Physiologic System Interfaces Using fNIR with Tactile Feedback for Improving Operator Effectiveness

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Abstract. This paper explores the validation of tactile mechanisms as an effective means of communications for integration into a physiologic system interface (PSI). Tactile communications can offer a channel that only minimally interferes with a primary or concurrent task. The PSI will use functional brain imaging techniques, specifically functional near-infrared imaging (fNIR), to determine cognitive workload in language and visual processing areas of the brain. The resulting closed-loop system will thus have the capability of providing the operator with necessary information by using the modality most available to the user, thus enabling effective multi-tasking and minimal task interference.

Keywords: physiologic system interfaces, functional near-infrared (fNIR), tactile, tactile communications.

1 Background

The data presented to humans on a daily basis by interactive electronic systems is ever-increasing. Physiologic system interfaces (PSIs) have been developed in response to this increasing demand on the user and utilize signals from the heart, brain, and skin to provide information to the control systems of these interactive platforms. Additionally, the increasing use of multi-modal communications systems allow for hands-free interaction between the user and the system. As a result, critical information can be conveyed in a two-way stream between the user and the system with minimal interference with the primary task at hand.

By integrating physiologic state data about the operator into a closed-loop system, human performance can be improved by augmenting the computer environment. This is accomplished through providing the operator with feedback through sensory channels that are not required, or minimally required, for working on the primary task. For example, if the subject is focused on a phone conversation, incoming auditory messages may not be heard or processed appropriately. In some scenarios, the new messages could even distract the subject, causing him or her to miss parts of the phone conversation. Because the relative importance or urgency of the new

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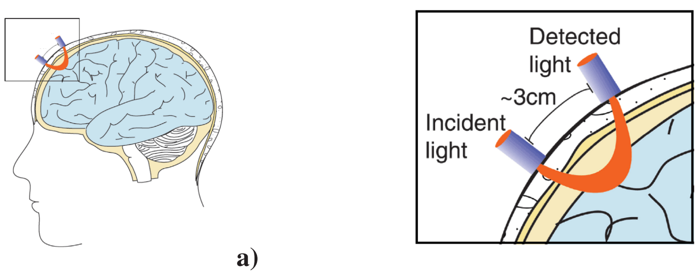
messages compared to the primary task would not always be known, the operator must be given all the information without significant decreases in comprehension.

1.1 Functional Brain Imaging with fNIR

One type of physiologic sensor that helps characterize a user's state is functional brain imaging, which can provide real-time data about the cognitive processes at work, such as working memory. Numerous technologies exist, but only a few would be appropriate for use in real world environments. For example, functional magnetic resonance imaging (fMRI) is widely used in studying the brain's activity, but is the size of a room and requires the subject lie motionless on a table. For this PSI to be widely usable, all component parts must be wearable and minimally intrusive on the subject.

Functional near-infrared imaging (fNIR) technology is a non-invasive technique that is an ideal choice for this PSI. Available systems can be small, comfortable, and easily placed on the user's head over the cortical areas of interest. Additionally, fNIR is relatively affordable, less constraining to the user, and easier to setup than other technologies.

The functionality of fNIR relies on the light transmission properties of oxy-compared to deoxy-hemoglobin in the near-infrared (NIR) part of the spectrum. The sensor emits multiple wavelengths of NIR light and then detects how much light of each wavelength passes through the skull and brain and returns to the surface of the head (Figure 1). The relative levels of the wavelengths provide a means of calculating, in real-time, the cortical blood volume and oxygenation changes due to neuronal activation [9]. This measure is essentially the same physiologic signal that fMRI detects. Additional benefits of fNIR include higher real-time accuracy, more robust operation in real-world environments, and vastly shorter (or nonexistent) training times [3,5] than competing EEG or fMRI technologies. Finally, in addition to measuring cognitive activity, the fNIR signal also includes other physiologic parameters, such as heart rate and respiration rate, which have a potentially useful role in the PSI.



a) b)

Fig. 1. Incident NIR light passes through scalp and skull to the cortex. Using scatter models, light reaching the cortex can be detected approximately 3 cm away. The amount of light detect is a function of extinction coefficient (attenuation) which in turn is a function of the tissue content. Using different wavelengths of NIR light, it is possible to solve for concentrations of hemoglobin and oxy-hemoglobin.

1.2 Tactile Communications

Visual and auditory modalities are commonly used for effectively presenting information to users; however, once these channels are overloaded, task performance may be reduced due to bottlenecks in the perceptual system. An alternative to these approaches is tactile stimulation, which would act as the output effector for this PSI system. Tactile mechanisms are capable of producing a distinguishable low resolution "image" or tactile icon (tacton) on the skin of the user [1] in a manner that can be discreet or even covert. Past studies have already shown that reaction times were improved with kinesthetic or vibrotactile cues, as opposed to auditory or visual cues [6,7], indicating the ability of users to recognize and distinguish tactile stimuli is greater than that of auditory or visual stimuli.

In addition to the proven ability of subjects to recognize and react to tactile stimuli, using tactile mechanism for communications rather than visual or auditory cues does not interfere with concurrent visual or auditory tasks [10]. Tactile mechanisms as a form of communications can convey messages or even situational awareness information without overloading the visual and auditory senses that are often already in use by the current tasks.

2 Objective

This paper introduces a PSI using functional brain imaging and a tactile feedback system to facilitate communication with an operator. Those most benefited by this particular system would be operators who rely heavily on visual and auditory stimuli for their primary tasks. This validation of a tactile system as a channel for communications presents an effective means to potentially increase task performance of a human user and thereby improve the effectiveness of the computing system. Such a system can optimize performance in an environment where individuals are taxed with high requirements. This is accomplished through informed, intelligent distribution of information presentation across multiple modalities.

Fig. 2 below demonstrates the concept of new information (such as feedback) being presented to the operator (shown as the secondary task). These new tasks require both perceptual systems and working memory systems (the spatial working memory tasks require visual cues and the verbal working memory tasks require auditory cues). The operator is capable of performing the primary task with a secondary task of the other modality (as the green check indicates), but not of the same modality (as the red X indicates). This is further emphasized by the renderings of the brain's cortical activity based on fMRI data, which shows different patterns of activity for each type, indicating the area is already very busy processing information.

Therefore, the addition of tactile feedback to this system presented in Fig. 2 would add another modality for communication to the already overloaded operator. Additionally, because some stimuli can be presented in multiple modalities, the system would be able to present the stimuli appropriately by only using modalities that are not in use for the primary task. This information would sometimes be known just by the nature of the actual task, but may often require functional brain imaging to know how the person is actually processing the information while performing the

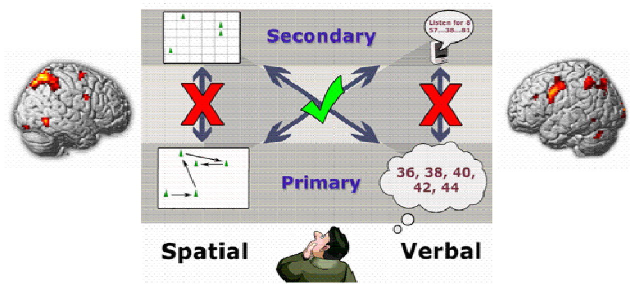


Fig. 2. Diagram of experimental setup for the PSI

task. For example, remembering a telephone number can be done either through a verbal strategy (by silently repeating the numbers) or by a spatial strategy (by visualizing the phone keypad and the path your finger would travel to dial the number). Therefore, it cannot be assumed that a user will always be taxed in the perceptual or memory system that is typically associated with a particular task.

In this study, task performance is monitored with an fNIR PSI interface and compares the use of tactile feedback (tactons) to the use of visual feedback (computer monitors). Performance is measured through time required for cognitive activation as determined by the fNIR oxygenation signal. The study essentially validates the use of tactons as an effective communications modality when compared to the traditionally and commonly used visual modality. By adding tactons to a system as a communications channel, this system increases the number of complementary modalities available for communications to the operator; providing additional channels that do not impinge on existing channels will lead to more effective communications as suggested by the media richness theory [2,4]. The goal of this research is focused on providing the dismounted warfighter with the information necessary to operate and survive in the most effective modality for the situation at hand.

2.1 Methods

The fNIR system to be used in this research, called OTIS, was developed by Archinoetics, LLC (Figure 3). OTIS is a completely non-invasive, continuous-wave fNIR system that is portable and supports up to two sensors that allow for sensing over areas of the scalp with hair, a distinct feature of this fNIR sensing system. Each sensor has two channels with a central emitter and two detectors. The system uses three wavelengths of NIR light and has a sampling frequency of 34.8Hz. [8]. OTIS communicates over Ethernet to a PC where custom software applications process and log the data.

The OTIS sensor will be placed on the subject's head over Broca's area to measure cognitive activity associated with language processing. Accordingly, the subject will be given a task that activates this area such that the tactile feedback indicates to them their success in performing the task. The performance of the subjects will be quantified as time to activation. In preliminary testing, subjects reported finding it

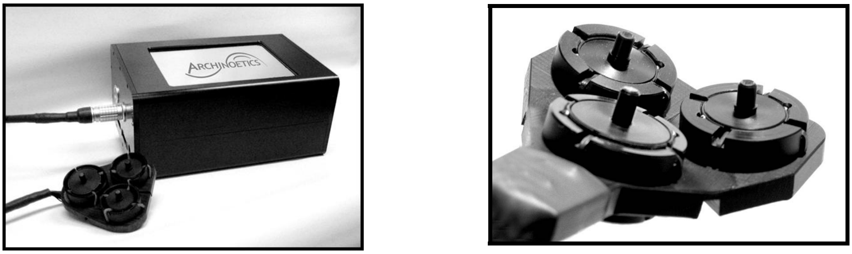


Fig. 3. Current generation of Archinoetics fNIR system and close up of sensor

useful to have feedback in the form of a visual graph indicating their level of success in trying to produce an activation on demand. Retrospective analysis of these trials has confirmed the benefit of this feedback, quantified in terms of an increased number of successful attempts to activate over a given number of trials.

Activation will be determined using custom, real-time cognitive activation detection algorithms. These detection algorithms have adjustable variables and settings that will remain constant between subjects and runs for consistent time-to-activation calculations. Each subject undergoes a calibration process for the fNIR system based on the decided settings for the detection algorithm.

3 Discussion

In addition to improving operator performance and system effectiveness, a PSI system with tactile feedback has multiple applications to improving information processing. The improvement of information processing applies to multiple categories of information content, whether surveillance, readiness status, situational, training, medical, or otherwise.

Validation of tacton discrimination capabilities and the effectiveness of tactons as an alternative means of communication has broad ranging potential in the public sector for any situation in which the audio-visual systems are already occupied. Tactile alerts are already present in many everyday devices, such as cell phones and PDAs, so its use as a communications system would be transparent to the user that already possesses these items. Such a form of tactile alerts can be used to discriminate between critical and non-critical information to be presented to the user via these devices.

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