AN OPTICAL BRAIN COMPUTER INTERFACE

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SUMMARY: This paper describes a novel approach to brain computer interfacing that uses optical analysis to provide physiological measures of brain function. We describe the optical analysis technique involved and the application of this method to development of our first prototype optical brain computer interface,

INTRODUCTION

An optical brain computer interface (OBCI) is a device, which translates physiological measures of thought processes, derived through optical interrogation techniques, into control signals capable of driving external computers independent of the peripheral nervous system. The optical method used in our current system is near-infrared spectroscopy. An optical window at 650-900nm allows light, within this range, to usefully penetrate the intact cranium and reach sufficient depths to probe the surface of the cerebral cortex [1]. The photons are mostly scattered and absorbed, but some are back-reflected and exit the head at positions up to a few centimeters away from their original source location. Both experimental and theoretical studies have shown that the photons travel in an arc-shaped path from source to detector [2]. Near-infrared spectroscopy can provide information regarding both haemodynamic and neural activity. The optical response due to haemodynamic activity is a much easier signal to acquire as it leads to 1-2% changes in signal amplitude, whereas the optical response due to neural firing only yields changes of 0.01-0.1% [3]. The cerebral haemodynamic response results from an auto-regulatory process responding to the metabolic demands of neuronal firings and takes 5-8sec. The faster optical response relating to neuronal firing is of the order of milliseconds but because it is of much smaller magnitude it requires averaging techniques to achieve acceptable signal to noise ratios. Franceschini and Boas [3] reported averaging blocks of 1000 trials and observing a 0.05% change in light intensity. It is for this reason that we have chosen to use the more accessible slow optical response related to cerebral haemodynamics for the first prototype OBCI.

MATERALS AND METHODS

Signal Acquisition: Our current NIR system is a single channel arrangement using two light emitting diodes (LEDs) of different wavelengths. Chromophores found in tissue, e.g. oxy-haemoglobin and deoxy-haemoglobin, have different attenuation spectra, which means that multi-wavelength systems can monitor changes in such chromophore concentrations [2]. LEDs at 700nm and 880nm, emitting a combined average power of less than 2mW/mm^2, are modulated at 4kHz and 5kHz and placed in direct contact with the scalp. The detector is an avalanche photodiode (APD), Hamamatsu C5460-01, which is connected 3-4cm from the light source via a 3mm diameter fibre optic bundle. Lock-in amplifiers, Ametek 5210, are used to reduce noise due to ambient light and the data is recorded at a sampling rate of 100Hz by a 16-bit A/D data acquisition card, Keithley PCMCIA16AI.

Mental Task Protocol: The mental task involved must be straightforward and relate to natural intent in order to make the device user-friendly. Motor imagery, i.e. the imagination of physical movement is one possibility for this protocol and is a well-established protocol for BCI control. The authors have measured a response due to motor imagery at C3/C4 of the 10-20 electrode placement system. In that work motor imagery was found to give a similar optical response to actual executed movement [4]. The response revealed characteristic changes in the haemoglobin concentrations during mental activation, i.e. an increase in oxy-haemoglobin and decrease in deoxy-haemoglobin concentrations. Our current BCI is based on these findings - characteristics of the vascular response due to motor imagery, that differ from the response during rest intervals, can be detected in real-tim and subsequently translated to a control output.

Signal Processing/Feature Extraction: From the light detected at each wavelength, changes in oxy-haemoglobin and deoxy-haemoglobin are calculated using the Modified Beer-Lambert Law. The algorithm implemented is based on that described by Cope [5]. Following this, the OBCI must identify, in real-time, characteristics of the vascular response during motor imagery and rest intervals. A straightforward threshold algorithm is used to determine if the cortical area beneath the optode is in an active or resting state. At each point in time a 20s window of data is analysed. A positive event, i.e. localized cortical activation, is noted if the average oxy-haemoglobin concentration is greater than a reference which is set to the maximum value occurring within the first ten seconds of the window. This is done to avoid false event identifications due to the effects of the Mayer wave, a spontaneous oscillation with a period of 10-15s [6].

User feedback: For motor imagery tasks, e.g. where the user imagines to continually clench and release a ball, the optical BCI delivers continuous visual feedback by means of a circle on the screen that shrinks and expands in response to changing haemoglobin levels. The purpose of using such feedback is to reinforce the mental imagery being used.

RESULTS

Five subjects participated in initial studies investigating the response due to motor imagery[4], upon which the operation of the OBCI is based. Three different subjects, partaking in one or two trials each, tested the first prototype online OBCI. All subjects possessed full motor control. Analysis of offline data averaged over a number of subjects and trials by applying the BCI's translation algorithm gave an accuracy of 75%. Using the simple threshold algorithm the system has an information transfer rate of around 3 bits/min. Details of this study are described elsewhere [7]. Although the current set-up is a low throughput device, the great advantage of the system is that training is so simple because the mental task involved does not require the user to master a new though process. Training involves subjects being asked to carry out a motor task initially, typically clenching a tennis ball, and then asked to visualise the task. Using this natural thought process has resulted in naïve users achieving immediate proficiency.

DISCUSSION

Physiological noise, namely the cardiac cycle, respiratory effects and the Mayer wave, are the greatest noise sources inherent in our system. The Mayer wave in particular can lead to feature classification errors as it can be of similar time-course and amplitude as the event-related response. An extension of the current system to multiple sites across the head will no doubt improve this performance as differential signals can allow localised changes of interest to be more easily seen. This new BCI modality requires a fresh approach to signal processing specific to the NIRS domain.

The nature of the slow vascular response means a low information transfer rate. Switching to a multiple channel system which although maintaining the same number of symbols per minute will allow more bits per symbol therefore increasing the performance of the device. To achieve optimum speed, acquiring the fast optical signal and attaining an evoked optical response will be essential. A recent study revealed a fast optical signal, showing a response of the order of milliseconds, correlating to the frequency of hand movement [8]. Another possibility to improve performance is to develop a hybrid system by integrating other brain monitoring modalities, such as EEG, with the optimal deployment of NIR techniques.

CONCLUSION

Near-infrared spectroscopy shows great potential as a signal acquisition tool for the development of accessible and practical brain computer interfacing. Optical methods avoid noise issues associated with electrical signals. Furthermore, an optical approach has various safety benefits - the user is isolated from electrical signals, NIR light is non-ionizing and is therefore suitable for long-term use, and the technique takes a completely non-invasive approach. The instrumentation is straightforward to use and does not require the use of gel to make contact with the skin.

Although the system performance as it stands is slow and needs better accuracy, the great advantage of the system is its accessibility. Lengthy training periods involved with BCI control can lead to a great deal of frustration in users and even abandonment of the device. The mental tasks required to operate the OBCI are straightforward and do not necessitate the learning of a completely new though process.

In this paper we have described our prototype optical brain computer interface, showing the feasibility of using optical methods as an alternative signal acquisition technique for BCI development. To improve the system's performance, we are currently evolving to multiple channels, refining current instrumentation and enhancing signal processing algorithms.

REFERENCES

[1] Jobsis F, Non-invasive infrared monitoring of cerebral and myocardial oxygen sufficiency and circulatory parameters. Science 1977; 198:1264-1267

[2] Chance B, Villringer A, Non-invasive optical spectroscopy and imaging of human brain function. Trends in Neuroscience 1997; 20(10): 435-442

[3] Franceschini M. A., Boas D.A., Non-invasive fast optical measurement of neuronal activity. Proceedings of the European Conference on Biomedical Optics, Munich, Germany, 2003

[4] Coyle S, Ward T, Markham C, McDarby G, Cerebral Blood Flow Changes related to Motor Imagery, using Near-infrared Spectroscopy (NIRS) presented at the World Congress on Medical Physics and Biomedical Engineering, Sydney, Australia, 2003

[5] Cope M, The development of a near infrared spectroscopy system and its application for non-invasive monitoring of cerebral blood flow and tissue oxygenation in the newborn infant. Ph.D., University of London, 1991

[6] Elwell CE, Springett R, Hillman E, Delpy DT, Oscillations in Cerebral Haemodynamics. Oxygen Transport to Tissue XXI. Ed. Delpy. New York, Kluwer Academic/Plenum Publishers: 57-65, 1999

[7] Coyle S, Ward T, Markham C, McDarby G, On the Suitability of Near-Infrared Systems for Next Generation Brain Computer Interfaces, Physiological Measurement, in press

[8] Wolf M, Wolf U, Choi J, Gupta R, Safonova L, Paunescu L *et al*, Functional Frequency-Domain Near-Infrared Spectroscopy Detects Fast Neuronal Signal in the Motor Cortex, NeuroImage 2002; 17:1868–75