off the floor or retrieve something from the other side of the room. Devices such as these would require some form of biosensor to control their actions and provide rational feedback to the operator. And lastly, he explained that taking advantage of available muscle groups not affected by a disability as critical. Biosensors directly attached these controllable muscles could provide for a more natural interface and one where a separate intermediate device is not required.

David feels biosensors are a huge field of opportunity for everybody, not just for those with disabilities. His reflection of his needs and experience is with complete understanding and recognition that computer keyboards, mice, tablets, video monitors, eye trackers, trackballs, video cameras etc. are all biosensors and that adapting them to the specific individual is the real challenge. Ultimately for him, when he designs something for himself to improve his daily life, the chances are that it will also be useful for someone else.

## 5 Summary

The accurate assessment of the users' cognitive states is essential to identifying and testing models of how cognitive processes operate and interact. The individual and the situation can affect the measurement of a cognitive state from a single type of sensor. Measurements from multiple sensors, when combined, are expected to produce more robust measurements of the users' cognitive states. Different sets of sensors can cross validate similar types of cognitive measures, such as stress which is measured by both eye tracking and relative blood flow. Also, different sets of sensors can fill in expected missing data. For example, the pressures on a computer mouse are primarily available during mouse interaction, eye tracking is primarily available when there are images to observe, and some sensor may have a ceiling or floor effect (e.g., maximum or minimum). Where single sensor system could be plagued with gaps of missing data, multiple sensors will be less prone to having this problem.

Our research employed a real time suite of physiological sensors to assess these cognitive states. Specific questions we examined included: What factors contribute to the users' cognitive states? What are effective ways to assess cognitive states? How can we predict the users' cognitive states in real-time tasks? Using real-time assessment of the users' cognitive states, we plan to adaptively filter information and adapt to the users' learning experience. We discuss the issues regarding the positive and negative factors of the different physiological measures, but in general combining the different measures can fill in temporal gaps in measurement and reaffirm newer measurement methods.

By looking at the real needs of two individuals with disabilities, we expanded the idea of psychometric feedback and connected it to real world needs that Joseph and David have for their everyday lives. Both men had physical disabilities that they described and spoke of increasing mobility and function for both work needs and personal needs.

## 6 Future Research Directions

Specific future research directions for persons with disabilities that emerge from this line of research include the following:

- The development of applications for students with attentional disabilities such as attention deficit disorder (ADD) and attention deficit hyperactivity disorder (ADHD). In particular, using biosensors to monitor cognitive load, attentional (and affective) engagement with academic and other cognitive tasks would be valuable. A goal would be effective monitoring (perhaps even through touches during task completion on an tablet device screen) and adaptation of tasks to recapture attention or reduce difficulty.
- For students with mild forms of autism or Asperger's syndrome, inputs from others' biosensors might provide them with indicators of others' levels of emotional engagement, frustration, etc., and might provide an alternative to interpreting facial expressions and tones in synchronous meetings and videoconferences.
- Monitoring levels of stress for students with disabilities (and others) might be an effective way to prevent accidents, and keep students working at optimal levels.
- The development of low-cost or easy-to-replicate assistive devices for specific purposes that incorporate biosensors.

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